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A Descriptive Plantation Typology and Coding System to Aid the Analysis of Ecological and Socio-Economic Outcomes

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Abstract
Purpose of Review After decades of intense academic and policy debate, a shared understanding of the term 'plantation' is still missing. More consistent terminology and plantation typologies are needed to enable comparability between plantation types and related ecological and socio-economic outcomes.
Recent Findings Previous research has provided some suggestions for a plantation typology, but a more systematic approach to typology formulation is still needed. Furthermore, previously proposed typologies almost exclusively deal with plantation forestry, ignoring the links with other plantation types.
Summary The aim of this review is to identify a comprehensive set of variables that can describe the range of different plantation types, specifically (but not exclusively) in the context of forestry. The typology was developed based on a participatory and iterative analytical process involving several expert stakeholders. The variables that contribute to constructing the typology are presented and explained in light of their influence on ecological and socio-economic outcomes. Variables include the following: (1) characteristics of planted organism (tree/non-tree), (2) species composition (monoculture/mixed), (3) origin of planted species (native/exotic), (4) plantation purpose (economic, social and environmental), (5) plantation intended use (provisioning, regulating and cultural services), (6) land ownership (public and private), (7) management responsibility (public and private), (8) management intensity (high-medium-low), (9) scale (large-medium-small) and composition (monoculture/mixed) in landscape, (10) original initiator of plantation establishment (external and internal) and (11) level of institutional arrangements (high-medium-low). The typology is then tested using three case studies. A code system is presented that scholars and practitioners can use to classify plantation types and provide the basis to aid further analyses.

Keywords Plantation · Typology · Ecological · Socio-economic · Impact · Outcomes

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Introduction

The generic term 'plantation' identifies a plot of land where one or more species are planted, including perennial or annual, exotic or native species. Much of the literature on plantations refers to trees planted for wood products [1, 2••], but the term 'plantation' is also sometimes used to refer to, among others, fruit trees, oil palm, rubber trees, sugarcane and managed bamboo systems [3, 4] (Fig. 1). Plantations are managed at

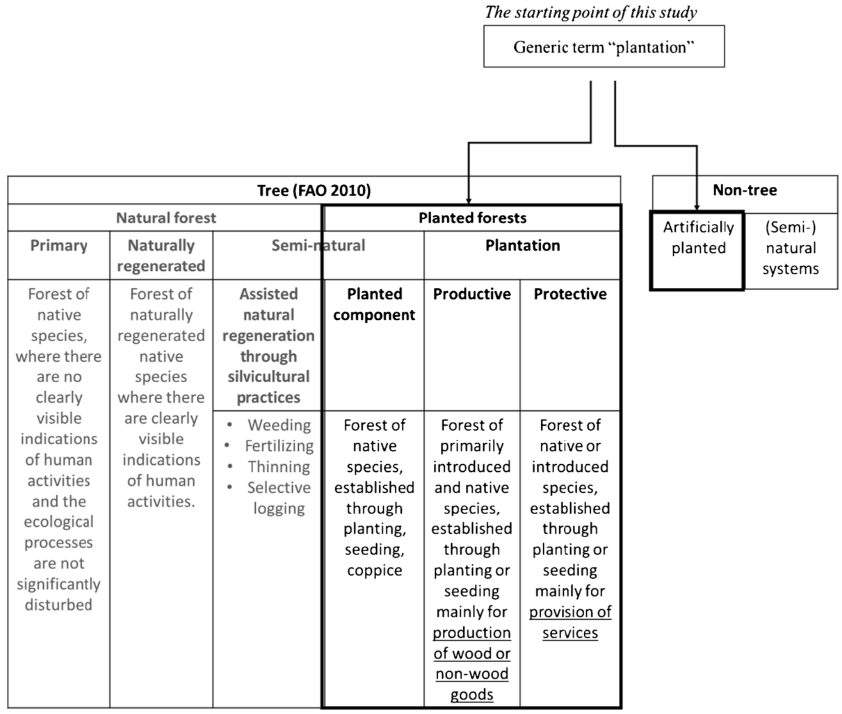

Fig. 1 The generic term 'plantation' is used in literature to refer to tree and non-tree organisms which are, at least partly, artificially planted. While a definition for planted forest has been developed by FAO (2010), there are no definitions for 'non-tree plantations'

different intensity levels for various purposes (economic, social and environmental) and uses (e.g. food, fibres, resins, biomass for energy, carbon, local livelihood support and land restoration). Plantations are established all around the globe, and their size can range from less than one to thousands of hectares [5••]. Plantation establishment, on public or private land, can be driven by external schemes or as a local initiatives. The management regime can be implemented by state-owned or private companies or by individuals or collectives.

After decades of intense academic and policy debate, providing a globally shared understanding of 'plantation', especially in the context of forestry, still poses serious challenges, with a plethora of definitions and interpretations [6•]. FAO and other international organizations and conventions are actively involved in harmonizing national definitions. Under the umbrella term of 'planted forests', the FAO groups together forests of native species which have a planted component (i.e. semi-natural forests) with monoculture plantations of native or exotic species (Fig. 1). The area of planted forests currently represents 7% of global forest cover (Fig. 5 in the appendix), and they are foreseen to continue expanding [7•].

There is still, however, a need to synthesise a glossary that is comprehensive at the global level and coherent at the local level. Operational definitions are well known to influence national and global estimates of forest cover, international and regional policies, and land use decisions at the local level [8•, 9]. Different plantation types deliver different ecological and socio-economic outcomes at local and global levels, including changes in ecosystem services delivery, changes in land or use rights, livelihoods and local development [2••, 10, 11, 12•].

Given the wide heterogeneity of the above-mentioned phenomena, the definition of and discussion around the term 'plantation' could benefit from the development of a typology, understood here as being an organized system of relative types, rather than universal classifications [13••]. While the latter are definitive and rule based and 'follow a black-and-white-model', typologies 'can accommodate shades of grey or variables that may be of a transitional nature', and 'might represent one or several attributes and include only those features that are significant for the problem at hand' [12•, p.3].

Previous research has identified some variables aimed at outlining a plantation typology in the context of planted forests [14, 15••], including the following: purpose, rotation length, use, intensity of management, scale of operation and ownership. Typology formulation could, however, benefit from an updated analysis for three main reasons: (1) existing typologies are not based on, nor aimed at a systematic formulation of plantation types founded on the comprehensive identification of relevant variables; (2) it is often unclear whether existing typologies are meant to be descriptive of plantation types, or explanatory of related ecological and socio-economic outcomes; and (3) proposed typologies almost exclusively deal with plantation forestry, excluding other types of plantations.

The aim of this review is thus to identify a comprehensive set of variables that can be used to describe the range of plantation types, specifically, but not exclusively, in the context of forestry.[1] Our typology is meant specifically for researchers and practitioners dealing with plantation-related issues, especially to provide a standardized basis for the analyses of ecological and socio-economic outcomes by means of literature reviews and/or empirical studies.

The rest of the manuscript is structured as follows: Sect. 2 explains the methods, including the process of variable identification; Sect. 3 describes and explains the variables in light of their influence on ecological and socio-economic outcomes and provides a testing ground and a code system for the typology using three case studies; Sect. 4 discusses the possible applications for the typology and outlines further research needs.

Methods

Theoretical Underpinning to the Formulation of Typologies

Typologies are used profusely in social science as analytical tools to categorize reality, albeit in a simplified manner. Typologies should aim at representing and possibly exhausting an overarching concept (in this article 'plantations') [17••, 18••]. Typologies are characterized by a kind hierarchy, meaning that the types are vertically related to the overarching concept. Definitions of technical terms are provided in Table 1.

The Identification of Variables for the Typology

The ideas proposed in this article are based on a participatory process that involved several expert researchers on planted forests, whose original aim was to produce a review of global literature synthesising the socio-economic outcomes of large-scale tree plantations on local communities [19]. Seven researchers from the Center for International Forestry Research (CIFOR) and the University of Helsinki were involved in developing a protocol to identify the correct framing for the study. Following initial meetings and brainstorm sessions among the authors, additional input was received from an additional group of seven experts and stakeholders from other organizations. Such organizations included the following: one expert in sustainable forestry from the World Wide Fund for Nature (WWF) Finland; five experts from international research organisations, namely the Finnish Natural Resources Institute, the University of Helsinki (Department of Forest Sciences, Helsinki University Centre for Environment, Department of Development Studies), CIFOR, the University of British Columbia (Faculty of Forestry); one expert from the private forest industry sector (Indufor Ltd).

The main challenge was to define the main units of analysis for the study, and in particular the term 'plantations'. The points of discussion, among others, were whether to include only wood and fibre sources and exclude foods and resins? Whether to include only tree species or also monocotyledons such as bamboo? Whether to consider industrial-scale plantations exclusively, or include smallholder and community initiatives? Whether to include plantations established under publicly funded restoration schemes? Whether to include outgrower schemes and other forms of contract tree farming? And how to define size and scale?

The issue of definitions, as often happens, was clearly multi-faceted, and exposed many grey areas. It represented, however, a fundamental step of the research design, since several stakeholders noticed that the final definition of 'plantation' would most likely influence the review findings and the consistency and generalisability of conclusions. Distinct types of plantations are in fact associated with, and embedded in specific ecological, socio-economic and political dynamics.

Once we eventually decided upon the plantation definition to adopt for the systematic review, we realized that the process used to decide was perhaps just as valuable as the research outcome itself. This process had in fact been highly participatory, interactive and deliberative, extending for several weeks and involving stakeholders with different interests and academic backgrounds. This allowed for a reflexive and iterative approach to depict the wide range of plantation types (Fig. 2). In this sense, researchers and experts can be considered repositories and analytical processors of scientific literature and knowledge.

We thus decided to formalize such knowledge in this article by means of formulating a plantation typology, to aid other researchers to discern among plantation types. Such formalisation consisted of synthesising the fundamental variables for a plantation typology. Once the variables were identified, we proceeded with the identification of some plantation types, supported by contextual examples based on existing scientific literature.

Limitations

The limitations of our formulation of plantation typology are discussed in reference to the following guidelines for typology formulation (a–d) [17••, 18••].

a. *Multidimensionality reduced to a matrix*

While many typologies can often be synthesized by two variables (cross-tabulated in a 2 × 2 matrix), some typologies may need more than two variables, resulting in a broader

[1] Including therefore all planted forests, i.e. semi-natural forests with planted components and plantations [16].

Table 1 Glossary of key technical terms

Term	Definition
Overarching concept	The overall concept measured by the typology.
Typology	An organized system of types that breaks down an overarching concept.
Type	The analytic units composing the typology.
Variable	An attribute or characteristic that is present or absent; or, alternatively, present or absent to varying degrees.
State	The possible states of a given variable along a scale, e.g. yes/no; high, medium, low.
Dimensionality	The number of variables that allow formulating different types within the typology.
Kind hierarchy	The hierarchical relation between the overarching concept and the types. All types are subordinated and influence the overarching concept.

To exemplify the glossary, we offer the following analogy. ‘Colours’ is an overarching concept, and its typology includes, among others, the following types: red, orange, yellow, green, blue, indigo and violet. The kind hierarchy implies that all the types described by the typology, e.g. red, orange, yellow, green, blue, indigo and violet, belong to the overarching concept of ‘colours’. These types can be discerned by a combination of variables, including for instance the colour temperature. This variable includes two possible states, i.e. cold colours or warm colours. The total number of variables describing the types indicates the number of dimensions of the typology. A typology expressed by only a single variable would be unidimensional and could be represented as a 1 × 1 matrix, or a scale; a typology expressed by two variables would be bi-dimensional, and could be represented as a 2 × 2 matrix, or a two-axis chart; a tri-dimensional typology could be expressed as 3 × 3 matrix, or a three-axis chart; typologies with more than three dimensions can be represented, for instance, with a branching tree diagram

matrix composed of several cells. Such is the case for the plantation typology presented in this article.

b. *Mutual exclusion and exhaustiveness of variables*

The variables should collectively contribute to exhaust the description of all plantation types. Furthermore, variables are usually mutually exclusive. Our methodological process was abductive, as we iteratively refined typology variables using the available literature and analytical process. We cannot, however, guarantee the identified variables to be exhaustive. In other words, other variables may exist that contribute to further discerning plantation types. The deliberative nature of the process does, however, provide a certain margin of confidence that the identified variables are the most relevant for a rather comprehensive identification of plantation typologies. While not common, non-exhaustiveness and non-exclusivity are accepted in the formulation of analytically interesting typologies. Rather than aiming to identify ideal types, i.e. perfect depictions of reality, our typology is oriented towards determining units that can be used for analytical purposes.

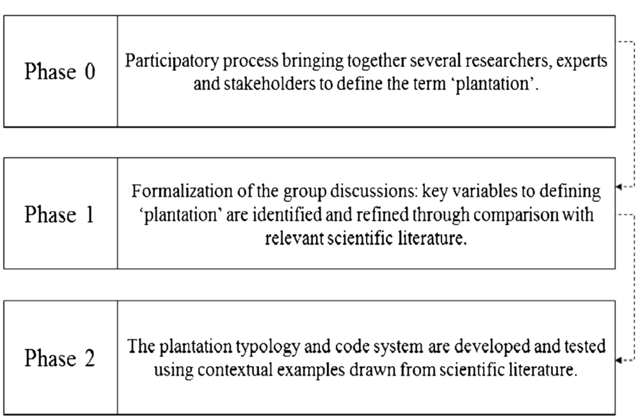

Fig. 2 The methodological process supporting this article

c. *Descriptive* vs *explanatory typologies*

Typologies can be descriptive or explanatory: the former include variables to describe the types, and the latter include variables that when combined allow to hypothesise and to explain outcomes. Our plantation typology is descriptive, since we aim at describing the variation in plantation types. Nonetheless, explanatory inferences can be evaluated on the ecological and socio-economic outcomes of individual plantation types based on descriptive typologies.

d. *Variable scales*

Conventionally, typologies are based on categorical variables (e.g. dichotomous and nominal). The use of interval, ordinal or even continuous variables is, however, not uncommon. In our plantation typology, some of these variables (e.g. characteristics of planted organism: tree/non-tree) are dichotomous, meaning that they only have two states which are mutually exclusive. Other variables can instead be understood as being ordinal (land ownership: public and private) or continuous (e.g. scale or management intensity: high-medium-low). Furthermore, the state of variables can be determined in absolute terms (e.g. species origin: native/exotic), while others are relative in the sense that they can only be determined in relation to each other and to the context (e.g. spatial scale: large-medium-small).

The Plantation Typology

Defining Variables

The typology is composed of 11 variables (Table 2): (1) characteristics of planted organism (tree/non-tree), (2) species composition (monoculture/mixed), (3) origin of planted species (native/exotic), (4) plantation purpose (economic, social and environmental), (5) plantation intended use (provisioning, regulating and cultural services), (6) land ownership (public and private), (7) management responsibility (public and private), (8) management intensity (high-medium-low), (9) scale (large-medium-small) and composition (monoculture/mixed) in landscape, (10) original initiator of plantation establishment (external and internal) and (11) level of institutional arrangements (high-medium-low).

1 Characteristics of planted organism

As a first step for the formulation of a plantation typology, we suggest distinguishing between tree and non-tree (e.g. grasses and herbaceous plants) plantations, because these have different life cycles, and therefore management requirements. Confusion may arise because of ambivalent terminology. In a strictly botanical sense, grasses are identified as monocotyledons and cannot undergo secondary growth. In a looser sense, herbaceous plants are defined in opposition to trees as having soft non-woody stems and a short reproductive cycle. Complementarily, trees are identified as being woody perennial plants, generally with a single stem bearing branches, and reaching a considerable height. For example, bananas, bamboos and palms are botanically speaking grasses (i.e. monocotyledons), but associated in some instances to trees because the stands of these plants have a forest like structure and appearance.

To solve this confusion, we adhere to the following definition of a tree, adopted by national and international forest organisations [8•]: plants capable of secondary growth reaching 5 m. This definition excludes for instance bamboo, palms, most fruit trees or agricultural crops, which are therefore all categorized under non-trees.

It should be noted that the other variables (2–11) included in this plantation typology were formulated and tested for tree plantations (Fig. 3). While we acknowledge that the typology might apply, partly or entirely, to non-tree plantations as well, we suggest that critical thinking is needed when applying the typology towards that use.

2–3 Composition and origin of planted species

Often, plantations are thought of as being mainly exotic monocultures of timber producing tree species established in tropical or subtropical regions (Fig. 6 in the appendix). Even though such plantations aimed at wood or fibre production in the tropics are dominant, the importance of native species plantations either in pure or mixed stands is increasing, in particular for the restoration of degraded lands [5••].

The number of different species or varieties planted contributes to enhanced biodiversity and ecosystem complexity, including, for instance, diverse and multi-strata canopies or flowering/seeding timing. Together with mixed species stands, using native species is often considered a fundamental

Table 2 Variables for the identification of plantation typology

Number	Variable	Variable states	Abbreviations
1	Characteristics of planted organism	Tree/non-tree	Tr/Nt
2	Species composition	Monoculture/mixed	Mo/Mi
3	Origin of planted species	Native/exotic	Na/Ex
4	Plantation purpose	Economic, social, environmental	Ec, So, Ec
5	Plantation intended use	Provisioning, regulating, cultural services	Pr, Re, Cu
6	Land ownership	Public, private	Pu, Pv
7	Management responsibility	Public, private	Pu, Pv
8	Management intensity	High-medium-low	Hi-Me-Lo
9	Scale and composition in landscape	Large-medium-small	La-Me-Sm
10	Original initiator of plantation establishment	External, internal	Ex, In
11	Level of institutional arrangements	High-medium-low	Hi-Me-Lo

The slash sign (/) is used to separate states that are generally dichotomous, e.g. tree/non-tree. The comma is used to separate states that are categorical (but may co-exist simultaneously), e.g. public and private. The hyphen is used to separate states that are ordinal, e.g. high-medium-low

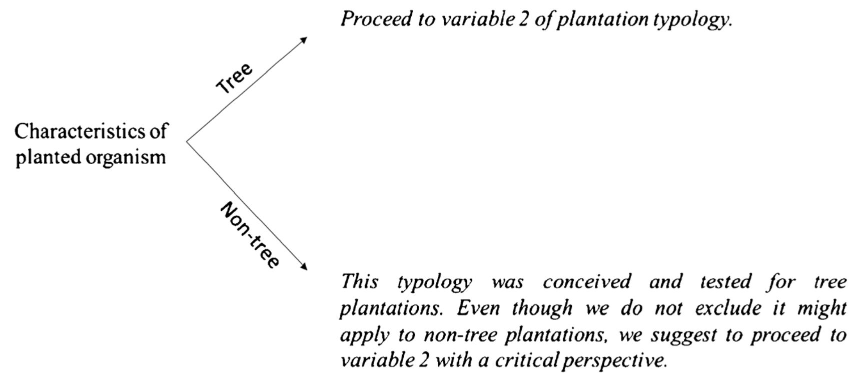

Fig. 3 The first variable of the plantation typology 'characteristics of planted organism' requires distinguishing between tree and non-tree plantations

prerequisite in afforestation for biodiversity and ecosystem conservation [10, 20]. This plantation typology thus requires distinguishing between monocultures and mixed plantations, and between plantations composed of exotic or native species.

4–5 Plantation purpose and intended use

Plantations are established to achieve various—and at times multiple—purposes that can be summarized as being economic, social and/or environmental. Plantations with economic or social purposes are also sometimes identified as productive plantations, i.e. oriented for domestic consumption or industrial production. Plantations with environmental purposes are sometimes also called protective plantations, and generally target the water-soil-nutrient nexus and/or carbon storage. Environmental plantations can also envelope social goals, for example promoting local development through carbon or biodiversity payments [21]. In reaction to the Clean Development Mechanism (CDM), and the Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes and related carbon markets, there has been an increase in recent years of plantations aimed at maximising carbon storage [22]. Since such plantations may also eventually be harvested or involve payments to local communities, they could also be considered a hybrid of economic, social and environmental purposes.

Given a certain purpose, intended uses include three states: provisioning, regulating and cultural. This categorisation is inspired by the Millennium Ecosystem Assessment [23] classification of ecosystem services. The uses can be multiple and not exclusive. Provisioning services include more tangible materials such as wood, fibres, fuels and resins for economic and social purposes, as well as edible products (e.g. fruits, seeds and syrups) (Fig. 4). Regulating services include carbon storage, soil protection and water regulation, pollination and habitat conservation. Cultural services include recreational activities, landscape beauty, spiritual values, sense of identity and belonging to a place.

Even though these states are not mutually exclusive, maximising provisioning services in very simple systems is generally detrimental to regulating services [5••]. Enhancement of regulating services most likely results in synergies with cultural services [24]. And while often successful in economic terms, simple production systems often fail to address other societal needs [2••].

6–7 Land ownership and management responsibility

Plantation ownership and management can be public or private, involving individual farmers, collectives, regional or state administrations and enterprises. These two states (public and private) are not mutually exclusive, in the sense that both land ownership and management responsibility can sometimes be of a mixed nature, including private and public entities. Furthermore, land tenure and management responsibilities can in some cases be disjointed, meaning that the entity managing the plantation is different from the entity owning the land. The case of China exemplifies this situation, whereby land is state or collectively owned but individual households are assigned land-use rights, which they exercise according to the government-defined land-use purpose [25]. The nature of land ownership and management is relevant to identifying plantation types because it can exert both positive and negative forces on local communities, for instance by influencing the status of, and access to plantation land and surrounding ecosystems and related services, and by influencing community life and relations, livelihoods, education and employment opportunities [26–28].

8 Management intensity

Plantations are, by definition, human managed systems, but management can be more or less intensive depending on the plantation's main purpose. Some studies have proposed proxies to determine the management intensity in semi-natural forests, including silvicultural practices and anthropogenic disturbances, such as plant spacing and age class, growth regime (natural regeneration vs artificial planting), rotation and cutting type, crop yield, irrigation, fertilizer and pesticide inputs and mechanization levels [29, 30]. Importantly,

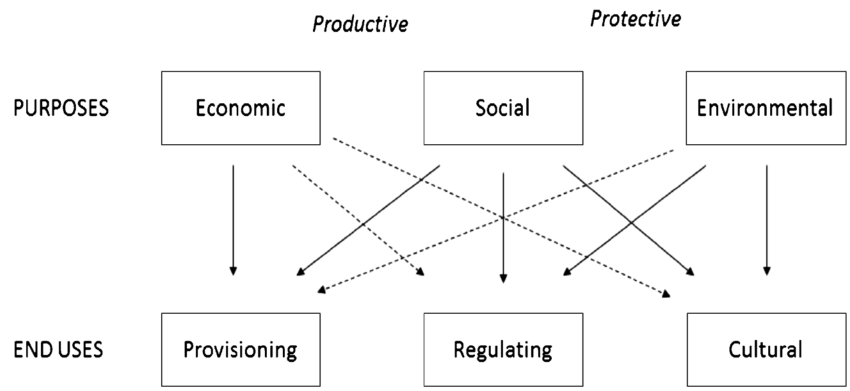

Fig. 4 The relationship between plantation purposes and uses

silvicultural practices also contribute to distinguishing between semi-natural forests with a planted component (native species established through planting, seeding and coppice) and plantations (exotic and native species, established through planting or seeding) as defined by FAO [16••] (Fig. 1). Another measure of management intensity is the difference between the current state and a reference natural state of the ecosystem [29].

Silvicultural practices specifically relevant in the context of plantations, and which are thus overlooked in the literature dedicated to semi-natural forests, regard the level of inputs (e.g. fertilizer and pesticides), level of extraction (e.g. % total biomass removed) and the level of modification (soil structural changes, tree species changes and genetic modification).

Management intensity is an important explanatory variable for plantation outcomes. Plantation estates of exotic monocultures managed on short rotation may provide maximum fibre supply but are likely to provide lower regulating and cultural services than a long rotation estate or mixed species and native tree plantations [5••]. Socio-cultural and ecological values are usually lower in highly managed plantations than in natural or semi-natural forests. Effects on biodiversity and ecosystem services largely depend on the condition of the original ecosystem being replaced by the plantation. For instance, plantations may have higher biodiversity levels than other intensive land uses such as agriculture [11, 21]. Intensively managed plantations, however, generally imply ecological trade-offs in the host and surrounding ecosystems [31]. Based on ecosystem functioning, several authors have discussed improved management practices for plantations to maximize synergies among desired ecosystem services, especially considering future challenges such as climate change [21].

9 Scale of plantations and composition in landscape

The physical scale of plantations can vary greatly. Trees on farms and woodlots planted by households and other smallholders tend to be very small, for example 0.2 ha is the average size in Amhara, Ethiopia [32]. Landholding fragmentation may more generally lead to landscapes similar to China, where relatively small forested patches are embedded into a mosaic of land uses [32]. Nonetheless, the lands of many smallholders or outgrowers can add up to a continuous large-scale area [33].

In South America, the continuous and very productive monoculture plantations generally extend for several hundreds of hectares [34]. In Uruguay, the average plantation size managed by non-industrial smallholders is around 150 ha, but private companies have started to buy or lease these lands two decades ago, eventually forming continuously forested blocks, some of which exceed 2000 ha [35]. Similarly, in Indonesia, plantations can occupy tens of thousands of hectares inside the concessions formed under public-private ownership [27], whereas in Spain the average size of the industry-managed eucalypt plantations is typically below 100 ha, with only the largest of them exceeding 400 ha [36].

When scale is considered responsible for certain outcomes, it is crucial to be understood in relation to the surrounding environment and the local perception of large and small [37]. It is equally important to distinguish between the landholding and the actual plantation area. The vast tracts of concessions in Indonesia, for example, may extend over hundreds of thousands of hectares, of which more than 50% may not be planted or suitable for plantations [38]. Moreover, in the statistics available, planted areas are often reported only at the regional level as detailed information regarding individual landholdings is rarely accessible. While categorization into small and large plantations can be performed at the regional or national level, no universal thresholds for scale seem to be meaningful due to the heterogeneity of contexts.

10–11 Original initiator of plantation establishment and level of institutional arrangements

Plantation establishment can be driven by external, top-down investments or arise from local level initiatives. By providing subsidies or know-how, governmental programmes can function as an engine for plantation development by individuals or communities at regional or national scales. Plantation establishment can also directly arise from bottomup initiatives, involving local communities in projects of communal or shared management. These two states (external and internal initiators) can, in some instances, co-exist. For example, when a plantation scheme is developed with a participatory process between an external entity (e.g. government and company) and local landholders, in some cases, external private investments can be a stimulus for locals to establish their own plantations based on imitation [26].

Motivations driving local landowners to afforest are complex, various and context-dependent, ranging from financial returns from forest products, to markets for ecosystem services, to nature conservation benefits [32, 39]. Such motivations are influenced by the landowners' economic and social condition, needs, ability to bear risks, access to capital and information and general level of empowerment [40].

Overall, different institutional arrangements can take place to combine the assets of investors (capital, technology and markets) with those of local communities and smallholders (land, labour and local knowledge). Such arrangements include land rental, contract farming and intermediate options, such as nucleus outgrower schemes [41]. The nature of such institutional arrangements influences plantations' environmental and social outcomes [42] because it involves various social actors in control of space and divisions and their power relationships [37, 43]. Examples include eco-compensation schemes or payments for ecosystem services, which are generally, but not exclusively, public-private agreements; and outgrowing schemes, which instead represent a more common form of private-private partnership established between smallholders and companies, where the former supplies wood resources to the latter for compensation.

Testing a Code System for Plantation Types

We propose that each plantation type can be described using a coding system. The code starts and terminates with square brackets [ ]. Within the brackets, the variables' states are described with an abbreviation (see Table 2). Each of the 11 variables must be described with one or more states. If the state of a variable is unknown, it can be signalled with a hyphen symbol -. The descriptions of the variables are separated by a vertical bar |. The code would thus look as so: [1|2|3|4|5|6|7|8|9|10|11], where the numbers represent the order of each variable.

In the following section, we test the code system using three selected cases (Table 3). The examples include the Chinese government-initiated smallholder conversion of cropland to forest programme, based on a public compensation scheme; the industrial scale, private-owned plantations in South America; and outgrower schemes in Southeast Asia, Africa and South America.

Case Study 1. China's Conversion of Cropland to Forest Programme

A range of regulations and economic instruments were introduced after China's catastrophic flooding and drought episodes in 1998 to promote the restoration of forests, hydrogeological systems and carbon storage. These included logging bans in the most sensitive areas and payments for ecosystem services or eco-compensation schemes at the regional and national scales [44, 45].

In 1999, China launched the nationwide Conversion of Cropland to Forest Program (CCFP) (Table 3). Also known as the 'Grain-for-Green' or the 'Sloping Land Conversion Program', the CCFP is considered a unique afforestation effort and the world's largest forest-related eco-compensation programme. The programme has invested more than USD 42 billion (by 2013), involving over 32 million rural households and 27 million ha of land converted [46].

The original intent of the policy was mainly to regulate ecosystem services (i.e. soil erosion and flood control), but after a couple of years, the scope of the programme expanded to include socio-economic goals, such as local development and livelihood support.

In the context of the CCFP, rural households are paid to revegetate sloping and marginal cropland that they previously managed under household leases. The compensation levels are regionally determined, and also depend on the purpose of the plantation (i.e. protection or production purposes). In addition to timber and non-timber trees, planted vegetation includes grasses, fruit and nut orchards. Over 27.55 million ha were converted, mainly into tree plantations [33].

Even though the land is managed by smallholders, the aggregated area of the tens of millions of small plots makes the programme large-scale at the landscape level, contributing to an already vast plantation area in China [47••]. Positive outcomes of the programme included the restoration of lost hydrogeological services at the local scale and increased household incomes; however, cases were also recorded of increased social inequality, diminished food security and trade-offs between provisioning services and biodiversity, and carbon sequestration and water and soil regulating services [33, 46].

Case Study 2. Industrial-Scale, Company-Operated Plantations in South America

Very few topics in forestry have raised as much controversy as industrial-scale, company-operated plantations. With generous state support as a core part of industrial development policies since the 1970s, this approach was prominently adopted in Brazil, Chile and Uruguay as a means to feed the newly planned pulp and paper mills and fulfil aims to develop

Table 3 Plantation types and codes from three case studies

<table>
<tr><th rowspan="2">Variables</th><th colspan="3">Case studies</th></tr>
<tr><th>1. China's Conversion of Cropland to Forest Program</th><th>2. Industrial-scale, company-operated plantations in South America</th><th>3. Smallholder outgrower schemes in Asia and Africa</th></tr>
<tr><td>1. Characteristics of planted organism</td><td>Mainly tree plantations, but also non-tree [Tr,Nt]</td><td>Tree plantations [Tr]</td><td>Tree and non-tree plantations [Tr]</td></tr>
<tr><td>2. Species composition</td><td>Mixed and monocultures [Mi,Mo]</td><td>Mainly monocultures [Mo]</td><td>Mainly monocultures [Mo]</td></tr>
<tr><td>3. Origin of planted species</td><td>Native and exotic [Na,Ex]</td><td>Mainly exotic [Ex]</td><td>Native and exotic [Na,Ex]</td></tr>
<tr><td>4. Purpose</td><td>Environmental and social [En,So]</td><td>Economic [Ec]</td><td>Economic [Ec]</td></tr>
<tr><td>5. Use</td><td>Primarily regulating services [Re]</td><td>Wood products [Pr]</td><td>Provisioning: wood, resins and food products [Pr]</td></tr>
<tr><td>6. Land ownership</td><td>Public [Pu]</td><td>Private [Pv]</td><td>Public or private [Pu,Pv]</td></tr>
<tr><td>7. Management responsibility</td><td>Private, smallholders [Pv]</td><td>Private [Pv]</td><td>Private [Pv]</td></tr>
<tr><td>8. Management intensity</td><td>From low to high, depending on the context [Lo,Me,Hi]</td><td>High [Hi]</td><td>Lower than large-scale company-operated plantations [Me,Lo]</td></tr>
<tr><td>9. Scale and composition in landscape</td><td>Large area in aggregate and fragmented [La]</td><td>Very large [La]</td><td>Medium-large and fragmented [Me,La]</td></tr>
<tr><td>10. Original initiator of plantation establishment</td><td>External (government-driven) [Ex]</td><td>External [Ex]</td><td>External or internal [Ex,In]</td></tr>
<tr><td>11. Level of institutional arrangements</td><td>High: the government compensate smallholders for changing land-use practices [Hi]</td><td>Low [Lo]</td><td>High: the company pays smallholders for providing input resources [Hi]</td></tr>
<tr><td>Codes</td><td>[Tr,Nt|Mi,Mo|Na,Ex|En,So|Re|Pu|Pv|Lo,Me,Hi|La|Ex|Hi]</td><td>[Tr|Mo|Ex|Ec|Pr|Pv|Pv|Hi|La|Ex|Lo]</td><td>[Tr|Mo|Na,Ex|Ec|Pr|Pu,Pv|Pv|Me,Lo|Me,La|Ex,In|Hi]</td></tr>
</table>

a world-class plantation-based forest industry [48, 49] (Table 3).

In contrast to African and Asian industrial-scale plantations, which are often established on lands leased from the state [26, 27, 50], their counterparts in South America are often owned and controlled directly by corporations [1]. In Brazil, most plantations are located along the Atlantic coastline adjacent to the mills and ports, mostly in the states of São Paolo and Bahía, and in most cases established on lands first cleared of natural forests centuries ago [51]. Brazil was also the first country in the world to approve genetically engineered tree plantations on a commercial scale in 2015 [52]. Plantations in Chile are mostly located in its south-central region and have been associated with clearances of natural forests in the last decades [48]. Uruguayan plantations were planted on vast tracts of former pampas grasslands that had been used for cattle grazing [53]. Common to all countries is the use of eucalypts and pines, which can grow very fast under the favourable environmental conditions.

The South American plantations generally occupy hundreds of hectares, often in the immediate vicinity of a mill [34, 54]. Despite some recent attempts by the companies to establish outgrower schemes [55] or expand plantation access to locals [53], most of these plantations are characterized by a low level of economic or political inclusiveness—both in Chile and Brazil, conflicts with social movements and indigenous groups for this and many other reasons have been widespread [56]. In Uruguay, conflicts have been less prominent due to clearer land tenure, among other reasons [35].

Case Study 3. Smallholder Outgrower Schemes in Asia and Africa

Smallholder plantations represent a source of income for rural households in developing and emerging countries. The establishment of such plantations can be motivated by external phenomena (e.g. imitation of nearby large-holders; governmental project) or arise from an internal drive, i.e. small local actors. The resources from the plantations may be used for personal consumption and/or sold or exchanged in local markets. In addition, partnerships may occur among local companies and smallholders, where companies (e.g. pulp and paper) pay the latter for providing input resources (e.g. wood) for their operations. Such companies may rely on outgrowers to complement or entirely meet their resource supply.

Variants of such outgrower schemes, also known as contract-farming, have been recorded in several countries [57]. Examples of smallholder involvement in commercial rubber and eucalypt plantations have been reported for India, Thailand, Southern China, Indonesia, Papua New Guinea and South Africa [58, 59].

Outgrower models can have mixed environmental outcomes. Positive effects may arise for instance in the context of multipurpose forestry, and negative effects may arise if plantations are established after clearance of natural ecosystems, or if sustainable management standards are not implemented [56].

These forms of private-private partnership can be beneficial to smallholders by means of community knowledge-based empowerment, capacity building, innovation transfer, local market growth and higher income compared to independent farming [59]. Risks associated with outgrowing partnerships may, however, include diminished livelihood resilience and independency; power imbalance between companies and smallholders, which may affect the decision or bargaining power of the latter; and exacerbation of social inequalities in the local communities (if contracts are not equally accessible by the farmers due to different levels of information, status or land resources) [58, 60]. Community-investor partnerships should not be considered as a 'silver bullet for reconciling private investment with local aspirations' [35, p.1].

Discussion and Conclusions

In this article, we have developed a plantation typology composed of 11 variables that describe the variation within plantation types (Table 2). We have described the relevance of such variables given their influence on ecological and socio-economic outcomes within and around plantation establishment. Moreover, we have exemplified and tested our typology by means of three contextually grounded case studies. As a result, we propose a code system that would allow researchers and practitioners to systematically describe each possible plantation type.

The purpose of the plantation typology is to aid researchers and practitioners dealing with ecological and socio-economic outcomes, mainly, but not exclusively, in the context of forestry. The typology and code system presented in this article are needed to ease searchability and comparability among cases [13••]. For example, in medical sciences, where systematic reviews are well-established, the terminology and related typologies are very clear, which facilitates searching for studies and comparing their results. The need for these kinds of comparisons are particularly pressing in forestry, since the debate is ongoing and there remains no evidence-based consensus as to the benefits and costs of plantations [61]. An additional value of our plantation typology is the possibility to model which combination of variables are most likely to produce the desired or undesired outcomes of certain plantation types [15••].

There is one main limitation of the typology that needs to be taken into consideration while applying it in practice. Identifying the state of each of the variables requires determining thresholds. However, as described in Sect. 3, universal thresholds cannot be determined for most of the variables, because of their context-specific nature. For example, the plantation scale (large-medium-small) can be defined only in measure of its surroundings at the landscape level [5]. Since universal thresholds cannot be determined, the correct application of the typology to a certain context depends on the judgement of the individual user. It is thus unlikely that consistency can be guaranteed across different users and studies. If applied coherently, however, the typology allows internal consistency to be maintained within individual studies. Furthermore, transparent and detailed reporting of the thresholds used in individual studies would help calibrate case study comparisons.

Future research could focus on further testing and refining the typology and the coding system by means of both conceptual and empirical analysis and identifying and developing regional or national-level thresholds for the typology variables.

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Compliance with Ethical Standards

Conflict of Interest Drs D'Amato, Malkamäki, Hogarth and Baral declare that no conflict of interest is reported.

Human and Animal Rights and Informed Consent This article contains no studies with human or animal subjects performed by the authors.

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FOREST OWNERS ASSOCIATION

Facts & Figures

2016/17

NEW ZEALAND PLANTATION FOREST INDUSTRY

Contents

SECTION 1

New Zealand Planted Forestry Highlights

New Zealand Planted Forestry Highlights

1,704,747 ha is the estimated net stocked plantation forest area at 1 April 2016. This is a reduction in the plantation area of 12,968 ha from 1 April 2015.

1

A RECORD **30.7 million m³** OF TIMBER WAS HARVESTED IN 2016, AN INCREASE OF 6.4% ON 2015, WITH 31.4 MILLION M³ EXPECTED TO BE HARVESTED IN 2018, ASSUMING LOG PRICES REMAIN STRONG.

2

$5.47 billion was the export value of forest product exports to June 2017, comprising $2.69b of logs and $2.8b of non-log forest products.

3

$3.55 billion is the total contribution of the forest industry to New Zealand's GDP; $1.39b from forestry and logging and $2.16b from downstream activity.

4

Source **Box 1** NEFD 2016
Source **Box 2 &3** SOPI December 2017
Source **Box 4** NZIER March 2017

New Zealand Planted Forestry in Summary

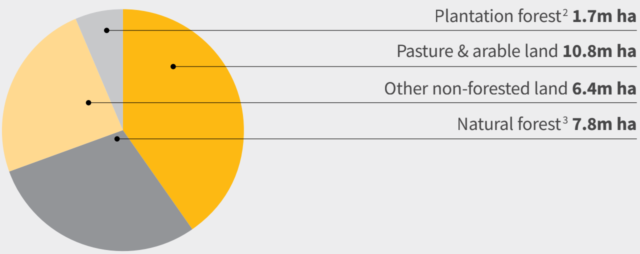
Area and standing volume statistics	1 April '14	1 April '15	1 April '16
Net stocked forest area (ha)			
Total estimated area	1,733,400	1,717,700	**1,704,747**
Growth characteristics			
Standing volume (000 m³)	488,603	501,716	**501,460**
Average standing volume (m³/ha)	282	292	**294**
Area-weighted average age (years)	16.8	17.1	**17.08**
Area by species (ha)			
Pinus radiata	1,559,100	1,544,500	**1,532,734**
Douglas-fir	105,100	105,000	**104,173**
Cypress species	9,900	10,100	**10,140**
Other exotic softwoods	23,000	22,400	**22,743**
Eucalyptus species	23,800	23,300	**23,182**
Other exotic hardwoods	12,500	12,500	**11,775**
Planting statistics	**Year ended 31 Dec '13**	**Year ended 31 Dec '14**	**Year ended 31 Dec '15**
New planting (ha)			
Total estimated new planting	3,500	2,500	**3,000**
Restocking	40,867	41,533	**39,948**
Harvested area awaiting restocking	44,642	53,903	**50,491**
Harvesting statistics	**Year ended 31 Mar '14**	**Year ended 31 Mar '15**	**Year ended 31 Mar '16**
Harvesting (ha)			
Area clear felled (ha)	46,001	49,896	**45,342**
Volume clear felled (TRVIB[1],000 m³)	23,437	26 ,492	**25,008**
Volume production thinned (TRVIB[1],000 m³)	244	325	**419**
Total volume removed (TRVIB[1],000 m³)	23,681	26,818	**25,427**
Average clear fell yield (m³/ha)	515	537	**552**
Area-weighted average clear fell age for *Pinus radiata* (years)	28.9	28.4	**29.1**
Estimated planted forest roundwood removal (000m³)[2]	30,258	29,602	**28,794**

Notes
[1] TRVIB is an abbreviation for Total Recoverable Volume Inside Bark.
[2] This is an indirect estimate based on the application of conversion factors to the various forest products.

Source **New Zealand Planted Forestry in Summary** NEFD 2014, 2015 & 2016

Land Use and Returns

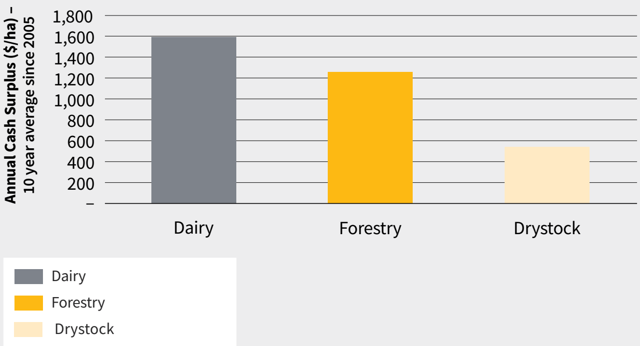
New Zealand Land Use[1]



Export Value Comparisons

Product	Area farmed[4] pasture only (hectares)	Export earnings (fob) average 2011-15	Export earnings per hectare
Red meat + Wool & hides[5]	5,397,855	$7,933,000,000	$1,470
Dairy Products	2,110,569	$13,356,000,000	$6,328
Forestry	1,684,209	$4,747,000,000[4]	$2,819

Annual Cash Surplus[6]



Notes

[1] Some data has not been revised since 2013.
[2] Plantation forest excludes harvest area awaiting replanting.
[3] This figure now includes regenerating natural forest as well as established natural forest.
[4] Farmed areas from Statistics NZ website, using "pastureland" only for beef, sheep and deer farms and excluding other land categories, notably mature and regenerating native bush. Forestry areas are based on plantations of exotic trees and harvested areas awaiting restocking including such land on various farm types, but again excluding mature and regenerating native bush. These areas are dated 30th June 2012.
[5] These figures are the average for 2014 and 2015 only.
[6] Dairy and Forestry is 10 year averages since 2005. Drystock is for East Coast hill country. Beef & Lamb NZ data.

Source **New Zealand Land Use** Various
Source **Export Value Comparisons** Statistics NZ
Source **Annual Cash Surplus** Scion Nov 2015

Comparative Export Earnings and Predictions

MPI anticipates that in the year to June 2018 export returns from New Zealand forest product exports will be **$5.66 billion**, which is ahead of horticulture returns. [1]

MPI Predictions for Primary Industry Sector Export Values 2021

($billions)

MPI Predictions for Primary Industry In-sector Export Values 2021

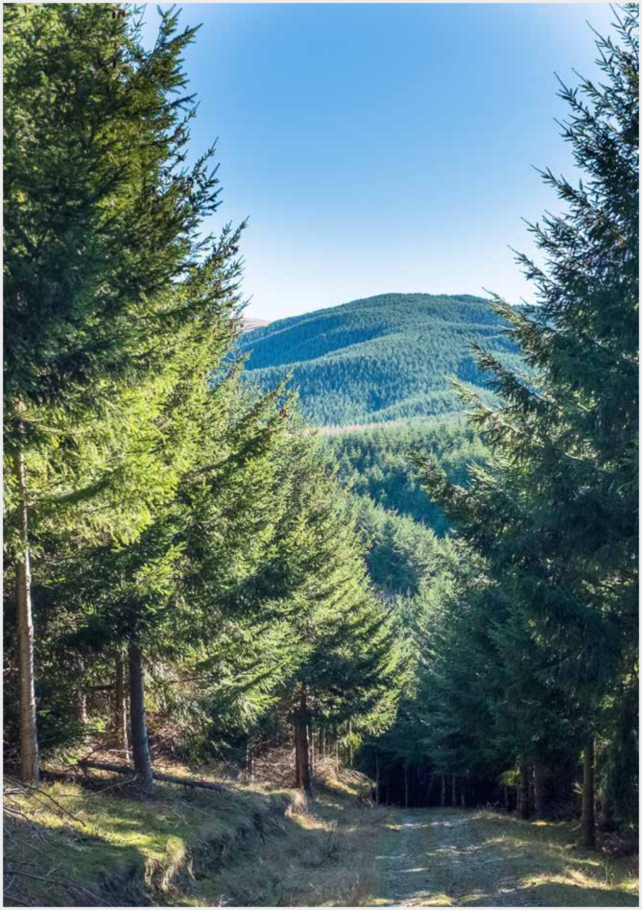
($billions)

Export	Billions $
Whole milk powder	$6.63
Butter, AMF & cream	$3.83
Non-log forestry	$3.14
Logs	$3.13
Sheepmeat	$3.02
Beef	$2.86
Kiwifruit	$2.22
Wine	$1.87
Wild capture seafood	$1.53
Skim milk & butter milk powder	$1.52
Apples & pears	$1.01
Wool & wool products	$0.91
Honey	$0.37

Source **Box 1** SOPI December 2017
Source **MPI predictions for Primary Industry In-sector & Sector Export Values 2021** SOPI June 2017

Contribution of the Main Plant Species to New Zealand GDP

Plant	Total impact on GDP in 2012	Ranking #
Ryegrass	$14,537,000,000	1
Pinus radiata	$4,454,000,000	2
Clover	$2,334,000,000	3
Kiwifruit	$807,000,000	4
Douglas-fir	$200,000,000	12
Eucalyptus	$41,000,000	23
Cypress	$17,000,000	32

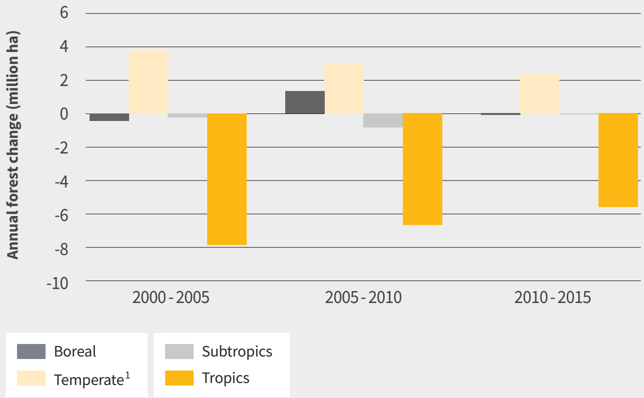


Source **Contribution of the Main Plant Species to New Zealand GDP** NZIER July 2016

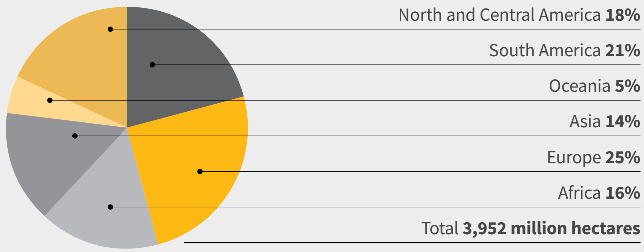
Global Forests

Net Annual Average Forest Area Change, by Climatic Domain

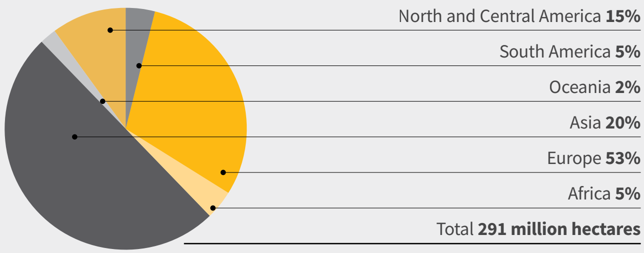
(million ha per year)



Global Forest Areas



Global Planted Forest Areas



Notes

[1] New Zealand = Temperate.

Source **Net Annual Average Forest Area Change** FAO State of the World's Forests 2016

Source **Global Forest Areas & Planted Forest Areas** FAO Global Forest Resources Assessment 2015

46% *Pinus* spp. makes up approximately 46% of the estimated 53.4 million hectares of planted production forest worldwide, with Eucalypts the next largest at 26%.

1

ACCORDING TO THE FAO "AFFORESTATION IS THE ACT OF ESTABLISHING FORESTS THROUGH PLANTING AND/OR DELIBERATE SEEDING ON LAND THAT IS NOT CLASSIFIED AS FOREST, WHILE REFORESTATION REFERS TO THE RE-ESTABLISHMENT OF FOREST THROUGH PLANTING AND/OR DELIBERATE SEEDING ON LAND CLASSIFIED AS FOREST, FOR INSTANCE AFTER A FIRE, STORM OR FOLLOWING CLEARFELLING."

2

Source **Box 1** FSC Strategic Review on the Future of Forest Plantations 2012
Source **Box 2** FAO Global Forest Resource Assessment 2010

SECTION 2

New Zealand Planted Forestry

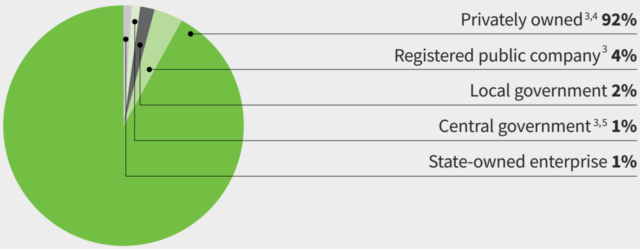
Planted Forest Mix and Ownership

The trees in **90%** of all New Zealand planted forests are *Pinus radiata*, with most of the rest growing in the South Island.

1

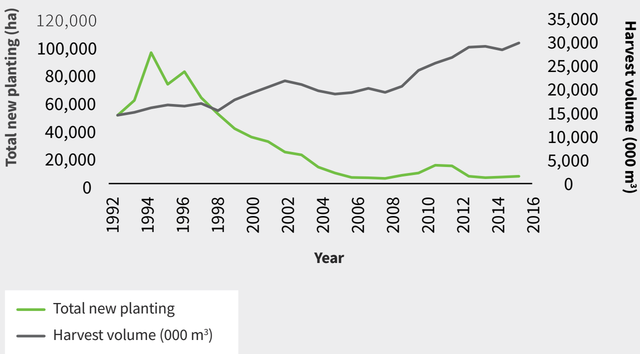
Planted Forest Ownership [1,2,6]

As at 1 April 2016



Forestry Plantings and Harvest Volumes

Year ended December 1992–2016



Notes

1 Ownership is based solely on the ownership of the forest irrespective of the ownership of the land.
2 Net stocked planted production forest area.
3 Note that significant changes in forest ownership occurred during 2003 resulting in large areas of forest previously owned by public companies now being privately owned.
4 "Privately owned" includes all privately owned forests. The legal entities included in this category are private companies, partnerships, individuals and trusts, which include Māori trusts and incorporations.
5 "Central Government" forests are predominantly Crown owned forests on Māori leasehold land. These forests are managed by the Ministry for Primary Industries.
6 Individual entries may not sum to totals shown due to rounding.

Source **Box 1 & Planted Forest Ownership** NEFD 2016
Source **Forestry Plantings and Harvest Volumes** Statistics NZ & MPI

Commercial Planted Forest Ownership and Management[1]

Forest Owner/Manager	Net stocked forest area (ha) 2012 As at 1 April	2014 As at 31 Dec	2015 As at 31 Dec	2016 As at 31 Dec
Hancock Natural Resource Group	235,000	225,000	219,000	189,084
Kaingaroa Timberlands	174,000	175,000	175,740	176,152
Rayonier/Matariki Forests	121,000	118,060	115,287	121,112
PF Olsen Ltd	71,000	109,182	115,766	115,766
Global Forest Partners LP	84,000	84,960	73,191	73,191
Ernslaw One	109,000	113,159	105,644	106,002
Crown Forestry (MPI)	46,000	19,000	17,081	12,772
Juken New Zealand	31,000	32,100	32,299	22,993
Pan Pac Forest Products	34,000	35,200	34,436	34,230
GMO Renewable Resources	26,000	19,000	19,990	19,250
Hikurangi Forest Farms	25,000	25,000	26,581	24,757
Wenita	25,000	27,570	25,210	24,020
Roger Dickie NZ	26,000	26,576	26,576	27,000
Port Blakely NZ Ltd	23,000	23,222	24,837	25,324
Forest Enterprises	21,000	21,000	20,000	19,727
City Forests	16,000	16,300	16,469	16,795
Lake Taupo Forest Trust	16,000	17,795	18,726	21,109
Summit Forests NZ Ltd	–	23,700	24,622	27,783
Ngāi Tahu Forest Estates Ltd	–	25,950	25,950	27,250
Others (under 10,000 ha)	629,000	629,556	644,150	644,150
Total Plantation Forest Area	**1,712,000**	**1,767,330**	**1,761,555**	**1,728,467**

Notes for page 13 and 14:

1 Where available, figures, from 2016 have been used – otherwise figures are from 2015.
- Kaingaroa Timberlands is managed by Timberlands Ltd.
- GMO Renewable Resources is a shareholder in Wenita.
- Roger Dickie NZ Forests are managed by Forest Management NZ LTD.
- Lake Taupo Forest Trust is managed by New Zealand Forest Managers.
- Others (under 10,000 ha) are estimated numbers only.
- Crown land includes land leased under Crown Forest Licence.
- Kaingaroa Timberlands is 42% owned by the NZ Superannuation Fund.

Source **FOA**

Ownership of Forest Land[1]

Firm/Entity	Underlying Land Status (Productive area (ha))				
	Freehold	Leasehold			Total
		Crown	Māori Inc.	Other	
Hancock Natural Resource Group	89,507	8,028	71,025	31,730	200,290
Kaingaroa Timberlands	1,393	–	181,869	1	183,263
Rayonier / Matariki Forests	54,544	30,893	28,961	5,800	120,198
Global Forest Partners LP	43,687	–	49,053	925	93,665
Ernslaw One	57,334	43,818	9,542	–	110,694
Crown Forestry (MPI)	1,522	–	10,404	2,368	14,294
Juken New Zealand	9,947	12,000	9,881	1,111	32,939
Pan Pac Forest Products	4,809	15,736	15,020	81	35,646
GMO Renewable Resources	17,850	–	1,460	340	32,939
Hikurangi Forest Farms	25,570	–	2,218	296	28,084
Wenita	5,620	–	–	19,590	25,210
Roger Dickie NZ	26,576	–	–	–	26,576
Port Blakely NZ Ltd	23,688	–	–	1,149	24,837
Forest Enterprises	20,410	–	–	–	20,410
City Forests	15,219	–	–	1,250	16,469
Lake Taupo Forest Trust	21,109	–	1,007	579	22,695
Summit Forests NZ Ltd	1,319	19,255	2,947	1,101	24,622
Ngāi Tahu Forest Estates Ltd	25,700	–	–	250	25,950
Totals	**445,804**	**129,730**	**383,387**	**66,571**	**1,038,781**

Notes:
[1] Where available, figures, from 2016 have been used – otherwise figures are from 2015.

Plantation Forest Management Statistics[1]

Firm/Entity	Forest Management (ha)	
	Investment Management (TIMO)[2]	Property Management[3]
Hancock Natural Resource Group	189,084	–
Hancock Forest Management	–	157,011
Kaingaroa Timberlands	–	183,263
Rayonier/Matariki Forests	–	–
PF Olsen Ltd	2,567	154,539
Global Forest Partners LP	10,215	73,191
Ernslaw One	–	–
Crown Forestry (MPI)	–	–
Juken New Zealand	–	–
Pan Pac Forest Products	–	35,624
GMO Renewable Resources	19,650	-
Hikurangi Forest Farms	–	–
Wenita	29,668	35,568
Roger Dickie NZ	27,000	–
Port Blakely NZ Ltd	–	–
Forest Enterprises	20,265	–
City Forests	–	–
Lake Taupo Forest Trust	–	–
Summit Forests NZ Ltd	29,047	29,047
NZ Forest Managers	–	88,500
Totals	**268,468**	**732,769**

Notes:
[1] Where available, figures, from 2016 have been used – otherwise figures are from 2015.
This table is designed to identify who **manages** NZ forests.
Within "management" there are 2 main categories:
[2] Timberland Investment Management (commonly referred to as a TIMO).
These organisations do not own any forest. Greenplan, Roger Dickie and Forest Enterprises are TIMOs, along with GMO RR, Hancock Natural Resource Group, New Forests, GFP etc. The forests are owned by retail investors or institutional funds.
[3] Property Management.
Planning and managing field operations, mapping and maintaining records.
Some entities carry out both functions within the same organisation, others carry out both for some parts of a forest estate and not others.

Source **FOA**

Environmental Certification[1]

Company	Forest Management area (ha)	
	FSC	PEFC
Hancock Natural Resource Group	184,228	156,332
Hancock Forest Management	156,332	156,332
Kaingaroa Timberlands	183,263	183,263
Rayonier/Matariki Forests	159,379	–
PF Olsen Ltd	52,446	5,273
Global Forest Partners LP	–	
Ernslaw One	142,922	–
Crown Forestry (MPI)	–	–
Juken New Zealand	40,869	
Pan Pac Forest Products	34,230	–
GMO Renewable Resources	13,630	–
Hikurangi Forest Farms	35,013	
Wenita	32,311	–
Roger Dickie NZ	–	–
FMNZ	–	–
Port Blakely NZ Ltd	34,342	–
Forest Enterprises	–	–
City Forests	20,860	–
Lake Taupo Forest Trust	21,109	–
Summit Forests NZ Ltd	29,047	–
Ngāi Tahu Forest Estates Ltd	26,150	–
NZ Forest Managers	57,000	–
Others (under 10,000 ha)	–	–

As of August 2016, there were
1,240,724 ha of New Zealand
forests certified by the Forest Stewardship Council.

Notes:
[1] Where available, figures, from 2016 have been used – otherwise figures are from 2015.
* From pg 5, Nsa 1,771,618 + area awaiting restocking 53,903 = 1,825,521

Source **FOA**

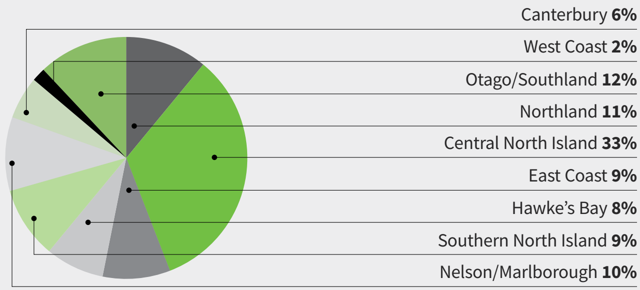
Planted Forests by Location

As at 1 April 2016

Estimated Total Forest Area[1,2]

Region	Estimated Total Forest Area (HA)		
	2014	2015	2016
Northland	191,512	188,416	**185,939**
Central North Island	573,966	569,297	**567,781**
East Coast	156,432	155,079	**156,099**
Hawke's Bay	133,324	134,841	**133,746**
Southern North Island	162,779	164,748	**159,977**
Nelson/Marlborough	168,421	169,783	**166,798**
West Coast	31,775	31,205	**31,422**
Canterbury	108,371	98,223	**96,860**
Otago/Southland	206,885	206,123	**206,126**
Total	**1,733,465**	**1,717,715**	**1,704,747**

Plantation Forests 2016[1,2]



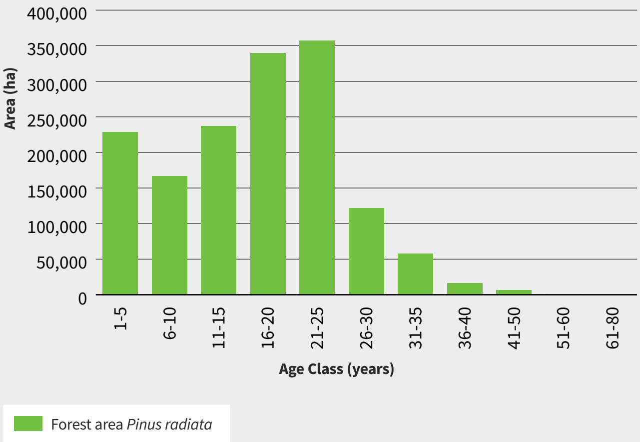
Notes
[1] Net stocked planted production forest area.
[2] Individual entries may not add to totals due to recording.

Source **Estimated Total Forest Area & Plantation Forests 2016** NEFD 2016

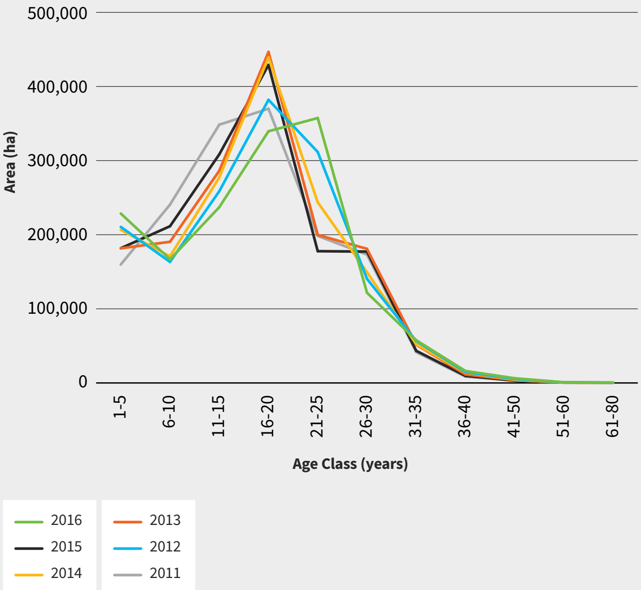
Net Stocked Area of *Pinus radiata*

By Age Class as at 1 April 2016

Forest Area 2016 by Annual Age Class[1]



Age Class Over Time 2011-2016[1]



Notes

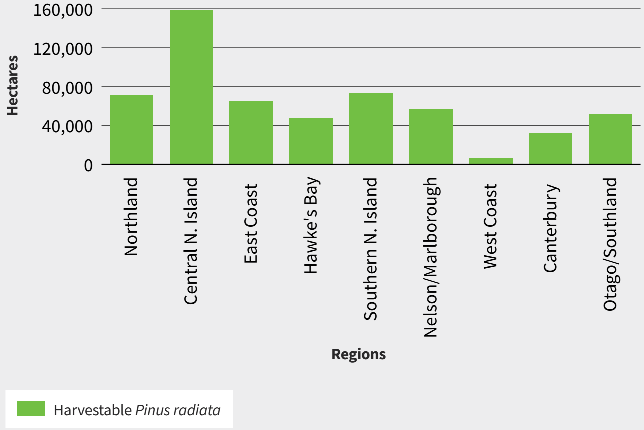
[1] The area is shown for each age in single years up to 35 years. After this, age classes are aggregated.

Source **Forest Area by Annual Age Class & Age Class Over Time** NEFD 2016

Harvestable *Pinus radiata*

Forest Area Planted in *Pinus radiata*

Of Harvestable Age (21+) Per Region (ha)

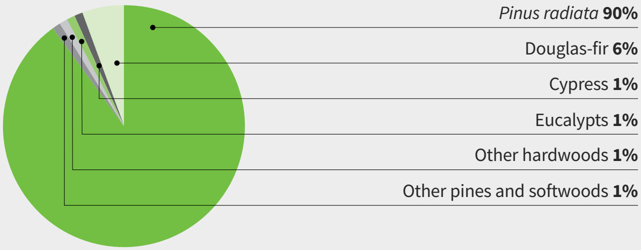


Source **Forest Area Planted in Radiata Pine** NEFD 2016

Plantation Species (ha)

As at 1 April 2016

Species Distribution - 2016 [1]



Minor plantation species

Other pines; *P. nigra, P. muricata, P. ponderosa*

Other softwoods; *Redwoods, Larch, Cryptomeria*

Indigenous species; *Kauri, Totara*

Other hardwoods; *Poplars, Acacia, Willows, Black Walnut, Paulownia, Oaks*

Eucalypts; *E. obliqua, E. fastigata, E. regnans, E. nitens, E. saligna, E. botryoides, E. pilularis, E. muelleriana, E. globoidea.*

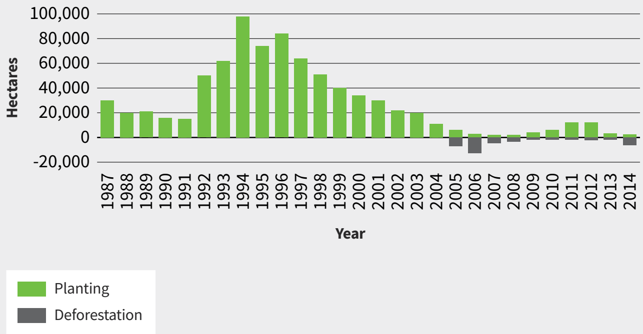
Approximate Harvest Age Over the Past Five Years

Species	Harvest Age
Pinus radiata	29 years
Douglas-fir	40 years
Cypress	34 years
Eucalypts	21 years

Source **Species Distribution – 2016** NEFD 2016
Source **Approximate Harvest Age Over the Past Five Years** SOPI June 2017

New Forest Planting and Deforestation

New Forest Planting (1987) and Deforestation (since 2005) [1,2]



Tree Stock Sales from 2009 to 2016

	Tress Stock Sales in Millions							
	2009	2010	2011	2012	2013	2014	2015	2016p
Pinus radiata	37.7	46.4	58.9	64.6	48.5	47.2	45.8	49.3
Total	**43.2**	**53.2**	**67.6**	**72.5**	**54.11**	**50.8**	**49.51**	**52.7**

p Provisional

Notes
[1] These estimates do not include immature forest cleared for other land uses.
[2] 2011 Deforestation figure: www.maf.govt.nz/news-resources/statistics-forecasting/statistical-publications/national-exotic-forest-description

Source **New Forest Planting (1987) and Deforestation (since 2005) & Box 1** NEFD 2016
Source **Tree Stock Sales from 2009 to 2016** MPI, Tree Stock Sales and Forest Planting in 2016

Typical Log Out-turn

Direct Sawlog Regime

Pruned and thinned. Final Crop Stocking 228 stems per hectare.

	Length	Volume	Value
Waste	8 m	0.18 m³	0%
Industrial grade logs	8 m	0.31 m³	7%
Sawlogs	15 m	1.15 m³	43%
Pruned logs	5 m	0.64 m³	50%
Stump	0.2 m	0.03 m³	0%
Total	**36 m**	**2.3 m³**	**100%**

Structural Regime

Pruned and thinned. Final Crop Stocking 487 stems per hectare.

	Length	Volume	Value
Waste	8 m	0.24 m³	0%
Industrial grade logs	8 m	0.41 m³	20%
Sawlogs	19 m	0.95 m³	80%
Pruned logs	0 m	0.00 m³	0%
Stump	0.2 m	0.01 m³	0%
Total	**35 m**	**1.61 m³**	**100%**

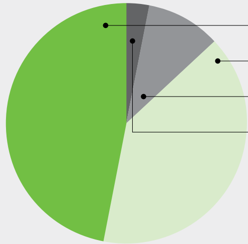
Notes
[1] Average site (Site Index 29 m, 300 Index 23 m³/ha/yr). Clearfelled at 28 years.

Source **Direct Sawlog Regime & Structural Regime** Scion

Forest Management Trends

For Year Ended 31 Dec 2016

Pinus radiata by Tending Regime – 2016

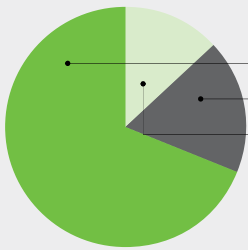


	%	2014 Hectares[1]	%	2015 Hectares[1]	%	2016 Hectares[1]
Unpruned without production thinning	41%	689,800	45%	700,00	**47%**	**715,100**
Pruned without production thinning	44%	651,000	41%	637,600	**40%**	**619,700**
Pruned with production thinning	13%	183,700	11%	173,500	**10%**	**158,200**
Unpruned with production thinning	2%	35,000	2%	33,300	**3%**	**39,700**

The area under an unpruned management regime continues to grow, to now about **50%** of the *Pinus radiata* forest estate. The area of production thinned *radiata* forest is also decreasing, now to about 13%.

1

Pinus radiata Harvest Volume by Log Type



Notes
[1] Hectares rounded to nearest hundred thousand.

Source ***Pinus radiata* by Tending Regime & Radiata Pine Harvest Volume by Log Type** NEFD 2016

Log Flow in the New Zealand Forestry Industry

Year Ended December 2016p

From natural forest
24,000

From plantation forest
30,491,000

Total log input
30,515,000

Log export
17,429,000

Processed in New Zealand
13,062,000

Forest residues
Not available

Processed in New Zealand
13,062,000

Chip export
300,000

Poles
400,000

Sawlogs and peelers
8,685,000

Pulp
2,793,000

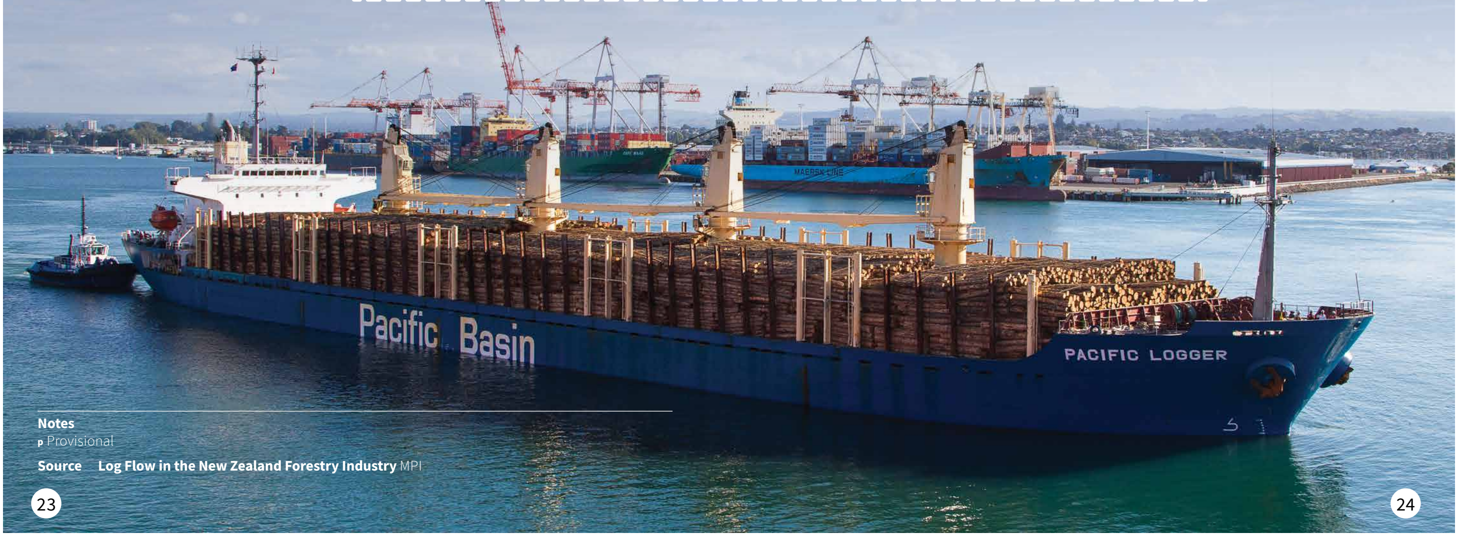
Reconstituted panels
884,000

Plywood
1,045,000

Sawmills
7,640,000

Plant residues (estimated)
3,908,250

Energy
Not available

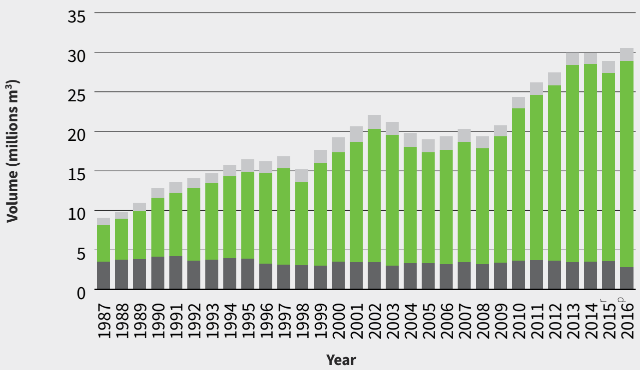


Notes
p Provisional

Source **Log Flow in the New Zealand Forestry Industry** MPI

Plantation Forest Harvest

for Year Ended 31 Dec 2016

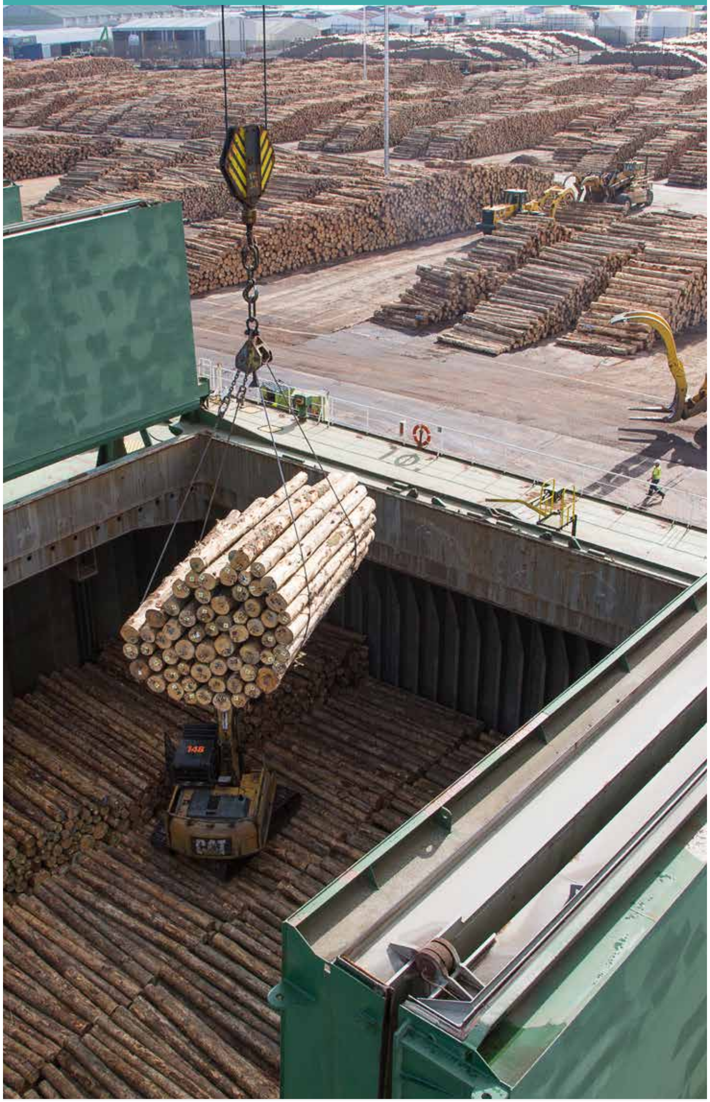


r Revised p Provisional

Source **Plantation Forest Harvest** MPI, MAF

SECTION 3

Export and Production



Top Export Destinations*

For Year Ended 31 Dec 2016

1. China (People's Republic of)
$NZ 2,222,935

Logs and poles	81.55%
Sawn timber/sleepers	5.71%
Wood pulp	9.27%
Paper and paperboard	2.15%
Panel products	1.14%
All other	0.19%

2. Australia
$NZ 597,300

Logs and poles	0.40%
Sawn timber/sleepers	21.49%
Wood pulp	14.71%
Paper and paperboard	23.67%
Panel products	21.57%
All other	18.16%

3. Korea (Republic of)
$NZ 482,794

Logs and poles	77.85%
Sawn timber/sleepers	6.89%
Wood pulp	10.96%
Paper and paperboard	3.84%
Panel products	0.46%
All other	0.00%

7. Indonesia
$NZ 117,366

Logs and poles	0.00%
Sawn timber/sleepers	25.49%
Wood pulp	50.90%
Paper and paperboard	2.12%
Panel products	21.47%
All other	0.01%

8. Philippines
$NZ 90,816

Logs and poles	0.01%
Sawn timber/sleepers	24.97%
Wood pulp	5.63%
Paper and paperboard	33.93%
Panel products	34.52%
All other	0.94%

9. Taiwan
$NZ 88,999

Logs and poles	22.25%
Sawn timber/sleepers	36.26%
Wood pulp	17.55%
Paper and paperboard	12.37%
Panel products	11.57%
All other	0.01%

13. Singapore
$NZ 39,891

Logs and poles	3.55%
Sawn timber/sleepers	11.96%
Wood pulp	80.48%
Paper and paperboard	1.35%
Panel products	1.50%
All other	1.16%

14. South Africa
$NZ 37,306

Logs and poles	0.00%
Sawn timber/sleepers	0.00%
Wood pulp	98.26%
Paper and paperboard	0.00%
Panel products	0.00%
All other	1.74%

15. Netherlands
$NZ 33,477

Logs and poles	0.00%
Sawn timber/sleepers	98.40%
Wood pulp	0.70%
Paper and paperboard	0.08%
Panel products	0.00%
All other	0.82%

4. Japan
$NZ 429,214

Logs and poles	15.09%
Sawn timber/sleepers	6.81%
Wood pulp	12.85%
Paper and paperboard	0.05%
Panel products	46.55%
All other	18.64%

5. India
$NZ 287,920

Logs and poles	84.57%
Sawn timber/sleepers	1.88%
Wood pulp	8.97%
Paper and paperboard	3.11%
Panel products	1.40%
All other	0.07%

6. USA
$NZ 242,201

Logs and poles	0.20%
Sawn timber/sleepers	79.07%
Wood pulp	0.00%
Paper and paperboard	1.51%
Panel products	15.12%
All other	4.10%

10. Viet Nam
$NZ 82,734

Logs and poles	7.02%
Sawn timber/sleepers	65.87%
Wood pulp	1.38%
Paper and paperboard	9.73%
Panel products	15.59%
All other	0.42%

11. Thailand
$NZ 74,938

Logs and poles	2.60%
Sawn timber/sleepers	41.77%
Wood pulp	28.83%
Paper and paperboard	24.97%
Panel products	1.47%
All other	0.35%

12. Malaysia
$NZ 58,183

Logs and poles	0.30%
Sawn timber/sleepers	13.83%
Wood pulp	24.74%
Paper and paperboard	42.60%
Panel products	18.53%
All other	0.00%

Notes

* Values are NZ$000 f.o.b. and may include items, e.g. some plywood items, for which no quantities are given. Paper and paperboard includes Newsprint for June 2011yr. All other forestry products include chips, mouldings, manufactures of paper and paperboard, furniture and miscellaneous forestry products. Other countries are all other countries to which New Zealand has exported forest products during the year.

Source **Top Export Destinations** Statistics NZ and FOA

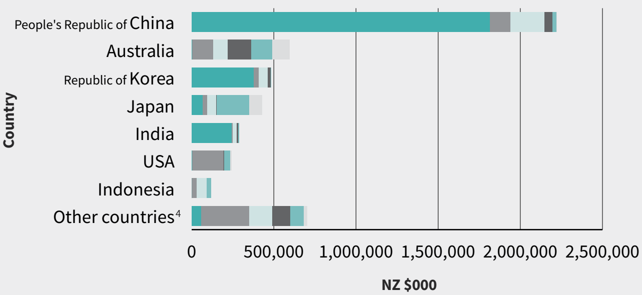
Export Value by Destination and Product[1]

for Year Ended 31 Dec 2016

Total Export Value by Main Countries of Destination

Country of Destination	Total Export Value (NZD$ 000) 2014	2015	2016
China (People's Republic of)	1,963,694	1,826,407	2,222,935
Australia	693,027	711,693	597,300
Korea (Republic of)	466,159	462,460	482,794
Japan	434,767	405,312	429,214
India	268,110	254,383	287,920
United States of America	173,398	224,286	242,201
Indonesia	145,542	150,097	117,366
Philippines	66,923	74,927	90,816
Taiwan	80,408	98,875	88,999
Viet Nam	66,923	74,927	82,734
Thailand	67,716	76,780	74,938
Malaysia	63,849	70,671	58,183
Singapore	n/a	n/a	39,891
South Africa	60,118	61,076	37,306
Netherlands	19,983	21,096	33,477
Other countries[4]	197,472	216,916	196,347
Total	**4,798,263**	**4,748,708**	**5,082,419**

Exports of Forestry Products by Main Countries of Destination



- Logs and poles
- Sawn timber/sleepers
- Wood pulp
- Paper and paperboard[2]
- Panel products
- All other forest products[3]

Notes

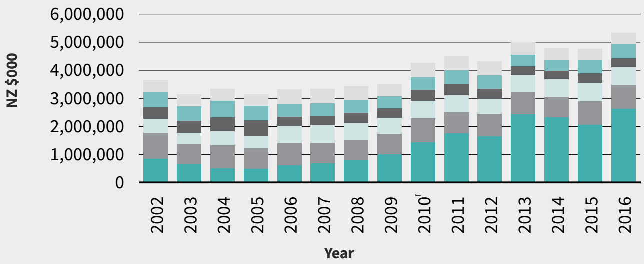
[1] Values are NZ$000 f.o.b. and may include items, e.g. some plywood items, for which no quantities are given.
[2] Paper and paperboard includes Newsprint for June 2011 yr.
[3] All other forestry products include chips, mouldings, manufactures of paper and paperboard, furniture and miscellaneous forestry products.
[4] Other countries are all other countries to which New Zealand has exported forest products during the year.

Source **Export Value by Destination and Product** Statistics NZ and FOA

Product Export Earners

for Year Ended 31 Dec 2016

Major Export Earners[1, 2]



- Logs and wood chips
- Sawn timber and sleepers
- Wood pulp
- Paper and paperboard
- Panel products
- Other forest products

r Revised

In 2016, **70% +** of New Zealand's log exports went to China. China has reduced domestic plantation harvesting and banned cutting natural forests, while the high pace of housing construction continues. However New Zealand sawn timber exports to China fell 16% in 2016.

1

2

Notes

[1] Paper and paperboard includes Newsprint data, therefore differs from Statistics NZ data
[2] Excludes re-exports. Newsprint data 12 months ending June 2010.

Source **Major Export Earners** Statistics NZ and FOA
Source **Box 1 & 2** SOPI June 2017

Exports of Forest Products

for Year Ended 31 Dec 2016

Production and Exports of Selected Forestry Products

Quantity exported[2]	Total production	Product
125,928	523,413	Veneer (m³)
51,748	398,760	Plywood[1] (m³)
601,896	759,948	Fibreboard (m³)
348,131	577,340	Other paper & paperboard (tonnes)
930,474	1,336,839	Wood pulp (tonnes)
1,735	4,242	Sawn timber (000m³)
17,428	30,514	Logs (000m³)
302,378	Not available	Wood chips (000BDU)

Quantity exported[2]
Total production

MPI expects pulp exports to rise to **$680 million** in the year to June 2018, up 3.8% from the 2017 year, with the main demand from China and emerging markets.

2

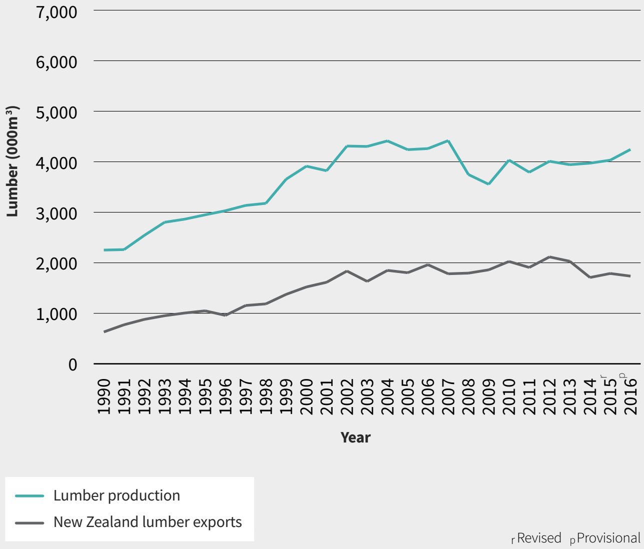
Notes
[1] Plywood includes laminated veneer lumber.
[2] Exports excluded re-exports.

Source **Production and Exports of Selected Forestry Products** MPI, Statistics NZ and FOA
Source **Box 1 & 2** SOPI December 2017

Lumber and Log Production and Exports

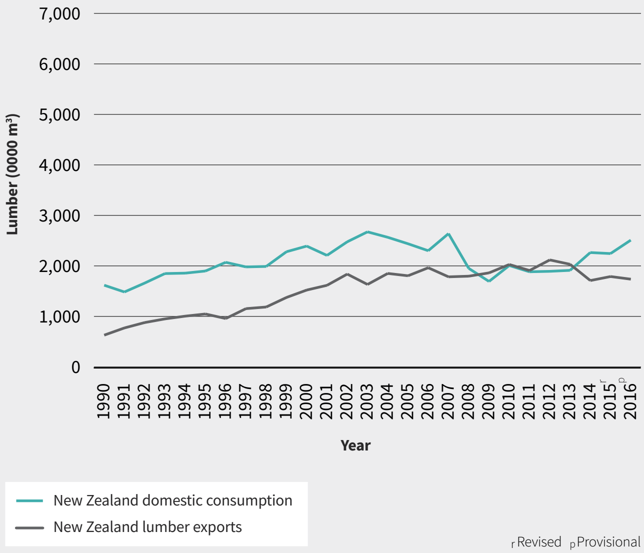
for Year Ended 31 Dec 2016

Lumber Production and New Zealand Lumber Exports



r Revised p Provisional

Domestic vs International Log Consumption



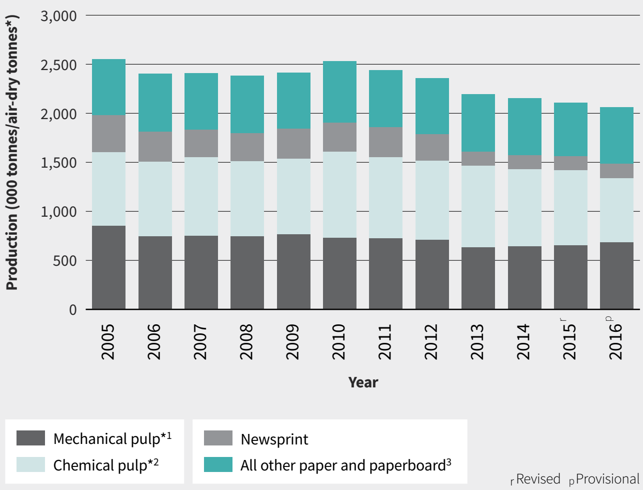
r Revised p Provisional

Source **Lumber Production and Exports** MPI

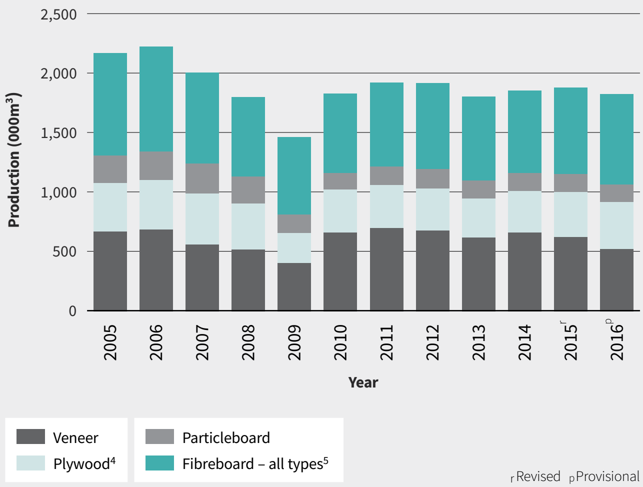
Paper, Pulp and Panel Products Production

for Year Ended 31 Dec 2016

Paper and Pulp Production



Panel Products Production



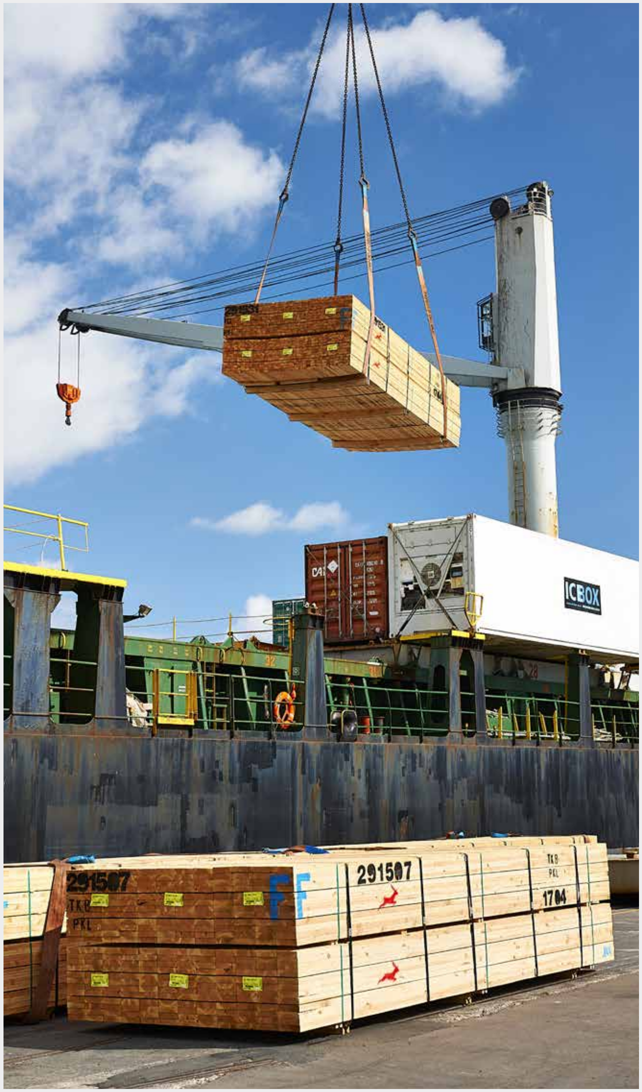
Notes

1 Mechanical Pulp is those export items in HS item grouping 4701. Values are in NZ$ free on board (f.o.b).
2 Chemical Pulp is those export items in HS groupings 4702, 4703, 4704 and 4705. Values are NZ$ free on board (f.o.b).
3 All other paper and paperboard includes printing and writing paper, other paper and paperboard.
4 Plywood includes laminated veneer lumber.
5 Fibreboard includes MDF, hardboard & softboard.

Source **Paper, Pulp and Panel Products Production** MPI

The export value of panel exports is expected to decline 3.4% to **$460 million** in 2018. Japan takes 40% of New Zealand panel exports and its construction industry is shrinking.

1



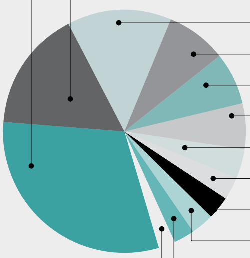
Source **Box 1** SOPI December 2017

Exports by Port

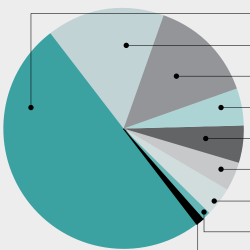
For Year Ended 31 Dec 2016

Port of Loading	Logs m³	Sawn Timber m³	Total m³
Tauranga	5,328,417	788,158	6,116,575
Whangarei	2,875,604	34,109	2,909,713
Gisborne	2,401,019	–	2,401,019
Napier	1,291,638	299,332	1,590,970
Wellington	1,230,195	9,831	1,240,026
Dunedin	964,790	93,811	1,058,601
Nelson	750,879	73,886	824,765
Picton	653,314	3,077	656,391
Christchurch	543,874	96,548	640,422
Invercargill	531,816	98,330	630,146
New Plymouth	409,183	–	409,183
Timaru	403,160	837	403,997
Auckland	63,313	236,617	299,930
Total	**17,447,202**	**1,734,536**	**19,181,738**

Log Exports by Port[1]



Sawn Timber Exports by Port[1]



Notes

[1] Ports with <1% not included.

Source **Log Exports by Port and Sawn Timber Exports by Port** Statistics NZ, Overseas Trade

SECTION 4

Health and Safety and Training

TOGETHER TOWARDS ZERO

The Forest Industry Safety Council is a pan-industry initiative to reduce and ultimately eliminate deaths and serious injuries in New Zealand plantation forestry, by;

- Improving leadership of safety
- Providing easy-to-use forest safety resources through **www.safetree.nz** website
- Sharing better information on what's causing injuries
- Getting companies and workers more competent
- Helping the sector adapt to the Health and Safety at Work Act 2015.

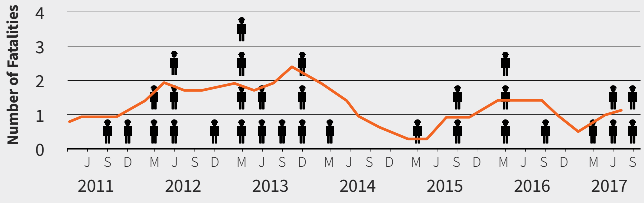
FOREST INDUSTRY SAFETY COUNCIL

safetree™ You are the key

www.fisc.org.nz

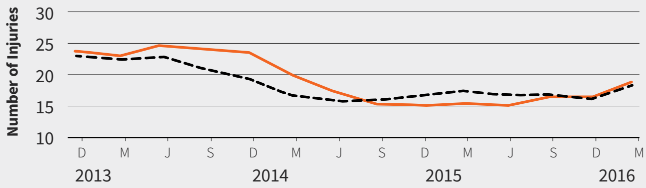
Health and Safety in the Forest Industry

Fatalities[1]



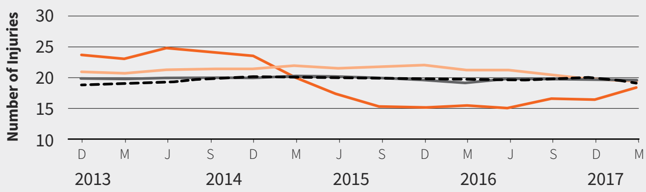
Severe Injuries[1]

rate of injuries to workers resulting in more than a week off work



How Do We Compare?[2]

rate of injuries to workers resulting in more than a week off work



Notes

1 Rolling average last four quarters.

2 Rolling average last four quarters per 1,000 workers.

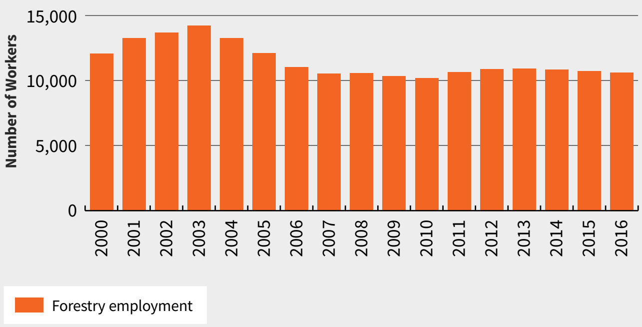
Source **Fatalities, Severe Injuries & How do we Compare** WorkSafe/MPI/FISC. Severe injury data is based on ACC claims where someone receives a period of weekly compensation within a quarter. Severe injury data lags by 6 months due to claim processing time.

Forest Industry Employment

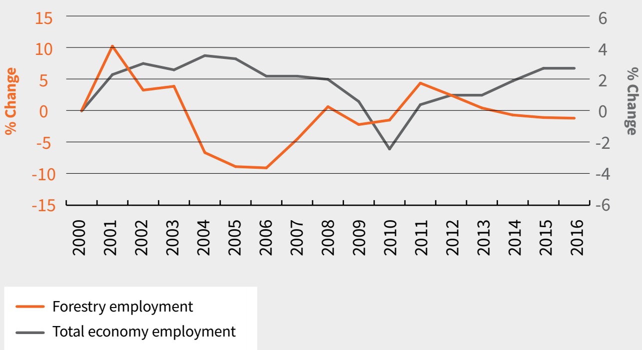
Occupational Employment

Jobs in top 5 occupations	2016
Forestry Worker	2,867
Logging Assistant	1,241
Production Manager (Forestry)	915
Forest Scientist	618
Logging Plant Operator	395

Forestry Employment



New Zealand Growth in Employment



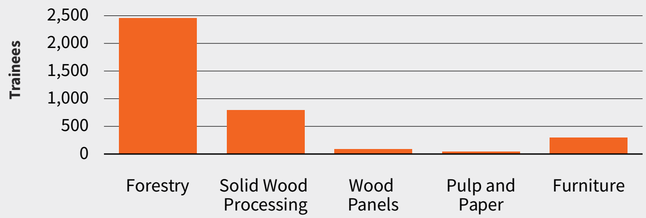
Notes

1 The data in this report relates specifically to the areas of the sector as defined by Competenz

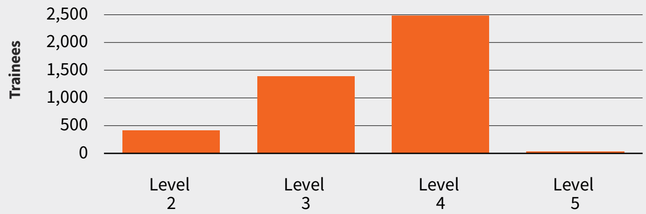
Source **Forest Industry Employment** Infometrics and Statistics New Zealand

Industry Training 2016

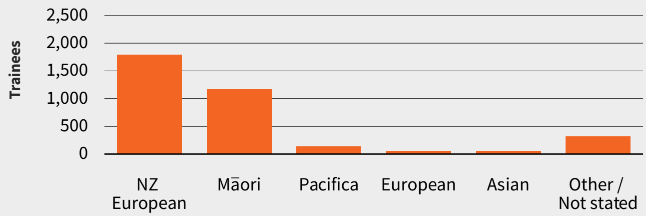
Trainee Count



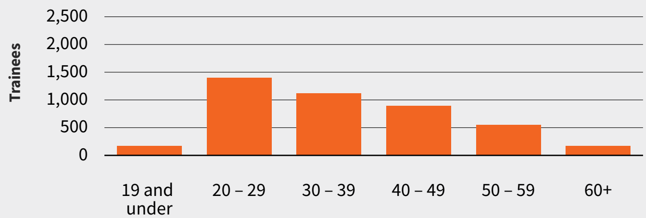
Trainee by Qualification Level



Trainees by Ethnicity



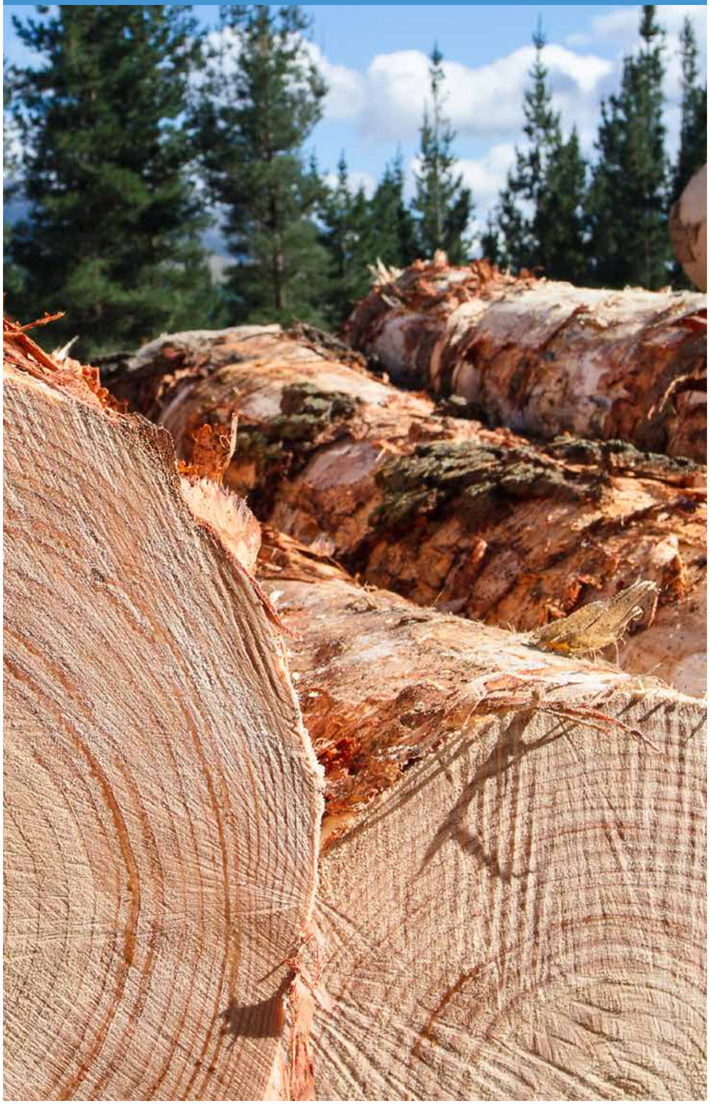
Trainees by Age



Source Competenz

SECTION 5

Supplementary Information



NZ Wood

Wood is the world's most renewable raw material. For this reason forests and the wood they provide are vital in the fight against climate change. As the effects of global warming impact on our environment, the use of renewable and sustainable building materials has never been so important.

The stages of the wood story – planting and renewal, growth, harvesting and use – are part of a renewable cycle that takes and stores carbon dioxide from the atmosphere, making wood a better-than-carbon-neutral building material.

Wood is the only construction material which has absorbed CO_2 from the atmosphere when produced, not emitted more

During its production, one tonne of:

- Concrete – has released 159 kilos of CO_2 into the atmosphere
- Steel – has released 1.24 tonnes of CO_2 into the atmosphere
- Aluminium – has released 9.3 tonnes of CO_2 into the atmosphere
- Wood, however, has absorbed a net 1.7 tonnes of CO_2 from the atmosphere, over and above the energy expended in growing, harvesting and processing.

The more timber you use in a house, the more CO_2 you remove from the atmosphere

- It takes around 20 trees to build an average house frame
- A steel house frame has added 4.5 tonnes of CO_2 to the atmosphere
- A wooden house frame has absorbed 9.5 tonnes of CO_2 from the atmosphere
- Choosing timber options for an average house can take around 20 tonnes net of CO_2 out of the atmosphere (saving the equivalent of 150 trips Auckland to Wellington, or 7.1 years of car use)
- Using alternative materials (concrete, steel, brick and aluminium) can add 24 tonnes net CO_2 to the atmosphere (costing the equivalent of 180 trips Auckland to Wellington, or 8.6 years of car use).

Using wood is something we can all do to help the environment. By demanding and using more sustainably produced wood, we can ensure that more trees will be planted and more carbon dioxide will be absorbed from the atmosphere.

The result is a better world for ourselves, our families and future generations. It's simple.

Wood. Our most renewable raw material.
www.nzwood.co.nz

Forest Growers Levy Trust

The Harvested Wood Material Levy came into effect on 1 January 2014 with a rate of 27 cents per tonne. The levy generated in the year to 30 June 2016 was $8,063,955 (ex GST). The proceeds from the levy are overseen by the Forest Growers Levy Trust which has contracted the Forest Owners and Farm Forestry Associations to manage the annual work programme. The annual work programme consists of research and work which will benefit the industry as a whole. More information, including the 2015 Annual Report, can be found at **www.fglt.org.nz**.

Source **Expenditure by Category** FGLT

How the FGL is Invested[1]

62.7%

RESEARCH SCIENCE & TECHNOLOGY

Sustainable intensification, diverse species/specialty wood products, Phytophthora sciences, Red needle cast, bio-protection, fire research, herbicide rates, riparian margin resilience, site productivity estimation, in-forest debarking, weed research, water quality monitoring and wilding pine management.

13.5%

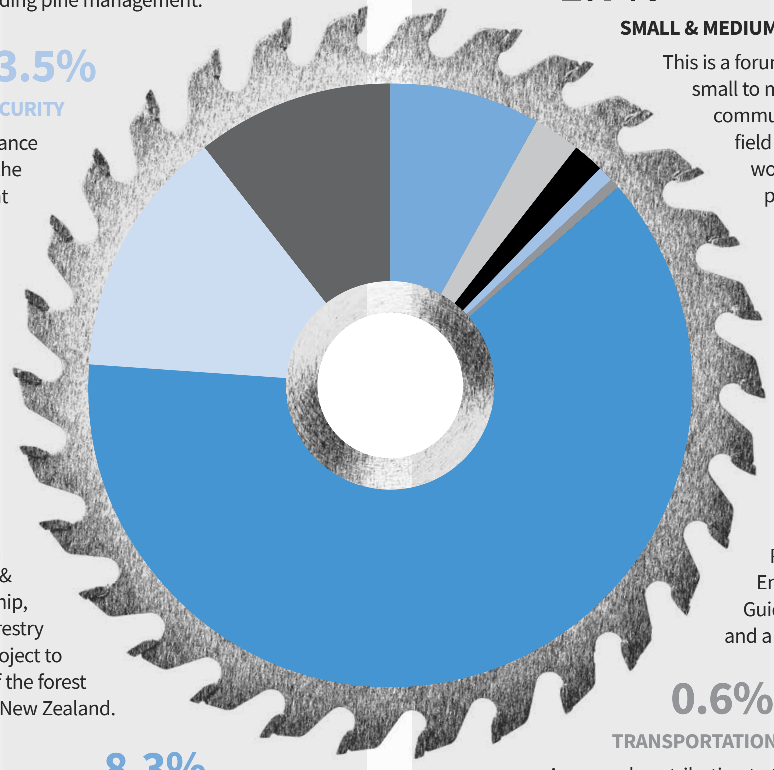
FOREST HEALTH & BIOSECURITY

Forest biosecurity surveillance and administration costs of the Government Industry Agreement (GIA) sector plan, and work with other sectors on a Nursery Biosecurity Scheme Guideline. Recent initiatives include a pest impact calculator and workshops.

10.3%

PROMOTIONS

NZ Wood, publications, external memberships such as Wood Council of New Zealand, International Council of Forest & Paper Associations, sponsorship, career promotion, and a forestry census and research project to measure the significance of the forest industry to New Zealand.



8.3%

HEALTH SAFETY & TRAINING

This is the joint industry contribution to major health, safety and training issues identified by the Forest Industry Safety Council, WorkSafe NZ and ACC. Publication of the Drug Alcohol Policy and standards development also feature.

2.3%

FIRE

This is a contribution to the Forest Fire Prevention Programme. A major fire risk awareness campaign is to target farmers and tourists, the prime causers of forest fires.

1.7%

SMALL & MEDIUM FOREST ENTERPRISES

This is a forum for owners and managers of small to medium sized forests. It includes communication activities such as field days, publications, website, workshops and newsletters. A new project 'Enhanced Technology Transfer' has been developed.

0.7%

FOREST RESOURCE & ENVIRONMENT

Developing policies on forest growing and environment issues, including forest certification, climate change, water allocation and the Resource Management Act. Projects include an update of the Endangered Species Management Guide, Forestry Information Sheets and a Planted Forest Information Portal.

0.6%

TRANSPORTATION

An annual contribution to the pan-industry Log Truck Safety Council, measuring forest owners' real use of rural roads, as well as research into the effect of electronic road user charges and the Road Safety in Schools (Share the Roads) programme. New projects in 2016 included GIS mapping, a study into the effectiveness of high productivity motor vehicles and the stability of 3-axle trailers.

Notes

[1] The Harvested Wood Material Levy came into effect in January 2014 with a rate of 27c per tonne. The levy generated in the year to May 2017 was $3,680,366. The levy runs until late 2019. More information is available at **www.fglt.org.nz**

Source **How the FGL is Invested** Forest Growers Levy Trust Annual Report 2016

NZ Forest Owners Strategic Plan

The Strategic Action Plan provides a pathway to shape a strong forest and wood products sector for the future.

The New Zealand plantation forest and wood products industry is based on wholly renewable resources, producing 100% of its products from plantation forests and recycled waste fibre; is New Zealand's largest biomaterial recycler and has a very low carbon footprint. In the future it will be substantially independent of non-renewable energy inputs apart from transport fuel (and even this could be sourced from New Zealand wood in the long run). The industry already provides greenhouse gas offsets, reducing New Zealand's overall carbon footprint.

Vision for the Plan

The vision target is that in the ten years to 2022 annual export earnings will more than double to $12 billion from a New Zealand forest and wood products industry that is:

- delivering innovative wood-based solutions from a sustainable resource to meet our customers' needs
- manufacturing a range of high-value, fibre-based products, including new biochemical and biofuel value streams
- recognised as a world-leader in timber-engineered building solutions
- underpinned by forest growing as a valued and profitable land use
- recognised as a key New Zealand growth industry, delivering strong economic and environmental benefits
- connected and collaborative across the value chain, from end-product to seedling
- characterised by industry players that have pride in the wood products industry, with the sector regarded as a preferred career option for our brightest talent

Sector Agreements

New Zealand Climate Change Accord 2007

This is an agreement between FOA/FFA, the Timber Design Society and eight NGOs acknowledging the contribution of indigenous and plantation forests to mitigate climate change through carbon sequestration.

The Accord endorses the principle of polluter pays, that policies must be broad-based and cover all greenhouse gases with all sectors taking responsibility and with time bound targets.

Expansion of both indigenous and plantation forests to achieve a net reduction in these emissions through offsetting is agreed.

Wood is acknowledged as a renewable, reusable and recyclable resource.

Eliminating illegal forest products 2008

The FOA, WPMA and Pine Manufacturers Association join NGOs in calling on the New Zealand government, importers, processors, retailers, New Zealand forest and plantation managers and processors of forest and plantation products, to strongly oppose the importation and use of illegally harvested and traded forest products in New Zealand.

Trading in illegal products contributes to deforestation, biodiversity loss and poverty.

Forest Industry Safety Council 2015

The FOA is participating in FISC as the pan-industry initiative. FISC has an independent cross sector board. FISC's mission is to reduce the rate of serious injury and fatalities in the New Zealand plantation forest sector, with an ultimate goal of eliminating them.

Log Transport Safety Accord 2008

This is an agreement between FOA/FFA, the Road Transport Forum New Zealand and the Log Transport Safety Council.

Issues identified to reduce the incidence of log truck accidents on roads include; regulatory compliance, investment in health and safety, 0800 public reporting, safe speeds, fatigue reduction, driver training, load weights, truck and trailer design, trailer operations, roading infrastructure, accident data recording and driver and public awareness.

Forest Government Industry Agreement for Biosecurity 2015

The FOA has signed a Government Industry Agreement to protect New Zealand forests from introduced pests, weeds and diseases.

Costs and decisions on prevention and responses are shared between the industry and Ministry for Primary Industries.

The Forest Biosecurity Surveillance programme began on 1 July 2016, covering all commercial plantations.

PineNet has also been set up as a forest industry network to respond to a major incursion. FOA has a contingent Memorandum of Understanding with AsureQuality for participation in a National Biosecurity Network.

New Zealand's Greenhouse Gas Inventory

The Carbon Cycle

Planting trees begins a cycle that continuously removes, releases and re-absorbs greenhouse gases such as carbon dioxide. As trees grow, they absorb carbon dioxide through the process of photosynthesis.

The carbon dioxide absorbed by the growing forest remains stored within the wood products used throughout the lifetime of the building structure or product.

When a structure or product reaches the end of its lifetime, the carbon dioxide is released back into the atmosphere as the wood decays or is burnt as fuel.

Wood can be recycled to extend its lifetime and slow down the natural release of carbon dioxide back into the atmosphere. Once the carbon dioxide is released, it is available to be re-absorbed by growing trees.

When wood materials decay or are burnt as fuel they release carbon dioxide that was absorbed during the growth of the trees and are therefore carbon neutral.

New Zealand's Greenhouse Gas Inventory – Key Points

In 2015, New Zealand's total gross emissions were 80.2 million tonnes of carbon dioxide (Mt CO_2-e). In 1990, gross emissions were 64.6 Mt CO_2-e.

In 2015, 23.7 Mt CO_2-e was removed from the atmosphere by the forestry sector, compared with 30.1 Mt CO_2-e in 1990. Forestry sector removals in 2015 reduced total gross emissions to 56.4Mt CO_2-e net.

Agriculture continued to be the largest contributor to New Zealand's Greenhouse Gas Emissions, with 48% of the total at 38.4 Mt CO_2-e, compared with energy at 40%.

Total CH_4 and N_2O emissions in 2015 attributable to dairy cattle, beef cattle, sheep and deer in 2015[1]

	Total emissions (million tonnes CO_2-e)	2015 Population (millions)	Emissions per animal (tonnes CO_2-3)	*Offset area (m) per animal
Sheep	10.13	29.12	0.348	5.5
Deer	0.60	0.90	0.676	10.8
Beef	6.40	3.55	1.803	28.7
Dairy	18.07	6.49	2.786	44.5

Notes

[1] Based on figures from the Agricultural Inventory Model, used in New Zealand's Greenhouse Gas Inventory 1990-2015 report published by MfE
All figures expressed in megatonnes of carbon dioxide equivalent (kt CO2-e)

* Square metres of new plantation required every year, at 20 years of age, to offset biological emissions of each animal.

Forests Removing Carbon

How is carbon removed from the atmosphere by New Zealand's forests?

Forests act as carbon sinks – a type of reservoir that removes and stores more carbon from the atmosphere than it releases. Trees use carbon dioxide (CO_2) as part of their 'breathing' cycle – taking in CO_2 and storing it within roots, trunks and branches – and releasing oxygen.

The amount of CO_2 a forest removes depends on the species grown and place in its growing cycle. A young forest will remove smaller amounts of CO_2 until the trees establish and enter a growing phase – this is when forests will remove the most carbon. As a forest ages and its growing process slows, it will revert to absorbing less carbon again.

At harvesting, the forest ceases to be a carbon sink but instead of releasing all the carbon it has stored, the harvested wood retains some of it. All wood products store carbon that will eventually be released, however the rate at which that carbon is released depends on the type of product and the type of treatment the wood has undergone. Studies are still being conducted into these release rates.

The amount of carbon removed by New Zealand's forests is therefore dependent on the coverage of forestland, the age and species of the trees and the rate of harvest. Exotic forest biomass carbon was 283 million tonnes in 2015. This was an increase of 150 million tonnes, or 114 percent, since 1990.

If carbon in the exotic forest soil is included, the total forest biomass carbon volume increased to 451 million tonnes in the same period, an increase of 189 million tonnes, or 72 percent.

A large proportion of the exotic forest estate is nearing maturity, and one harvested, the biomass stocks will temporarily reduce.

Source 1990 to 2015 National Greenhouse Gas Inventory

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Reporting a Suspected Pest/Disease

Eucalyptus nitens induced with myrtle rust infection

Photo credit: CSIRO

Don't go down in history as the person who noticed something but didn't tell.

Keep our forests free of new pests and diseases.

Myrtle rust arrived in New Zealand from Australia in early 2017. The rust infects members of the myrtle family, which includes eucalypts, feijoas and guavas as well as native plants such as pōhutakawa, rata and mānuka.

MPI has been attempting to eradicate the disease to prevent it becoming established in New Zealand.

If you believe you've found something that shouldn't be here, phone MPI's hotline on **0800 80 99 66**. They will arrange for whatever photos, samples and site visits are necessary.

Or, email to; **Info@mpi.govt.nz**, with 'Reporting a suspected pest/disease' in the subject line, and make sure to include contact name, phone number and location of the discovery. Photos of the pest and plant damage would be useful.

Terms, Names and Sites

Area and volume

- A hectare (ha) = 100 x 100 metres.
- A cubic metre (m^3) = 1 metre x 1 metre x 1 metre.
- An average *Pinus radiata* tree yields 2.4 m^3 of wood at harvest.
- 1 hectare of 28 year-old *Pinus radiata* contains between 650 and 800 m^3 of wood.
- 1 hectare grows up to 28 m^3 of wood each year.
- A log truck and trailer carries approximately 30 tonnes of logs.
- A log ship contains approximately 30-35,000 tonnes of logs.

Organisations by abbreviations

FAO	Food & Agriculture Organization of the United Nations
FGLT	Forest Growers Levy Trust
FIEA	Forest Industry Engineering Association
FISC	Forest Industry Safety Council
MfE	Ministry for the Environment
MPI	Ministry for Primary Industries
NEFD	National Exotic Forest Description
NZIER	New Zealand Institute of Economic Research
WPMA	Wood Processors and Manufacturers Association

2016/17 Facts & Figures organisation sites

Competenz	www.competenz.org.nz
FISC	www.safetree.nz
FAO	www.fao.org/forestry
MfE	www.mfe.govt.nz
MPI	www.mpi.govt.nz
NZIER	www.nzier.org.nz
NZFOA	www.nzfoa.org.nz
NZ Forests Portal	www.nzplantedforests.org
Scion	www.scionresearch.com
Statistics NZ	www.stats.govt.nz
WPMA	www.wpma.org.nz
WorkSafe NZ	www.business.govt.nz/worksafe

Log Pricing Data

Log Type, Pricing Point and Market	Mar-11 Quarter	Jun-11 Quarter	Sep-11 Quarter	Dec-11 Quarter	Mar-12 Quarter	Jun-12 Quarter	Sep-12 Quarter	Dec-12 Quarter	Mar-13 Quarter	Jun-13 Quarter	Sep-13 Quarter	Dec-13 Quarter	Mar-14 Quarter	Jun-14 Quarter	Sep-14 Quarter	Dec-14 Quarter	Mar-15 Quarter	Jun-15 Quarter	Sep-15 Quarter	Dec-15 Quarter	Mar-16 Quarter	Jun-16 Quarter	Sep-16 Quarter	Dec-16 Quarter
EXPORT (NZ$ per JAS m³ f.o.b)																								
Pruned – Japan, Korea	179-197	155-181	161-173	146-155	144-513	154-163	153-166	144-190	168-192	169-209	177-201	181-206	171-198	158-190	146-187	165-236	186-199	121-199	189-211	121-228	220-230	204-236	184-207	180-225
A Grade – Japan	132-144	133-148	123-132	112-122	110-117	110-122	116-118	103-125	128-138	136-153	143-162	137-169	142-165	104-142	110-140	127-169	134-150	81-133	90-133	81-141	118-166	146-169	138-162	138-162
J Grade – Japan	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
K Grade – Korea	130-148	125-145	108-114	105-112	94-109	104-116	103-110	90-121	112-131	114-147	132-156	127-159	133-159	96-137	101-134	117-163	124-143	99-126	91-125	91-135	99-158	135-162	124-157	135-167
Pulp	129-137	110-176	109-118	98-112	87-100	84-111	91-120	79-102	106-108	108-123	128-131	119-154	125-140	110-122	92-108	112-135	117-121	65-107	73-110	65-118	55-138	120-143	111-134	125-140
All grades average per quarter	**150**	**147**	**130**	**120**	**114**	**121**	**122**	**119**	**135**	**145**	**154**	**157**	**154**	**132**	**127**	**153**	**147**	**116**	**128**	**123**	**148**	**165**	**152**	**161**
DOMESTIC (NZ$ per tonne delivered at mill)																								
P1	128-147	130-152	132-152	127-134	120-134	127-170	120-136	122-149	135-150	142-158	126-157	132-156	129-155	131-155	132-154	134-154	139-164	135-170	135-174	135-174	140-187	142-195	140-193	142-186
P2	110-127	122-130	114-130	111-128	110-127	110-123	111-126	111-123	120-121	121-133	114-125	121-127	126-126	119-130	125-126	121-130	116-136	116-133	116-133	105-170	129-182	134-188	130-192	102-189
S1	88-98	99-125	99-105	99-103	95-100	95-98	95-102	95-104	97-102	103-110	102-120	102-123	98-112	101-111	103-109	98-108	108-112	100-109	100-108	96-109	102-118	104-123	105-123	105-126
S2	92-103	86-105	94-108	93-101	88-100	88-97	88-96	90-97	95-98	101-107	90-110	90-113	92-118	91-123	101-110	98-109	96-109	85-109	85-105	85-109	90-114	90-118	80-116	93-120
L1 and L2	72-103	74-115	78-95	76-91	90-110	83-92	80-89	77-96	84-100	88-105	78-111	80-113	77-123	78-78	81-87	85-103	97-139	78-95	78-94	78-109	79-130	71-132	74-130	82-138
S3 and L3	82-92	81-92	82-89	79-87	66-81	76-79	77-80	77-86	92-90	83-100	75-106	75-102	86-108	90-115	81-100	86-100	88-100	69-96	76-90	69-96	68-106	82-119	69-107	71-112
Run of bush	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pulp	47-57	48-61	49-61	49-54	49-55	49-55	47-49	48-53	46-50	46-51	47-54	46-54	44-55	46-55	45-55	49-54	50-55	31-54	31-55	31-55	31-59	44-59	31-61	40-52
All grades average per quarter	**96**	**101**	**99**	**95**	**95**	**95**	**93**	**95**	**97**	**103**	**101**	**102**	**104**	**102**	**101**	**102**	**103**	**102**	**102**	**102**	**110**	**114**	**111**	**111**

2015/16 Facts & Figures organisation sites

Competenz	www.competenz.org.nz
FAO	www.fao.org/forestry
MfE	www.mfe.govt.nz
MPI	www.mpi.govt.nz
NZIER	www.nzier.org.nz
NZFOA	www.nzfoa.org.nz
NZ Forests Portal	www.nzplantedforests.org
Scion	www.scionresearch.com
Statistics NZ	www.stats.govt.nz
WPMA	www.wpma.org.nz
WorkSafe NZ	www.business.govt.nz/worksafe

The photos on pages 3, 7, 9, 16, 18, 20, 23, 24, 25, 26, 30, 36, 42, 44 and 50 came from Phil Taylor, Port Blakely NZ Ltd.

Notes
* Limited response – very small volume traded.
.. Data not available.

Source **Log Pricing Data** MPI

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A systematic review of the socio-economic impacts of large-scale tree plantations, worldwide

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ABSTRACT

Since their widespread introduction in the 1980s, large-scale tree plantations have seen contestations over their socio-economic impacts. With the establishment of new plantations on the rise, a review of the literature examining their impacts on local communities is needed to inform policies and practices. In this systematic review, we followed an *a priori* protocol to reduce the selection biases inherent to conventional literature reviews, and considered both grey and peer-reviewed literature. Of the 20,450 studies identified in our literature search, only 92 studies met our predefined inclusion criteria. However, only 22 studies presented a clear comparator and considered confounding factors in their analysis. Of the 251 impacts identified in this sample, most impacts across the nine categories were characterised as predominantly negative impacts attributed to large-scale tree plantations. Impacts on employment (22% of reported impacts/of which 41% predominantly negative), land (21%/81%), livelihoods (12%/48%) and the often intertwined social impacts (20%/69%) were the most commonly considered categories, within which a majority of studies agreed on the impact dynamics when in similar contexts, resembling the dynamics observed in other large-scale land-based investments. Most impacts were reported from Southeast Asia (34% of reported impacts), South America (29%), Africa (23%) and Australasia (12%). We corroborate that costs of large-scale tree plantations for residents tend to be front-loaded, especially when plantations have displaced customary land uses, and possible benefits to accrue over time, moderated by the emergence of local processing and complementary livelihood activities. However, given the methodological inconsistencies in our sample and the under-representation of areas known to have undergone plantation development, strong global evidence on the long-term socio-economic impacts of large-scale tree plantations remains limited.

1. Introduction

Although we can trace the origins of large-scale tree plantations to the colonial era, they have seen increasingly widespread adoption since the 1980s as an alternative source of raw material for tree-based commodities (Bull et al., 2006; Evans, 2009). Tree plantations are often characterised by high density monocultures of non-native species, established to meet increasing commercial demands and reduce the exploitation of natural forests (Chazdon et al., 2016; D'Amato et al., 2017a; Pirard et al., 2016a). Such plantations are also often posited as a means of mitigating the effects of climate change through carbon sequestration in woody biomass (Ingram et al., 2016; Kröger, 2016). Recent estimates place the global extent of planted forests at 278 million ha in 2015 (Payn et al., 2015), with large-scale plantations of fast-growing tree species occupying 54 million ha in 2012 and predicted to double in extent by 2050 (Indufor, 2012).

The establishment of large-scale tree plantations remains a highly contentious issue among researchers, practitioners and stakeholders (Baral et al., 2016; Gerber, 2011; Kröger, 2011; Schirmer, 2013). Much of the criticism has been directed at their negative environmental

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impacts, commonly caused by the clearing of natural forest prior to plantation establishment (Brockerhoff et al., 2008; Farley et al., 2005; Liao et al., 2012). However, residents exposed to the establishment of large-scale tree plantations also experience a range of impacts, both positive and negative. These impacts are likely to resemble those of other large-scale land-based investments, as they share key features in terms of their physical extent and social disruption in rural areas.

It has been shown that the land acquisition for large-scale agricultural plantations carries a risk of threatening or displacing customary land uses (Cotula et al., 2014; Hall et al., 2015); particularly in Africa and Southeast Asia, where most rural areas remain under land use without formal recognition by the state (Deininger, 2003; Inguanzo, 2014). Investors targeting such areas have tended to align with the interests of influential elites (e.g. politicians, privileged, chiefs, elders) de facto responsible for allocating resources and benefits, and capturing these unless held accountable for their proper distribution among customary land users (Cotula et al., 2014; McIntyre et al., 2015). Significant concentration of land can further threaten access to land by customary land users (Peters, 2009; Toulmin, 2009). Where in place, formal titles are portrayed as being effective safeguards against illegal seizures of land (World Bank, 2010); where not, the gradual processes of land formalisation could threaten communal arrangements and exacerbate inequalities in access to land (Alden Wily, 2011; Dwyer, 2015; Milne, 2013).

In terms of employment and livelihoods, Hunsberger et al. (2017) found that labour intensity in large-scale feedstock plantations is modified by mechanisation and investment phase, with land clearing and crop planting requiring much more labour per unit area than other phases. Labour intensity could also decrease due to efficiency gains achieved through land concentration (Wilkinson and Herrera, 2010). On average, rural residents in lower-income countries derive an estimated 28% of their total income from natural areas (Angelsen et al., 2014); and so the (lost) value of displaced livelihoods could possibly be higher than the (gained) value of labour per unit area (Schoneveld et al., 2011). Impacts are likely to depend on the trade-offs between the new and past employment and livelihoods in terms of labour intensity and value creation (Hunsberger et al., 2017). The type of business model – whether arranged such that the investor controls all means of production, or arranged, for example, so that residents are contracted with direct involvement in production through the large-scale plantation - could affect the trade-offs (Little and Watts, 1994; Vermeulen and Cotula, 2010a). In addition, plantation agriculture and biofuel production have often favoured migrant workers over residents for their greater acceptance of physically demanding labour and precarious contracts often described as exploitative (Deininger et al., 2011b; Lenard and Straehle, 2010). Outsourcing - with a significant role for contractors to undertake most of the tasks on the ground - has been pointed to as worsening working conditions with fewer guarantees for the sub-contracted workforce (ILO, 2016).

Additional impacts could follow the conversion and management of land for tree plantations that could modify the provision of pre-existing ecosystem services with links to human health and well-being (Howe et al., 2014; Scovronick and Wilkinson, 2014). Roads and other infrastructure, of which economies of scale are often beyond the reach of residents and governments in rural areas, in turn, could benefit from land-based investments by external investors (Byerlee et al., 2017). However, disparities in access to resources, utilities or opportunities could shape the perceptions of fairness among residents, between residents and migrants, or between residents and investors, increasing social tensions (Gerber, 2011; Hall et al., 2015; Norton and de Haan, 2012).

Such socio-economic impacts have never been subject to a global review in the context of large-scale tree plantations across different contexts of geographical location, commercial purpose and ownership structure. Our synthesis will also help to identify knowledge gaps and highlight patterns across the literature that promote best practice or changes to existing practices (Haddaway et al., 2016).

Our review thus aims to answer three main research questions: 1) What are the direct and indirect socio-economic impacts of large-scale tree plantations for local communities? 2) How do impacts differ across contexts? 3) What are the patterns, biases and gaps in the available evidence?

2. Methods

Systematic reviews aim to identify the most reliable research on a given question in a manner that minimises selection biases in the literature search and screening process. We used an *a priori* systematic review protocol published as Malkamäki et al. (2017), which was prepared based on the guidance for systematic reviews by the Collaboration for Environmental Evidence (CEE, 2013). This protocol defined the structuring components of the systematic review framework (population, intervention/exposure, comparator, impact and contextual factors) as applied to large-scale tree plantations, and their operationalisation in the literature search and screening process to identify relevant studies from bibliographic databases and organisational sources.

Definitions of these components are provided in detail in Malkamäki et al. (2017), and were developed through a participatory process and a stakeholder workshop in May 2016 involving seven experts from academic, civil society and private sector organisations. The following definitions and scopes were used to guide the identification of relevant studies:

Relevant populations: Local households and communities who reside inside or near to an area where at least one large-scale tree plantation is present. Here, the term *local* is not used to delineate populations within a particular distance from the plantation site as these may vary from area to area. However, non-local processors and consumers of plantation-sourced commodities further down the value chain - who are not impacted by the physical presence of the plantation site - are not considered.

Relevant intervention/exposure: Large-scale tree plantations established and managed for commercial purposes by private or public actors external to the local community. This definition excludes large-scale forest restoration programmes and outgrower partnerships as such. Tree species included are those falling under the FAO (2012) current definition of a *forest*; i.e. those able to reach a minimum height of five meters, hence rubber trees are included. Commercial purposes for which the plantations must be primarily designated are those derivable from the relevant tree species, including pulpwood (e.g. cellulose), sawnwood (e.g. construction), fuelwood (e.g. combustion), latex/rubberwood and carbon credits, or a combination of these.

Relevant impacts: Intentional and unintended changes to human well-being that are felt directly or indirectly due to the establishment or management of a large-scale tree plantation. These should fall under one of the nine impact categories: land, employment, livelihoods, cash income, infrastructure, health, regulating ecosystem services, cultural ecosystem services or social impacts (Table 1).

Apart from the initial list of potential impacts proposed in the stakeholder workshop, the design of impact categories drew from the literature on impacts of other land-based investments and links between ecosystem service provision and human well-being (Chapter 1; Fisher et al., 2014; Howe et al., 2014). To adapt these concepts into the context of tree plantations, we drew from the impact logic by Ingram et al. (2016).

The very final working definitions for the nine categories could only be assigned after we understood the range and types of all reported impacts. Taking into consideration the multi-dimensionality of some concepts also meant dealing with higher levels of complexity. For example, food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2003, p. 29). Of the four dimensions of food security (Gross

Table 1
Working definitions of impact categories.

Category	Working definition
Land	Impacts caused by the process of land acquisition and its direct consequences, including changes in formal or customary access to land with or without compensation, concentration of land ownership, and changes to availability of and access to local food or fuel.
Employment	Impacts related to wage employment, including labour intensity, working conditions and the roles of outsourcing and migrant workers. Local processing and nurseries, which depend on the physical presence of the plantation, are included.
Livelihoods	Impacts on conditions for engaging in previous or other livelihood activities; not including cash income and wage employment.
Cash income	Impacts on monetary earnings at individual, household and community levels, and changes to income-based poverty levels.
Infrastructure	The delivery - or lack thereof - of roads, schools, clinics, electricity and water-related infrastructure.
Health	Impacts on health due to injury, pesticide usage, disease vector or change to nutritional status.
Cultural ecosystem services	Impacts on human well-being related to changes to ecosystem function that support recreation, traditions, aesthetics, identity and sense of place.
Regulating ecosystem services	Impacts on human well-being related to changes to ecosystem function in regulating water quantity and quality, soil fertility, shade, erosion and micro-climate.
Social	Impacts on social fabric (migration, demographics, trust, equity, conflict, legality, morality) and social ties among residents, between residents and migrants, or between residents and investors.

et al., 2000), physical food availability as well as physical and economic access to food are reflected in the "land" category, while food utilisation falls under the "health" category. Stability of the other three dimensions is considered across categories. Hence, it is important to note the possible interactions and overlaps between the nine categories. Although changes to inequality (whether between classes, ethnicities, genders or generations) is considered under the broad category of "social" impacts, considerations of who can and wants to access benefits are important across all categories (Fisher et al., 2014; Hall et al., 2015).

Literature searches were conducted in July 2016 and updated in April 2017 using English language searches in Web of Science (5856 hits), Scopus (9373), CAB Abstracts (9939) and Google Scholar (1990) (for complete search strings, see Malkamäki et al., 2017). In Google Scholar, only the first 200 hits as sorted by relevance were exported for screening. All search results were then merged into a single database before removing duplicate studies. To complement these database searches, we searched for relevant literature from 48 organisational sources, which include research institutes (e.g. French Agricultural Research Centre for International Development), civil society organisations (e.g. World Rainforest Movement) and intergovernmental bodies (e.g. International Tropical Timber Organization); the list can be accessed through Malkamäki et al. (2017). Although searches were conducted in English, also French, Portuguese and Spanish studies identified in these searches were included in screening. Fig. 1 summarises the key stages in the review process.

Of the 20,450 individual search results, only 111 studies met our inclusion criteria of relevant populations, intervention/exposure, and impacts. We were unable to acquire the full texts of 72 additional studies for screening, and excluded previous versions of studies using the same data (e.g. working papers that preceded journal articles). These 111 studies underwent data extraction using a standardised data extraction sheet (Appendix 1), the design of which relied on principles common to qualitative meta-synthesis, including systematic coding of variables (CEE, 2013). When studies presented multiple case studies from distinct geographical or institutional contexts, we coded such cases separately. Thus, we have more "case studies" than the total number of included "studies," and will retain this terminology to refer to them separately.

We soon realised that characterising the impacts either as positive, negative or mixed was challenging. Some studies did not provide a clear indication or statement of the nature of impacts, which meant that case-specific, deliberative interpretations by the authors of this paper had to be made in order to assign a characterisation, while also ensuring inter-reviewer consistency in interpretation. After assigning characterisations for the reported impacts within each case study, we also tracked possible associations between impact categories, noting whether they were of a mutually reinforcing (negative impacts leading to negative impacts or positive impacts leading to positive impacts) or negating (positive impacts leading to negative impacts or vice versa) nature.

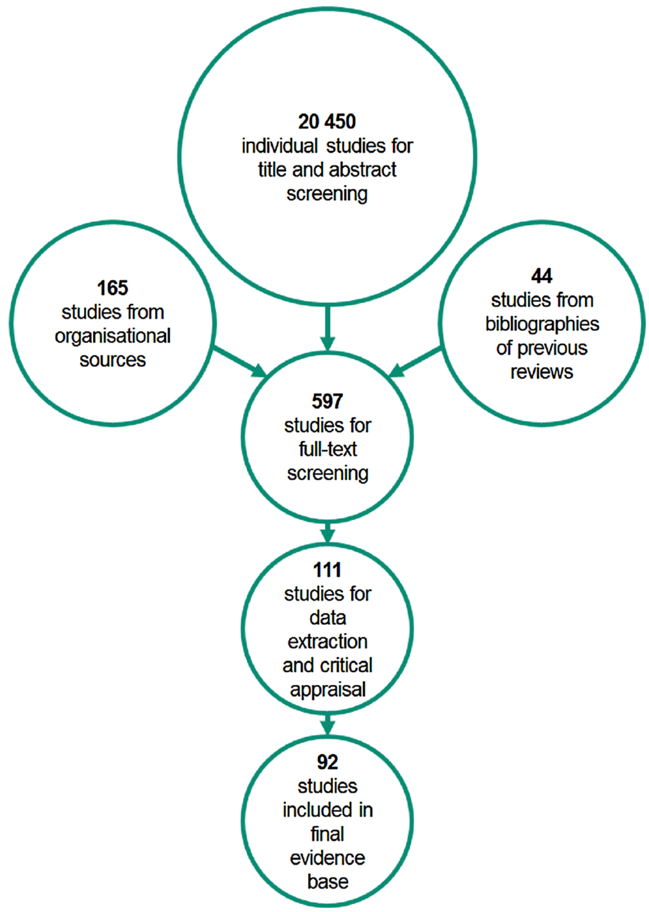

Fig. 1. Literature searches and screening results.

The data extraction sheet also included a quality appraisal of included studies, which included nine criteria (Table 2). The baseline criterion for study inclusion was that key results and conclusions had to be logically derived and supported by the data and methods presented. Of the 111 studies, only 92 studies met this criterion, of which six were published in Portuguese, nine in Spanish and 77 in English; no French studies met the criteria for inclusion in this final set. We further divided these studies into two groups based on additional quality criteria that were considered critical. Group A studies had to consider confounding factors that could have influenced the validity of their data and methods, and they had to use an appropriate comparator in their research design (with/without; before/after). Only 22 studies (25 case studies) met these two criteria. The remaining 70 studies (80 cases) are categorised as Group B, even though there was considerable variation

Table 2
Applied quality criteria.

Baseline criterion
Key results and conclusions are logically derived and supported by the data and methods
Critical additional criteria
Confounding factors that could have influenced the validity of data and methods are considered
A clear and appropriate comparator is present
General additional criteria
Key terms and concepts are clear, replicable and reliable
Data collection methods are clear, replicable and reliable
Sampling selection is explained
Sampling selection is justified
Data analysis methods are clear, replicable and reliable
Key conclusions and recommendations are logically derived and supported by the results

among studies with respect to their quality, with eight of them considering confounding factors and 14 using a comparator in their study design. Variation in Group B is even more pronounced in terms of general additional criteria, although it should be noted that a few studies in Group A did not meet all general additional criteria either. Selected details of all included studies are provided (Appendix 2). The raw data and a record of studies excluded at different stages of the review have been made (data set) accessible.

Because of the insufficient number of cases using common statistical methods, we were unable to perform any quantitative meta-analyses of the data. Although descriptive statistics were used to provide an overview of the evidence base, studies were synthesised qualitatively based on their reporting of impacts in each of the nine impact categories.

3. Results

3.1. Overview of the evidence base

3.1.1. Temporal and geographical distribution

The publication years of all 91 studies are shown in Fig. 2, indicating increasing research interest in the subject area in the past ten years (although there is another small peak in published literature between 2005 and 2008). Based on an analysis of incentives provided for plantation establishment and the timing of data collection, research tends to be conducted soon after plantations are introduced for the first time or changes in government policy encourage their further development. For example, South American tax incentive programmes attracted new investments into pulp mills and plantations at the turn of the last century (Almeida et al., 2008; Carámbula and Piñeiro, 2006). In Australia, investments into plantations in the early 2000s also followed the introduction of favourable tax regulations for projects under the Managed Investment Scheme (O'Toole and Keneley, 2010). Investments into plantations and the corresponding rise in associated studies in Eastern Africa and the Indochinese Peninsula, especially into rubber in Cambodia and Laos[1], are generally more recent, reflecting investor interest in acquiring and selling carbon credits and government policies granting land concessions to investors (Gironde and Peeters, 2015; Lyons and Westoby, 2014). Of the 71 cases specifying the incentives underlying plantation establishment, 76% report that government support played a key role in promoting investments in capital-intensive plantations.

Of the 82 case studies reporting the timing of plantation establishment, most examine the impacts between five to 15 years after establishment (Fig. 3). More than half of these (52%) also deal with impacts within 15 years after plantation establishment, which may lead to an overemphasis on front-loaded impacts.

[1] It is worth noting that Vietnam and Thailand have been characterised by the expansion of smallholder tree plantations since the 1990s, rather than expansion in large-scale plantations by external actors (Hall, 2011; Sikor, 2012).

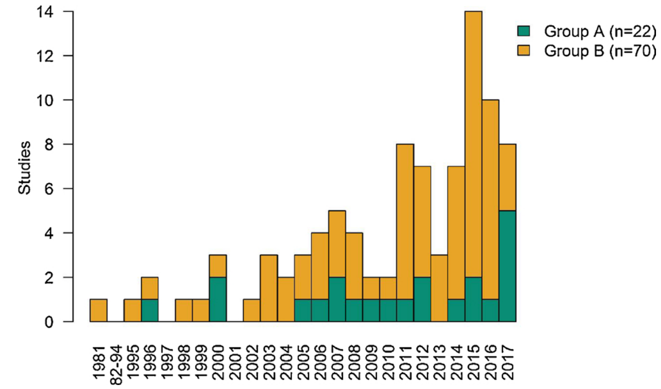

Fig. 2. Studies by publication years.

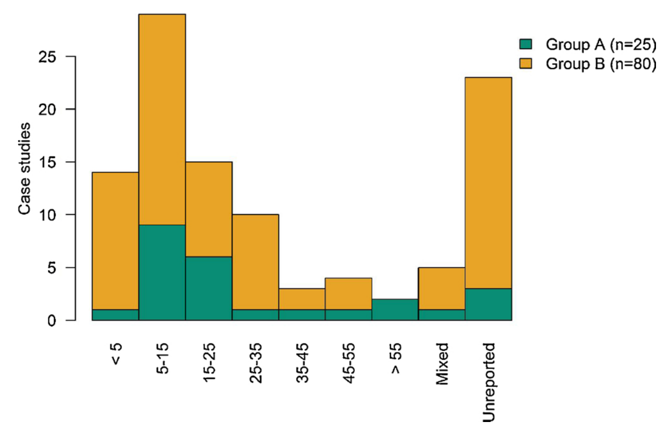

Fig. 3. Case studies by time between plantation establishment and data collection.

The geographical locations of the 105 cases by plantation type (primary tree species and designated commercial purpose) are mapped in Fig. 4. Even though we did not restrict our search to a specific geographical area, recorded cases are concentrated in Australasia, South America, Southern Africa, and Southeast Asia. However, some areas known to have significant coverage of large-scale tree plantations were not represented in our evidence base. These include the northern countries of South America, the Iberian Peninsula, and the southern United States (which was represented by only one case). Our evidence base thus shows a geographical bias towards certain regions or even certain countries, such as Cambodia and Chile.

3.1.2. Methods used in the studies

Most studies were qualitative in nature and based their reporting of impacts on local perceptions (Table 3). Studies using quantitative indicators are more commonly paired with quasi-experimental research designs in our sample. In both groups, socio-economic impacts have been studied using a range of methods, with key informant interviews being most commonly reported. We also recorded potential conflicts of interest in 18 out of 92 studies (20%).

3.1.3. Aggregate summary of the impacts

Altogether, the 105 cases reported 251 impacts that were grouped under nine categories (Fig. 5). The most frequently reported impacts are those related to "employment" (22%), "land" (21%), "social" impacts (20%) and "livelihoods" (12%). Most impacts are reported from Southeast Asia (34%), South America (29%), Africa (23%) and Australasia (12%). While most categories provide a rather balanced representation across continents, it appears that impacts related to "land" are more common to Africa and Southeast Asia in relation to other continents.

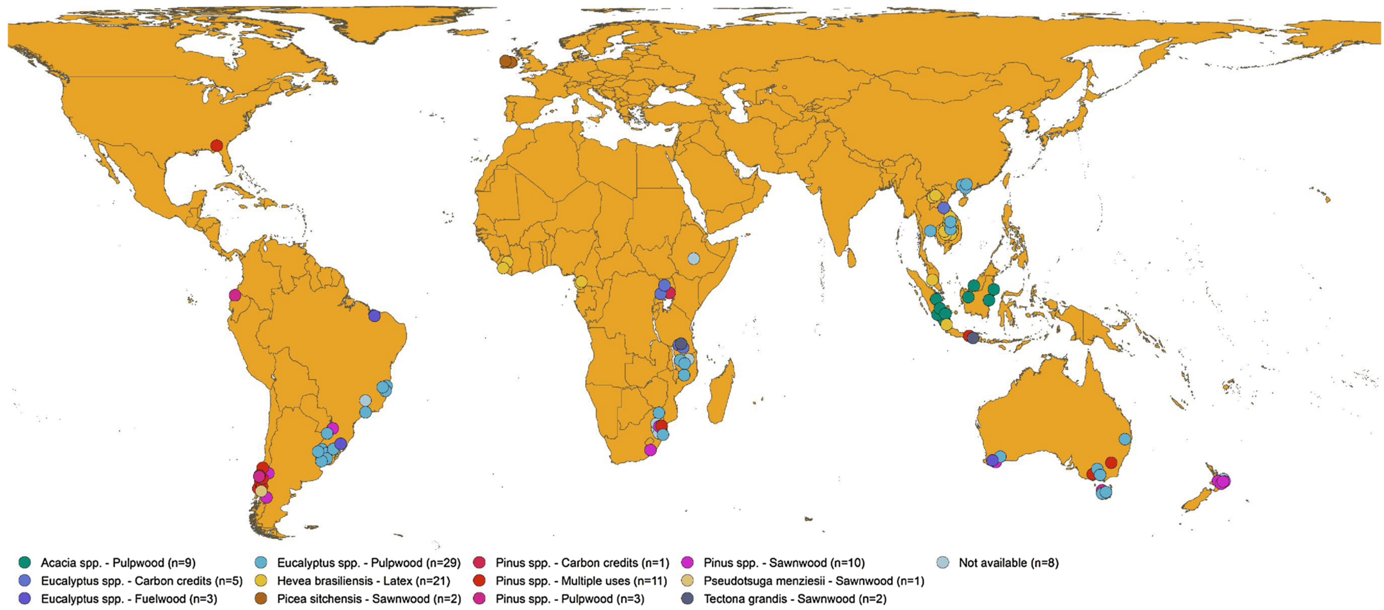

Fig. 4. Geographical distribution of case studies by plantation type.

Table 3
Overview of the methods used.

	Group A 25 case studies		Group B 80 case studies		Total 105 case studies	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Approach						
Qualitative	**9**	36%	**52**	65%	**61**	59%
Of which, perception-based	**6**	67%	**45**	87%	**51**	84%
Quantitative	**10**	40%	**13**	16%	**23**	22%
Of which, perception-based	**5**	50%	**7**	54%	**12**	52%
Mixed	**6**	24%	**15**	19%	**21**	19%
Of which, perception-based	**2**	33%	**8**	53%	**10**	50%
Design						
Quasi-experimental	**20**	80%	**11**	14%	**31**	30%
Non-experimental	**5**	20%	**69**	86%	**74**	70%
Method						
Household-level surveys (e.g. village)	**6**	24%	**20**	25%	**26**	25%
Area-level surveys (e.g. municipality)	**4**	16%	**4**	5%	**8**	8%
Key informant interviews	**8**	32%	**37**	46%	**45**	43%
Focus group interviews	**1**	4%	**4**	5%	**5**	5%
Mixed	**6**	24%	**15**	19%	**21**	20%

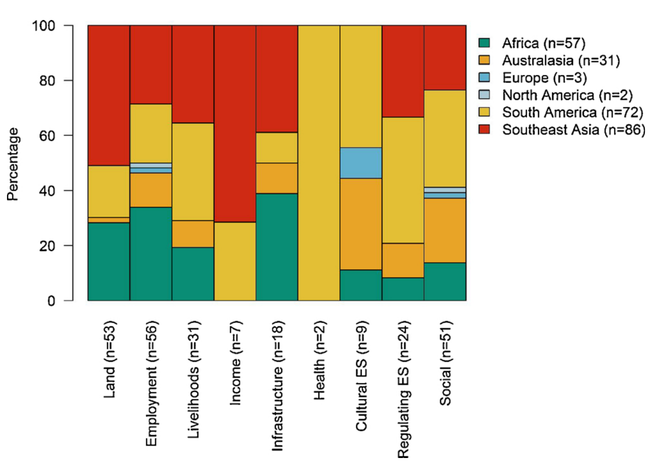

Fig. 5. Geographical distribution of impacts by category.

Although only studies in Group A have a comparator and consider confounding factors, reported impacts across categories and groups A and B lean towards negative assessments (Fig. 6). Of all the 53 impacts in category “land,” of which most are reported from Southeast Asia (51%) and Africa (28%), 81% are characterised as predominantly negative impacts. For “employment,” “social,” “livelihoods,” “regulating ecosystem services” and “infrastructure,” the corresponding figures are 41%, 69%, 48%, 79% and 28%, respectively. Two impacts are characterised as “neutral” (plantations not affecting well-being for better or worse), two as “unmet” (plantations not having contributed to well-being as per objectives) and two as “unreported” (plantations affecting well-being; unreported whether the change is for better or worse). When examining, for example, employment intensity, poverty rate or value accumulation, the baseline status clearly influences whether the impacts are perceived as positive or negative. Impacts are intended as measures of marginal change rather than in absolute terms.

Only 13 cases in our sample consider gendered dimensions of impacts. Ethnic dimensions are considered by 25 cases, all of which concern minority groups within the wider community. Interestingly,

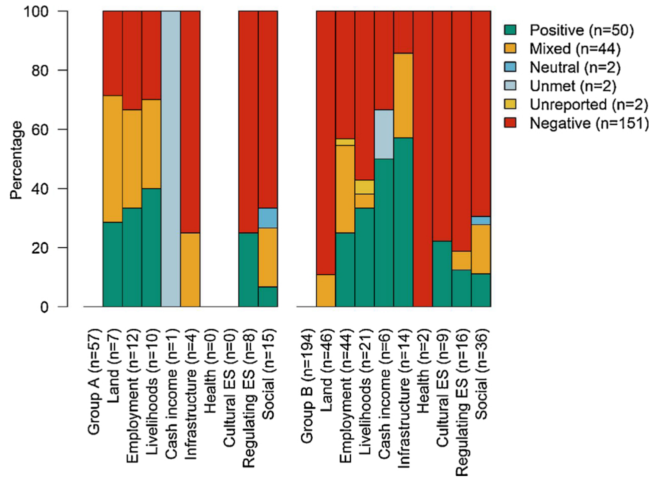

Fig. 6. Share of impacts by group and category.

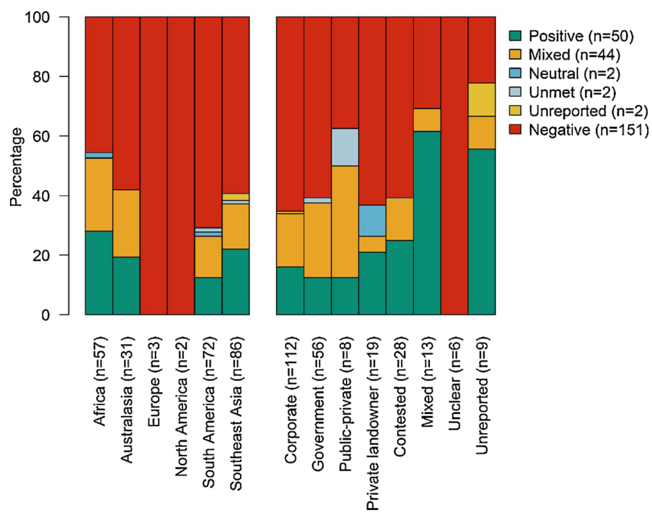

Fig. 7. Share of impacts by geographical location and ownership structure.

the presence or absence of management certifications that can include grievance mechanisms was mentioned in only 27 cases. However, in cases where plantations are not certified, certification is unlikely to be mentioned. Their actual effects on impacts are considered in only five cases. However, ownership structure is usually well-covered in our sample. Land being formally owned by the government is much more common to Africa (42% of cases on continent) and Southeast Asia (26%) than in South America (7%) and Australasia (6%). When assessments of impacts are contrasted with geographical locations and ownership structure at the aggregate level (Fig. 7), neither of them seems to explain variation in impacts. Similar to the other contextual factors (gender, ethnicity, certification), a more nuanced picture can only be drawn by analysing the cases separately.

Impacts were also found to fall into overlapping categories and the categories themselves may share overlapping characteristics (Fig. 8). Hence, community well-being is manifest as a complex spatial-temporal and social-ecological system. A total of 81 associations between categories from 52 case studies are found; 91% of them are of a mutually-reinforcing nature. For impacts on previous livelihood activities, for example, and for which the loss of land tends to be detrimental (Daranth et al., 2015; Myllylä and Takala, 2011), the labour offered by plantations can offer some relief (at least for some) (Bleyer et al., 2016). Associations are most frequently observed between categories "land" and "social" (16%) and "employment" and "social" (15%), within which a clear tendency of negative impacts to accumulate is found.

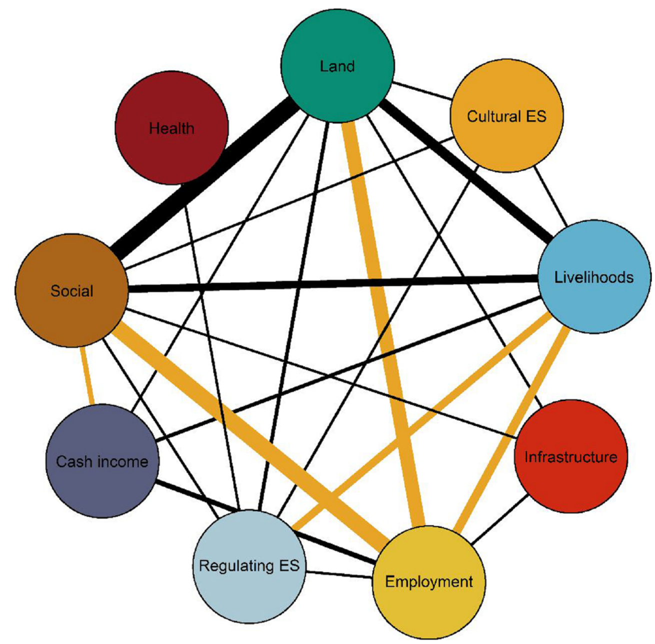

Fig. 8. Associations between categories.

How certain categories were framed led inherently to the recording of either positive or negative characterisations. The "land" category, for example, tends to emphasise the often-inevitable land losses caused by plantation establishment. Some categories were also broader than others, such as that of "social" impacts. Hence, we refrain from making statistical comparisons of characterisations between categories that are not directly comparable, focusing rather on building a synthesis of the cases under each category and naming the most interesting and illustrative examples (for a discussion of the significance of such mixing of means and ends for environmental management, i.e. "category mistakes," see Wallace and Jago, 2017).

3.2. Impacts by category

3.2.1. Land

The immediate impacts after land acquisition are reported by seven Group A cases and 46 Group B cases. Overwhelmingly, these cases are characterised by negative impacts. When in place, formal land titles for local residents seem to provide greater bargaining power over land transactions, enabling, not guaranteeing, a higher acceptance of plantation investments. However, property formalisation as part of plantation projects has also become a means for dispossession, as demonstrated in some Southeast Asian cases.

Within Group A, there are three cases characterised as having mixed impacts, two as positive and two as negative. Pirard et al. (2017) compare perceptions of impacts across plantation types in Indonesia. They find that government-managed pine and teak plantations with longer rotations in Java permitted a greater access to land and resources than acacia plantations that were more recent with shorter rotations for fast-growing species in contested areas on Kalimantan, which were viewed as more intrusive and competitive for land. Manzanal et al. (2011) report on negative impacts following the earmarking of vast areas for commercial forestry by the government in northern Argentina. This reportedly led to a concentration of ownership and higher land prices, pushing the families without formal title or investment capacity to out-migration. In neighbouring Uruguay, those with recognised land titles are reported to have benefitted from the concentration of land into foreign hands and the subsequent rise in land prices, by selling or leasing their lands to corporations in anticipation of, for example, early retirement (Piñeiro, 2012). In this same case, acquisitions by corporations were seen more positively than acquisitions by foreign pension funds aimed at securing financial assets in plantations with limited management, and hence fewer jobs created. In Cambodia, villagers lost access to natural forests as part of the formalisation of government land as concessions; with only the few having formal land titles reported to have received reasonable compensations for their land (Gironde and Peeters, 2015). Tanzanian villagers entered a leasing arrangement with the government-owned corporation and received regular cash transfers in exchange (not specified how much and for whom), but found themselves prevented from expanding rice production to meet the needs of a growing population (Johansson and Isgren, 2017).

Changes in access to land is also the main impact reported in Group B cases. An overwhelming majority report perceptions of negative impact, with 36 cases mainly from Africa and Southeast Asia finding people losing customary access to land or forest with little or no compensation (see Purnomo et al., 2014 for a prime example from Indonesia). In Mozambique, Bleyer et al. (2016) found that the closer the plantation is, the more difficult accessing vital resources becomes (which is one of the rare cases considering the effect of distance). Eight cases also correlate the land loss with reduced food security. Friis et al. (2016) report on decreased rice production due to land conversion in newly-formalised Laotian concessions, while Ehrnström-Fuentes and Kröger (2017) report that food security reduced due to a combination of decreased local production due to land conversion and a general increase in food prices in Uruguay. Ehrnström-Fuentes and Kröger (2017) also stress that the concentration of land in the hands of foreign corporations has inflated prices and intensified competition over land; consequently, farming activities of the poorest landowners in rural Uruguay are reported to have become unviable. Similar findings from privately-held plantations in southern Brazil and New Zealand indicate that the concentration of land is a more prominent issue in regions with relatively secure land titles (Almeida et al., 2008; Wall and Cocklin, 1996). An interesting mixed impact in Group B is reported from Thailand, where a corporation bought the land titles from previously indebted smallholders; despite the land loss, this one-time compensation enabled some to recover economically and invest elsewhere (Barney, 2004).

Land being seized by coercion is reported in 13 cases. While recent examples come from Cambodia and Laos where the granting of concessions to private investors has displaced local land uses in rural areas that are not officially recognised (Gironde and Peeters, 2015; Kenney-Lazar, 2012; McAllister, 2015), examples dating back several decades come from South Africa and neighbouring Swaziland, from times when plantation development was driven by the government (reported in Chirwa et al., 2015; Menne and Carrere, 2007; Tropp, 2003). The South African “land grabs” have also led to a difficult land reform process (Chirwa et al., 2015).

3.2.2. Employment

There are 12 Group A case studies and 44 Group B case studies reporting employment-related impacts, the majority of which report negative perceptions. The presence of local processing appears to be correlated with more positive impacts on employment; on the other hand, in permissive institutional environments, characterised by weak labour regulation and/or implementation, the presence of sub-contracting was linked to inferior working conditions.

Within Group A cases, there is frequent debate over the job creation per unit area of tree plantations relative to other land uses. One case from Tasmania, Australia, describes eucalypt and pine plantations as generating an average of 0.33 and 1.8 jobs per 100 ha between 2006 to 2008, respectively, while other primary sector land uses created slightly more jobs (Schirmer, 2009). In Indonesia, the rate of residents with employment experience was never lower than a third for any given settlement across teak, pine and acacia plantations – this is considered as an indication of substantial job creation on plantations, with little variation in perceptions between men and women and migrants and natives (Pirard et al., 2017). With new infrastructure and increased demand for services to support forestry operations, however, secondary (i.e. manufacturing) and tertiary (i.e. service) sectors are reported to have expanded and started hiring people in New South Wales, Australia (Schirmer et al., 2005). Generally, cases point to the need to have local wood processing to improve employment impacts, although this in itself is insufficient. A case from New Zealand shows that only the presence of these additional processing jobs can enable plantations to generate more employment per unit area than agriculture, yet such jobs are commonly created in urban centres and so are often distant from the site of plantation establishment (Fairweather et al., 2000).

Our sample also shows that plantation jobs are often temporary, part-time, or both. For instance, the one case from the southern United States documents the employment of migrants from Central American countries on guest visas, who do not enjoy the security of permanent contracts (Sarathy and Casanova, 2008). Another case from pine plantations in south-central Chile states that less than 5% of contracts are permanent (Unda and Stuardo, 1996). Similarly, the outsourcing of basic plantation jobs to contractors is said to have worsened conditions for sub-contracted workers in Laos (Barney, 2007). Another case from corporate-owned eucalypt plantations in Uruguay shares the main features of other cases and leads to a mixed characterisation (Carámbula and Piñeiro, 2006): these plantations generate precarious employment, one of the reasons lying with the responsibilities of contractors, not having standards for wages and contracts in place; however, with more people coming into the area, the tertiary sector provides more jobs compared to areas that see only grazing or small-scale agricultural activities.

Group B largely backs the findings of Group A. One frequent finding is that plantations do not offer stable employment, but instead bring mostly temporary jobs without benefits associated with permanent contracts, as reported in cases from Brazil, Indonesia and Mozambique (Almeida et al., 2008; German et al., 2016; Tyynelä et al., 2002). Pirard and Mayer (2009), however, note that village-based male workers travelling distances up to 50 km from their homes for particular plantation-related tasks, the total labour needs for these workers by the public-private acacia plantation in South Sumatra is quite evenly spread or staggered through the year, and from year to year through the seven-year rotation. Liberian corporate-owned rubber plantations serve as counterexamples, where significant employment opportunities with substantial benefits are reported to have been created, albeit alongside a lack of transparency in formation and distribution of salaries among workers (Verité, 2012).

A few cases in Group B report on the exclusion of women from plantation-related work for various reasons, such as their traditional family roles (Bleisch et al., 2006; Negede et al., 2015; Ramos and Bonilla, 2008). An older case from Malaysian rubber plantations argues that women’s lower cost of labour makes them attractive to employers (Heyzer, 1981), possibly induced by wage discrimination. However, a high rate of women’s employment is found in plantation nurseries in Uruguay, with women receiving wages higher than the regional average (Cárcamo, 2007).

3.2.3. Livelihoods

Thirty-one cases fall in this category, 10 in Group A and 21 in Group B. Here, prior land use, the associated trade-offs following conversion to tree crops, and time since plantation establishment play key roles in determining the nature of impacts.

In Group A, two impacts are characterised as positive due to the small-scale tree planting opportunities that emerged after the establishment of corporate-managed tree plantations in China and Uganda (Ainembabazi and Angelsen, 2014; D’Amato et al., 2017b). Two other positive characterisations from Indonesia are linked to the perceived benefits of complementary livelihood opportunities such as resin tapping, fuelwood collection and intercropping on the long-standing government-managed teak and pine plantations (Pirard et al., 2017). In South Africa, a government-managed plantation operator granted access to plantations and thereby supported other livelihoods based on the free collection and sale of timber and fuelwood; however, the range of available non-timber forest products (NTFPs) was found to be greater in other ecosystems, leading to a mixed characterisation (Mensah et al., 2017). In Pelluhue, Chile, a quarter of participants, perceived an increase in opportunities for small-scale enterprises following establishment of corporate-owned pine plantations; however, a quarter of participants also perceived a reduction in the range of possible uses of the plantation compared to the natural forests they replaced (Alfonso et al., 2016).

Negative impacts were mostly related to the loss of, or restrictions to previous livelihood activities. For example, a case concerning Cambodian villagers reports that livestock grazing came to an end once customary access was suppressed, and access to fishing and hunting areas were reduced following the establishment of rubber concessions (Gironde and Peeters, 2015). In Chile, eutrophication of coastal waters was linked to the increased run-off of nutrients from pine and eucalypt plantations on steep slopes, pushing fishermen further out to sea in search of target species and reducing the overall productivity of fisheries (Van Holt et al., 2017).

As in Group A, one of the main negative impacts reported in Group B was the reduced access to and availability of NTFPs after plantation establishment. Where plantations replaced or reduced the extent of natural forests, the resulting reduction in NTFPs had negative impacts on livelihoods across a range of countries, including Cambodia, Chile and South Africa (Daranth et al., 2015; Karumbidza, 2005; Navarro et al., 2005). Negative changes to livelihood activities due to rubber concessions displacing customary shifting cultivation systems were also reported in Cambodia (Prachvuthy, 2011). Instead, in Niassa, Mozambique, the seasonal jobs that emerged were viewed more positively as being complementary to traditional agriculture (Nube et al., 2016). Environmental issues caused by plantations were also reported to indirectly affect other livelihood activities, thus demonstrating a clear interaction between "livelihoods" and "regulating ecosystem services." In Ecuador, for example, the reduction in fish populations in rivers was perceived to be the result of plantation-induced changes to soil and water (Ramos and Bonilla, 2008).

Positive impacts in Group B were related to changes in livelihood activities made possible by plantation establishment such as partly enhanced conditions for beekeeping in Uruguayan eucalypt plantations (Malkamäki et al., 2016), and improved agricultural production in Laos following the introduction of intercropping between rows of planted trees (Levall and Prejer, 2013). An enabling factor in both cases was the permissive attitude of the corporate owner of the plantation, although the risk of communities losing their self-determination is noted. In Argentina, the free collection and sale of a valued mushroom (*Suillus luteus*) abundant in pine plantations of private landowners provided a complementary source of income for the poorest households and women in particular, although the contribution of this new income to overall livelihood conditions remains unclear (Fernández et al., 2012). Ofoegbu (2014) reports on similar impacts from South African corporate-managed plantations. Acciaresi et al. (2015) found changes in perceptions in a long-term study from central Argentina, where only 18% of informants representing diverse local stakeholder groups saw the introduction of government-owned pine plantations as positive in the 1980s due to its displacement of sheep herding, while 30 years later 89% thought plantations were positive. This change was driven by the perception of sheep herding itself becoming ecologically unsustainable during the period; moreover, residents, including most herders, witnessed a recovery of the soil following plantation establishment. Simultaneously, local eco-tourism was stimulated, offering alternative livelihood opportunities. While most herders had changed from nomadic to localised herding practices, those who did not change their practices remained in opposition.

3.2.4. Cash income

In this category, there is one case in Group A and six in Group B dealing with actual monetary earnings of residents. The only case in Group A finds that income-based poverty has not decreased in areas near Chilean privately-held pine plantations, in contrast to expectations (Unda and Stuardo, 1996). Areas with more than 20% afforestation rate are also reported to have a higher incidence of poverty than areas with less than 5%. The most afforested areas also see the highest proportion of indigenous people relying on subsistence agriculture and the highest incidence of poverty in Chile, although this seems to have been the baseline status preceding the arrival of plantations.

Within the six Group B cases, four cases come from Indonesia and three of them show positive impacts. Although Tyynelä et al. (2002) note an increased average household income at the community level in West Kalimantan, these benefits are not evenly spread among households due to disparities in accessing jobs on acacia plantations, of which ownership has been contested. In a similar context in South Sumatra, residents view the work on plantations as providing minor, but complementary flows of additional cash income during the months when village-based agricultural work is not available (Pirard and Mayer, 2009). Firdaysy (1999) notes that contrary to expectations, the incidence of income-based poverty did not change after the establishment of a rubber plantation in Lampung. However, one case from West Kalimantan reports significant contributions to household income and well-being at both the individual and community levels due to livelihood interventions undertaken by the corporate investor, including intercropping of subsistence crops and engagement of locals in small-scale tree planting (Greenhill et al., 2017). Here, the direct involvement of residents in tree production through the large-scale plantation (combined with intercropping) also helped to meet seasonal income gaps.

The other two cases in Group B report impacts on cash income that did not directly result from employment opportunities. Andersson et al. (2015) found a correlation between an increased area of tree plantations and increased income-based poverty among communities in south-central Chile. However, tree plantations are reported to account for only 2.1% of the total area of the municipalities in the sample, and the influence of the confounding factor related to possible changes in land use in the remaining areas remains unclear. Finally, negative changes to pre-existing income sources were reported in Laos by Baird and Fox (2015), where only a fraction of residents earned income from working on the rubber concessions and their wages were adjusted according to fluctuations in commodity prices.

3.2.5. Infrastructure

There are four cases reporting on infrastructural impacts in Group A and 14 cases in Group B. Within Group A, three negative infrastructural impacts are reported, although both Manzanal et al. (2011) and Peeters (2015) report on perceptions of neglected infrastructural development in Argentinian pine plantations and Cambodian rubber concessions, respectively, rather than the effects of infrastructure creation per se. In Tanzania, a government-managed teak plantation is reported to have cut access to existing roads and paths that villagers were no longer allowed to use (Johansson and Isgren, 2017). In Indonesia, acacia plantations were perceived as opening up inaccessible areas with road infrastructure development, although corporations managing the plantations did not intentionally carry out infrastructural improvements, leading to a mixed characterisation (Pirard et al., 2017).

Of the 14 cases reporting on infrastructural impacts in Group B, most reported impacts are characterised as positive, whereas cases reporting positive and mixed impacts alike found that investments by corporations have improved infrastructure through the construction and provision of roads, housing, electricity, water, and other social services, including schools and medical clinics (e.g. Bleyer et al., 2016; Ofoegbu, 2014; Palma, 2008; Potter and Lee, 1998; Westoby and Lyons, 2016a). Nevertheless, the issue of who really wanted and could access the benefits remains largely unclear, and where land and livelihoods were reportedly displaced, e.g. in Uganda, infrastructural improvements were seen as secondary priorities (Westoby and Lyons, 2016a). Similar to Group A, cases reporting negative and mixed impacts cite insufficient or absence of infrastructural development, or else unequal access to the infrastructure that was created. For example, Leys and Vanclay (2010) find that the lack of infrastructural investment for wood processing in New South Wales, Australia, hampered local socio-economic development; on the other hand, Bues (2011) finds that a corporate that was granted a concession by the Cambodian government had blocked villager access to existing roads in Ratanakiri.

3.2.6. Health

The evidence base for health impacts is very limited, with only two Group B cases. Both report negative impacts, which are related to the working conditions on Chilean pine plantations and at a Uruguayan eucalypt nursery (Cárcamo, 2007; Navarro et al., 2005). Both cases cite the use of pesticides as causing deterioration in worker health.

3.2.7. Cultural ecosystem services

Within this category, no cases qualified into Group A. Nine cases under Group B are found, of which only one includes a comparator. Seven report negative impacts such as disruption of traditional landscapes and related feelings of belonging and identity in Ireland and Australia (Fléchard et al., 2007; Williams et al., 2003). A case from Chile cites the difficulty of passing on traditional knowledge about natural environments and livelihoods after plantations replaced natural forests and disturbed sites of cultural value (Barreau et al., 2016; Ehrnström-Fuentes and Kröger, 2017). A Brazilian case by Azevedo and Fialho (2015) specifically report on negative impacts on the local *gaucho* culture, caused by the increasing number of wild boars near plantations after their establishment that damaged livestock central to the culture. Tomlinson et al. (2000) state that government-managed pine plantations reduced opportunities for tourism in New Zealand, although Palma (2008) finds, a few years later, that corporate-managed pine plantations offered a new venue for various recreational activities elsewhere in New Zealand. Acciaresi et al. (2015) also report on the contribution of plantations to local eco-tourism in Argentina after environmental management attitudes and standards were improved in the 1990s.

3.2.8. Regulating ecosystem services

As with cultural ecosystem services, impacts on regulating ecosystem services were often linked to changes in livelihood activities. Eight Group A cases and 16 Group B cases were identified. Six Group A studies dealing with acacia, eucalypt, pine and teak plantations in Australia, Chile, China, Indonesia and Tanzania find negative impacts on water quantity or quality, and associated soil and nutrient cycles that affect agricultural productivity (Alfonso et al., 2016; D'Amato et al., 2017b; Gordon et al., 2012; Johansson and Isgren, 2017; Pirard et al., 2017), although the Indonesian teak and pine plantations with longer rotations are reportedly perceived to have improved water flows and controlled for erosion (Pirard et al., 2017).

Of the 16 Group B cases, 13 cases report negative impacts mainly concerning water quantity or quality, but also address impacts on soil erosion and wild fauna (e.g. Ehrnström-Fuentes and Kröger, 2017; Oliveira, 2011; Olwig et al., 2015). Vihervaara et al. (2012) report diverging opinions on the impact of eucalypt plantations on water availability for other uses in Durazno, Uruguay, with half of respondents being very worried and the other half being slightly or not at all worried. Positive characterisations include enhanced control of fire outbreaks with help from established fire brigades, and increased fertility of soils previously considered unsuitable for agriculture (species is left unreported) (Myllylä and Takala, 2011; Wall and Cocklin, 1996). The linkage to human well-being in this category is primarily drawn from perceptions of impacts rather than measured ecological changes in the delivery of regulating ecosystem services after plantation establishment. The impacts seem to be similar regardless of the tree species, although eucalypt plantations represent 46% of the cases in this category.

3.2.9. Social

Under social impacts, 15 Group A cases and 36 Group B cases were identified. In Group A, most cases report on negative changes to social fabrics after plantation establishment. Plantations are expectedly reported to have increased tensions between residents and other groups or actors, rooted in conflicts over land acquisition, competition over jobs, and the exclusion of residents from decision-making.

In cases from Ireland and Australia, small-scale afforestation by residents is perceived to be less conflictual than that done by large-scale corporations (Schirmer, 2007). In the southern United States, the arrival and constant relocation of sub-contracted migrant workers has kept them from integrating into communities and also restricted their access to help in the event of injury (Sarathy and Casanova, 2008). A Cambodian case highlights the absence of credible grievance mechanisms, hampering the possibility of re-establishing trust following violations and disputes between residents and investors (Peeters, 2015). In Laos, the officials are reported to have violated the previously recognised right to access land (Barney, 2007), while in Argentina, people were forced to illegally clear new land after losing their customary access to land and consequently had criminal charges pressed against them (Manzanal et al., 2011).

There is some evidence that plantations have also increased intra-community conflicts. An example of residents losing their trust to forestry comes from Australia, wherein plantation development had relied on government subsidies in the early 2000s that crashed after the financial crisis of 2008, leaving behind perceptions of mismanagement among the affected communities. Those working in forestry felt frustration that their work was undermined by past wrongdoings by other residents. Community structure is also reported to have changed in Southeast Asia, as those who lost their customary access to land after plantation establishment in Cambodia left to find low-skilled jobs in Vietnam (Gironde and Peeters, 2015). In Laos, the same phenomenon was attributed to a complex set of linkages between ecological degradation and village socio-economics, while remittances sent back home reportedly helped the families to make new investments in their land (Barney, 2007). Unda and Stuardo (1996) also report on how the displaced livelihoods in Chile led to out-migration following land acquisition and conversion, leaving residents, many of which were indigenous, with fewer children and forcing schools and other services to close. Positive cases in Group A find increases in populations in other areas; for example, declining populations in rural Uruguay increased after timber harvests, rejuvenating the countryside (Carámbula and Piñeiro, 2006).

Cases in Group B reported mostly negative impacts on social ties. Changes in neighbourliness and moral standards are reported across geographical contexts (e.g. González-Hidalgo and Zografos, 2017; Myllylä and Takala, 2011; Tropp, 2003), and three cases report on increased crime, the fear of increased crime following the arrival of outsiders, and dense tree stands providing cover for criminals (Bues, 2011; Heyzer, 1981; Ramos and Bonilla, 2008). Residents themselves have also been charged as criminals for organising resistance to tree plantations (e.g. Baird and Fox, 2015; Navarro et al., 2005), although extensive resistance in Sarawak, Malaysia, is reported to have led to previously non-existent legal protections on land access rights of indigenous groups (Barney, 2004). In Australia, in both Tasmania and the South West, the certification of eucalypt plantations and active stakeholder dialogue is reported to have brought the residents and private investors closer together (Dare et al., 2010). Kenney-Lazar (2012) and Machoco et al. (2016) - in Attapeu, Laos, and Zambezia, Mozambique, respectively - also cite the many broken promises of corporate investors and the government to have cemented distrust between them and the residents.

In Group B, the skewed distribution of benefits from plantation projects is frequently reported to have led to increased inequality among residents (e.g. Ehrnström-Fuentes and Kröger, 2017; Tomlinson et al., 2000; Tyynelä et al., 2002). Corporate responsibility programmes in African countries were also criticised either for favouring elites in charge of distribution or being conditional on the generosity of individual corporations (Bishop, 2006; German et al., 2016; Westoby and Lyons, 2016b).

4. Discussion

The study of the local socio-economic impacts of large-scale tree plantations has focused on impacts related to land acquisition, creation and conditions of wage employment, and changes to conditions of various livelihood activities. Frequently, such impacts are also intertwined with changes in local social relations. Our findings largely corroborate the dynamics observed in other large-scale land-based investments.

We found that residents holding formal titles to land seem to have more positive attitudes towards plantation establishment, although such cases are few and do not exclude the co-existence of negative impacts elsewhere. In our sample, issues with land acquisition are more prominent in regions with weak recognition of access to land at an individual level, predominantly in Cambodia and Laos (Dwyer, 2015; Inguanzo, 2014). Residents with secure land titles, found in Australia and Uruguay with well-functioning land markets, seem to have benefitted from increasing value of their land owing to intensified competition. However, prices or compensations throughout our sample have rarely been perceived to be fair. There could be many reasons for this, one of them possibly deriving from the information asymmetries between residents and investors (or elites) (Asiama et al., 2017).

Negative impacts accrued due to land acquisition are accentuated when plantations do not bring sufficient employment opportunities to compensate for livelihoods that were frequently based on customary access to land. Jobs on large-scale tree plantations are often seasonal and precarious, and tend to become available only during land clearing or tree planting (although these tasks could also be phased by compartments on very large plantations). Labour per unit area on tree plantations is unlikely to match that of agriculture or biofuels (Deininger et al., 2011b; Hunsberger et al., 2017; Pirard and Mayer, 2009), although the picture could change if the additional value-adding steps - from seedling production through wood processing – are accounted for (Hassan, 2003). However, such steps may not occur locally, nor treat women and men equally, and have tended to be more prominent in higher-income countries.

Sub-contracting in forestry is a common practice (Garforth et al., 2005); based on our sample, this tends to be as commonly associated with inferior working conditions as in most other sectors (ILO, 2016). One explanation could be that tree plantations rarely occupy the most fertile soils suitable for agriculture and instead tend to expand in remote areas, wherein labour regulations are difficult to enforce (Deininger et al., 2011a). The use of migrant labourers is also common in forestry, arguably due to their greater acceptance of physically demanding forestry work and temporary contracts (Lenard and Straehle, 2010). Possibly this could be also due to their possession of more relevant skills, which could become necessary for the few permanent jobs available. Increased competition over jobs and land, and new or reinforced ethnic divisions, were also seen as a source of social tensions locally (Norton and de Haan, 2012), although such cases in our sample took place mainly in the populous nations of Southeast Asia. Impacts are likely to have gendered dimensions as well (White and White, 2012), although very few cases in our sample considered these.

Whether overall impacts are positive or negative depend on what the prior land uses were (and therefore what was lost and whether the opportunity cost is adequately compensated for), how long plantations have been part of the landscape, and who wanted and could access the compensatory opportunities. With more recently established plantations, perceptions focus on what has been lost; longer-established plantations see residents enjoying more of the opportunities arising from plantations. This indicates that costs tend to be front-loaded and the benefits accruing over time, although such benefits may not be comparable to those that existed from previous or alternative land uses. For younger generations there may also be few alternative options in remote areas in the first place (Chinsinga and Chasukwa, 2012; Mwaura, 2017).

It appears that forestry has favoured a highly centralised business model, although complementary livelihoods on plantations (e.g. intercropping, beekeeping) seem to have become more common recently. Combined wage employment and on-plantation intercropping could enhance the complementarity function of plantations in helping residents to overcome seasonal income gaps. The benefits provided by more inclusive models and corporate responsibility programmes may also be precarious in nature. For example, access to plantation sites has tended to be contractual to control risks associated with open access (e.g. fire) and the benefit-sharing arrangements have tended to favour local elites due to inadequate accountability mechanisms (cf. Cotula et al., 2014). Finally, the often limited (economic and political) agency of those affected by plantation establishment over decisions and processes that can profoundly change their lives is an important concern regardless of the impacts being positive or negative (Vermeulen and Cotula, 2010b). We corroborate the need to consider distributional issues upfront and reinforce mechanisms for governing risks and accountability also in the context of large-scale tree plantations (Goetz et al., 2017; Moog et al., 2015; USAID, 2018).

The studies reviewed here show that the socio-economic impacts of large-scale tree plantations have been mostly negative for those residing inside or near to them. The degree of agreement between studies, within the same geographical and institutional contexts as well as between groups A and B, is high for most categories (Table 4). With only 22 studies using a comparator and considering confounding factors, geographical gaps, topical and temporal research emphases, and methodological inconsistencies identified, strong global evidence on the longer-term socio-economic impacts remains limited. For categories with a high degree of agreement, confidence in results can still be considered relatively high despite limitations in evidence (IPCC, 2010).

The majority of the 251 impacts are situated under categories with high degree of agreement between groups A and B, suggesting that findings in Group B, in those categories, are generally valid despite

Table 4
Qualitative indication of uncertainties in the evidence base.

	Land	Employment	Livelihoods	Cash income	Infrastructures	Health	Cultural ES	Regulating ES	Social
Cases[a]	7/46	12/44	10/21	1/6	4/14	0/2	0/9	8/16	15/36
Agreement[b]	High	Medium	High	Medium	High	–	Medium	Medium	High
Evidence[c]	Medium	Medium	Medium	Limited	Limited	Limited	Limited	Limited	Medium

[a] Group A/Group B.
[b] Within similar context, between groups A and B.
[c] Type, amount, quality, consistency.

limitations in scientific rigor. The measures of scientific validity that were chosen to appraise the quality of the studies can also favour quasi-experimental designs over more critical, ethnographic designs. The different designs and ontologies can also sometimes be disconnected or even irreconcilable (Klenk and Meehan, 2015; Miller et al., 2017). The discourse of evidence-based policy as a global response to global sustainability challenges has also tended to overlook issues of power and politics (e.g. who controls resources, whose voice is being heard, what knowledge is relevant to policy), calling for self-reflexive and deliberative governance to complement evidence-based policy in sustainability-related decision-making (Elgert, 2010; Emmenegger et al., 2017). Hence, validity can be determined from multiple sources, not merely from systematisation with confounders and counterfactuals that can even be difficult to establish in some situations.

The evidence base is largely characterised by local perceptions of impacts, which are powerful in shaping current and future behaviour (Sultana, 2011). Perceptions must also be understood in relation to local expectations, preferences and aspirations, which can be complex, multivalent and historically determined (Emirbayer and Goodwin, 1994). For the purposes of this review, however, it should be recognised that studies may only represent a snapshot in time in an ever-changing context. People that can hold rather divergent perceptions on tree plantations in the first place may feel differently, for example, once the initial benefits available during the labour-intensive planting phase cease, and women may perceive impacts differently from men due to their varying roles and tasks in the community (Anderson et al., 2013; Ingram et al., 2014; Pirard et al., 2016b).

Dealing with studies drawn from different disciplines and methods, as well as with a wide range of often intertwined socio-economic impacts, proved to be challenging. As most studies on the topic rely on non-experimental designs, it is challenging to interpret these as either positive or negative characterisations, or to estimate the respective magnitudes of impacts, especially with changes over time. The lack of clear and common indicators and coherent terminology across studies further complicate interpretation and comparisons. Systematic reviews also tend to fall short in capturing the explanatory nuances of qualitative studies (Bondas and Hall, 2007).

Studying the impacts of large-scale tree plantations using different methods (possibly through interdisciplinary approaches) continues to be necessary to better understand the extent, patterns and dynamics of specific impacts, preferably paying attention on impacts with longer incubation periods (of which there was a relative lack of) and using clear indicators (Adams et al., 2016; Miller et al., 2017). For example, using a quasi-experimental before-after-control-intervention (BACI) design could help to establish causal linkages between impact categories that were not well-represented in the sample, including cash income, health and ecosystem services (Sills et al., 2017). The influence of contextual factors related to plantation management and governance (e.g. certification) need to be also studied more carefully.

5. Conclusions

With our review identifying only 92 relevant studies out of an initial total of 20,450 search results, of which only 22 presented a comparator and accounted for confounding factors, strong evidence on the socio-economic impacts of large-scale tree plantations remains limited. Most studies on the topic have also emphasised the impacts occurring soon after plantation establishment: changes in access to land and livelihoods (negative), wage employment (mixed) and the often intertwined social impacts (negative).

Most impacts across the nine categories can be characterised as negative, especially when considering changes in customary access to land and livelihoods. We also found an uneven distribution of research among regions; it is thus probable that reports on respectively negative and positive impacts are to a great extent determined by geographical (and potentially topical) distribution in the sample. Positive impacts, which are relatively few and do not necessarily come without problems, coincide with secure individual land titles and the ability to negotiate land transfers, complementary roles between plantations and other land uses, and the generation of stable employment, in particular through wood processing. Benefits also tend to accrue over time, although they may not be fully comparable to those that existed from previous land uses. Keeping in mind that trade-offs are certainly ubiquitous and take various forms across regions, the argument that large-scale tree plantations are more beneficial than costly to local communities is poorly supported by our systematic review on an aggregate basis.

Evidently, there is a need for more research that uses a clear comparator in the study design and accounts for confounding factors. Further research is needed in certain regions where there is a lack of research, for instance the Iberian Peninsula and the southern United States. The use of other potentially relevant languages, including Chinese, Indian and Indonesian, which were not considered here, would certainly extend the evidence base by providing access to a larger sample. More research is also needed on impact categories that were under-represented in our sample, such as changes in cash income, health, and ecosystem services. Besides, having longitudinal data that monitors changes in perceptions and impacts over time would be extremely useful. Studies should also go beyond impact assessments and take a closer look at the drivers of plantation-related policies that are likely to affect human well-being.

Conflicts of interest

None

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Appendix A. Supplementary data

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Production, restoration, mitigation: a new generation of plantations

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Production, restoration, mitigation: a new generation of plantations

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Abstract Forests provide a wide variety of ecosystem services and international conventions and national policies for climate change mitigation and biodiversity conservation recommend forest protection and restoration. However, global forest cover continues to decline, and recent evidence suggests deforestation rates are accelerating. Against this background the area of planted forests has increased globally. Recognizing the substantial potential of well-managed forest plantations, the new generation plantations (NGP) platform was launched in 2007. NGP encourages well-managed planted forests in the right places to conserve biodiversity and meet human needs. Here we describe the NGP approach and analyze data and information from NGP participants and others over 10 years. This shows that NGP participants are responsible for c.11.1 million ha of land, much of it previously degraded or abandoned; 43% is managed as timber plantations, with the remainder being wildlife reserves, restored natural forest, grassland and agriculture. NGP case studies illustrate a range of biodiversity, conservation and socio-economic achievements. These achievements, considered together with future projections of timber demand and of the land available for restoration to tree cover, demonstrate the potential of well-managed plantations to protect natural forests, provide timber, conserve biodiversity and mitigate climate change. The NGP concept works in a variety of countries and contexts; participants have shown that it is possible to produce timber while maintaining and enhancing ecosystems

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and contributing to socio-economic development. We present the case for forest production, restoration and mitigation/adaptation to limit climate and other environmental risks and to improve the resilience of landscapes.

Keywords Afforestation · Reforestation · Restoration · Conservation · Adaptation · Mitigation

Introduction

Stop forest degradation while producing more wood

In 2015 the total global area of planted forests, defined as forests established through planting and/or deliberate seeding of native or introduced species, was 277.9 million hectares (FAO 2000). They represent an increasing proportion of the global forest area, providing a significant and rising proportion of global roundwood production (Payn et al. 2015). Jurgensen et al. (2014) showed that planted forests supplied 33% of the global production of industrial round wood from all types of forests in 2012 (c. 770 billion m^3 per year out of a total global production of 1.683 billion m^3). Estimates provided by Carle and Holmgren (2008) indicate a potential of planted forests to produce up to two-thirds of the global industrial roundwood demand, rising to as much as 80% in 2030.

Increased production from planted forests is important, as demand for wood-based products will grow to unprecedented levels over the coming decades (WWF 2012). By 2050, the world's population is projected to reach 9.7 billion (UNDESA 2015). But rising numbers of people are only part of the story: at the same time, economic growth, urbanization and increasing prosperity are driving greater consumption (Kharas 2017). Meeting these growing demands will increase the already huge pressure on the world's natural resources—and wood is no exception. WWF's Living Forests Model projects that wood harvesting will more than double by 2030, and almost quadruple by 2050: from 3.4 million m^3 in 2010, to 7.6 million m^3 in 2030 and 13.1 million m^3 by mid-century (WWF 2012). However, there are limits to how much wood can be harvested from natural forests. So where is all that wood going to come from?

Following an encouraging decrease in the rates of deforestation during the last twentieth and early twenty-first century (FAO 2015), recent evidence suggests that deforestation rates are again increasing (Global Forest Watch 2017). Land degradation due to change in land use and land cover is estimated to cost about US $231 billion per year, and the annual cost of loss of tropical forests and rainforests is approximately US $43–65 billion (Climate Focus 2017).

There is some confusion around the terminology on forest restoration, reforestation and afforestation in the literature, with the terms sometimes used interchangeably (e.g. Griscom et al. 2017). However, according to FAO definitions (www.fao.org/docrep/006/ad665e/ad665e04.htm) reforestation refers to forest regeneration as part of normal forestry activity (e.g. after harvest) where the land use (forest) has not changed. In contrast, afforestation is forest established (restored) at sites where the land use has not been forest for a period. Stanturf et al. (2014) have extensively reviewed the forest restoration literature with emphasis on functional restoration i.e. restoration of forests to support societies with resources and services.

More wood to support sustainable development

In the Paris Agreement on climate change, almost every nation agreed a commitment to hold “the increase in the global average temperature well below 2 °C above preindustrial levels” (UNFCCC 2015). The Paris Agreement calls on parties to “take action to conserve and enhance … sinks and reservoirs of greenhouse gases … including forests” and encourages “incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries.” A recent estimate suggests that natural climate solutions such as conservation, restoration and improved land management actions across global forests, wetlands, grasslands and agricultural lands can provide over a third of the cost-effective climate mitigation needed between now and 2030 to achieve the goals of the Paris Agreement (Griscom et al. 2017).

Additionally, calculations of the mitigation potential of forests and forestry often fail to include all the important elements of mitigation. Many studies, as for example Griscom et al. (2017) focus only on the mitigation effects of storing carbon in ecosystems. The considerable substitution effects of using wood or woody biomass instead of fossil fuels or instead of energy-intensive materials such as cement, steel, aluminum, cotton or plastics receive far less attention, even though this is a core issue (Oliver et al. 2014). Wood and woody biomass play a key role in the transition to a bioeconomy. The Nordic and Baltic countries are heading towards carbon neutral societies by 2050 (Nordiska Ministerrådet 2009; IEA 2013), with woody biomass supplying 50–97% of renewable energy (Rytter et al. 2016) in all countries except Norway and Iceland, which are rich in hydropower and geothermal energy, respectively. Currently there are no single or general conversion factors available to accurately describe the substitution effects of using wood-based materials or fuels in place of fossil-based counterparts. These effects depend on both the exact system and materials that are replaced, and what they are replaced with. As such the issue is similar to the intense discussions on carbon debt repayment or carbon sequestration parity (Ter-Mikaelian et al. 2015; Bentsen 2017): the issue and models are so complex that the presumptions and the selection of model used for analysis become the key factor controlling the results and thereby conclusions (Bentsen 2017). Such a complexity is not helpful for society and decision-makers wanting to make the best science-based choices; but leaving the substitution effect out of the scope is not a good solution either, and may lead to severe misunderstandings regarding the potentials for sustainable forestry and forest restoration to mitigate climate change.

An example of this is Naudts et al. (2016) who concluded that the restoration of Europe’s forests did not contribute to the mitigation of climate change—a conclusion reached by ignoring the mitigation effects of substituting fossil fuels and energy-intensive materials with wood and woody biomass. However, the climate mitigation potential of highly productive planted forests that provide large quantities of wood and woody biomass is much larger than that assumed if only carbon storage in the standing biomass of the forest ecosystem is considered (Bentsen 2017; Gustavsson et al. 2017; Taeroe et al. 2017). This potential only reaches its peak once these resources are efficiently utilized.

Upcoming technologies such as biorefineries (www.Borregaard.com), bio carbon capture and storage (CCS) based on e.g. chemical-looping combustion (www.nordicenergy.org/flagship/negative-co2) and reverse photosynthesis (www.sciencealert.com/scientists-have-found-a-way-to-induce-reverse-photosynthesis) are promising technologies at various stages of maturity—and perhaps will become core technologies in a future bio-economy. New wood processing and construction technologies (e.g. mass-timber) incorporate engineered wood products such as cross-laminated timber and laminated veneer lumber which combine smaller wood elements to form strong structural units. Such technologies, along with conventional wood use in construction, have the potential to use substantial amounts of sustainably produced wood including for uses which substitute for steel and concrete. Such uses of wood may make an important contribution to the negative emissions needed to meet global climate goals (Smith et al. 2015).

Sustainable intensification: synergies between production, protection and mitigation

The issues outlined above raise the important question of what potential there is for well-managed plantations to "take the pressure off" natural or old-growth forests in future (Aienmababazi and Angelsen. 2014; Secco and Pirand 2015). Secco and Pirand conclude that there is a reduction in degradation of natural forests with the expansion of tree plantings. They suggest that "a promising way forward may be the promotion of highly productive plantations in strategic places where agricultural rents are low, while taking action at the demand level to avoid a rebound effect whenever the price elasticity of demand for wood products is high." In addition to wood production, there is good evidence that planted forests can compensate for the loss of natural forests in terms of forest area, habitat for biodiversity and ecological function (Brockerhoff et al. 2013). Although even reduced impact forestry systems (selective logging etc.) may have some local negative effects on biodiversity, plantations can add diversity at a landscape scale and protect ecosystem services by lessening the impacts of pests and diseases (Boyd et al. 2013).

There is, then, considerable potential for increasing productivity in planted forests and in restored forest landscapes to meet the expected and sharply increasing need for wood and woody biomass (WWF 2012) as well as for climate mitigation. However, sustainable development requires production to be balanced with the need for multiple other forest ecosystem services; intensively managed plantations covering all of the restored areas will not achieve this. To promote a more sustainable model, in 2007 WWF launched the new generation plantations (NGP) platform, with the participation of a number of companies and government forest departments that manage plantations (see www.newgenerationplantations.org). The idea was to identify and promote better practices for plantation design and management, learning and sharing experiences from around the world. Although they approach the issue from different perspectives and contexts, participants share a belief that as tree plantations grow over the coming decades they can—and must—bring real benefits to people and nature.

Productive forest land and the wood and woody biomass produced are crucial resources to support the sustainable development of society. We give particular attention here to wood production due to its importance to the economic pillar of sustainability and to its potential for mitigating climate change. However, it is a prerequisite that production is balanced with other forest functions and ecosystem services, such as protecting water resources, amenity values and habitats for biodiversity. Productive forestry is commonly viewed as a threat to these other forest functions, and thereby seen as part of the problem. We argue that productive forestry, usually in planted forests, can be part of the solution.

NGP is based on the premise that well-managed planted forests in the right places can help conserve biodiversity and meet human needs, while contributing to sustainable economic growth and local livelihoods according to four overarching principles:

- Maintain ecosystem integrity.
- Protect and enhance high conservation values.
- Develop through effective stakeholder involvement processes.
- Contribute to economic growth and employment.

The platform recognizes the need to expand planted forests as a solution to meeting the world's growing demand for forest resources while combating the loss and degradation of natural forests and other areas of high conservation value. NGP acts as a forum to take the management of planted forests forwards. Over the last 2 years topics have included:

- The role of forests in combating climate change;
- Social values, building a sense of ownership, and co-operative models;
- Recreating native woodland;
- Sustainable intensification.

Analysis

Replacing deforestation with forest restoration

Ending deforestation and degradation in forests by 2030—as envisaged in the Sustainable Development Goals (SDG15.2) and the New York Declaration on Forests—will require expansion of a range of plantation types (WWF 2012). Thus it is important that the NGP approach and the analysis presented here are rooted in forest landscape restoration—FLR; that is restoring multifunctional landscapes to improve human wellbeing rather than ecological restoration with an objective of restoring to a valued reference system. WWF's Living Forests Report projects that around 250 million additional hectares of new planted forests—including plantations—need to be established between 2010 and 2050. Figure 1 shows this requirement mapped by continent. These planted forests would take many forms and produce a wide range of timber and woody biomass products depending on site conditions—from pure conifer to mixed broadleaves and conifers of native as well as non-native species including coppiced willow and poplar in cooler northern and temperate regions. Closer to the equator, mixed planted forests of native species for high-quality timber products, or "fast-wood" acacia and eucalyptus plantations are some of the relevant silvicultural systems—but all assume no loss of natural forests. Intensively managed commercial plantations in tropical regions can produce wood fibre particularly efficiently: For example in Scandinavia 720,000 ha of semi-natural coniferous forestry or managed forest plantations are required to produce a million tonnes of pulp in a year, while managed eucalyptus plantations in Brazil can produce the same amount on just 140,000 ha (IBA 2015). However in Scandinavia, North America and other boreal and temperate regions sustainable timber production is nevertheless critically important to the mix of economic and social objectives.

In many regions there is potential to regain lost forest cover and assist the recovery of forest landscapes through afforestation or restoration (Stanturf 2015; Stanturf and Madsen 2002), including by using mosaics of new plantations, restored natural forests and responsible farming. There is a general lack of appreciation that plantations can add benefit as part of restored landscape mosaics (see for example discussion and citations in Secco and Pirand 2015 and Stanturf et al. 2014) and NGP has an important role in sharing best

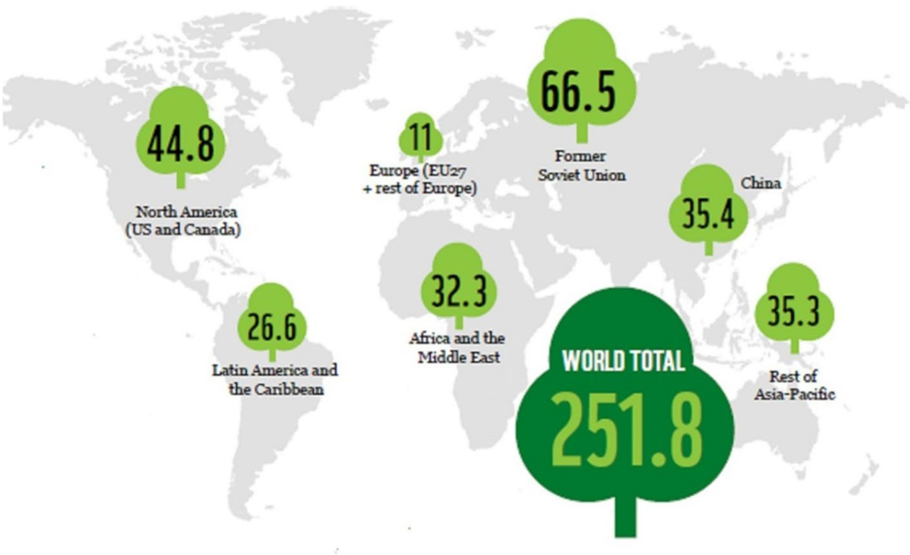

Fig. 1 Projected expansion of tree plantations (in million ha) under WWF's living forest model. *Source*: IIASA/WWF 2012. Living forests report

practice examples of this. The Bonn Challenge, launched in 2012, aims to begin the restoration of 150 million hectares of deforested and degraded lands by 2020, and 350 million hectares by 2030. Many countries have included large-scale forest restoration pledges as part of their national climate change plans, and various multi-country initiatives have been launched. Sustainable land-use mosaics and restoration of forest cover are critical components of strategies to enhance ecological integrity and conserve biodiversity in many regions. Figure 2 shows the areas of land globally where there is potential for restoration

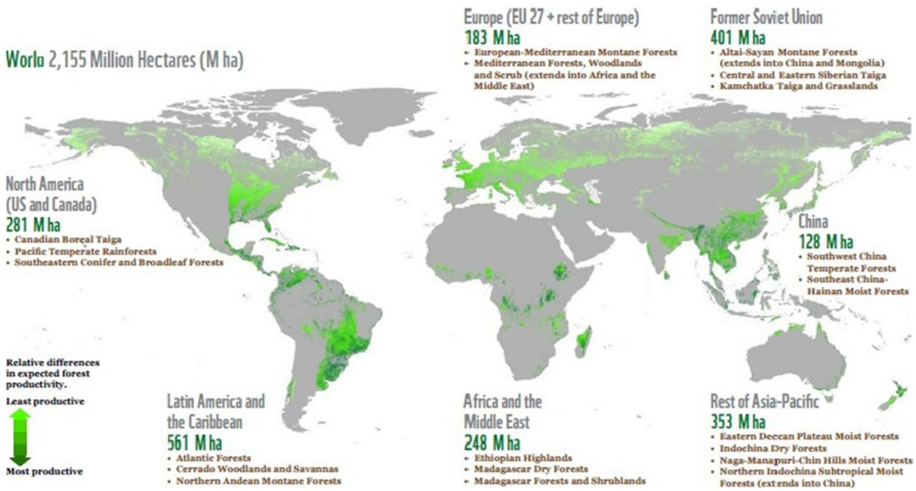

Fig. 2 Areas of land suitable for restoration of forest cover. *Source*: WWF. 2012. Living forests report

of forest cover. Since 2012 extensive forest fires and insect damage has changed the data in Fig. 2 for North America. Future analyses will describe the restoration of these areas and the extent to which resilience has been improved. The figure also indicates the potential forest productivity based on mean annual increment (MAI) of above-ground carbon.

New generation plantations: status after 10 years

The NGP platform aims to share and promote high standards of plantation management around the world. The participants manage over 11 million ha of land worldwide. Managed and facilitated by WWF International, NGP is a worldwide collaboration and knowledge exchange platform between forestry companies, governments and civil society. It has close links with organizations such as the Forest Stewardship Council (FSC) forest certification scheme and the International Union of Forest Research Organisations (IUFRO), particularly the Task Forces on Sustainable Planted Forests for a Greener Future and on Forest Adaptation under Global Change, both of which have a worldwide membership (see www.iufro.org/science/task-forces). Participants in NGP publicly disclose data on the areas of land for which they have responsibility, on the proportion of this area which is managed as sustainable plantations in line with NGP principles, on the FSC certified area, and additional information on previous land use, current objectives etc. (see www.newgenerationplantations.org/en/participants). These data are supplemented by participant reports, case studies and information provided when hosting NGP study tours and workshops (see participant documents at www.newgenerations.org/en/library). Together these data submissions and reports support the analysis that follows. In addition, data provided by the FAO Global Forest Resource Assessment (FAO 2015) and published analyses of the FAO data (e.g. Payn et al. 2015) has been used. These analyses show what NGP has achieved in the last 10 years. The progress that has been made in reporting and linking the work of NGP with the wider international agenda and consideration is given to the implications of the forestry and climate change challenges outlined above. Lastly we consider the potential for NGP to further develop the themes of production, restoration and mitigation.

Table 1 shows the areas of land managed by NGP participants by country in 2017. The area of forest plantation within the NGP managed areas, the percentage certified by FSC and the land-use histories are also shown. Because of NGP commitments to ecosystem integrity, conservation and stakeholder involvement (www.newgenerationplantations.org/en/participants), relatively small proportions of NGP land is in plantation forestry (c. 43% overall) with the remaining areas being wildlife reserves, restored natural forests, grassland or agricultural land. (In the case of some greenfield developments, notably in Mozambique, only a small area has been planted to date due to ongoing consultation with communities and other stakeholders). Often plantations are within a mosaic of these non-forestry land uses, and this type of landscape-scale diversity has been demonstrated to enhance the provision of ecosystem services and social benefits (see Tables 1, 2). In many countries FSC certification is considerable, whereas in others it has not been adopted for a range of reasons. Land-use history varies and can have a significant impact on how plantation forestry has changed the provision of ecosystem services.

Plantations can bring degraded land back into productive use (Table 1), alongside restoring natural ecosystems and the services they provide. The NGP overarching principles and FSC certification ensure sustainable forest management, including the avoidance of wall-to-wall planting for timber production. Productive areas are treated as part of a larger forest management unit, incorporating ecosystem functions, natural habitats and socio-cultural components. In Rwanda, Uganda, Tanzania and the UK 100% of the land area managed

Table 1 The area of land managed by new generation plantation participants shown by country. The areas managed as plantations for timber production and percentage of this certified by FSC are shown along with a short description of land-use history. The original data are from NGP disclosures and are used for the analysis presented in Table 2

Country	NGP participants' land area	NGP participants' plantations area	% of plantations FSC certified	Land-use history
Argentina	358,867	197,754	66	Primarily cattle ranching and farming, to lesser extent forestry
Brazil	2,953,595	1,491,686	80	Cattle ranching and farming
Chile	1,827,767	1,221,996	97	Cattle farming and agriculture
China	166,200	87,900	98	Mostly previous plantations, some barren land
Ghana	32,000	7000	0	Degraded forest land due to intensive logging
Laos	3900	2300	0	Degraded land due to shifting cultivation and war
Mozambique	356,000	9368	0	Degraded land due to intensive logging, shifting cultivation and charcoal production
Portugal	119,009	99,285	100	Eroded, abandoned, low productive lands
Rwanda	9992	9992	0	Planted forests (buffer zone area)
South Africa	263,486	173,015	100	Grasslands or agricultural areas
Tanzania	8221	8221	31	Unused land, some of it agricultural
Uganda	21,967	21,967	100	Planted forests and sugar plantation
UK	873,000	870,000	100	Mostly agricultural land
Uruguay	805,333	538,072	97	Cattle grazing
Others[a]	3,319,400[a]	0	n/a	Largely natural and semi-natural forest
Total	11,118,737	4,738,556	90	

[a]Some NGP participants also manage for production areas of natural/semi-natural forest which are not classified as plantations

Table 2 An analysis of the ecosystem services provided by the sustainable plantations managed by NGP participants. These evaluations are based on the data and information presented in Table 1 shows the ecosystem services provided by NGP managed and mainly FSC certified forests in relation to the previous land uses. The approach and categorization of ecosystem services follows that of Barala et al. (2016)

	Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)		Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)
Provisioning services					*Regulating services*				
Food production	↑	↓	↑	↓	Fresh air regulation	↑	↑	≈	↑
Timber production	↑	↑	↓	↑	Carbon sequestration and storage	↑	↑	≈	↑
Medicines	↑	↑	≈	↑	Natural hazard regulation	↑	≈	≈	↑
Freshwater	↑	≈	↑	↑	Water purification	↑	↑	↑	↑
					Disease regulation	≈	≈	↑	≈
					Pollution	↑	≈	↓	↓
					Erosion prevention and soil protection	↑	↑	↑	↑
Habitat and species services					Cultural services				
Habitat for species	↑	≈	↑	↑	Spiritual and religious value	↑	↑	↑	↑
Maintenance of genetic diversity	≈	≈	↑	↑	Aesthetic value	↑	↑	↑	↑

Table 2 (continued)

	Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)		Degraded and abandoned	Cattle ranching, grassland and low intensity grazing	Plantation forestry and intensive logging	Shifting cultivation (agri.)
					Recreation and ecotourism	↑	≈	↑	↑

by NGP participants is classified as plantations and these plantations are often mixtures of both native and introduced species in landscape mosaics.

NGP management aims at benefiting the people living alongside them by providing jobs and income as well as funding local infrastructure, often in remote areas where economic opportunities are few. Likewise, plantations that follow FSC principles and criteria help to clarify land rights, uphold the rights of indigenous peoples, and maintain or enhance the social and economic well-being of forest workers and local communities. When companies that manage NGP-plantations engage with local communities the aim is that they become channels for inclusive green development (e.g. Mondi Zimele in South Africa—http://www.mondizimele.co.za).

NGP examples

Evidence collected by NGP over the years shows how many models for sustainable land use offer opportunities for innovative financing combined with new opportunities for economic development, especially in rural areas where jobs, innovation, and investments are much needed. It has been shown that economic development can be combined with conservation, including restoration and climate adaptation, at the same time a number of NGP participants have demonstrated sustainable models for bringing degraded land back into productive use. Full details of the case studies being run by NGP participants are available at www.newgenerationplantations.org/en/casestudies. However some indication of their achievements in summarized here:

- In Portugal NGP participant Navigator manage eucalyptus plantations which now account for around a fifth of the country's total forest cover. These areas include plantation landscapes of high conservation value. Navigator has built biodiversity conservation into its forest management framework and their management aims to maintain and enhance conservation value.
- In the UK the Forestry Commission has successfully worked with partners to bring osprey (*Pandion haliaetus*) back to the Lake District.
- In Chile Forest Mininco maintains areas of natural habitat to protect endemic trees such as *Araucaria* sp. and endangered mammals such as the southern river otter (*Lontra provocax*) and birds including the red-headed magellanic woodpecker (*Campephilus magellanicus*).
- In Brazil for NGP participants (Fibria, Suzano, Veracel, Kimberly-Clark) manage more than 2 million hectares of land in the Atlantic forest biome. Around half of this is planted with eucalyptus, almost all of it on former grazing land that had become heavily degraded. On the other half, native forest is naturally regenerating or being actively restored—with a particular focus on establishing corridors between remaining fragments of forest, and conserving native vegetation in riparian zones and on steep slopes. Fibria has also set up community tree nurseries to help improve employment opportunities and incomes for local people where job-opportunities are limited. Fibria has particularly targeted women and disadvantaged groups, who have seen a significant increase in their household incomes. So far the community nurseries supply only around 10% of Fibria's seedlings, so there is significant scope for them to expand.
- In Uruguay UPM Forestal Oriental owns around 200,000 hectares of former agriculture land where it is enabling yatay palms to recover. UPM has worked with local experts to build a palm conservation strategy into its plantation design, which includes protecting or relocating young and mature trees and connecting isolated palm groves. The palm

trees add structural diversity and provide a source of food for numerous animal, bird and insect species. The palm fruits and seedlings also provide a potential source of income for local people.

- In South Africa SiyaQhubeka Forests (SQF), a partnership between Mondi and local community organizations, worked with the government, environmental NGOs and the park authority to develop a scientific method to determine which areas of iSimangaliso Wetland Park (a World Heritage site) were suitable for commercial plantations and which should be returned to their natural state. Subsequent work has extending the habitat for wildlife such as elephants and rhinos and providing a buffer around core habitat areas. The wetland delineation method has since been adopted across all Mondi's properties and by the rest of the forestry industry in South Africa.
- In Minqin China the desert continues to encroach on agricultural land at a rate of 3–4 m every year. Desert expansion, land infertility and lack of water have brought continuous decline in living standards for local communities. The Chinese government supports tree planting to combat desertification, but previous projects have met with limited success however in new by FuturaGene, a subsidiary of Suzano, is running a field trial to test which species grow best in desert conditions and to develop suitable management practices, enabling farmers to maximize the social, economic and environmental benefits of tree plantations. FuturaGene aims to identify suitable species/clones for different uses and develop a set of best management practices for each.

NGP: providing ecosystem services and attracting investors?

According to the Progress Report on the New York Declaration on Forests (2017), investments in the transition toward sustainable land use offer financial returns while meeting demand. Sustainable land use is not only essential for mitigating climate change, it also offers financial benefits in the form of increased yields and higher quality commodity supplies. Despite the current huge pressure on land resources, large areas of land are in a degraded state—global estimates vary from almost 1 billion hectares to more than 6 billion hectares (Gibbs and Salmon 2015).

Table 2 shows an analysis of the ecosystem services provided by the plantations managed by NGP participants. The approach and categorization follows that of Barala et al. (2016) with the current ecosystem services of managed forests indicated in relation to those of the previous landuse. These evaluations are based on the data and information presented in Table 1 and provided annually in NGP disclosures (http://newgenerationplantations.org/en/participants/), as part of participant openness and transparency policy. NGP participants lead by example in disclosing information about their plantation practices and are nearly 100% FSC certified and with 70% allocation of GRI (www.globalreporting.org). The analysis presented in Table 2 illustrates the importance of taking a more holistic approach to addressing big challenges like food, water and energy security, biodiversity conservation, poverty alleviation and climate change adaptation—and that this is best achieved at a landscape scale. The case studies summarized above show how NGP participants have sought to balance competing demands within a given area: optimizing productive land uses such as agriculture and forestry, while maintaining vital ecological functions and providing for the needs of people.

Successful landscape approaches recognize that ecosystems and human society are interdependent. They seek to build resilience on both sides, enabling both social and ecological systems to adapt to and recover from shocks like fires, floods and droughts.

Discussion

It is time for the implementation of holistic solutions

Improved forest management offers large and cost-effective mitigation opportunities, many of which could be implemented rapidly without changes in land use or tenure. In principle some restoration activities may not need to reduce yield, but in practice most foresters find that activities like reduced impact logging can increase short term operational costs while others, like extending harvesting cycles, result in reduced near-term yields. This shortfall can be met by implementing what Griscom et al. (2017) call the reforestation pathway, which includes new commercial plantations and has the largest low-cost mitigation potential. In addition, the improved plantations pathway seeks to increase wood yields by mainly extending rotation lengths from the optimum for economic profits to the optimum for wood yield (Griscom et al. 2017). However problems can arise if harvesting machinery and sawmills are set up for the average sizes from conventional rotation lengths and if conventional rotation times were a factor in projected returns on investment.

Planted forests may seem of low value in terms of the habitats they support for biodiversity compared with what old-growth or primeval forests hold. However, this is rarely a relevant comparison. Forest degradation and conversion has taken place over centuries and even millennia; the more relevant reference for biodiversity and ecosystem services is the currently degraded land where afforestation takes place, rather than the old-growth forests that were historically lost. It could be argued that for the production services the relevant comparisons are the production systems of the alternative construction materials such as concrete and steel.

What history has taught?

Equally relevant is to consider the timeframe for restoration of ecosystem services. Case studies of forest restoration in temperate zones particularly describe some very long-lasting processes (Stanturf 2016; IUFRO SPDC 2017; WRI 2017). In severely degraded landscapes in the temperature zone, restoration may initially be rather slow. The suitable tree species may be restricted to pioneer species, which can tolerate the harsh site conditions, which may include unfavorable soil, microclimate or moisture conditions. Biotic factors such as grazing or browsing ungulates may also pose a threat to the young trees. In some cases, site conditions may initially be so unsuitable for young native trees that non-native species may be the only ones that establish and grow: they may serve as the main species in at least the first generation, or as nurse species if the initial site conditions are somewhat better (Madsen et al. 2017). Later, as site conditions improve, a wider range of species may be planted either under the shelter of the nurse crop or of the first generation when that has reached maturity. This process may take place over several rotations and adaptation to future climate needs to be considered by the choice of species planted, sown and naturally regenerated during the following generations.

In Europe, practically all forest land has been cleared at some point and only very little remains of what is considered old growth (Spiecker 2002), and in Brazil, only 7–8% of the original Atlantic Rainforest has been left (Ribeiro 2009). Much of the forest land has been cleared and land use changed for a period, so much of what we now think of as forest is the result of afforestation or forest landscape restoration. Today, these forests are capable of producing many more ecosystem services than our predecessors probably imagined, and more wood. The mean productivity of Brazilian eucalyptus plantations reached 39 m^3/ha year in 2014, having evolved from less then 15 m^3/ha year in 1970, as result of investments in research and development, primarily seeking to improve the genetics of the plantations and forest management techniques (IBA 2015). Throughout the twentieth century the general picture on a hectare-basis is increasing standing volume, harvest and increment (Spiecker 2002) and there is potential to further increase productivity. Rytter et al. (2016) provides a good example reviewing the potentials for the Nordic and Baltic forests to contribute to the political goals of developing carbon neutral societies by 2050. They concluded that there is large and unredeemed potential to increase forest productivity (50–100%) at the stand scale even further and within the next tree generation (50–100 years) than has been achieved historically.

The concept works in practice

Over the last 10 years, NGP has demonstrated a concept that works. Planted forests make up only around 7% of forest cover worldwide, but supply a third of the total global production of industrial roundwood (Jurgensen et al. 2014). The data on changes of ecosystem services (Table 2) indicate that over and above roundwood production, plantations which are managed in line with the NGP approach can be part of the solution to the global challenges of climate mitigation, conservation of biodiversity and natural capital, and poverty alleviation. In a variety of countries and contexts, participants have shown that it's possible to produce timber efficiently and profitably while maintaining ecosystems and contributing to socio-economic development. And that doing so can open up new opportunities to create shared value for communities, restore degraded and deforested land, and contribute to climate change mitigation and adaptation.

In an increasingly complex world of limited resources and volatility, fundamental changes are required in production models, business paradigms and governance, where a new generation plantations can provide the ecological infrastructure to build a green future. A future where well placed and managed plantations provide opportunities and value for people living alongside them, opportunities to restore degraded ecosystems and build resilience, opportunities to increase the supply of renewable raw material while sparing natural forests. Success will depend on how intelligently and sensitively we integrate a mosaic world of different cultures and values, where areas for agriculture, industry, forestry, infrastructure and cities coexist with nature.

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Ministry for Primary Industries
Manatū Ahu Matua

Sustainable Management of New Zealand's Forests

New Zealand's Third Country Report on the Montreal Process Criteria and Indicators

Acknowledgements

This report was prepared primarily by the following Ministry for Primary Industries staff from the Policy and Trade Branch: Alan Reid, Gerard Horgan, Parnell Trost, John Novis, Steven Cox, and Ian Payton (consultant).

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New Zealand Government

FOREWORD

Remarkably, forest managers were thinking about the sustainability of the supply of timber from forests in Germany in 1713. Since then, the concept of what constitutes "sustainable forest management", and its objectives, has evolved. Sustainable forest management now recognises the diverse range of values, goods and services provided by forests and forest ecosystems.

The Montreal Process provides a framework of criteria and indicators for countries to report internationally on progress towards achieving sustainable forest ecosystem management for both planted and natural forests.

This is New Zealand's third national report under the Montreal Process. The report is a valuable contribution to our understanding of sustainable forest management, and it includes information on the full set of seven criteria, and 54 of the indicators. The report provides an overview of the current state of New Zealand's forests and covers a range of the environmental, commercial, social and cultural issues associated with those forests.

This report is an opportunity to acknowledge the achievements and developments in the period since the last report in 2008. These include:

- a significant focus by both Government and industry on the health and safety of workers in the forestry industry;
- a 50 percent increase in sustainable harvesting;
- the standing volume of plantation forests has increased due to an increase in the average age of the estate;
- improvements in the quality of the data relating to both the forests and their wider ecosystems;
- improving the understanding of threats to natural forests and control options;
- efforts to improve the management of wilding pines;
- the ongoing focus on biosecurity;
- $12.27 million being committed to forestry innovation projects under the Primary Growth Partnership Programme, of which $6 million was from industry; and
- the introduction of a forest growers' levy which was expected to raise $8.2 million for industry-good activities in 2014.

The Montreal Process, and this report, provides an important benchmark against which we can demonstrate our progress in future years, and contribute to the international understanding of sustainable forest management.

Hon Jo Goodhew
Associate Minister for Primary Industries

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THE STATE OF NEW ZEALAND'S FORESTS

The Montreal Process criteria and indicators provide a common framework for members to monitor and report on trends in progressing towards sustainable forest management. This is New Zealand's third national report, following previous reports in 2008 and 2003. This report includes comment on all 54 indicators, and is an assessment as at mid-2014.

Overview of New Zealand's forests

New Zealand has a total of 10.1 million hectares[1] of forests[2], covering 38 percent of the land area (Figure 1.1A). This includes 8.0 million hectares of indigenous forests and 2.1 million hectares of plantation forests. These forests are fundamentally different in their biological characteristics, management objectives, and respective roles in fulfilling the needs of New Zealand society.

Indigenous forests

The Crown is the major indigenous forest owner. Through the Department of Conservation, it manages about 5.2 million hectares (76 percent) of New Zealand's tall indigenous forests for conservation of biodiversity, heritage and recreational purposes. The bulk of this Crown-owned forest resource is protected in perpetuity in national parks, scenic reserves and other conservation areas (Figure 1.1B).

Plantation forests

New Zealand's plantation forests are dominated by one species; radiata pine *(Pinus radiata),* which accounts for 90 percent of the planted area. Ninety-four percent of the plantation forest estate is in some form of private ownership, with the principal management objective being the commercial production of timber.

Following a period of expansion of the plantation forest estate through to the early 2000s, there has been a small decline in net area of about 3 percent. This reflects, in part, the conversion of plantations to more profitable agricultural land uses. Large areas of plantation forest have shifted from listed companies to various forms of private ownership over the last decade.

Key points for each criterion

Criterion 1 Conservation of Biological Diversity

The area of publicly owned indigenous forest protected by legislation has increased by 3.7 percent since 2006, and the majority of tall indigenous forests (76 percent) remains in public ownership.

Measuring and monitoring the health of indigenous forest (and non-forest) ecosystems across New Zealand continues to be a focus. Over the last decade, a national biodiversity monitoring and reporting programme has been developed to assess whether the ecological integrity of public conservation lands is being maintained.

Since 2007, 12 threatened taxa have improved in status as a result of successful species management, and 59 have worsened in status. No taxa were found to have become extinct since the previous threat status assessment.

Criterion 2 Maintenance of productive capacity of forest ecosystems

For both indigenous and plantation forests, harvest levels are well within the limits for sustaining the resource.

1 This report uses satellite imagery-based estimates of forest areas comprising tall indigenous forest, regenerating indigenous forest, and the gross plantation forest area and a broader definition of what constitutes a forest than used previously. For plantation forests, the satellite imagery-based estimates are of gross areas to better match international reporting requirements. Previous reports used net stock areas, which are also used at times (and clearly identified) in this report.

2 The definition of forest is woody vegetation of at least 1 hectare that will exceed 30 percent canopy cover and 5 metres height at maturity. This results in the inclusion of a significant area of regenerating indigenous forest.

Standing volumes in plantation forests have increased steadily over recent years and this growth is expected to continue as more forestry plantings approach maturity. Harvested volumes have also increased, but at a slower rate, as much of the forest is still in its first rotation.

The area of indigenous forest with approved plans or permits for sustainable timber production declined by 26 percent between 2007 and 2013, and currently stands at 84 000 hectares. Recent analysis suggests that about 250 000 hectares of privately owned indigenous forests have the potential to be managed for sustainable timber production.

Criterion 3 Maintenance of forest ecosystem health and vitality

Annual economic losses from diseases affecting plantation forests are estimated at $83 million; slightly more that the estimate for 2008 of $82 million. In 2013, less than one percent of the total plantation forest area was affected by insects, and about ten percent of the total plantation forest area was affected by diseases. The diseases involved mostly affect growth and wood quality.

Despite ongoing control efforts, possums, ungulate and other vertebrate pests significantly affect indigenous forests. However, understanding of the distribution, abundance and impact of possums in New Zealand indigenous forests has improved greatly since 2005 and the more recent implementation of a biodiversity monitoring and reporting programme. It is estimated that 81 percent of the indigenous forest area is affected by possums.

Criterion 4 Conservation and maintenance of soil and water resources

In 2011, the government issued a National Policy Statement for Freshwater Management, and amendments in 2014 provide direction to local government on the management of water resources.

New Zealand has a number of documents that address the mitigation of impacts from plantation forestry operations on soils and water. Since 2008, two new documents have been published: the *New Zealand Forest Road Engineering Manual,* and the *New Zealand Standard NZS AS 4708:2014 Sustainable Forest Management.* Updates have been completed on the *New Zealand Environmental Code of Practice for Plantation Forestry*, and the *Standards and Guidelines for the Sustainable Management of Indigenous Forests.* These documents are supported by, and widely promoted by, the industry.

Criterion 5 Maintenance of forest contribution to global carbon cycles

Forest carbon stocks increased between 1990 and 2012 by 7.4 percent to 3 298 million tonnes of carbon. Of this total, 86.2 percent was in indigenous forests and 13.8 percent in plantation forests.

About 7 percent (57.83 petajoules) of New Zealand's primary energy supply comes from forest biomass. This has increased 44 percent since 2008.

Criterion 6 Maintenance and enhancement of socioeconomic benefits of forests to meet the needs of societies

Production from New Zealand's plantation forests has increased significantly since 2008. A total of 30.5 million cubic metres of roundwood was harvested in the year ended March 2014. This represented 6 percent of the estimated standing volume of plantation forests of 494 million cubic metres.

The majority (57 percent) of this production was exported as logs or chips. The remainder was processed into sawn timber (4.1 million cubic metres sawn), panel products (1.9 million cubic metres), pulp (1.5 million air dried tonnes), and paper and paperboard (0.7 million tonnes).

Production from indigenous forests was 24 000 cubic metres, or less than 0.1 percent of the total harvest.

The harvesting and processing of wood products generated:

- export earnings from logs and wood products of $5.2 billion for the year ended June 2014;
- work for 17 415 employees in forestry and first-stage processing for the year ended February 2013;
- a contribution to gross domestic product (GDP) from forestry and logging plus wood and paper products of $3848 million for the year ended December 2013, or 2.6 percent of total GDP.

Employment has declined over the past decade, due to a combination of increasing productivity, restructuring within the sector, and changes in market and foreign exchange conditions. Longer term, there is potential for additional employment as plantings in the 1990s mature, and new uses for wood and fibre are commercialised.

Forestry workers experienced an inflation-adjusted 15.7 percent increase in real earnings between 2010 and 2014.

Health and safety in the industry has been a challenge, and reducing the number of fatalities and serious injuries is a high priority for both government and industry.

Debate is growing on how to recognise environmental services, including from forests, and how New Zealand can maintain its natural capital through policy actions and initiatives. Although environmental services remain largely unpriced, targeted grants support the treatment of erosion-prone land. Also, eligible landowners may participate in the New Zealand Emissions Trading Scheme.

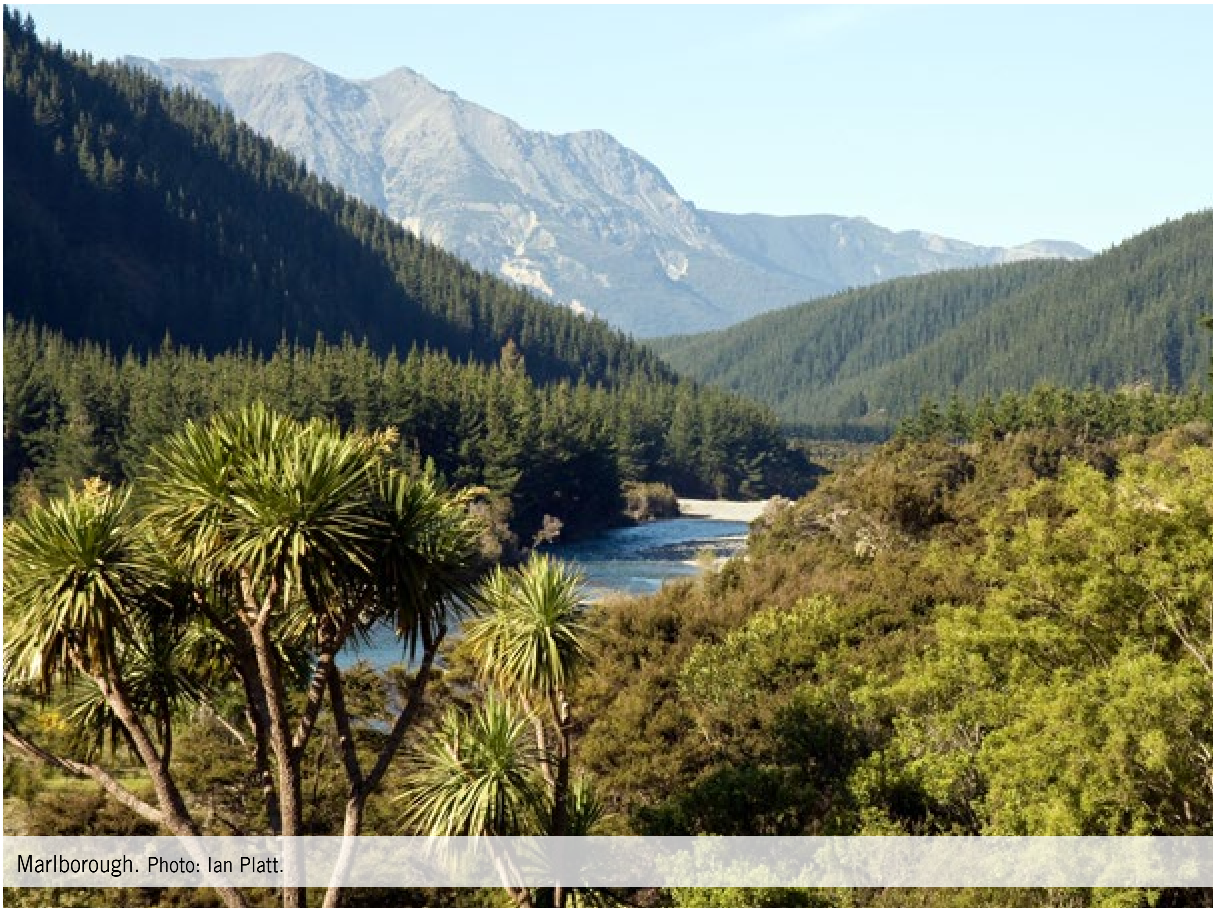
Criterion 7 Legal, institutional and economic frameworks for sustainable forest management

New Zealand has a well-established and robust legal framework supporting the sustainable management of natural and physical resources, including forests. This framework focuses on protecting the status of indigenous forests and managing all land uses in an integrated fashion.

The commercial forestry taxation regime has been stable since 1991. The New Zealand Government is open to foreign investment and regulations are liberal by international standards. New Zealand has a liberal trade policy, and it engages in trade liberalisation forums and is a party to several regional bilateral and plurilateral trade agreements.

New Zealand's property transfer system provides a secure, transparent system for protecting the rights of individual and multiple owners. The system is defined in legislation, providing certainty for investment in the industry. There are clear provisions of redress for both contractual and property issues.

Research and technologies for sustainable plantation forest management are extensive and continue to be developed. A range of new funding mechanisms and initiatives have been implemented that span the forestry value chain. These include the collaborative National Science Challenges, contestable research funds and business-led co-funding programmes such as the Primary Growth Partnership.



Marlborough. Photo: Ian Platt.

Assessed trend of selected indicators

A summary of New Zealand's performance is provided below. Fifteen key indicators have been selected from across the seven Montreal Process criteria to cover range of the environmental, commercial, social and cultural components of sustainable forest management in New Zealand. "Traffic lights" show the trend since 2008 as neutral (►), positive (▲) or negative (▼) changes.

Trend	Indicator
▼	**Indicator 1.1.a** Area and percent of forest by forest ecosystem type, successional stage, age class, and forest ownership or tenure
▼	**Indicator 1.2.b** Number and status of native forest-associated species at risk, as determined by legislation or scientific assessment
►	**Indicator 2.d** Annual harvest of wood products by volume and as a percentage of net growth or sustained yield
▲	**Indicator 3.a** Area and percent of forest affected by biotic processes and agents (e.g. disease, insects, invasive species) beyond reference conditions
▲	**Indicator 4.2.a** Proportion of forest management activities that meet best management practices or other relevant legislation to protect soil resources
▲	**Indicator 4.3.a** Proportion of forest management activities that meet best management practices, or other relevant legislation, to protect water related resources
▲	**Indicator 5.a** Total forest ecosystem carbon pools and fluxes
▲	**Indicator 6.1.a** Value and volume of wood and wood products production, including primary and secondary processing
▲	**Indicator 6.1.c** Revenue from forest based environmental services
▼	**Indicator 6.3.a** Employment in the forest sector
▼ Injuries	**Indicator 6.3.b** Average wage rates, annual average income and annual injury rates in major forest employment categories
▲ Wages	**Indicator 6.3.b** Average wage rates, annual average income and annual injury rates in major forest employment categories
►	**Indicator 7.1.a** Legislation and policies supporting the sustainable management of forests
►	**Indicator 7.2.a** Taxation and other economic strategies that affect sustainable management of forests
▲	**Indicator 7.3.a** Clarity and security of land and resource tenure and property rights
▲	**Indicator 7.4.b** Development and application of research and technologies for the sustainable management of forests

Key forestry statistics[3]

Tall indigenous forest		6.8 million hectares
Regenerating indigenous forest		1.2 million hectares
Plantation forests	– gross area	2.1 million hectares
	– TOTAL forest area	10.1 million hectares
Plantation forests	– net stocked area	1.7 million hectares
	– roundwood removals	30.3 million cubic metres
	– log exports	17.1 million cubic metres
Forest Stewardship Council (FSC) certified plantation forest (sourced from FCS website)		
	– gross area	1.5 million hectares
	– net stocked area	1.1 million hectares
FSC certified indigenous forest		12 000 hectares
Privately owned (tall) indigenous forest		1.65 million hectares
Privately owned indigenous forest under sustainable forest management plans and permits (under the Forests Act 1949)		84 000 hectares
Department of Conservation (DOC)		
	– tall indigenous forest	5.2 million hectares
	– regenerating indigenous forest	0.4 million hectares
	– TOTAL forest area	5.5 million hectares
Queen Elizabeth II (QEII) National Trust covenanted forest area		64 000 hectares
Ngā Whenua Rāhui Fund covenanted forest area		142 000 hectares
TOTAL protected forest area (DOC + QEII + Ngā Whenua Rāhui)		5.7 million hectares

3 Forestry statistics are generally as at March 2014.

Figure 1.1A: Distribution of different types of forest

Note: The thin lines mark administrative regions.

Source: Land Cover Database.

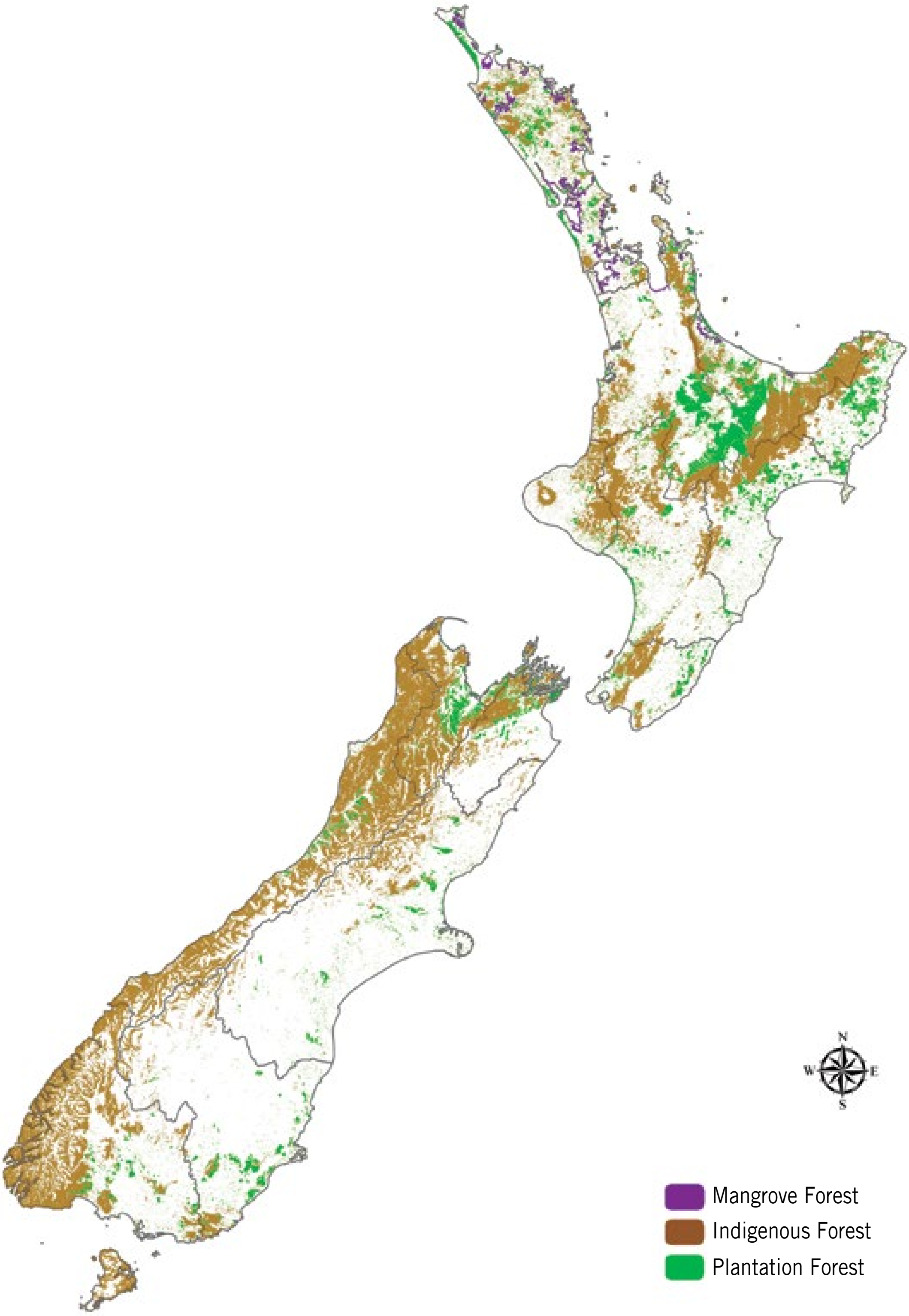
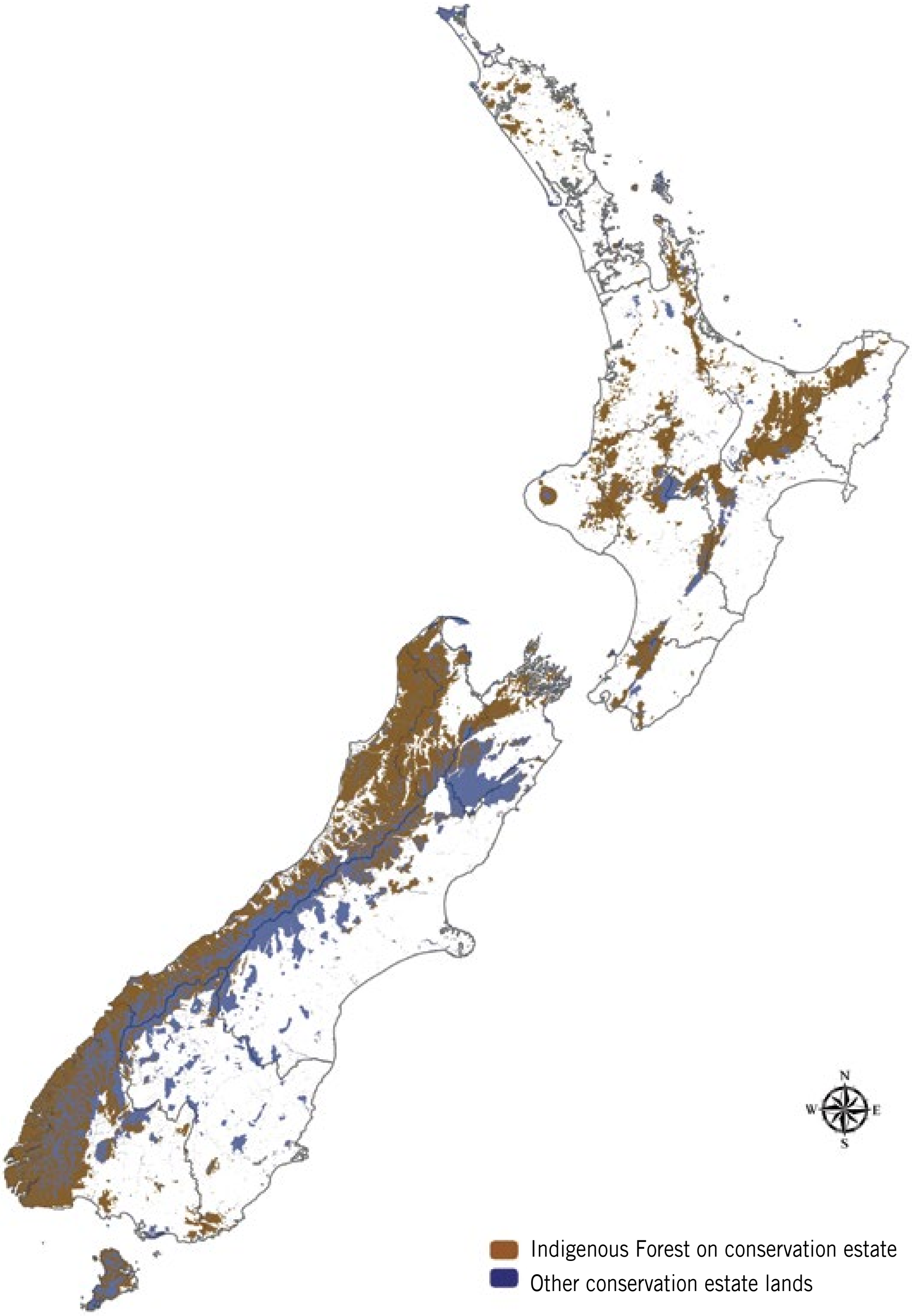


Figure 1.1B: Distribution of public conservation land in New Zealand

Note: The majority of public conservation land is found in the central North Island and west of the mountain range traversing the South Island. The thin lines mark administrative regions.

Source: Land Cover Database.



INTRODUCTION

Forests are home to 70 percent of the world's terrestrial animals and plants, providing the essential components of food, clothing and shelter. Forests are renewable resources and rich, resilient ecosystems. When managed sustainably, they can provide society with essential goods and services – timber, medicine, food, water and employment – and conserve biodiversity, for generations to come.

The 1987 report of the World Commission on Environment and Development, *Our Common Future* (the Brundtland Report), highlighted the urgency of progressing sustainable development without depleting natural resources or harming the environment. Five years later, the United Nations General Assembly sought a report on progress made towards sustainable development and convened the United Nations Conference on Environment and Development (UNCED) in 1992, at Rio de Janeiro (the Earth Summit). The objectives were to build on the hopes and achievements of the Brundtland Report in order to respond to global environmental problems, and to agree major treaties on biodiversity, climate change and forest management.

One of those agreements was the *Principles for Forest Management*. Along with *Agenda 21* and the *Rio Declaration*, it was adopted by more than 178 countries, including New Zealand. The guiding objective of the Principles is:

> …to contribute to the management, conservation and sustainable development of forests and to provide for their multiple and complementary functions and uses (United Nations General Assembly, 1992).

The Preamble to the *Principles for Forest Management* states that:

> Recognizing that the responsibility for forest management, conservation and sustainable development is in many States allocated among federal/national, state/provincial and local levels of government, each State, in accordance with its constitution and/or national legislation, should pursue these principles at the appropriate level of government (United Nations General Assembly, 1992).

Among other things, the Principles state that:

> …forest resources and forest land should be sustainably managed to meet the social, economic, ecological, cultural and spiritual needs of present and future generations…
>
> and
>
> The provision of timely, reliable and accurate information on forests and forest ecosystems is essential for public understanding and informed decision-making and should be ensured.

Following UNCED, Canada convened an International Seminar of Experts on Sustainable Development of Boreal and Temperate Forests in 1993 at Montreal. The seminar focused on criteria and indicators (C&I) and how they can help define and measure progress towards sustainable development of forests.

The Montreal Process

The Montreal Process was subsequently formed in Geneva, Switzerland in June 1994. The Montreal Process is the Working Group on Criteria and Indicators (C&I) for the Conservation and Sustainable Management of Temperate and Boreal Forests.

Membership of the Working Group is voluntary. The 12 member countries are Argentina, Australia, Canada, Chile, China, Japan, the Republic of Korea, Mexico, New Zealand, the Russian Federation, the United States of America and Uruguay. Together, these countries hold 90 percent of the world's temperate and boreal forests and 49 percent of all the world's forests, and are the source of 49 percent of the world's roundwood production.

European countries with temperate and boreal forests work as a region under the framework of the Ministerial Conference on the Protection of Forests in Europe.

Criteria and indicators

The Montreal Process C&I provide a common framework for member countries to monitor, assess and report on trends in forest conditions with respect to the full range of forest values and, in turn, on national progress towards sustainable forest management (SFM). They represent a holistic approach to forest management, and provide information essential to the focusing of policies and research that promote SFM.

Seven criteria characterise the essential components of SFM, while 54 indicators provide a way to measure those components. The C&I are not performance standards.

The Montreal Process C&I are not static. The Working Group, with important input from the science-based Technical Advisory Committee, periodically reviews and refines the C&I to reflect new research findings, advances in technology, and an increased capability to measure indicators. The result is a contemporary and agreed international C&I framework that can continue to enable member countries to report progress towards SFM. This report uses the third edition of the C&I published in 2009 by the Montreal Process Working Group.

Why is New Zealand involved in the Montreal Process?

There is ever-increasing understanding of the valuable role of forests in providing a wide range of environmental services, both within the forests and also as part of the sustainable management of the wider landscape. It is important for New Zealand to demonstrate its achievements in promoting sustainable forest management.

New Zealand participates in the Montreal Process, and applies the agreed Montreal Process C&I for the sustainable management of all its indigenous and plantation forests as part of this. New Zealand finds the holistic approach to Montreal Process C&I an effective means for reporting the many environmental services of forests, as well as how these interact.

Domestically New Zealand's experiences in the Montreal Process and the preparation of country reports have allowed:

- more effective communication on the status of efforts towards sustainable forest management;
- monitoring of the trends in the status of the indicators in order to focus domestic policy development and research initiatives towards areas of weakness, or a weak evidence base, in sustainable forest management;
- education of the public about sustainable forest management and the different environmental services provided by forests;
- demonstration of how C&I-based reporting can be the basis for other forms of natural resource management.

The Montreal Process also attracts an international audience with an interest in assessing sustainable forest management and contributes to the dialogue on global sustainable forest issues. In addition, the Montreal Process has collaborated effectively with other C&I-based organisations such as Forests Europe and the International Tropical Timber Organization (ITTO) on addressing these issues. This report, *New Zealand's Third Country Report on the Montreal Process Criteria and Indicators* is New Zealand's contribution to the wider value proposition for the Montreal Process, including by:

- fulfilling international obligations and the expectations that arose from the United Nations Conference on Environment and Development (1992), and in particular from the Principles for Forest Management;
- participating in subsequent developments, including agreements in the United Nations Forum on Forests and progress in regional and global discussions and forest reporting under the Food and Agriculture Organization of the United Nations (FAO);
- demonstrating a national commitment to sustainable forest management for all forests;
- demonstrating the sustainability of the country's plantation forests and wider timber harvesting policies;
- building, through the collaborative approach to the Montreal Process, enduring relationships with the countries, organisations and individuals that are also interested in sustainable forest management and that can, individually and collectively, be key influencers of international forest policy;
- being an authoritative and respected participant in international forestry processes.

New Zealand's ability to report on criteria and indicators

This report includes comment on all 54 indicators. Some of these comments are comprehensive, both qualitatively and quantitatively; others are more descriptive. Where data are not available for inclusion in this report, the indicator reports endeavour to describe what information has nevertheless been collected.

The distinction between New Zealand's commercial plantation forests and its largely protected indigenous forests is a special feature of the New Zealand forest estate. This fundamental difference in the management of the forests is also reflected in the availability of data to support the Montreal Process criteria and indicators. In most instances, more detailed information is available on plantation forest than on indigenous forest. Recent national monitoring programmes and international reporting are resulting in better information for indigenous forests.

Quality of information and trends against indicators

This is New Zealand's third national report and is an assessment as at mid-2014. The quality of information used for each indicator was assessed against its availability and coverage, and expressed as high, medium or low.

Trends have been assessed against the positions described in the *2008 New Zealand report,* and for revised indicators for Criterion 7, on the basis of available information. For some indicators, quantitative data enable these assessments to be made; for others, qualitative evaluation has been required. In some instances, negative trends are associated with better information and enhanced understanding of the indicator. For all indicators, "traffic light" symbols have been used to express these trends, showing neutral (▶), positive (▲) and negative (▼) changes.

Natural forest or indigenous forest

The Montreal Process Working Group uses the term "natural forests". The New Zealand reporting uses the term "indigenous forests". The use of "indigenous" is consistent with New Zealand's Resource Management Act 1991 and Forests Act 1949. The former refers to "…indigenous vegetation" and "…indigenous fauna", while the latter uses the word "indigenous" to mean a species of flora or fauna "…that occurs naturally in New Zealand or arrived in New Zealand without human assistance" (section 2(1)).

Co-ordinating agency and contributors

The Ministry for Primary Industries (MPI) has taken responsibility for co-ordinating information gathering and for writing this report. MPI is seen as the appropriate agency as it leads government involvement in domestic and international sustainable forest management.

Other government departments that contributed to the compilation of the report were the Department of Conservation and the Ministry for the Environment. MPI acknowledges the contributions made by these organisations.

Review

A draft report was externally reviewed by the Ministry for the Environment and the Department of Conservation. However, responsibility for the contents of the final report lies with MPI.

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CRITERION 1:
CONSERVATION OF BIOLOGICAL DIVERSITY

Forests, and particularly indigenous forests, support a substantial proportion of the planet's biological diversity and terrestrial species. Biological diversity enables an ecosystem to respond to external influences, to recover after disturbances and to maintain essential ecological processes.

Human activities and natural processes can impact adversely on biological diversity by altering and fragmenting habitats, introducing invasive species, or reducing the population or ranges of species. Conserving the diversity of organisms and their habitats supports forest ecosystems and their ability to function, reproduce and remain productive.

Table 1.1 lists the indicators covered in this section.

Table 1.1: Indicators for Criterion 1 – quality of information and trends

Criterion 1: Conservation of biological diversity		Quality of information	Trend
	Ecosystem diversity		
1.1.a	Area and percent of forest by forest ecosystem type, successional stage, age class, and forest ownership or tenure	M/H	▼
1.1.b	Area and percent of forest in protected areas by forest ecosystem type, and by age class or successional stage	M/H	▲
1.1.c	Fragmentation of forests	M/H	▶
	Species diversity		
1.2.a	Number of native forest-associated species	M	▶
1.2.b	Number and status of native forest-associated species at risk, as determined by legislation or scientific assessment	M	▼
1.2.c	Status of on site and off site efforts focused on conservation of species	M/H	▲
	Genetic diversity		
1.3.a	Number and geographic distribution of forest-associated species at risk of losing genetic variation and locally adapted genotypes	Indig. L/M Exotic H	Indig. ▲ Exotic ▼
1.3.b	Population levels of selected representative forest-associated species to describe genetic diversity	M	▶
1.3.c	Status of on-site and off-site efforts focused on conservation of genetic diversity	L/M	▲

KEY

L = low	Neutral	▶
M = medium	Positive	▲
H = high	Negative	▼

NEW ZEALAND OVERVIEW

Key changes since 2008 are the:

- use of satellite imagery, which continues to improve resource data on the forest estate;
- development of a National Biodiversity Monitoring and Reporting Programme to assess the ecological integrity of public conservation lands;
- application of the New Zealand Threat Classification System, which indicates that 12 threatened taxa have improved in status, but the status of 59 taxa has worsened;
- new technologies for reducing and eradicating mammalian pests and preventing their reinvasion of sensitive habitats, which are creating opportunities to reintroduce endangered fauna and flora to areas they formerly occupied;
- enhancement of efforts to understand genetic diversity of iconic species.

Recent satellite-based estimates put New Zealand's total forest area[4] at 10.1 million hectares or 38 percent of the total land area. This consists of tall indigenous forest (6.8 million hectares), regenerating forest (1.2 million hectares) and exotic plantations (2.1 million hectares). Tall indigenous and regenerating forest area has declined slightly over recent decades. The area of plantation forest expanded steadily through the 1990s but has since declined slightly due to conversion to more profitable agricultural land uses, notably dairy farming. While most indigenous forests remain in public ownership, plantation forests are now largely privately owned.

Coastal Pohutakawa, Bay of Islands. Photo: Ian Platt.

Over 70 percent of tall indigenous forests are protected by legislation or covenant and managed for the protection of indigenous biodiversity by the Department of Conservation, the Queen Elizabeth II National Trust and the Ngā Whenua Rāhui Fund. The latter is a contestable government fund providing protection for indigenous ecosystems on Māori land. The area of publicly owned indigenous forest protected by legislation has increased by 3.7 percent since 2006.

Publicly owned indigenous forests typically occur in large (> 500 hectares) blocks. Conversely small indigenous forest fragments (< 10 hectares) occur mostly on private land. Recent studies on the value of small forest fragments for preserving indigenous biodiversity suggest that, to maximise the retention of indigenous biodiversity, forest fragments need to be fenced to exclude farm stock and game animals; and introduced pests such as brushtail possums, mustelids and rats need to be reduced to low levels.

New Zealand's indigenous forests are characterised by a high degree of endemism. Human settlement introduced a large number of exotic plant and animal species, many of which have had detrimental effects on the indigenous biota. While the major biodiversity losses associated with early human settlement have been stemmed, indigenous biodiversity has continued to decline over the last century. Over the last decade, the Department of Conservation has developed a National Biodiversity Monitoring and Reporting Programme to assess whether the ecological integrity of public conservation lands is being maintained.

The risk of extinction of resident native taxa is assessed on a three-yearly basis[5] by expert panels convened by the New Zealand Department of

4 Includes all land within the forest margin, irrespective of whether or not it contains trees. For plantation forests, this includes harvested areas that will be replanted.

5 The interval between assessments has recently been raised to 5 years.

Conservation. Threat rankings are based on the estimated size of the national population and predicted population trends. Since the last threat status assessment, 12 threatened taxa have improved in status as a result of successful species management, and 59 have worsened in status.

New technologies for reducing and eradicating mammalian pests and preventing their reinvasion of sensitive habitat are creating opportunities to reintroduce endangered fauna and flora to areas they formerly occupied. "Mainland Islands" use intensive multi-pest control or exclusion to reduce pest mammal populations, as well as detailed biodiversity monitoring to assess the extent to which ecological restoration goals are being achieved. Fenced sanctuaries that exclude the full range of pest mammals are often community-led forest restoration projects. Together with expanding the numbers of near-shore, pest-free island sanctuaries, they are allowing an increasing number of people to see and interact with rare and endangered flora and fauna.

The understanding of genetic variation in indigenous forest-associated species remains limited. Most studies focus on rare or endangered taxa. The most comprehensive account comes from studies of threatened avifauna. Low levels of genetic diversity are present in most threatened endemic birds, and in other plant and animal groups that have been studied. In the commercial forestry sector, the dominance of a single exotic species, radiata pine, creates biotic risks that are exacerbated when it is grown in large-scale monoculture. The ability to counter these risks through breeding programmes relies on the preservation of genetic diversity. Changes to forest ownership and institutional frameworks over recent decades may be placing some of the existing radiata pine gene pool at risk.

The Department of Conservation's National Biodiversity Monitoring and Reporting Programme provides information on the population status of selected forest-associated species or species groups (weeds, ungulates, possums, palatable tree species, birds) that are considered to influence the diversity (including genetic diversity) of forests on public conservation land. Indigenous plant species greatly outnumber exotic weeds in number and abundance in forests on conservation land, and this has not changed over recent years. Introduced ungulates and brushtail possums are widespread in forests. Both are less abundant in beech than in non-beech forests. Palatable tree species such as kāmahi, māhoe and broadleaf are regenerating across public conservation lands, although there are local sites where pest mammals are preventing their regeneration. Population size structures of these palatable indicator species have been maintained over the last decade. However, mortality rates have exceeded recruitment, so current regeneration patterns may not be maintained. Results also show that indigenous forests support at least twice as many native bird species as introduced ones, in both beech and non-beech forests.

Efforts to understand and maintain the genetic diversity of iconic species such as kiwi, tuatara and kauri have gathered pace over recent decades and are now widely supported. However, little or nothing is known about the genetic variability of most endemic species, and few are being actively managed to ensure genetic diversity is retained.

Young kauri forest, Waipoua, Northland. Photo: Ian Platt.

INDICATOR 1.1 ECOSYSTEM DIVERSITY

Maintenance of the variety and quality of forest ecosystems is necessary for the conservation of species. Without sufficient habitat size, adequate connectivity, necessary structural diversity and appropriate protection and management measures, species may decline and become vulnerable to extinction.

These indicators provide information on the areas and extent of ecosystem types, forest area under formal protection, and the effects of fragmentation.

Indicator 1.1.a Area and percent of forest by forest ecosystem type, successional stage, age class, and forest ownership or tenure

Recent satellite-based estimates put the total forested area[6] of New Zealand at a little over 10 million hectares, composed of tall indigenous forest (6.8 million hectares), regenerating forest (1.2 million hectares) and plantation forest (2.1 million hectares). Tall indigenous and regenerating forest area has declined slightly (< 1 percent) over recent decades. Plantation forests expanded steadily through to the early 2000s, but have since shown a small (about 3 percent) decline as some existing plantations are converted to more profitable agricultural land uses, notably dairy farming. While most tall indigenous forests (76 percent) remain in public ownership, large areas of plantation forest have shifted from publicly listed companies to various forms of private ownership over the last decade.

Quality of information: M/H

Progress against indicator: ▼

Rationale

This indicator provides information on the areas and extent of forest ecosystem types, including successional stage, age class and the nature of tenure or ownership. The sustainability and stability of forest ecosystems may depend on their size and diversity. If these are not maintained, forest may become vulnerable to habitat degradation and loss. Tenures or ownership types may have a variety of management regimes associated with them – each with a different impact on biological diversity.

6 Includes all land within the forest margin, irrespective of whether or not it contains trees. For plantation forests, this includes harvested areas that will be replanted, forest roads and infrastructure.

NEW ZEALAND'S REPORT

Before human settlement, most of New Zealand below the climatic treeline was forested. The arrival of Māori, about 750 years ago, precipitated widespread forest destruction. This, combined with a second wave of forest clearance by European settlers in the 19th and 20th centuries, resulted in the loss of about three-quarters of the original forest cover.

Forest area by forest type

The most recent estimate of forest area[7] is a little over 10 million hectares, or 38 percent of New Zealand's total land area of 26.8 million hectares. This includes tall indigenous forest (6.8 million hectares), regenerating forest (1.2 million hectares) and plantation forest (2.1 million hectares) (Table 1.2). These figures are higher than previously reported, largely because they are based on a broader definition of what constitutes forest[8] than has traditionally been used by the forest industry and government agencies.

More detailed mapping of indigenous forests (Shepherd et al, 2005) based on satellite imagery from 1999–2003 highlights the dominance of beech and other broadleaved species, and the extent to which some areas of New Zealand now have little remaining indigenous forest cover (Figure 1.1A, Table 1.3).

The Land Use and Carbon Analysis System (LUCAS) analyses show that tall indigenous forest area has declined slightly (< 1 percent) over recent decades, but that it remains the predominant forest cover in New Zealand. Regenerating forest, much of which is dominated by the indigenous species mānuka and kānuka, has also shown a slight decline over the same period largely as a result of agricultural intensification or transition to other forest species. Plantation forests expanded steadily through to the 2000s, but over the last decade have declined a little (about 3 percent) as some existing plantations have been converted to more profitable agricultural land uses, notably dairy farming (Figure 1.2).

7 Produced by the Land Use and Carbon Analysis System (LUCAS) for the NZ Greenhouse Gas (GHG) inventory.

8 Woody vegetation of at least 1 hectare in extent that will exceed 30 percent canopy cover and 5 metres height at maturity. For plantation forests, the area reported is the gross forest area and includes harvested areas awaiting replanting.

Table 1.2: Forest area and percentage by forest class (2012)

	Area (000 ha)[1]	% forest area	% total land area
Tall indigenous forest	6 833	67.3	25.5
Regenerating forest	1 234	12.1	4.6
Plantation forest	2 094	20.6	7.8
TOTAL	**10 161**	**100.0**	**37.9**

Note 1: Gross area.
Source: Ministry for the Environment, 2014.

Table 1.3: Indigenous forest area and percentage by forest class (1999–2003)

Indigenous forest class	Area (000 ha)	% total indigenous forest area
Podocarp	65.2	1.0
Broadleaved	348.3	5.3
Beech	2 184.4	33.3
Podocarp-broadleaved	1 246.5	19.0
Beech/broadleaved	98.1	1.5
Podocarp-broadleaved/beech	1 831.8	27.9
Kauri	91.6	1.4
Coastal	5.2	0.1
Unspecified indigenous	501.0	7.6
Subalpine scrub	193.1	2.9
TOTAL	**6 565.2**	**100.0**

Source: Shepherd et al, 2005.

Mangroves are found around the coasts of the northern half of the North Island. There is one species *(Avicennia marina)* that forms a shrub or small tree. Estimates based on satellite imagery put the area of mangrove communities at about 28 000 hectares, increasing at a rate of about 60 hectares per annum. Most mangrove communities do not attain forest status (as per the definition). Whether this is the result of environmental constraints or human activity is not clear.

Current estimates based on grower surveys[9] put the net stocked area of plantation forest at a little over 1.7 million hectares. Radiata pine is the predominant species grown for timber in New Zealand and, together with Douglas-fir, makes up 96 percent of the total plantings (Table 1.4). Over the last decade, the area of radiata pine forest has declined by 4.7 percent (76 700 hectares), eucalypt forests have declined by 38 percent (13 400 hectares), other exotic hardwood species by 35 percent (6800 hectares) and other exotic softwoods by 13 percent (3700 hectares). Conversely the area of Douglas-fir has increased marginally (2.4 percent), and there has been a substantial (about 70 percent) increase in cypress plantings, albeit from a low base (Figure 1.3).

9 National Exotic Forest Description.

Forest area by age class

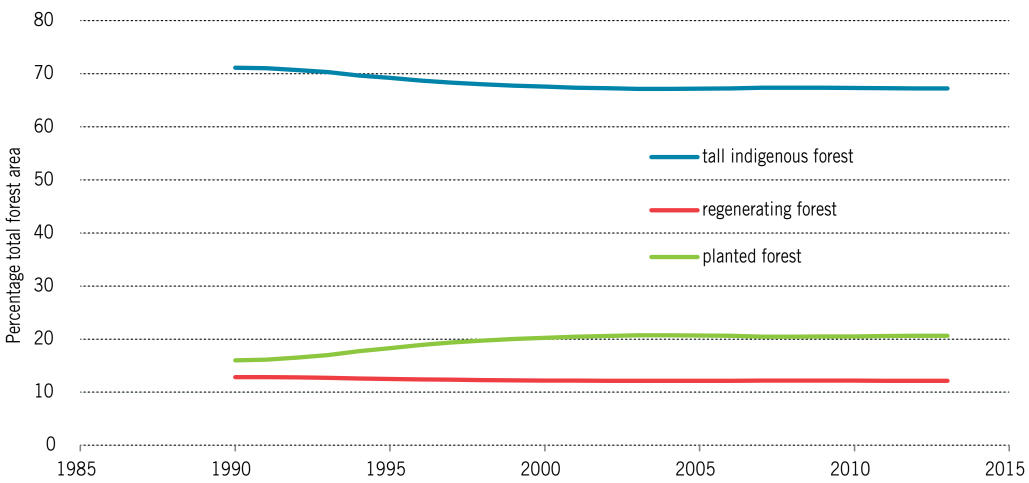
Information on forest age (Figure 1.4) is only available for plantation forests. These have an average area-weighted age of 16.8 years. Thirty percent of the plantation forest estate is aged between 16 and 20 years, and only 5.6 percent is older than 30 years.

Forest area by ownership

In 2013, 5.18 million hectares (76 percent) of New Zealand's tall indigenous forests were in public ownership and managed on behalf of the State by the Department of Conservation. The remaining 1.65 million hectares were in private (including Māori tribal) ownership.

The ownership of plantation forests over the last decade has changed substantially (Table 1.5). In

Figure 1.2: Changes to New Zealand's forest area since 1990



Source: Ministry for the Environment, 2014.

Table 1.4: Plantation forest area (net stocked) and percentage by species or species group (2013)

	Area (000 ha)[1]	% Total plantation forest area
Radiata pine	1 553.7	89.9
Douglas-fir	106.5	6.1
Cypresses	10.1	0.6
Other exotic softwoods	23.6	1.4
Eucalypts	22.0	1.3
Other exotic hardwoods	12.6	0.7
TOTAL	**1 728.5**	**100.0**

Note 1: Net stocked area. Excludes 51 900 hectares of harvested area awaiting replanting.
Source: Ministry for Primary Industries, 2014a.

particular, large areas of forest previously owned by public companies have been transferred to private ownership. Private owners include private companies, partnerships, pension funds, individuals and trusts, as well as Māori trusts and incorporations. "Central government" forests are predominantly government-owned forests on Māori leasehold land that are managed by the Ministry for Primary Industries (Crown Forestry).

Sources of information

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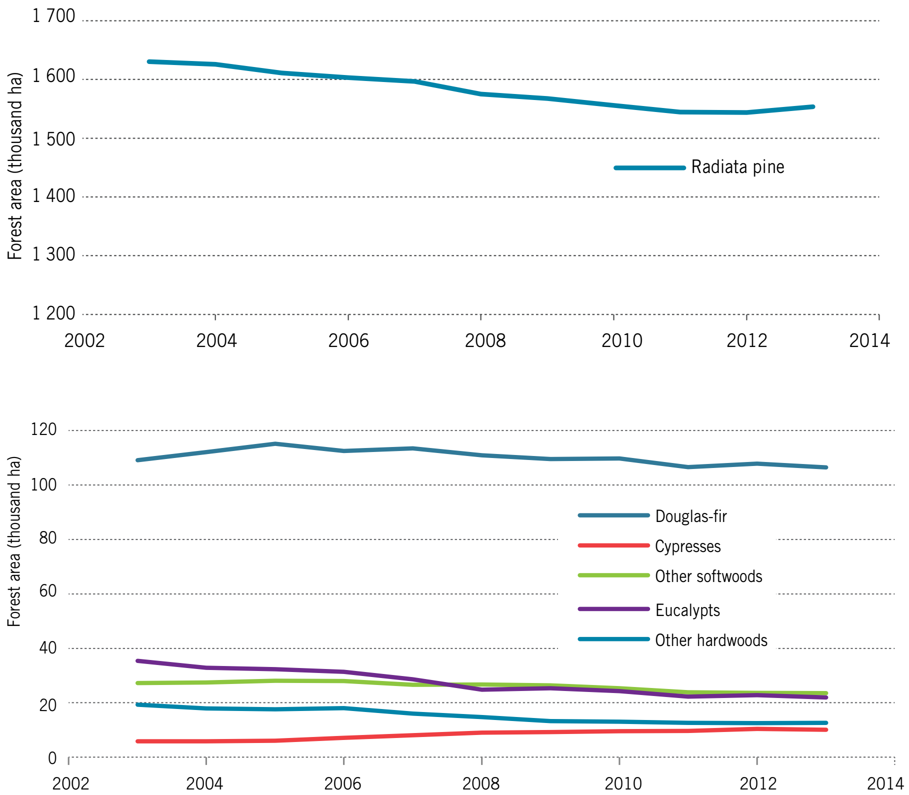
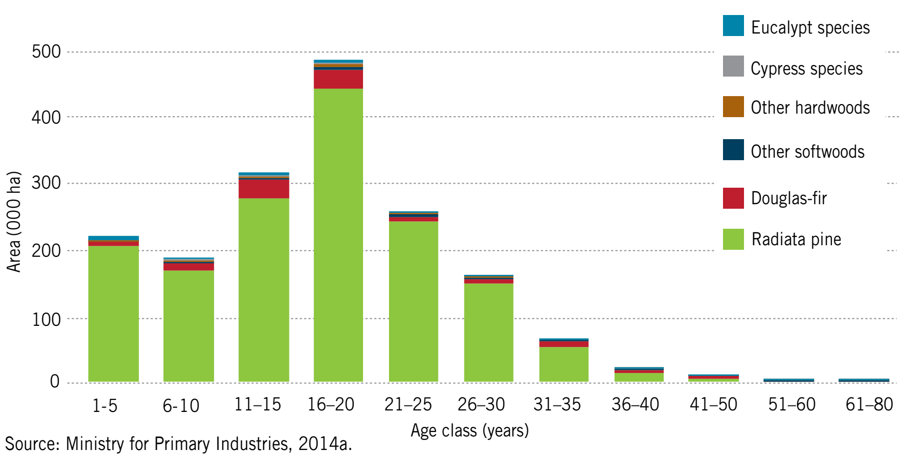
Figure 1.3: Changes to plantation forest area (net stocked) between 2003 and 2013



Sources: Ministry of Agriculture and Forestry, 2004; Ministry for Primary Industries, 2014a.

Figure 1.4: Plantation forest area (net stocked) by age class and species



Source: Ministry for Primary Industries, 2014a.

Table 1.5: Plantation forest area by ownership category (2003–2012)

Ownership category[1]	2003		2007		2012[2]	
	Area (000 ha)[3]	% of total area[4]	Area (000 ha)[3]	% of total area[4]	Area (000 ha)[3]	% of total area[4]
NZ-registered public company	829	45.4	244	13.7	16	0.9
Privately owned	852	46.6	1 421	79.4	1 591	92.5
State-owned enterprise	42	2.3	32	1.8	13	0.7
Local government	58	3.2	56	3.1	46	2.7
Central government	45	2.5	37	2.1	54	3.1
TOTAL	**1 827**	**100.0**	**1 790**	**100.0**	**1 720**	**100.0**

Notes: 1. Ownership is based solely on the ownership of the forest, irrespective of the ownership of the land.
2. The latest year for which these data are available.
3. Net stocked plantation production forest area.
4. Totals may not add due to rounding.

Sources: Ministry of Agriculture and Forestry, 2004 and 2008; Ministry for Primary Industries, 2013.

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Indicator 1.1.b Area and percent of forest in protected areas by forest ecosystem type, and by age class or successional stage

In New Zealand, indigenous forests cover about 8 million hectares or 30 percent of the total land area. Over 70 percent of these forests are protected by national legislation. In the seven-year period (2006–2013) for which data are available, the area of indigenous forests in public ownership increased by 3.7 percent.

Quality of information: M/H

Progress against indicator: ▲

Rationale

This indicator provides information on the area and extent of forest by ecosystem type, age class or successional stage protected to safeguard biological diversity and representative examples of forest ecosystem types. This indicator will also help identify forest types of conservation value that are in need of protection. The level of formal protection given to forests is a reflection of the importance society places on their conservation.

NEW ZEALAND'S REPORT

Forest area in protected areas by forest type

New Zealand's protected areas are defined by national legislation. This legislation includes the Wildlife Act 1953, Reserves Act 1977, Queen Elizabeth the Second National Trust Act 1977, National Parks Act 1980, Conservation Act 1987 and the Crown Forest Assets Act 1989. The Department of Conservation is the lead government agency charged with conserving New Zealand's natural and historical heritage. Conservation is defined in the Conservation Act 1987, as:

> … the preservation and protection of natural and historic resources for the purpose of maintaining their intrinsic values, providing for their appreciation and recreational enjoyment by the public, and safeguarding the options for future generations (section 2(1)).

Recent estimates of New Zealand's forest cover put the total area of indigenous forest at about 8 million hectares, or 30 percent of the total land area. This is split between tall indigenous (85 percent) and regenerating (15 percent) forests. Over 70 percent of these forests are protected under legislation administered by the Department of Conservation, the Queen Elizabeth II National Trust and the Ngā Whenua Rāhui Fund (Table 1.6). The latter is a contestable Ministerial fund established in 1991 to provide funding for the protection of indigenous ecosystems on Māori land. Its scope covers the full range of natural diversity originally present in the landscape.

Table 1.6: Forest area protected to safeguard biological diversity and representative examples of forest ecosystem types

Agency providing protection	Forest type	Area (000 ha)
Department of Conservation	Tall indigenous forest	5 181
	Regenerating forest	358
	Tall indigenous plus regenerating forest	5 539
Ngā Whenua Rāhui Fund	Tall indigenous forest	116
	Regenerating forest	26
	Tall indigenous plus regenerating forest	142
Queen Elizabeth II National Trust	Indigenous forest	64
ALL AGENCIES	All indigenous forests	5 745

Sources: Department of Conservation (undated); Ngā Whenua Rāhui Fund (undated); Queen Elizabeth II National Trust (undated).

Table 1.7: IUCN classification of tall indigenous forests managed by New Zealand's Department of Conservation

IUCN category		Indigenous forest area (000 ha)		
		2006	2008	2013
Ia	Strict Nature Reserve: protected area managed mainly for science.	160	160	158
Ib	Wilderness Area: protected area managed mainly for wilderness protection.	37	37	36
II	National Park: protected area managed mainly for ecosystem protection and recreation.	1 947	1 947	1 966
III	Natural Monument: protected area managed mainly for conservation of specific natural features.	1 424	1 444	1 573
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention.	19	19	19
TOTAL FOREST AREA WITHIN PROTECTED AREAS		**3 587**	**3 607**	**3 752**
V	Protected Landscape/Seascape: protected area managed mainly for landscape/ seascape conservation and recreation.	4	4	6
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems.	n.a.	0	10
Unclassified		1 404	1 392	1 413
TOTAL FOREST AREA		**4 995**	**5 003**	**5 181**

Source: Department of Conservation, 2005.

Tall indigenous forests in public ownership (that is, those managed by the Department of Conservation) are also classified using the International Union for Conservation of Nature (IUCN) protected area categories (Table 1.7). This allows the level of legislative protection to be assessed against internationally recognised criteria. In the seven-year period (2006–2013) for which data are available, the area of publicly owned indigenous forest protected by legislation increased by 3.7 percent. The Parliamentary Commissioner for the Environment has called for conservation lands to be reclassified to better reflect their indigenous biodiversity values. If this occurs, the area estimates for some IUCN categories are likely to increase substantially.

Forest area in protected areas by age class or successional stage

New Zealand does not have the data available to report on this part of the indicator.

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Indicator 1.1.c Fragmentation of forests

The extent of fragmentation in New Zealand's indigenous forests showed little change between 2000 and 2012. Most tall indigenous forests occur in large (> 500 hectares) tracts of land that are in public ownership. Small indigenous forest fragments are mainly found on privately owned land. The value of forest fragments for preserving indigenous biodiversity has been the subject of several studies over recent decades. To maximise the retention of indigenous biodiversity in these fragments, both farm stock and introduced pests such as brushtail possums and rats need to be excluded.

Quality of information: M/H

Progress against indicator: ▶

Rationale

This indicator provides information on the extent to which forests are being fragmented over time by human activities and natural processes. Fragmentation may lead to the isolation and loss of species and gene pools, degraded habitat quality, and a reduction in the forest's ability to sustain the natural processes necessary to maintain ecosystem health.

NEW ZEALAND'S REPORT

Forest fragmentation has been linked to the loss of indigenous biodiversity, increased establishment of invasive species, and changes to the way in which ecosystems function. Two factors stand out. The first is that, as forests become more fragmented, the ratio of forest edge to core forest area increases. Forest-edge habitats are more prone to summer drying, damage from severe winds, and invasion by fauna and flora from the adjacent non-forest communities. Many forest-associated species struggle to survive in the uncertain forest-edge environment. The second factor is the effect that the loss of continuous habitat has on the ability of species to forage, to reproduce and to disperse. Where forest fragments are sizable and in close proximity to one another, these effects may not be large. However, as the size of the fragments reduces and the distance between fragments increases, species with larger home ranges are forced to forage beyond their primary habitat and those with limited ability to disperse become isolated within their fragments and are no longer able to contribute to the wider gene pool.

The New Zealand Land Cover Database (LCDB) enables changes to the fragmentation of tall indigenous forests[10] to be assessed between 2000 and 2012 (Tables 1.8 and 1.9). The results show little change over this period. However, they show a marked difference between publicly owned indigenous forests that are managed for conservation purposes, and those in private ownership. The vast majority (about 93 percent) of indigenous forest land in public ownership is contained in tracts that are larger than 500 hectares. Away from the conservation estate, this figure drops to about 62 percent. Conversely most (about 80 percent) of small indigenous forest fragments are found on privately owned land.

10 Includes LCDB indigenous forest and broadleaved-hardwood forest classes.

Table 1.8: Number of tall indigenous forest fragments

Size of fragment (ha)	Conservation land			Non-conservation land			All forest land		
	2000	2008	2012	2000	2008	2012	2000	2008	2012
< 10	13 487	13 145	13 130	54 021	53 995	54 423	67 508	67 140	67 553
10–50	2 563	2 573	2 574	8 862	8 851	8 845	11 425	11 424	11 419
50–100	556	568	568	1 047	1 036	1 055	1 603	1 604	1 623
100–500	688	678	682	750	736	733	1 438	1 414	1 415
> 500	339	334	333	154	153	153	493	487	486
TOTAL	**17 663**	**17 299**	**17 287**	**64 834**	**64 770**	**65 209**	**82 467**	**82 069**	**82 496**

Source: Ministry for Primary Industries analysis.

Table 1.9: Percentage of tall indigenous forest area

Size of fragment (ha)	Conservation land			Non-conservation land			All forest land		
	2000	2008	2012	2000	2008	2012	2000	2008	2012
< 10	0.6	0.6	0.6	9.8	9.7	9.8	2.7	2.7	2.7
10–50	1.3	1.3	1.3	11.6	11.6	11.6	3.4	3.4	3.4
50–100	0.9	1.0	1.0	5.0	5.0	5.1	1.6	1.6	1.6
100–500	4.1	4.1	4.1	11.6	11.4	11.3	4.2	4.2	4.2
> 500	93.1	93.1	93.1	62.0	62.2	62.1	88.2	88.2	88.2
TOTAL	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Ministry for Primary Industries analysis.

The value of small forest fragments for preserving indigenous biota in what are nowadays often highly developed landscapes has been the focus of several studies over recent decades. A survey of isolated kahikatea (*Dacrycarpus dacrydioides*) stands on farmland in the Waikato Basin (Figure 1.5) demonstrated that, even in unfenced remnants, much of the original native flora had managed to survive (Smale, 2004; Smale et al, 2005). Fencing to exclude stock allowed a diverse native understorey to re-establish over several decades (Figure 1.6). Most adventive species within the forest fragments were pasture grasses or herbs and, within 20 years of removing grazing, these had been largely suppressed by taller native vegetation. A small group of persistent invasive weeds, notably privet, barberry, ivy and tradescantia, had the potential to hinder indigenous recovery if not adequately controlled. Remnant size did not affect the rate or success of the recovery. The best predictor was the length of time since the forest fragment had been fenced to exclude stock.

Figure 1.5: Grazed kahikatea forest fragments

Photo: Mark Smale.

In a similar study of forest fragments dominated by tawa (*Beilschmiedia tawa*) in the central Waikato, excluding stock enabled a dense thicket of native saplings to develop in the understorey within 15 years (Dodd et al, 2011; Innes, 2009; Innes et al, 2010). However, where pest herbivores, notably brushtail possums, were not also culled, regeneration of palatable canopy species such as mangeao (*Litsea calicaris*) was suppressed in favour of less palatable sub-canopy tree species. Where fragments had been fenced for 30–40 years, soil was less compacted, litter decomposition rates increased, and invertebrate densities were up to 100 times those found in unfenced fragments. The downside of these changes was a significant increase in ship rat numbers, presumably attracted by the enhanced supply of seeds, invertebrates, lizards and nesting birds. To maximise indigenous biodiversity in these forest fragments, both farm stock and pests such as brushtail possums and rats need to be excluded.

Focusing on broad species groups, however, does not tell the full story. For example, a study of beetle assemblages in Waikato kahikatea forest fragments (Harris and Burns, 2000) concluded that they had a rich indigenous beetle fauna and represented important refuges in the pastoral landscape. This contrasts with a study of ground beetles *(Coleoptera, Carabidae)* in forest fragments in a similar agricultural

Figure 1.6: Ungrazed kahikatea forest fragments

landscape in the lower North Island (Lövei and Cartellieri, 2001). Here botanically diverse and well-maintained forest fragments were found to contain few carabid species compared with a nearby large forest tract. Increased risk of predation in small forest patches and the limited dispersal ability of endemic carabids were cited as likely causes of the reduction in species richness.

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INDICATOR 1.2 SPECIES DIVERSITY

The greatest and most readily recognisable aspect of biological diversity is the variety of species and their population levels. A key objective for the conservation of biological diversity is to slow down the rate of population decline, and species depletion and extinction due to human factors. Changes in species population levels and distribution may also provide an early warning of changes in ecosystem stability and resilience, as will increases in the number of invasive, exotic forest-associated species.

Indicator 1.2.a Number of native forest-associated species

New Zealand's indigenous forests are characterised by a high degree of endemism. Human settlement introduced a large number of exotic plant and animal species, many of which have had detrimental effects on the indigenous biota. While the major biodiversity losses associated with early human settlement have been stemmed, indigenous biodiversity has continued to decline over the last century. Over the last decade, the Department of Conservation has developed a National Biodiversity Monitoring and Reporting Programme to assess whether the ecological integrity of public conservation lands is being maintained.

Quality of information: M

Progress against indicator: ▶

Rationale

This indicator provides information on the health of forest ecosystems through the number of native forest-associated species. Knowledge of the number of native forest-associated species highlights the importance of certain forest types in meeting conservation objectives and in understanding the relationships species have within ecosystems. The loss or addition of species in an ecosystem can provide valuable insights into the overall health and productivity of that system.

NEW ZEALAND'S REPORT

New Zealand is an archipelago in the southwest Pacific with a long isolation from major landmasses and a strongly endemic indigenous biota. It was one of the last places on earth to be settled by humans. Birds rather than mammals were the dominant terrestrial vertebrates, and slow-growing evergreen forests without any major influence from natural fire predominated below the climatic treeline. The arrival of first Polynesian, and later European, settlers precipitated widespread reductions in forest cover and major losses of indigenous biodiversity. Notwithstanding these effects, much of the forest landscape and species composition of New Zealand still bears a pre-human imprint.

New Zealand's remaining indigenous forests are now largely conserved from clearance or significant modification under a statutory framework that applies to forests on both private and public lands. The conservation of remaining indigenous forest remains a core objective of Government policy, with the *New Zealand Biodiversity Strategy* published in 2000. There is also a suite of private initiatives and private-public accords. While the major biodiversity losses have been stemmed, indigenous biodiversity has continued to decline.

A concerted effort has been made to provide a coherent nation-wide picture of New Zealand's biological diversity. For terrestrial groups of plants and animals, this information is updated by specialist groups, as part of the Department of Conservation's triennial assessment[11] of changes to the conservation status of indigenous taxa (Table 1.10).

This information covers all terrestrial ecosystems, not just forests. Points to note are the high levels of endemism found in most groups, and the much greater degree of taxonomic uncertainty associated

11 The interval between assessments has recently been increased to five years.

Table 1.10: Number of indigenous species, described species and introduced species

Species	Estimated number of indigenous species	Number of taxa[1] that have been described	Percentage of described species that are endemic	Number of described species known to be threatened	Number of introduced species in the wild
Mosses, liverworts and hornworts	1 184	1 122	35	45	36
Ferns and fern allies	233	210	45	12	52
Conifers	24	21	100	0	40
Flowering plants	2 912	2 193	85	223	2 453
Invertebrates	c. 40 000	c. 19 400	c. 66	255	2 246
Amphibians	4	4	100	3	3
Reptiles (terrestrial)	100	58	100	20	1
Terrestrial and freshwater birds	107	107	57	42	37
Terrestrial mammals	3	3	100	3	32

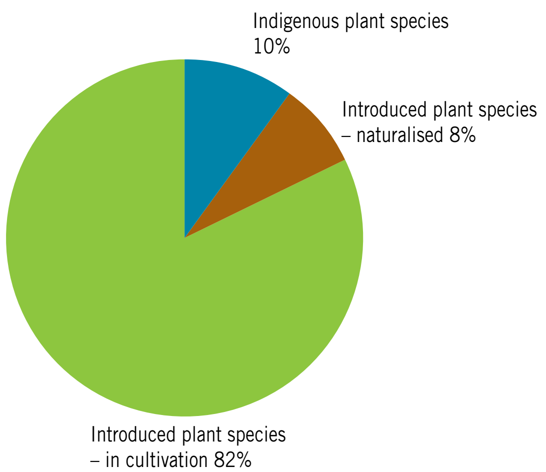
Note 1: Includes species and subspecies.
Source: Data are sourced from the New Zealand Threat Classification Series lists (2008–2011) compiled by specialist groups for the Department of Conservation.

with the invertebrates. For flowering plants it is also worth noting that, while natural ecosystems now contain an almost equal number of indigenous and introduced species, these are but a small fraction of the total number of introduced plant species present in cultivation (Figure 1.7).

Measuring and monitoring the health of indigenous forest (and non-forest) ecosystems across New Zealand continue to be a focus for New Zealand's Department of Conservation. Over the last decade, the department has developed a National Biodiversity Monitoring and Reporting Programme (NBMRP)[12] to assess whether the ecological integrity of public conservation lands is being maintained. Ecological integrity is the ability of the indigenous biota, abiotic features and natural processes to function in sustainable communities, habitats and landscapes. It encompasses all levels and components of biodiversity, and can be assessed at a local, regional or national scale. The system uses information from vegetation and animal surveys, expert-driven threat listings of ecosystems, and land tenure and management information to assess (i) the status and trend of indigenous dominance on conservation land, and (ii) the effectiveness of weed and pest management on the status of native and introduced species. The NBMRP also provides (i) an early warning of threats to native species, and (ii) a basis for prioritisation for management intervention. From an operational standpoint, the system is still in its infancy. As the temporal and spatial coverage of the monitoring data increases, our understanding of the importance of ecosystems in meeting conservation objectives, and of the relationships species have within ecosystems, is expected to improve.

The value of understanding the relationships species have within ecosystems has recently been demonstrated in what has been termed the "Battle for Our Birds". Beech species, which are a dominant component of many New Zealand indigenous forests, flower and fruit heavily in some years and not in others. Flowering and fruiting in abundance is termed masting. Mast years are triggered by above-average temperatures the previous summer and can therefore be predicted. They generally occur every

Figure 1.7: Percentage of indigenous and introduced species of flowering plants present in New Zealand



Sources: Hitchmough, 2013; Bellingham, et al, 2013.

12 Previously termed the Natural Heritage Management System.

four to six years. A heavy mast can produce about 50 million seeds (250 kilograms) per hectare. In years without mast, native bird and animal populations can tolerate the low levels of rats and stoats that are present. During a mast year, rat, mice and later stoat numbers increase dramatically, which has devastating consequences for the native species. Larger hole- or ground-nesting birds such as kiwi, kākā and whio are highly susceptible to stoat predation. Smaller species such as mohua, orange-fronted kākāriki, bellbird, riflemen and robin are sensitive to both rats and stoats, as are the two New Zealand bat species.

Increased predation associated with a beech mast in the year 2000 badly affected mohua populations throughout the South Island. On Mt Stokes in the Marlborough Sounds, the population that was being monitored was wiped out. The news is similarly bad for the orange-fronted kākāriki. In the past decade, rats and stoats have wiped out some breeding strongholds and reduced other local populations by up to 85 percent. Fewer than 400 birds now remain in three subalpine beech forest catchments in Canterbury (the Hawdon, Poulter and Hurunui).

Based on temperature records, the 2013/14 summer was predicted to be a major mast flowering season for beech. Monitoring at locations throughout the South Island confirmed very heavy seed falls in the northern South Island and southeastern Otago, and moderate seed falls in eastern Fiordland and west Otago beech forests. Data from seed monitoring sites and rat tracking tunnels were analysed to determine where the highest predator impacts would occur in spring 2014. Predators in these areas were targeted using aerially applied 1080 poison baits during the spring and summer of 2014/15. In total, predator control was applied over about one-third (700 000 hectares) of beech-dominated forests.

Mast seeding is also a breeding cue for some indigenous bird species, most notably the kākāpō, an endangered flightless parrot. Nesting in the southern South Island population of kākāpō occurs only when the podocarp species rimu (*Dacrydium cupressinum*) and pink pine (*Halocarpus biformis*) have abundant fruiting years (Harper et al, 2006).

Mountain beech forest, Southern Alps, Canterbury. Photo: Ian Platt.

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New Zealand robin.

Indicator 1.2.b Number and status of native forest-associated species at risk, as determined by legislation or scientific assessment

The New Zealand Threat Classification System uses a nationally agreed set of criteria to assess the risk of extinction of resident native taxa. Rankings are based on the estimated size of the national population and predicted population trends. The number of populations, the number of mature individuals in the largest population, and the area occupied by the taxon are also taken into account when assessing the threat status. Since the last threat status assessment, 12 threatened taxa have improved in status as a result of successful species management, and 59 have genuinely worsened in status.

Quality of information: M

Progress against indicator: ▼

Rationale

This indicator provides information on the number and status of forest-associated species at risk or in serious decline. As a result, these species may require specific action or intervention to ensure their survival. The number of species at risk and their status is a measure of the health of forest ecosystems and their ability to support species diversity.

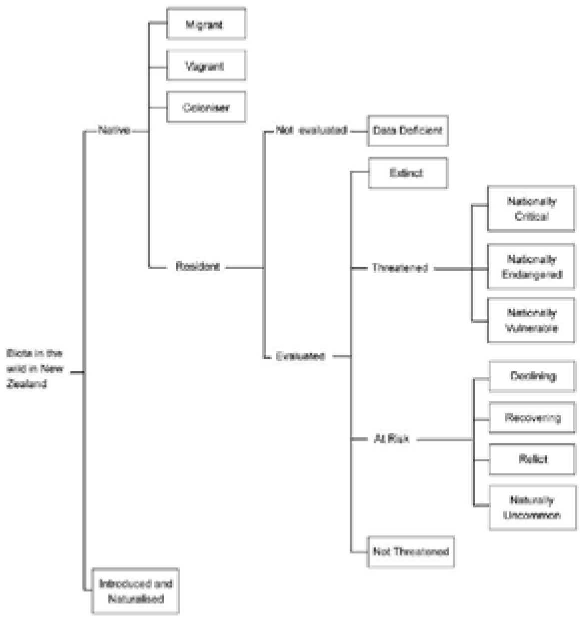
NEW ZEALAND'S REPORT

The New Zealand Threat Classification System (Townsend et al, 2008) developed by the Department of Conservation uses a set of nationally agreed categories and criteria to assess the risk of extinction for 23 groups of land, freshwater and marine organisms that are present in the New Zealand region. Assessments are revised every three years[13] by a series of expert panels, and the results published in the New Zealand Threat Classification Series (for example, Hitchmough, 2013) and other refereed publications.

The Threat Classification System uses a standardised process to allocate a threat ranking to resident native taxa (Figure 1.8). This is a qualitative process undertaken by expert panels. Rankings are based on the estimated size of the national population and ongoing or predicted population trends (Table 1.11). The total number of populations, the number of mature individuals in the largest population, and the total area occupied by the taxon are also taken into account. Taxa for which information is insufficient to determine a threat ranking are classed as data deficient.

A summary of the most recent assessment of the conservation status of New Zealand's land biota (Table 1.12) shows a high degree of knowledge of the threat status of vertebrate groups (amphibians, birds, mammals, reptiles) and vascular plants (ferns, conifers, flowering plants), but much less understanding of the lower plant (mosses, liverworts, hornworts) and the invertebrate groups that make up the bulk of the indigenous land biota. It also omits

Figure 1.8: Structure of the New Zealand Threat Classification System



Source: Townsend et al, 2008.

13 The interval between assessments has recently been increased to five years.

Table 1.11: Primary criteria for assessing threatened, at risk and not threatened taxa

Population trend	Total number of mature individuals					
	<250	250–1000	1000–5000	5000–20 000	20 000–100 000	>100 000
> 10% increase		NV/Naturally Uncommon (NU)	NU/ Relict	NU/Recovering	Not Threatened NU (Range Restricted) Relict	
Stable (± 10%)		NE/NU	NV/NU	NU/Relict		
10–30% decline		Nationally endangered (NE)			Declining	
30–50% decline			Nationally vulnerable (NV)			
50–70% decline			NE			
> 70% decline	Nationally critical (NC)					

Source: Redrawn from Townsend et al, 2008.

Table 1.12: Summary of threat rankings for land biota in the New Zealand region between 2008 and 2011

Status	Mosses, liverworts & hornworts	Ferns and fern allies	Conifers	Flowering plants	Invertebrates	Amphibians	Reptiles (terrestrial)	Terrestrial & freshwater birds	Terrestrial mammals
Nationally critical	31	9	0	146	115	1	6	10	0
Nationally endangered	10	3	0	59	58	0	3	10	0
Nationally vulnerable	4	2	0	70	68	2	8	19	1
Total threatened	**45**	**14**	**0**	**275**	**241**	**3**	**17**	**39**	**1**
Declining	1	4	0	98	45	1	27	6	1
Recovering	0	0	0	7	7	0	3	9	0
Relict	2	1	0	12	102	0	11	4	0
Naturally uncommon	122	34	3	590	924	0	10	18	0
Total at risk	**125**	**39**	**3**	**707**	**1078**	**1**	**51**	**37**	**1**
Total threatened and at risk	**170**	**53**	**3**	**982**	**1319**	**4**	**68**	**76**	**2**
Data deficient	131	1	0	76	1169	1	8	2	1
Extinct since human arrival	0	0	0	8	7	3	2	54	0
Migrant	0	0	0	0	0	0	2	2	0
Vagrant	6	1	0	11	12	0	5	50	1
Coloniser	2	0	0	17	0	0	0	4	0
Not threatened	45	155	19	1254	1803	0	22	29	0
Introduced and naturalised	36	52	40	2453	2246	3	1	37	32
Total species assessed	**390**	**262**	**62**	**4801**	**6556**	**11**	**101**	**254**	**36**
Total extant indigenous species assessed	**354**	**210**	**22**	**2340**	**4310**	**4**	**100**	**107**	**3**
Estimated number of indigenous species	**1184**	**233**	**24**	**2912**	**c. 40,000**	**4**	**100**	**107**	**3**
% of indigenous species assessed	**30**	**90**	**92**	**80**	**11**	**100**	**100**	**107**	**100**

Source: Hitchmough, 2013.

two major groupings: the fungi and the lichens. As for the species estimates in the previous section, this information covers all terrestrial ecosystems, and not just forests.

Since the previous threat status assessment (Hitchmough et al, 2007), 12 threatened taxa have genuinely improved in status as a result of successful species management, and 59 have worsened in status. The status of many more taxa has changed for better or worse as a result of improvements in our knowledge of them, changes in the interpretation of information about them, or changes to the categories and criteria following revisions to the Threat Classification System. No taxa were found to have become extinct since the previous threat status assessment, but some that are believed to have been extinct for many decades or even centuries were added to the list of extinct taxa.

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New Zealand fantail.

Indicator 1.2.c Status of on site and off site efforts focused on conservation of species diversity

New technologies for reducing and eradicating mammalian pests and preventing their reinvasion of sensitive habitat are creating opportunities to reintroduce endangered fauna and flora to areas they formerly occupied. "Mainland Islands" are being created using intensive, multi-pest control to reduce pest mammal populations, and detailed biodiversity monitoring is undertaken to assess the extent to which ecological restoration goals are being achieved. Fenced sanctuaries that exclude the full range of pest mammals are encouraging community-led forest restoration projects. Together with the expansion in the numbers of near-shore, pest-free island sanctuaries, they are allowing an increasing number of people to see and interact with rare and endangered flora and fauna.

Quality of information: M/H

Progress against indicator: ▲

Rationale

This indicator provides information that describes on site (or *in situ*) and off site (or *ex situ*) efforts to conserve species diversity. Some forest species and habitats may have declined to such an extent that intervention is required to safeguard them for the future.

NEW ZEALAND'S REPORT

The arrival of Europeans in New Zealand led to an influx of exotic plants and animals. These included a suite of mammals, most of which had few or no natural enemies in this country, that multiplied rapidly and have caused major damage to forests and forest-associated species. Deer, goats and pigs depleted forest understories and impeded regeneration. Australian brushtail possums caused widespread damage to forest canopies. By far the greatest threat to the indigenous fauna came from stoats, feral cats, rats, mice and possums, which decimated populations of vulnerable endemic species throughout the forests of mainland New Zealand. Historically, these threats have been countered to some extent by sequestering endangered species, particularly birds, on predator-free offshore islands.

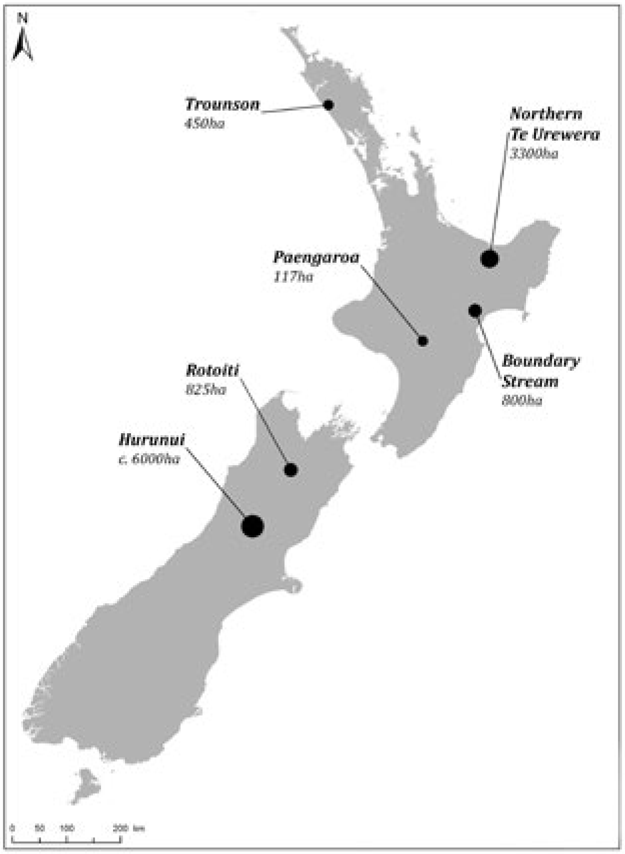
The development of increasingly sophisticated technologies for reducing and eradicating mammalian pests and preventing their reinvasion of sensitive habitat, and an increasing public desire to "restore the dawn chorus" have led to a number of initiatives to reintroduce iconic indigenous fauna to areas they formerly occupied, and where the public can see and interact with them.

The Department of Conservation pioneered the concept of "Mainland Islands" in the mid-1990s. Six sites were established, covering 11 500 hectares of largely forested land, with a further 8000 hectares monitored as reference areas (Figure 1.9). While a range of ecological criteria was used to select the sites, the greatest weighting was given to the potential to recover threatened species (Saunders, 2000). At each site, intensive, multi-pest control is used to drastically reduce the density of pest mammals, and detailed biodiversity monitoring is undertaken to assess the extent to which ecological restoration goals are being achieved. A recent audit of the programme concluded that pest mammal control at Mainland Island sites has been reasonably successful, that as a result some native bird and plant species have done very well, and that some of the bird translocations have led to the establishment of new viable populations. Similar, local initiatives are now found in many parts of New Zealand.

The development of predator-proof fencing that can exclude the full range of pest mammals is encouraging an increasing number of community-led projects aimed at restoring forested habitats to their former glory. The largest of these is the Maungatautari Ecological Island Trust, which has built a 47-kilometre predator-proof fence around a 3400-hectare block of old-growth indigenous forest in the central North Island (Figure 1.10), eradicated all the pest mammals except mice within the fenced area, set up a network of tracks for people to explore this pest-free wilderness, and begun to reintroduce threatened native species such as kiwi, kākā, takahē and tuatara. Other initiatives using predator-proof fences include the Karori Wildlife Sanctuary, which occupies a former water supply catchment in Wellington City, and the Orokonui Ecosanctuary just north of Dunedin.

The other notable effort to conserve species diversity is the restoration of near-shore islands that the public are able to visit. The long-standing example is Kapiti Island (1965 hectares) which lies about 5 kilometres off the west coast of the southern North Island. This was established as a nature reserve in 1897. Goats were eradicated from the island in 1928, followed by cats, deer, sheep, cattle, pigs and dogs. Possums were eradicated between 1980 and 1986 in the first-ever successful operation of its kind. The last of the mammalian pests, kiore and Norway rats, were finally eradicated in 1996 using an aerially applied anticoagulant poison. Kapiti Island is now home to a number of rare and endangered bird species, including little spotted kiwi, stitchbird or hihi, kōkako, takahē, brown teal, kākā and saddleback. Public access is carefully controlled by the Department of Conservation to minimise the opportunity for pests to reinvade.

Figure 1.9: Location of Mainland Island sites established by the Department of Conservation



Source: Ministry for Primary Industries.

The other high-profile example of a near-shore island sanctuary is Tiritiri Matangi Island, a 220-hectare scientific reserve in the Hauraki Gulf, 28 kilometres north of Auckland City. Tiritiri Matangi is now managed by the Department of Conservation, assisted by volunteers and a community group, the Supporters of Tiritiri Matangi. The island was set aside as a reserve in the mid 1970s. Restoration of the indigenous plant communities began in the mid 1980s, and since that time 15 new fauna species have been re-established there: 11 bird, 3 reptile and 1 invertebrate species. Some of these species have now reached population levels that can sustain "harvest" for translocation to other restoration projects. The island has also been used as a research site by tertiary education institutions, with over 70 postgraduate research projects completed to date (Galbraith and Cooper, 2013).

The ability to eradicate pest mammals from island sanctuaries has also been applied to a number of offshore islands in the New Zealand region and elsewhere. The largest of these, Campbell Island, was successfully rid of Norway rats during the winter of 2001. Rats had been present since before 1840 and had successfully eliminated all native land birds and most of the smaller seabirds from the 113-square-kilometre main island. In just under a month, 120 tonnes of cereal bait containing the anticoagulant toxin brodifacoum were spread across the island by four helicopters. In 2005, after several checks including using specially trained dogs, Campbell Island was declared rat free. The removal of rats from the main island allowed the reintroduction of the Campbell Island teal, which had previously been restricted to nearby rat-free Dent Island.

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Figure 1.10: Maungatautari Ecological Island Trust fence. **Photo: Ian Payton.**

INDICATOR 1.3 GENETIC DIVERSITY

Genetic diversity is the variation of genes within populations and species. As the ultimate source of biological diversity at all levels, it is important for the functioning of healthy forest ecosystems. Threats to gene pools come from climate change, catastrophic events, and human activities and pressures.

Loss of genetic variation reduces the ability of species to adapt to environmental change; and for society to maximise the potential benefits available from forest species – for example, for medicines and other bio-resources. High levels of genetic diversity within populations are usually a measure of their greater potential for survival. The loss of genetic variation within species also results in forest ecosystems that are less resilient to change.

Indicator 1.3.a Number and geographic distribution of forest-associated species at risk of losing genetic variation and locally adapted genotypes

Understanding of genetic variation in indigenous forest-associated species remains limited. Most studies focus on rare or endangered taxa. The most comprehensive account comes from studies of threatened avifauna. Low levels of genetic diversity are present in most threatened endemic birds, and in other plant and animal groups that have been studied. The dominance of a single exotic plantation species, radiata pine, creates biotic risks, which are exacerbated when it is grown in large-scale monoculture. The ability to counter these risks through breeding programmes relies on the preservation of genetic diversity. Changes to forest ownership and institutional frameworks over recent decades may be placing some of the existing radiata pine gene pool at risk. Similar issues surround other plantation species, notably Douglas-fir, the eucalypts and the cypresses. Most exotic non-tree forest-associated species are not at risk in this way.

	Indigenous species	Exotic species
Quality of information:	L/M	H
Progress against indicator:	▲	▼

Rationale

This indicator provides information on the number and distribution of forest-associated species at risk of losing genetic variation across their population. This erosion in genetic variation makes species less able to adapt to environmental change and more vulnerable to extinction. Some local populations with unique gene pools may also risk being swamped by larger populations introduced intentionally, by accident, or by natural processes.

NEW ZEALAND'S REPORT

Indigenous species

Understanding of genetic variation within and between populations of indigenous species is still in its infancy. Based on the handful of botanical studies that have been done, low genetic diversity appears to be a feature of New Zealand's indigenous tree species. This is thought to result from bottlenecks associated with repeated glaciations during the Pleistocene.

Most studies of genetic variability in indigenous species have focused on rare or endangered taxa, with the aim of ensuring that conservation efforts target the full range of genetic diversity. Examples include the endemic root parasite *Dactylanthus taylorii*, which typically occurs in small, isolated populations and is threatened by possums and rats that browse the inflorescences (Ecroyd, 1996). Genetic analysis across the species range identified four populations as the most genetically distinct at the national level, and recommended that these be targeted for management (Faville et al, 2000). More recently the genetic variability of all known populations of the endangered tree daisy *Olearia gardneri* was assessed to determine the most appropriate conservation measures for this species. Despite considerable emphasis on "ecosourcing" in plant recovery programmes, the study concluded that this might not be the best strategy for *O. gardneri*, due to its breeding system and population size (Barnaud and Houliston, 2010).

By far the most comprehensive account of genetic variation in indigenous species comes from studies of New Zealand's threatened avifauna (Jamieson, 2009). Historically, populations of endemic birds have declined as a result of hunting and habitat loss (Worthy and Holdaway, 2002), and continue to decline as a result of introduced predators. Low genetic diversity is a feature of most of New Zealand's threatened endemic birds, with small island populations typically containing less diversity than their larger mainland counterparts (Boessenkool et al, 2007).

Low levels of genetic diversity in historical and recent specimens of the takahē *(Porphyrio hochstetteri),* a large flightless rail, suggest a dramatic population decline in the period before European settlement, and provide molecular support for the hypothesis that the species was hunted to extinction over most of its range by early Māori (Grueber and Jamieson, 2011).

This contrasts with the kākāpō *(Strigops habroptilus),* a large flightless nocturnal parrot, which was still relatively common in southern New Zealand at the time of European settlement but which is now critically endangered. Here the mainland population, which had higher levels of genetic variation, has been driven to near extinction by introduced predators, while the island population, which exhibits very low levels of genetic variability, is being intensively managed to try to ensure the survival of the species (Robertson, 2006).

The takahē.

Similar reductions in genetic diversity have been demonstrated for species such as the saddleback *(Philesturnus carunculatus),* mohua *(Mohoua ochrocephala)* and kōkako *(Callaeas cinerea),* all of which are threatened by mammalian predation (Innes et al, 2010). However, not all of the endemic avifauna follow this pattern. A recent study of genetic diversity in the stitchbird or hihi *(Notiomystis cincta),* an endangered honeyeater, found the sole remaining island population retained high levels of genetic diversity relative to other New Zealand avifauna with similar histories of decline (Brekke et al, 2011).

The challenge for conservation managers is to balance the short-term risks to threatened species, which for the fauna tend to be predator-related, against the longer-term requirement to maintain genetic diversity in order to maximise the ability of species to respond to future challenges (Jamieson et al, 2008).

Exotic species

The commercial forestry sector in New Zealand is based almost entirely on exotic plantations that are dominated by a single species, radiata pine. In its natural range, this species is restricted to five discrete populations: three in coastal California and two on small islands off the coast of Mexico. Since the early 1950s, radiata pine has been the subject of a large and intensive breeding programme (Burdon et al, 2008; Dungey et al, 2009), which has provided substantial genetic gains and received strong uptake from the New Zealand forest industry (Burdon, 2010).

The dominance of a single exotic species creates biotic risks, which are exacerbated when that species is grown in large-scale monoculture. The risks take two main forms. The first is that pests or diseases that may or may not be present in the native environment become established and run rampant. The second occurs when species are grown outside the climatic or edaphic range of their native environment. For radiata pine, which comes from a winter-rainfall environment but which is grown on summer-moist sites in New Zealand, this increased risk is from fungal diseases such as the foliar pathogen *Dothistroma septosporum*, which first infected New Zealand plantations in the early to mid-1960s.

During the 1980s, forest industry and research organisations established the Radiata Pine Breeding Cooperative to manage the tree breeding and own the genetic resources of radiata pine (Burdon, 2008). This was superseded in 2000 by the Radiata Pine Breeding Company, which now owns and manages the genetic resource, including that of the original landrace populations that underpin the main, elite and production populations used by today's forest industry.

The large-scale shift of plantation forests from public to private ownership since the 1980s has resulted in a loss of institutional knowledge of stands covenanted to protect genetic resources, and created incentives to prioritise short-term financial returns over issues concerned with the longer-term security of the industry. The change from forestry to more profitable agricultural land uses, notably dairy farming, has also been responsible for the loss of some covenanted stands.

For researchers, the shift from bulk funding to a more contestable model, in which funding outcomes are heavily influenced by the forest industry, has constrained their ability to investigate issues that are not seen as immediate priorities by the industry. On the regulatory front, continued strengthening of biosecurity requirements is making it more difficult to import new or replacement genetic material. Despite these concerns, the general view in the forest industry is that, with radiata pine now entering its fourth generation of breeding, there remains more than enough genetic diversity for new selections against disease (J Butcher, personal communication, 2014). Similar issues surround other plantation species, notably Douglas-fir, the eucalypts and the cypresses (Dungey et al, 2012a, 2012b). Most non-tree exotic forest-associated species are not at risk in this way.

New Zealand kea.

The challenge for both government regulators and industry representatives is to balance the requirement for industry profitability against the need to maintain the genetic diversity of the key forestry species in order to maximise the ability of researchers to respond to future challenges.

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Indicator 1.3.b Population levels of selected representative forest-associated species to describe genetic diversity

The National Biodiversity Monitoring and Reporting Programme (NBMRP), recently implemented by the Department of Conservation, is providing improved information on the population status of selected forest-associated species or species groups (weeds, ungulates, possums, palatable tree species, birds) that are considered to influence the diversity (including genetic diversity) of forests on public conservation land. Indigenous plant species greatly outnumber exotic weeds in number and abundance in forests on conservation land, and this has not changed over recent years. Introduced ungulates and brushtail possums are widespread in forests. Both are less abundant in beech than in non-beech forests. Palatable tree species such as kāmahi, māhoe and broadleaf continue to regenerate across public conservation land, although there are local sites where pest mammals are preventing their regeneration. While the population size structures of these palatable tree species have been maintained over the last decade, mortality rates have exceeded the rate of recruitment, so current regeneration patterns may not be maintained. Results also show that indigenous forests support at least twice as many native bird species as introduced ones, in both beech and non-beech forests.

Quality of information: M

Progress against indicator: ▶

Rationale

This indicator provides information on the population status of selected forest-associated species that are considered to reflect the genetic diversity present in forest ecosystems. Some forest species support or rely heavily on particular forest structures, patterns, associations and processes and can therefore be used to describe the status of genetic diversity in forests as a whole.

NEW ZEALAND'S REPORT

Most indigenous forest species occupy a small proportion of their former range, owing to the large-scale forest clearance in New Zealand following first Polynesian and later European settlement. The main exceptions to this are the beech forests in the South Island, which still occur over a large part of their pre-settlement range.

The Department of Conservation's recently implemented National Biodiversity Monitoring and Reporting Programme (see Indicator 1.2.a) provides information on the population status of selected forest-associated species or species groups (weeds, ungulates, possums, palatable tree species, birds) that are considered to influence the diversity (including genetic diversity) of forests on public conservation land. Data are obtained from a nationally representative set of permanent plots that was established in 2002–2007 and re-measured in 2009–2014 (Allen et al, 2009; Payton et al, 2004).[14] Results from a partial re-measurement of the plot network provide the first national-scale assessment of the trends in the diversity of New Zealand's indigenous forest ecosystems (MacLeod et al, 2012).

Trends in the population status of the influential introduced species (see also discussion on these species as invasives under Indicator 3.a), as assessed from results across the NBMRP plot network, show the following:

- **Indigenous plant species greatly outnumber exotic weeds** in forests on public conservation land. Although weeds are widespread, most occur at low frequency. The number and abundance of weed species did not change significantly between measurements. Forests in national parks had fewer weed species than those on other types of public conservation land. Plots closer to grasslands or settlements had a higher percentage and number of weed species than those further away (Table 1.13).
- **Introduced ungulate (deer, goats) populations** – a serious threat to indigenous species diversity because they can substantially alter the structure and composition of forests, and have no natural

14 These plots were initially established to estimate biomass carbon stocks for New Zealand's greenhouse gas inventory.

Table 1.13: Number and frequency of weed species on indigenous forest plots

	2002–2003	2009–2012
Number of indigenous species	704	731
Number of weed species	122	127
Percentage of plots with weeds	40.5	32.6
Mean number of weed species per plot	1.7 (± 0.5)	1.5 (± 0.4)
Mean percentage of weed species per plot	3.4 (± 0.9)	3.1 (± 0.9)

(*n* = 328)

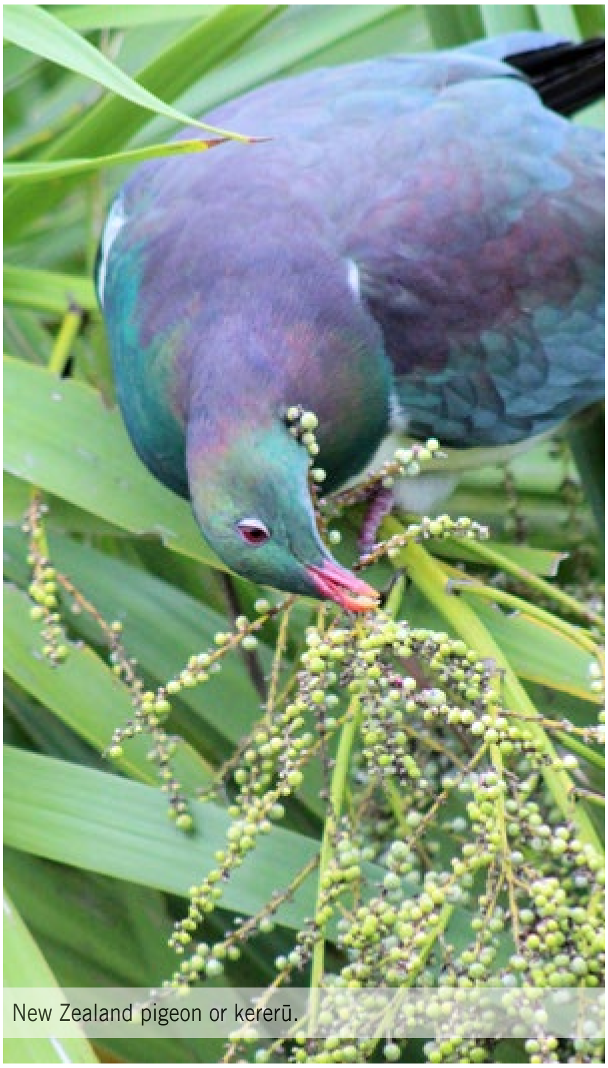
Source: MacLeod et al, 2012.

predators – were mostly at low abundances compared with those observed from the 1950s to 1970s (Forsyth et al, 2011). This is likely to be due to the sustained effects of commercial and recreational hunting and Department of Conservation control measures. In the most recent measurement[15] of the NBMRP plot network, ungulates were present at 75 percent of the sampling locations.

- **Australian brushtail possums** – originally introduced to establish a fur trade, and primarily arboreal browsers – were present at 80 percent of forest sampling locations on the NBMRP plot network. As with ungulates, possums have strong preferences for broadleaved tree species, and have little impact on beech or podocarp canopies (Payton, 2000).

The NBMRP also measures changes in the indigenous species affected by introduced species. Kāmahi (*Weinmannia racemosa*) is an important indicator in this regard. It is used to assess the status and trend of palatable tree species because it forms forest canopies throughout much of New Zealand and is highly palatable to both ungulates and possums. Death of adult trees in this species has been attributed to possums (Rogers and Leathwick, 1997) and failure of regeneration to ungulates (Payton et al, 1984). At a national scale, the size class structure of kāmahi in New Zealand forests did not change between 2002–2007 and 2009–2012, and this pattern was consistent between beech and non-beech forests. However, for kāmahi and other palatable tree species such as māhoe and broadleaf, mortality rates have exceeded recruitment over the last decade, so current regeneration patterns may not be maintained (Bellingham et al, 2014).

Results from the assessment of forest bird community composition show that indigenous forests support at least twice as many native bird species as introduced ones. This pattern is consistent across forest types (beech versus non-beech) and does not differ between national park and other conservation land. Encouragingly, the most abundant and widespread species in indigenous forests include some of New Zealand's main avian pollinators and seed



New Zealand pigeon or kererū.

15 Data for animal (ungulate, possum, bird) populations were not recorded during the initial measurement of the NBMRP plot network.

dispersers (bellbird, tūī, silvereye) and cavity nesting birds such as tomtits, riflemen and kākāriki, which are susceptible to mammalian predation. Of concern is the relatively low occupancy estimates for kererū (about 35 percent), New Zealand's primary large-seed disperser, and mohua or yellowhead (about 5 percent), a cavity nesting species known to be highly susceptible to mammal (rat, stoat) predation.

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Australian brushtail possum.

Indicator 1.3.c Status of on site and off site efforts focused on conservation of genetic diversity

Efforts to understand and maintain the genetic diversity of iconic species such as kiwi, tuatara and kauri have gathered pace over recent decades and are now widely supported. However, little or nothing is known about the genetic variability of most endemic species, and few are being actively managed to ensure genetic diversity is retained.

Quality of information: L/M

Progress against indicator: ▲

Rationale

This indicator provides information that describes on site (or *in situ*) and off site (or *ex situ*) efforts to conserve genetic diversity within species. Some species have suffered from a loss of genetic variability due to population decline and a reduction in their former range and distribution. Continued loss of genetic variability will threaten the viability of these species and may accelerate a decline that may lead ultimately to extinction.

NEW ZEALAND'S REPORT

The Department of Conservation is the central government agency charged with protecting New Zealand's indigenous flora and fauna. Strategies for conserving individual species or species groups are published in Threatened Species Recovery Plans. These specify the steps that need to be taken to prevent extinction and return the species to a non-threatened state. Recovery plans are primarily used by departmental staff to allocate resources and guide work programmes. They also provide a framework for initiatives with tangata whenua, community interest groups, landowners, researchers and members of the public. The following examples provide a glimpse of efforts to conserve the genetic diversity of several iconic New Zealand species.

Kiwi (*Apteryx* spp.) are nocturnal forest dwellers. Until recent decades, their decline went largely unnoticed. The current recovery plan (2008–2018), which is the third since 1991, covers all five formally described species and the recognised variations within these. Since 1991 the conservation focus has shifted from research (first plan) and raising public awareness (second plan), to increasing management efforts to halt the decline in genetic diversity in each of the taxa (third plan). Funding for kiwi protection from public and private sources, including corporate sponsorship, has increased significantly over recent years. Despite this, much remains to be done. Populations of the three most abundant species are either confirmed (brown kiwi, *A. mantelli*) or assumed (great spotted kiwi, *A. haastii*; tokoeka, *A. australis*) to be still be in overall decline. Although declines of the critically endangered rowi (*A. rowi*) and Haast tokoeka have been arrested, their low numbers mean they remain vulnerable. Little spotted kiwi (*A. owenii*) are extinct on the mainland, but are increasing in numbers on several offshore islands and in predator-free sanctuaries on the mainland.

Today about 70 community groups actively protect kiwi over a combined area of 50 000 hectares, and Department of Conservation recovery programmes protect another 70 000 hectares of kiwi habitat. In addition to predator control, kiwi eggs from populations of the most critically endangered taxa are harvested from the wild, and the chicks reared in predator-free surroundings. When large enough to fend off predators, the birds are returned to their original habitat. Despite the ongoing decline of some taxa, there are positive signs: there is strong public awareness of and engagement with the plight of the kiwi; the research programme has provided a sound basis for their management; and population trends are generally positive where effective conservation management is being applied.

The tuatara (*Sphenodon punctatus*) is the sole survivor of an order of reptiles that flourished during the age of the dinosaurs, some 200 million years ago. Before humans arrived, it was found throughout mainland New Zealand, but today survives only on a small number of offshore islands. During the past 100 years, tuatara populations have become extinct on 10 of these islands. There is good evidence to link the decline of tuatara with the presence of rats. On islands where rats are present, tuatara numbers are low and there are few if any juveniles in the population. In addition to preying on eggs and juvenile tuatara, rats compete for the invertebrates, lizards and nesting seabirds on which tuatara feed. Researchers have developed captive breeding techniques and identified the role of temperature in determining the sex of hatchlings. Populations removed from islands during rat eradication campaigns have been boosted using these techniques, and show renewed vigour when returned to their predator-free island homes. New breeding populations are also being established on predator-free islands, including some where the public are able to see and interact with the reptiles.

At the time of European settlement, kauri (*Agathis australis*) was a dominant tree species in the lowland forests of northern New Zealand. As a result of excessive timber extraction during the 19th and early 20th centuries, mature stands of the species are now largely restricted to publicly owned reserve land. Giant individual trees (for example, Tāne Mahuta, Te Matua Ngahere), some of which are over 1000 years old and exceed 4.5 metres in diameter, are accorded special status and have become major tourist attractions.

Kauri dieback was first observed on Great Barrier Island in the early 1970s (Gadgil, 1974). Symptoms included yellowing foliage, canopy thinning and occasional tree death. Affected trees frequently had lesions on the lower trunk and main roots, which bled copious quantities of resin. The causal agent is a previously unknown species of *Phytophthora*, currently referred to as *Phytophthora* taxon Agathis or PTA. These are fungus-like microorganisms that live in the soil and are spread through the movement of soil and water. Over the last decade, surveys have identified PTA at numerous sites throughout Northland, Auckland and, most recently, the Coromandel Peninsula. This has led to concerns over the continued survival of iconic kauri trees, the loss of genetic variability within the species, and the flow-on effects for kauri-dominated ecosystems that support flora and fauna not found elsewhere.

The response of national and regional government agencies has been to establish a joint management agency team to co-ordinate efforts to limit the further spread of the disease, and to research options for

Kauri dieback, Pakiri.

treating infected or threatened trees. While it is premature to say whether efforts to contain the disease have been successful, recently published research (Horner and Hough, 2013) suggests that phosphite,[16] which is used to combat other *Phytophthora* diseases, is an effective agent against PTA.

These are but three examples of an ever-increasing number of on site and off site programmes aimed at conserving the genetic diversity of New Zealand's endemic flora and fauna. However, the positive note sounded here needs to be balanced against the realisation that little or nothing is known about the genetic variability of most endemic species, and that only a very small percentage are being actively managed to ensure genetic diversity is retained.

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16 Phosphorous acid.

Kiwi.

CRITERION 2:
MAINTENANCE OF PRODUCTIVE CAPACITY OF FOREST ECOSYSTEMS

Many communities depend on forests directly or indirectly for a wide range of forest-based goods and services. The sustainable provision of these services is clearly linked to the productive capacity of the forest. If this capacity is exceeded, there is a risk of ecosystem decline or collapse.

For forests to be sustainable, it is necessary to understand the levels at which goods and services may be extracted or used without undermining the functioning of forest ecosystems and processes. The nature of goods and services provided by forests change over time due to social and economic trends, and technological developments. Change in the productive capacity of forests may be a signal of unsound forest management practices or other agents that are affecting forest ecosystems in some way.

Table 2.1 lists the indicators covered in this section.

Table 2.1: Indicators for Criterion 2 – quality of information and trends

Criterion 2: Maintenance of productive capacity of forest ecosystems		Quality of information	Trend
2.a	Area and percent of forest land and net area of forest land available for wood production	H	►
2.b	Total growing stock and annual increment of both merchantable and non-merchantable tree species in forests available for wood production	M/H	▲
2.c	Area, percent and growing stock of plantations and native and exotic species	L/H	►
2.d	Annual harvest of wood products by volume and as a percentage of net growth or sustained yield	M/H	►
2.e	Annual harvest of non-wood forest products	L/M	▲

KEY

L = low	Neutral	►
M = medium	Positive	▲
H = high	Negative	▼

NEW ZEALAND OVERVIEW

Key changes since 2008 are:

- a decrease of about 3 percent in the area of plantation forests available for wood production;
- an increase in the standing volume of wood in plantation forests to about 512 million cubic metres, reflecting an increase in the average age;
- the publication of a new set of regional and national wood availability forecasts;
- the ongoing development in the use of indigenous plant extracts in skincare and medicinal products.

The total forest area available for wood production is 1.9 million hectares. This is dominated by the plantation forest estate, which contributes 1.7 million hectares. These statistics have changed little over the last decade. While the area of plantation forests decreased by 3 percent between 2007 and 2013, the estimated standing volume has increased by 18 percent to 512 million cubic metres over this period – as a result of the increasing area-weighted average age.

In 2014, radiata pine accounted for 90 percent of the plantation forest estate (by area); the next most common species was Douglas-fir at 6 percent. Total harvested volume was 30.3 million cubic metres, up from 20 million cubic metres in 2007.

The area of indigenous forest available for wood production under approved plans and permits declined by 26 percent between 2007 and 2013, and currently stands at 84 000 hectares. Total harvested volumes, which fluctuated between 16 000 and 18 000 cubic metres annually between 2007 and 2012, increased to 26 000 cubic metres in 2013. Recent analysis suggests that about 250 000 hectares of privately owned indigenous forests have the potential to be sustainably managed for timber production with an annual sustainable yield of about 300 000 cubic metres, over 90 percent of which would be from beech species. Estimates of the area of indigenous plantations range from 100 to 2500 hectares. Most are small and many may not have been established for the sole purpose of producing timber.

Non-wood forest products industries are not well developed in New Zealand. On a national basis, trapping and hunting of introduced brushtail possums and deer for pelts, fibre and meat, and honey production are still the main focus. The number of animals harvested varies considerably from year to year in line with market conditions. The harvesting and exporting of sphagnum moss, which has been a significant factor in the economy of the West Coast of the South Island, has declined over recent years.

New non-wood forest product industries based on the use of indigenous plant extracts for skincare and other medicinal purposes continue to develop. Research trials and small-scale production of edible mycorrhizal fungi and ginseng are being developed in some production forests. Māori also traditionally harvest medicinal herbs.

Red, silver and mountain beech, Victoria Range, North Westland. Photo: Ian Platt.

Indicator 2.a Area and percent of forest land and net area of forest land available for wood production

The total area of forest land and the area of forest land available for wood production have decreased slightly over the last decade. This is largely the result of plantation forests being converted to more profitable agricultural land uses following harvest.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator measures the availability of forest land for wood production compared with the total forest area of a country. It provides information that will help assess the capacity of forests to produce wood to meet society's needs.

NEW ZEALAND'S REPORT

Indigenous forests

Recent analyses of satellite imagery put the area of tall indigenous forest in New Zealand at about 6.8 million hectares. A further 1.2 million hectares are classified as regenerating forest. With one exception,[17] all publicly owned indigenous forests are protected for the conservation of indigenous biodiversity. Analysis of privately owned indigenous forests (Griffiths and Wooton, 2012) indicates that about 360 000 hectares of tall forest classes contain targeted commercial species (rimu, tawa, and red and silver beech) and that in over 70 percent of this area, volumes are likely to be sufficient to support commercial harvesting. Currently about 23 percent of these forests have approved sustainable forest management plans and permits.

Privately owned indigenous forests harvested for timber are managed under the Forests Act 1949 (Part 3A, amended 1993), which specifies provisions and procedures for their sustainable management. These provisions are administered by the Ministry for Primary Industries, which approves sustainable management plans and permits and enforces compliance.

17 The exception is a 12 000-hectare block of beech forest in western Southland.

Table 2.2: Areas and percentages of forest land available for wood production (000 hectares)

	2003	2007	2013
Total plantation forest area[1]	**1 827**	**1 826**	**1 780**
Area available for wood production	1 827	1 826	1 780
Percentage available for wood production	100	100	100
Total indigenous forest area[2]	**8 080**	**8 071**	**8 067**
Area available for wood production[3]	79	113	84
Percentage available for wood production	1	1	1
Total forest area	**9 907**	**9 897**	**9 847**
Area available for wood production	1 906	1 939	1 864
Percentage available for wood production	19	20	19

Notes: 1. Net stocked forest area plus harvested areas awaiting replanting at 31 March 2003, 2007 and 2013.
2. Includes regenerating forest.
3. Area under approved sustainable forest management plans and permits at 1 April 2003, 2007 and 2014.

Sources: 1. Ministry of Agriculture and Forestry, 2004, 2008; Ministry for Primary Industries, 2013.
2. New Zealand Land Use Map 1990–2008. (Data on post 2008 indigenous forest area changes provided by the Land Use and Carbon Analysis System (LUCAS) team at the Ministry for the Environment.)
3. Ministry for Primary Industries, 2014b.

Plantation forests

Data on plantation forest areas available for wood production are based on grower surveys and reported annually in the National Exotic Forest Description. This publication records net stocked forest area, including harvested areas awaiting restocking. All plantation forests in Table 2.2 are considered to be available for wood production. Some additional areas have been planted primarily to protect highly erodible soils.

The area of plantation forest peaked at 1.84 million hectares in 2006, and since then has declined by about 3 percent.

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Southern rata forest, Fox Glacier, South Westland. Photo: Ian Platt.

Indicator 2.b Total growing stock and annual increment of both merchantable and non-merchantable tree species in forests available for wood production

Despite a 3 percent reduction in the area available for wood production, between 2007 and 2013 the standing volume of plantation forests has increased by 18 percent. Recent estimates suggest that the standing volume of indigenous forests has remained stable over the last decade at a little over 3200 million cubic metres. The potential for sustainable harvest of timber from privately owned indigenous forests is conservatively estimated to be 300 000 cubic metres per annum, most of which is red or silver beech.

Quality of information: M/H

Progress against indicator: ▲

Rationale

This indicator measures the growing stock and annual increment of forest area available for wood production to meet society's needs. The annual increment and growing stock can be related to the volume harvested each year to provide a means to demonstrate the sustainable management of forest resources.

NEW ZEALAND'S REPORT

Plantation forests

Despite a small reduction in the area available for wood production over the last decade, the standing volume of New Zealand's plantation forests, as estimated by the National Exotic Forest Description, has increased by an average of 9 million cubic metres per annum. The increase in standing volume is reflected in the average age of plantation forest stands, which has increased from 13.7 to 16.4 years over the same period (Table 2.3).

Total standing volume is the volume of wood contained in stems of all age classes. It includes some non-recoverable volume (commonly about 15 percent), but excludes bark.

Radiata pine (90 percent) and Douglas-fir (6 percent) are the main plantation species in New Zealand. The mean annual increments for these species over the New Zealand plantation forest estate, as estimated by the National Exotic Forest Description yield tables, are given in Table 2.4.

Table 2.3: Stem volume and stand age in plantation forests available for wood production

	2003	2007	2013
Area available for wood production[1]	1 827	1 826	1 780
Total standing volume[2]	398	434	512
Area-weighted average age[3]	13.7	14.8	16.4

Notes: 1. Net stocked forest area (000 ha) plus harvested areas awaiting replanting at 1 April 2003, 2007 and 2013.
2. Total stem volume (million m^3, under bark).
3. Age (years).

Sources: 1. Ministry of Agriculture and Forestry, 2004, 2008.
2. Ministry for Primary Industries, 2014a.

Table 2.4: Mean annual increment of total recoverable volume (cubic metres per hectare)

Stand age (years)	25	30	35	40
Radiata pine	17.6	19.2	20.0	20.2
Douglas-fir	11.8	13.1	13.9	14.8

Source: Ministry of Forestry, 1996.

Table 2.5: Mean annual increment (cubic metres per hectare) for indigenous timber species

Species	Botanical name	Mean Annual Increment (m^3/ha)
Kauri	*Agathis australis*	1–9[3]
Rimu	*Dacrydium cupressinum*	1.2–1.8[2]
Red beech	*Fuscospora*[1] *fusca*	6–10[3]
Mountain beech	*Fuscospora*[1] *cliffortioides*	5–8[3]
Silver beech	*Lophozonia*[1] *menziesii*	6–11[3]
Tawa	*Beilschmiedia tawa*	< 1[3]

Notes: 1. Formerly the genus *Nothofagus*.
2. Not specified whether total or total recoverable volume.
3. Total recoverable volume.

Sources: 1. G Stewart, 1991.
2. J Wardle, 1984.
3. P Wardle, 1991.

Indigenous forests

Current estimates suggest that, at a national scale, wood volumes in indigenous forests have remained stable over the last decade at a little over 3200 million cubic metres. Broadleaved species (notably the southern beeches) contribute 88 percent of this volume, and coniferous species (notably the podocarps) the remaining 12 percent (Beets et al, 2009). The potential for sustainable harvest of timber from indigenous forests in private ownership is conservatively estimated at about 300 000 cubic metres per annum standing volume, of which about 200 000 cubic metres would be sawlog quality. At least 90 percent of this timber is red or silver beech (Griffiths and Wooton, 2012; KPMG, 2013). Current indigenous wood removals are predominantly silver beech, with lesser amounts of red beech, hard beech and rimu.

Limited data on annual increment are available for the main indigenous timber species (Table 2.5).

Sources of information

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Indicator 2.c Area, percent, and growing stock of plantations of native and exotic species

The National Exotic Forest Description continues to provide comprehensive data on exotic plantation forests, including details on area, and growing stock by species or species groups. There is no consolidated assessment of indigenous plantation area or standing volume.

Quality of information: L/H

Progress against indicator:

Rationale

This indicator provides information on the nature and extent of plantation forests. Changes in the area of plantation reflect society's present and future needs or the impact of competing land uses on forest cover. The use of both native and exotic plantation species may enhance the range and quantity of goods and services available.

NEW ZEALAND'S REPORT

Exotic plantations

Almost all of New Zealand's timber production comes from exotic plantation species. Radiata pine and Douglas-fir predominate, and together account for over 95 percent of the total area and the total standing volume (Table 2.6).

While the area of exotic plantations in New Zealand has declined over the last decade (see Indicator 1.1.a), the standing volumes of the two main species have continued to increase: radiata pine by 27 percent and Douglas-fir by 54 percent (Figure 2.1). These increases are a result of the maturing of the new plantings in the mid-1990s.

Indigenous plantations

Estimates of the total area of indigenous plantations range from 100 to 2500 hectares. The largest areas were established by the former New Zealand Forest Service following logging of old growth indigenous forests. They were primarily indigenous conifers (kauri, rimu and tōtara). Most of these historical plantings are on land that is now managed by the Department of Conservation, and are therefore unlikely to be harvested. Most present-day plantings are small (< 1 hectare) and have been established for a mix of purposes.

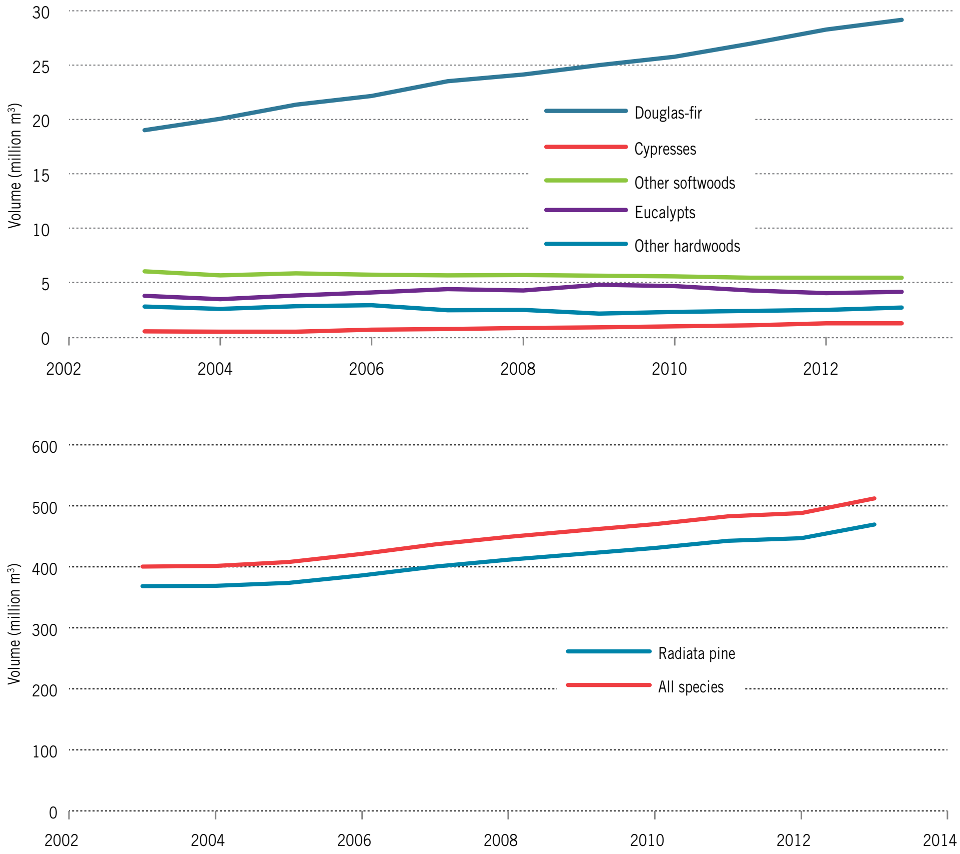
Table 2.6: Area and growing stock of exotic plantation species or species groups (as at 2013)

Species or species group	Area (ha)	Percentage of total area	Growing stock (million m³)	Percentage of total growing stock
Radiata pine	1 553 700	89.9	469.5	91.7
Douglas-fir	106 500	6.1	29.2	5.7
Cypresses[2]	10 100	0.6	1.2	0.2
Other softwoods[3]	23 600	1.4	5.4	1.1
Eucalypts[4]	22 000	1.3	4.1	0.8
Other hardwoods[5]	12 600	0.7	2.7	0.5
TOTAL	**1 728 500[1]**	**100.0**	**512.1**	**100.0**

Notes: 1. Excludes 51 900 hectares that have been harvested and await replanting.
2. *Cupressus macrocarpa, C. lusitanica*, and other *Cupressus* species.
3. Pines (other than radiata), firs (other than Douglas-fir), larches and redwood.
4. All *Eucalyptus* species.
5. Broadleaved trees including Tasmanian blackwood, walnut, oak, poplar, willow, paulownia, birch, alder and elm.

Source: Ministry for Primary Industries, 2014.

Figure 2.1: Change in the standing volume of plantation forest species or species groups between 2003 and 2013



Sources: Ministry for Primary Industries, 2012–2014, *National Exotic Forest Description*; Ministry of Agriculture and Forestry, 2003–2011, *National Exotic Forest Description*.

Sources of information

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Indicator 2.d Annual harvest of wood products by volume as a percentage of net growth or sustained yield

Current and future trends in available and harvested wood volumes are described for New Zealand's plantation and indigenous forests. For both classes of forest, the actual and forecasted harvest levels are well within the limits for sustaining the forest resource.

Quality of information: M/H

Progress against indicator:

Rationale

This indicator compares actual harvest levels against what is deemed to be sustainable. The purpose is to assess where forests are being harvested beyond their ability to renew themselves or are being under-utilised for wood products.

NEW ZEALAND'S REPORT

Plantation forests

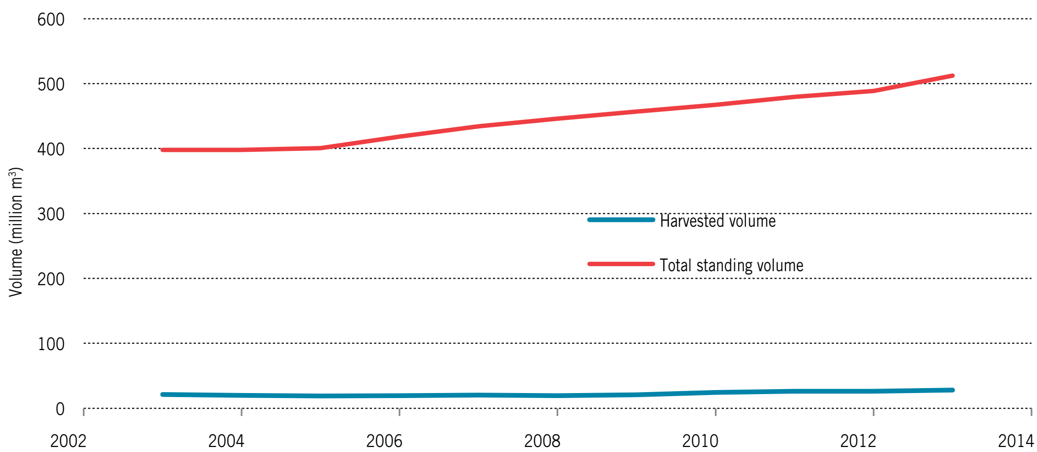
New Zealand plantations are dominated by radiata pine (90 percent) and Douglas-fir (6 percent). The volume of wood harvested annually is estimated from the quantities of processed wood products and export log volumes. Non-industrial wood removals are considered to be insignificant.

For plantation forests, most of which are now in private ownership, the annual volume of wood that can be harvested is not prescribed by any central agency. Standing volumes have increased steadily over recent years (Figure 2.2), and this growth is expected to continue as more forestry plantings reach maturity. Harvested volumes have also increased, but at a slower rate.

To assist with forest industry planning the Ministry for Primary Industries (formerly the Ministry of Agriculture and Forestry) has compiled regional wood availability forecasts for radiata pine and Douglas-fir. These were produced with the assistance of major forest growers and industry consultants. They cover the period from 2008 to 2040. Minor plantation species have not been included because of their insignificance to the overall wood supply.

The national forecasts presented here are the sum of the regional forecasts. Four scenarios are provided for radiata pine and one for Douglas-fir. The modelling uses the age class distribution of the forests (Figure 2.3) and the harvesting intentions of the large-scale forest owners (> 1000 hectares of forest) for the first

Figure 2.2: Changes in harvested and standing volumes from New Zealand plantations between 2003 and 2013



Sources: Ministry of Agriculture and Forestry, 2004–2012, *National Exotic Forest Description*; Ministry for Primary Industries 2013–2014b.

10 years to estimate an expected harvested wood volume for each year (Figure 2.4).

The following are the four scenarios applied to radiata pine:

Scenario 1 assumes all owners will harvest their forests when their forests reach the age of 30 years. This scenario shows the unconstrained availability of radiata pine from New Zealand plantations.

Scenario 2 assumes large-scale owners will harvest in line with their stated intentions, and small-scale owners will harvest their forests at age 30.

Scenario 3 assumes a non-declining yield, with a target rotation age of 30 years. Under this scenario, the potentially available volume increases to over 30 million cubic metres per year from 2020.

Scenario 4 is the same as for scenario 3 except that total wood availability is allowed to decrease from 2034 (the end of the current rotation). Wood availability increases to over 35 million cubic metres per year from 2022 before reducing to 28 million cubic metres per year from 2037.

It should be noted that while Scenarios 1 and 2 are theoretically possible, they are unlikely to be realised because New Zealand does not have the infrastructure capacity to deal with the rapid rise in wood volumes forecast for the mid 2020s.

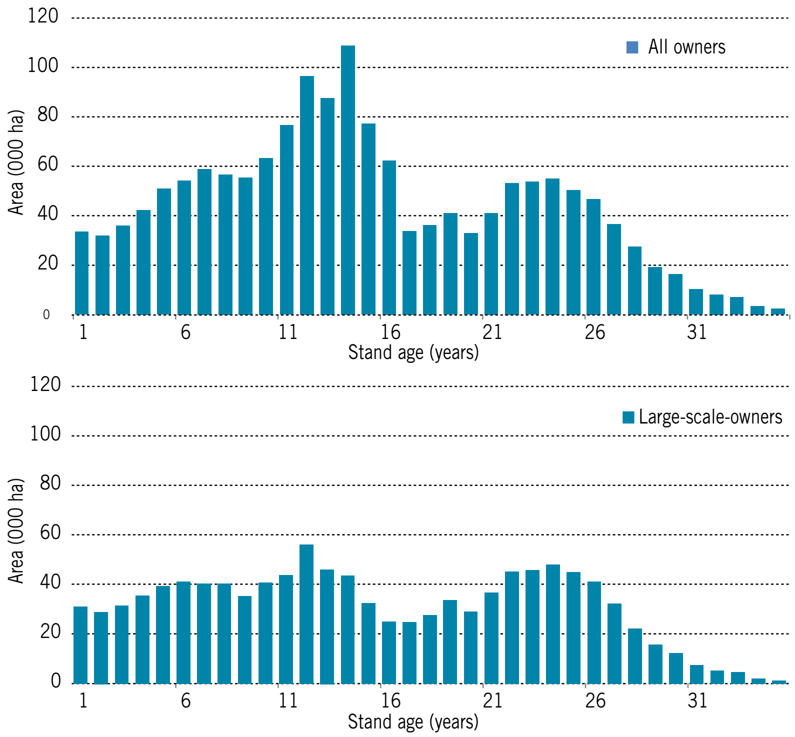
The availability of Douglas-fir wood is forecast to remain below 1 million cubic metres per annum through to 2024, and to have increased to 2.5 million cubic metres per annum by 2040.

Indigenous forests

The Forests Act 1949 was amended in 1993 to bring an end to unsustainable harvesting on private land and clearfelling of indigenous forest. Under the legislation, indigenous timber can only be produced from forests that are managed in a way that maintains continuous forest cover and ecological balance. Management systems must ensure that the forests continuously provide the full range of products and amenities, in perpetuity, while retaining the forests' natural values. Only single trees and small coupes can be felled for timber production.

Currently about 84 000 hectares of indigenous forest are approved for sustainable management for timber production, with an allowable annual harvest of 78 000 cubic metres standing volume. Actual

Figure 2.3: Age class distribution of New Zealand radiata pine plantations as at 1 April 2008



Source: Ministry of Agriculture and Forestry, 2010.

harvested volumes from 2006 to 2012 have fluctuated between 16 000 and 19 000 cubic metres (Figure 2.5). This means that actual harvest represents between 20 and 25 percent of the allowable harvest. It is likely that this difference is due to competition from imported wood products (some of which may not be from sustainably managed and legally harvested forests), and the relatively high costs of sustainable forest management. A recent legislative change that allows the salvage of wind-thrown trees from conservation land is expected to increase the volume of the indigenous timber harvest over the next few years.

Sources of information

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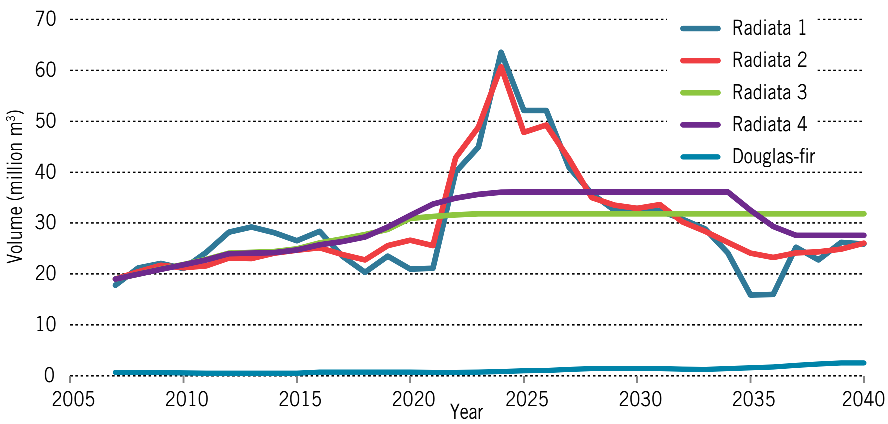
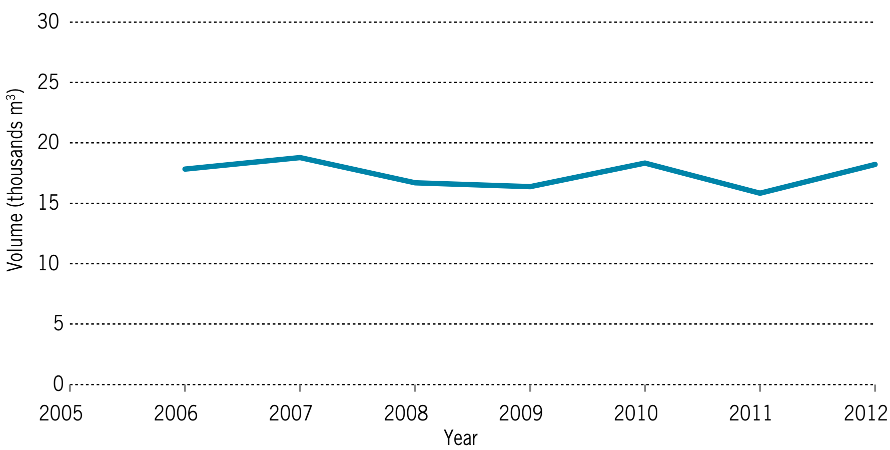
Figure 2.4: National wood availability forecasts (2008–2040) for radiata pine and Douglas-fir



Source: Ministry of Agriculture and Forestry, 2010.

Figure 2.5: Change in wood volumes harvested from New Zealand's indigenous forests between 2006 and 2012



Source: Ministry for Primary Industries, 2014a.

Indicator 2.e Annual harvest of non-wood forest products

New Zealand's forest estate supports a number of smaller industries that are unrelated to timber production. These range from beekeeping and the collection of sphagnum moss, through to game hunting and possum trapping. One of the growth areas involves the use of indigenous plant extracts in skincare and medicinal products. This activity was highlighted in the 2008 report and continues to attract commercial interest. It draws on both traditional Māori knowledge of, and research on, New Zealand's plant species. The 2003 and 2008 country reports commented on the opportunities for incorporating secondary crops (such as ginseng and edible mushrooms) into forest management systems. Work in this area continues and several commercial trials are under way.

Quality of information: L/M

Progress against indicator: ▲

Rationale

This indicator reports on the sustainability of the harvest of non-wood forest products. The wellbeing of indigenous and other communities dependent on non-wood forest products may be closely allied to the forest's ability to maintain its productive capacity over time.

NEW ZEALAND'S REPORT

Non-wood forest products (NWFP) are a small, but increasing, component of the forestry scene in New Zealand. The past 20 years have seen the range of products grow from game meat, honey and traditional extracts to a broader base, incorporating secondary crops and plant derivatives for skin care, health products and food ingredients. This growth has been based on research and trials by both private investors and government agencies.

The two principal activities within the NWFP sector have been beekeeping and hunting (including trapping). In 2013, 647 enterprises[18] were involved in beekeeping, hunting and trapping (Statistics New Zealand, 2015). Collectively these enterprises had an employee count of 1320 workers.[19] The majority of these enterprises were small-scale operations (that is, self-employed workers or small companies with fewer than five employees).

The number of business enterprises involved in beekeeping has grown strongly in recent years from 352 in 2000 to 502 in 2013 (Statistics New Zealand, 2015). These enterprises represent operators with a commercial number of hives.[20] A proportion of these beekeepers will rely strongly on forest and bush lands for nectar and pollen, while others will utilise these areas for part of the season and focus on pastoral land.

Enterprise numbers for hunters and trappers have been in the range of 140 to 170 over the past decade, up from 120 in 2000. These enterprises are engaged in the hunting of game meat (wild deer, goats and pigs), the management of pests, and the trapping of the Australian brushtail possum for fur and pelts. None of these animal species is native to New Zealand, and most are considered a threat to New Zealand's indigenous flora and fauna.

Medicinal extracts from indigenous plant species

A number of indigenous plant species have traditionally been used by Māori for medicinal purposes. These plants include:

- karamū – the leaves are boiled down for an extract that is good for the urinary system;
- koromiko – the leaf ends are boiled down as a tonic for dysentery and diarrhoea;
- makomako/wineberry – the leaves make a tea that is

18 An enterprise is a business or service entity, which can be a self-employed individual, a company, a partnership or a voluntary agency.

19 Employee count refers to paid employees. It is a head count of salary and wage earners sourced from taxation data.

20 Nationally there were 4279 registered beekeepers in 2013 but the majority of these owners had fewer than 5 hives, and 86 percent had fewer than 50 hives. Beekeepers with more than 350 hives are considered commercial operators.

soothing and cleansing for sore and dusty eyes;
- mānuka/tea tree – used to soothe burns (a sedative) and treat fevers and colds.

This knowledge of the health benefits of particular plant species has been passed down from generation to generation by Māori. Small quantities of these extracts continue to be collected for the private use of individuals and families. Another customary activity has been to collect berries from a number of indigenous trees and shrubs, including the kōtukutuku. The berries are harvested primarily for private use.

The medicinal properties of these indigenous plant species have attracted considerable interest over the past 20 years from the research community and health sector. A number of commercial ventures have developed around nutritional supplements, antibacterial oils and health remedies (New Zealand Trade & Enterprise, 2013). Māori have been significantly involved in these business and research initiatives, frequently drawing on customary Māori knowledge.

Plant extracts for skincare products and food ingredients

New Zealand's geographic isolation has meant that around 80 percent of all indigenous plant species are endemic, that is, they are not native to anywhere else in the world. This distinctive flora is only starting to be researched and provides opportunities to commercialise a range of new plant extracts for food ingredients and skincare products. New Zealand's "... flora produce unique flavours that can be used in the development of novel ingredients for foods and beverages with significant export potential" (Plant & Food Research, 2011, p 31).

A number of innovative businesses have been established to develop these opportunities. They draw on the increasing international demand for natural products and remedies, sourced from sustainably grown products. The companies generally have a strong export focus and their markets include Asia, the Pacific Rim, North America and Europe (New Zealand Trade & Enterprise, 2013).

The research being undertaken by public and private research agencies is focusing on both the commercialisation of new products and ways to improve the sustainable management of the forest resource. Plant & Food Research (a Crown Research Institute) is "working with Māori partners to develop new foods and ingredients based on indigenous flora and fauna, particularly traditional food plants and seafood, as well as new technologies and techniques to manage the production of native plants" (Plant & Food Research, 2011, p 30).

Honey production and related products

Honey production is one of the long-standing uses of the forest estate. Apiarists take advantage of the nectar and pollen sources available in the bush, particularly the early season nectar flow, which is critical for building up hive strength and populations. A number of New Zealand's monofloral honeys are derived from the forest estate. These include mānuka, rātā, rewarewa and tāwari. Apiarists locate their hives along the bush line or within forested areas. The national figures on the number of apiarists (and honey production) do not distinguish between those who rely predominantly on pasture or those focused on forest lands.

Nationally there were 4279 registered beekeepers in the June 2012/13 season (ranging from individuals with a single hive through to companies). Total honey production amounted to 17 825 tonnes (Ministry for Primary Industries, 2013). Production figures are weather dependent, and have varied between 9450 and 17 825 tonnes between 2008 and 2013. The average production over this six-year period was 12 526 tonnes. Production and beekeeper numbers have been increasing over the past decade. This has been driven in large part by the export market, in particular, the demand for mānuka honey. Export volumes were in a range of 2400 to 3300 tonnes between 2002 and 2005 and reached 8000 tonnes in the June 2012/13 season.

In addition to honey, apiarists produce beeswax, honey powder, honeydew, propolis (an antibiotic gum or resin) and bulk bees (principally for export).

The harvesting of honey from woodlands has the potential to affect forest ecosystems in terms of the availability of nectar and pollen for indigenous birds and insects. Limited research has been undertaken on this issue and beekeepers have been encouraged to adopt a conservative management approach when assessing stocking rates.

The Department of Conservation monitors the beekeeping concessions on public conservation land and will revoke concessions if there is evidence of pressure on the local ecology.[21] Stocking density is naturally constrained by climatic conditions and the physical terrain.

Possum fur and skins

Commercial hunting and trapping are important management tools in controlling the possum population in New Zealand, which is estimated at 30.3 million. Without control efforts, the population has the potential to reach 48 million (Warburton et al, 2009). The major commercial products derived from possums are pelts, fibre for garments and pet food. A number of attempts have been made to establish a possum meat industry. However, areas from which the meat can be sourced are limited, owing to the presence of tuberculosis in several regional possum populations.

Harvest volumes have been erratic over recent decades, owing to fluctuations in the price for fur and pelts.[22] When fur has been out of favour as a fashion item, fewer than 500 000 possums have been commercially harvested in a season. During periods of high prices, the commercial harvest has exceeded 3 million.

After struggling in the 1980s and early 1990s with low fur and pelt prices, the fur industry has gradually re-built itself, as a result of local companies taking more control of processing and recent advances in yarn manufacturing which has allowed possum and merino fibre to be blended. Possum fibre is gaining increased attention as the "fur is 70% warmer than wool. It has superior thermal qualities because the fur is hollow inside so traps heat within its fibres" (Burlingham et al, 2008, p 3). The commercial harvest of possums (for fur and pelts) is currently in the order of 1.3 to 1.5 million per annum (Warburton, 2008). The harvest has grown as the per kilogram price of possum fibre (plucked) has more than doubled since the beginning of the last decade and is in the order of $100 to $110 per kilogram. "The use of plucked possum fur as a component in blended yarn is now well established in the New Zealand yarn industry with the total value of this industry estimated to be in the order of $50 to $70 million per annum" (Warburton, 2008, p 8).

An emerging use for possums is as a high-quality pet food (mainly for the export market). Research has shown that possum meat is high in unsaturated fatty acids, omega 3 and 6. The initiatives to date have been focused on the Bay of Plenty and East Cape.

The current level of commercial harvesting has a limited impact on possum numbers. The Department of Conservation and TBfree New Zealand (supported by the agricultural sector) undertake extensive programmes to control possum numbers.

Commercial and recreational game hunting

The game animals hunted in New Zealand include red deer, fallow deer, chamois, Himalayan tahr, wild pigs and wild goats. None of these species is native to the country. They were introduced by the early European settlers for their meat, hides and fur, and they quickly became established in New Zealand's indigenous forests.

Deer are the major game species hunted in New Zealand by recreational and commercial interests. New Zealand's feral deer population is estimated at 250 000 nationally (McKinnon, 2001). The population is spread across the conservation estate, commercial forests and upland pasture. Recreational hunters take approximately 50 000 head a year. In the 1990s and the early part of this decade, commercial deer hunters were removing 10 000 to 30 000 feral deer a year (Stringleman, 2004). Commercial deer recovery (for venison) fell sharply in 2002–2003, with a tightening of export requirements for wild venison and a decline in venison pricing. The commercial recovery of feral deer has recovered in recent years, but remains a small element of the overall venison industry.

New Zealand has developed a strong international reputation for game hunting, and a number of commercial operators now provide guided hunting tours. The Department of Conservation and the major forestry companies operate concession systems for commercial hunting operations and they issue hunting permits for private individuals.[23] A number of game estates have also been established, mainly to cater

21 The Department of Conservation has produced national guidelines for the location of beehives on public conservation land. The guidelines recognise honey production and the wintering over of hives as being generally compatible with conservation land values.

22 The market for pelts has until recently been dependent on overseas fashion trends and the requirements of fashion houses.

23 The concession and permit system is used to monitor the number of hunters and to control access to blocks where visitor numbers are high or where forestry operations are under way.

for overseas trophy hunters. These estates normally include substantial areas of bush and forest lands.

Generally no restrictions on the number of deer that can be taken apply, except "for popular herds such as Fiordland wapiti and Blue Mountains fallow deer, where systems of ballots and bag limits are in place" (Department of Conservation, 2001, Policy Statement on Deer Control, Section 4). The Department of Conservation periodically monitors deer populations and has generally found that the numbers removed by commercial and recreational hunters are insufficient to reduce feral deer densities to levels that protect ecosystems from damage.[24] The Department supplements commercial and recreational hunting with additional control measures.

Sphagnum moss collection

A regionally important non-wood forest product is sphagnum moss, principally the variety *Sphagnum cristatum*. The moss is collected primarily from swamp areas in the forests and bush lands of the West Coast of the South Island. Harvested areas normally return to a stable condition after three to five years. The harvest is mainly exported to Japan and Southeast Asia. The annual value of exports during the 1990s ranged from \$13 million to \$18 million, and has since fallen back to \$4.0 to 4.5 million in 2011–2013 (Plant & Food Research, 2013).

24 Even at low densities, deer can prevent the regeneration of key native plant species.

New Zealand exporters target the premium orchid market, which requires long strands from mature sphagnum plants. The Department of Conservation now manages the majority of the sphagnum moss collection sites and monitors the concessions for their environmental impact.

New opportunities for non-wood forest products

Research trials on the potential for incorporating secondary crops into the plantation estate have been under way for some years. The emphasis has been on edible mycorrhizal mushrooms[25] and crops such as ginseng. The intention is to incorporate these crops into the normal plantation management regimes for exotic species.[26] The crops under investigation are high-value, low-volume commodities, which could significantly increase the viability of plantation forestry. The advantage of growing these crops in New Zealand is that forest owners can supply the traditional off-season in the northern hemisphere. A number of commercial trials and small-scale production blocks have been established.

25 Mycorrhizal mushrooms are those that live in a symbiotic relationship on and in the roots of suitable host plants.

26 In the case of high-value mycorrhizal mushrooms, such as Périgord black truffle, the returns would justify setting up dedicated plantations for their production (that is, a truffière), rather than incorporating them into the normal plantation system.

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CRITERION 3:
MAINTENANCE OF FOREST ECOSYSTEM HEALTH AND VITALITY

The maintenance of forest health and vitality is dependent upon the ability of the ecosystem's functions and processes to recover from or adapt to disturbances. While many disturbance and stress events are natural components of forest ecosystems, some may overwhelm ecosystem functions, fundamentally altering their patterns and processes and reducing ecological function.

Decline in forest ecosystem health and vitality may have significant economic and ecological consequences for society, including a loss of forest benefits and the degradation of environmental quality.

Information gained on the impacts of biotic and abiotic processes and agents may inform management strategies to minimise and mitigate risk. The maintenance of forest ecosystem health and vitality is the foundation of sustainable forest management.

Table 3.1 lists the indicators covered in this section.

Table 3.1: Indicators for Criterion 3 – quality of information and trends

Criterion 3: Maintenance of forest ecosystem health and vitality		Quality of information	Trend
3.a	Area and percent of forest affected by biotic processes and agents (e.g. disease, insects, invasive species) beyond reference conditions	M/H	▲ (Positive)
3.b	Area and percent of forest affected by abiotic agents (e.g. fire, storm, land clearance) beyond reference conditions	M	► (Neutral)

KEY

L = low	Neutral	►
M = medium	Positive	▲
H = high	Negative	▼

NEW ZEALAND OVERVIEW

Key points are that:

- surveillance, reporting and research are directed to a range of pest and weed problems, covering both planted and indigenous forests and also urban areas;
- surveillance targets high-risk sites such as areas around ports, parks and tourist regions;
- the needle cast and needle blight diseases that affect commercial planted forests are prominent threats; but drier climatic conditions and more efficient treatments have reduced the impacts of some pathogens;
- a range of other diseases affect a range of plantation forest species, including eucalypts, cypresses and Douglas-fir;
- a focus is on limiting spread and finding effective treatment of the kauri forest dieback pathogen *Phytophthora* taxon Agathis;
- possums, ungulate and other vertebrate pests seriously affect indigenous forests and associated habitats, and efforts to monitor and control these pests are continuing;
- efforts are under way to survey and manage the spread of wilding conifers displacing low stature vegetation areas in both the North and South Islands;

- storms, especially wind, fires and fire risk, affect all forests, especially planted forest.

New Zealand planted forests continue to be relatively free of serious or widespread pests and diseases that could affect management and commercial value. However, the risk of pest, weed and disease incursions from established populations in other countries remains; especially from expanding trade and travel movement across the border. Indigenous forests require control measures to counter adverse impacts of long-established introduced pest and weed species. Widespread vertebrate pests (both possums and other species) cause browse and predation damage.

An estimated 10 percent of the plantation forest estate was affected by diseases in 2013. Major outbreaks of *Cyclaneusma* needle cast and *Dothistroma* needle blight are generally similar in extent on a year-to-year basis. The diseases involved mostly affect tree growth rates and wood quality, rather than resulting in mortality.

Wind is the major abiotic agent affecting New Zealand's forests, having impacts on the commercial value of planted forests. Historical records indicate that about 0.21 percent of the net stocked plantation forest area is lost annually due to wind damage and further research using historic data is improving prediction of risk of wind damage in planted forest. Windthrow is common in indigenous beech forests and a key factor in the natural ecology. Wind damage is less common in other indigenous forest types and the damage varies with species. Less frequent also is extensive windthrow across a range of forest types. Cyclone Ita in April 2014 was one such storm, which resulted in an assessed 40 880 hectares of windthrow damage to indigenous forests in the South Island's West Coast region.

The forest area affected by fire varies significantly from year to year, but by international comparisons the impact is small. Damage to planted and indigenous forests over the six-year period from 2007 to 2013 is about 4000 hectares and 500 hectares respectively.

Indicator 3.a Area and percent of forest affected by biotic processes and agents (e.g. disease, insects, invasive species) beyond reference conditions

In 2013, less than 1 percent of the total plantation forest area was affected by insects and about 1 percent of the total plantation forest area was affected by diseases, the most important of which are: Cyclaneusma needle cast, Dothistroma needle blight, Armillaria root rot and Nectria flute canker.

The introduced Australian brushtail possum continues to be widespread in indigenous forests. Forest health records indicate that, in 2013, possums affected eight percent of the plantation forest estate.

Quality of information: M/H

Progress against indicator: ▲

Rationale

This indicator identifies the impact of biotic processes and agents have on forests. Where change due to these agents and processes occurs beyond a critical threshold, forest ecosystem health and vitality may be significantly altered and a forest's ability to recover could be reduced or lost. Monitoring and measuring the effects of these processes provide information helpful in the formulation of management strategies to mitigate risk.

NEW ZEALAND'S REPORT

Forest area affected by insects and diseases

Historically, very few insect problems have been noted in plantation forests, apart from one species of bark beetle *(Hylastes ater)* that can be associated with seedling death (Bulman, 2008). All major exotic plantation forests are inspected at least once a year for signs of newly established pests or diseases: forest health assessments are undertaken, and damage by biotic and abiotic agents estimated and recorded.

The most important fungal diseases affecting pine plantations are: needle cast *(Cyclaneusma minus),* needle blight *(Dothistroma septosporum),* root rot (*Armillaria* spp.) and flute canker *(Neonectria fuckeliana (syn. Nectria fuckeliana).* Diseases in plantations of other species include:

- **Swiss needle cast** *(Phaeocryptopus gaeumannii)* **affecting Douglas-fir.** The disease is well established in New Zealand stands, affecting growth rate with a range of severity nationally but having most impact in warmer and northern sites. Direct control through spraying is not considered economic, but trials of varieties that may be less susceptible to the disease on the more affected sites are under way.
- **Cypress canker *(Seiridium* spp.) affecting a number of cypress species.** Severity of the disease varies with species, site, climate and inoculum loadings. About 75 percent of New Zealand stands are estimated to be affected to some extent.
- **Various root and leaf pathogens affecting eucalypts.** New Zealand has about 23 000 hectares of plantation eucalypt species. At least half of that area is affected by insect pests (mainly *Paropsis* beetle in the central North Island and Southland) and diseases (caused by various leaf spot fungi) in the central North Island.

Table 3.2 identifies the planted forest area affected by insects and diseases in 2013. The most recent estimated of the economic losses from diseases affecting plantation forests is a cost of about $83 million per annum (Table 3.3); slightly more than the estimate for 2008 ($82 million). In both 2003 and 2008, *Cyclaneusma* needle cast and *Dothistroma* needle blight were the pathogens that caused the most loss, but outbreaks of these diseases have been less extensive in recent years (Table 3.4). Drier conditions and more effective copper spray formulations have reduced *Dothistroma* incidence, while the reduction in forest areas in the central North Island through land conversions has diminished the spray requirement. The production of resistant clones has helped to reduce *Cyclaneusma* incidence.

Damage to radiata pine due to *Nectria* flute canker remains confined to the lower South Island of New Zealand and management regimes have reduced the disease incidence in stands. This disease was first recognised in the early 2000s but may have been established in New Zealand for some years prior.

Incidences of both cypress canker and diseases in eucalypt species have increased. Dutch elm disease affecting urban trees remains confined to the Auckland area and control involves a trapping programme for the disease vector beetle species.

Kauri dieback disease caused by the pathogen *Phytophthora* taxon Agathis (interim name) affects kauri of all ages and is present in a number of the northern kauri forests. Work is under way to detect the extent and pattern of spread of the pathogen, and more formal identification of the fungus and methods of control. Surveys of distribution are continuing. Publicised hygiene measures to limit physical spread include footwear cleaning and forest access management.

Invertebrate invasive pests – wasps

Four species of social wasps, accidentally introduced to New Zealand, are now established and classed as pests. Two of the four species are vespulid wasps (common and German); the other two species are paper wasps (Asian and Australian).

Social wasps are a pest of urban, rural and natural ecosystems. They pose a health risk; affect the profitability and safety of industries such as beekeeping, horticulture, forestry and tourism; and upset the ecological balance in native ecosystems. Wasps are a significant pest in forest areas, especially in beech forests where high populations can develop due to their attraction to honeydew – a sweet exudate of tree-dwelling scale insects. In forests, wasps can displace birds by competing for food such as honeydew, or by driving them from the habitat. Control methods are largely through chemical use either by direct destruction of nests or through bait carried back to nest by foraging wasps.

Table 3.2: Forest area affected by insects and diseases (2013)

Disturbance	Planted forest area (000 hectares)[1]	% of total plantation forest[2]
Disturbance by insects	14	>1
Disturbance by diseases	174	10

Sources: 1. Bulman, 2014.
2. Derived from Ministry for Primary Industries, 2014a.

Table 3.3: Economic losses from diseases affecting plantation forests

Disease	Tree species or genera affected (scientific name)	Loss/cost ($ million per annum)	Operational response
Cyclaneusma minus	*Pinus radiata*	$38	Breeding for resistance
Dothistroma septosporum	*Pinus radiata*	$19.8	Copper spray, silviculture, breeding
Diplodia (vector-*Sphaeropsis sapinaea*)	*Pinus radiata*	$4	Avoid pruning in summer
Neonectria fuckeliana (syn. *Nectria fuckeliana*)	*Pinus radiata*	$10	
Others	*Pinus radiata*	$8	Not specific
Phaeocryptopus gaeumannii	*Pseudotsuga menziesii*	$2.3	Breeding for resistance
Cypress cankers	*Cupressus spp.*	$1	Site and species selection, breeding
Research diagnosis and surveillance	All plantation species	$3	
TOTAL		**$83.1**	

Sources: Bulman, 2014; Kimberley et al, 2011.

Vertebrate invasive pests – possum

The introduced Australian brushtail possum *(Trichosurus vulpecula)* is considered a major forest pest in New Zealand. Possums are widespread, can attain high densities and browse on some canopy and sub-canopy trees. Possums are also significant predators of some indigenous native birds and invertebrates.

Possums living in or adjacent to plantations commonly use radiata pine as a seasonal food source, including foliage and cones, which subjects the trees to browse and secondary physical damage. Historic reports of possum damage in planted forest indicate the greatest reported damage coincided with significant cycles of replanting and establishment, such as in the 1960s and then again in the 1990s, indicating possums' preference for young stands.

Trappers' control of possum numbers in accessible areas, with the currently high prices for possum fur, and the effective outcomes of the bovine tuberculosis control programmes (see below) are two key factors helping control possums numbers across the New Zealand planted forest estate. Forest owners and managers report that possum numbers have remained constant over the last five years and damage is generally minimal due to both factors. However, while trappers are controlling possum numbers in accessible areas, populations are still high in some remote areas. Some report isolated damage in planted forests adjacent to some indigenous forest areas where control measures have been limited.

Based on forest health inspection records in the forest health database (Table 3.5), the area affected by possums has continued to decrease. Over the five-year period from 1998 to 2002 just over 2900 (580 per year) records of possum damage were made. Numbers declined to 260 per year during 2003 to 2008, and since then (2009 to mid 2014) about 150 records of possum damage have been logged. With the average area affected at 200 hectares per record, this equates to 30 000 hectares over the entire estate.

Possums can carry bovine tuberculosis (Tb). TBfree New Zealand, a government-industry partnership (previously the Animal Health Board), supports research into, and treats forest areas for, control of possums where the spread of Tb into livestock is a problem. Sodium monofluoroacetate (1080), applied across forest areas in aerial spread baits to control possums and other vertebrate pests, remains a core method for large-scale control. This attracts both opposition and support from the public, but is currently regarded as the most practicable extensive

Table 3.4: Trend in incidence of major diseases in plantation forests

Description	Tree species or genera affected (scientific name)	Year(s) of latest outbreak	Area affected (000 hectares)	Severity of disease during 2008–2013
Dothistroma needle blight	*Pinus radiata*	2013	61	Reducing incidence favoured by climatic conditions and more effective copper formulation
Dothistroma needle blight	*Pinus radiata*	2006	130	
Dothistroma needle blight	*Pinus radiata*	2002	183	
Dothistroma needle blight	*Pinus radiata*	1995	115	
Dothistroma needle blight	*Pinus radiata*	1989	119	
Cyclaneusma needle cast	*Pinus radiata*	2013	40	Reducing incidence favoured by increased use of resistant clones
Cyclaneusma needle cast	*Pinus radiata*	2000	150	
Cyclaneusma needle cast	*Pinus radiata*	1999	200	
Swiss needle cast fungus	*Pseudotsuga menziesii*	No specific outbreaks	40	Constant incidence nationally but greater in North Island stands
Cypress canker	*Cupressus* spp. *x Cupressocyparis* spp. & *Chamaecyparis* spp.	No specific outbreaks	7.5	Increased incidence over time attributed to multiple factors. (climate, species choice sites, inoculum loadings) Variable severity of infection affecting about 75% of stands
Various	*Eucalyptus* spp.[1]	Root and foliage pathogens No specific outbreaks	25	Increased incidence over time. Variable severity of infection affecting about 50% of stands

Note 1: Insect pest damage in eucalypts, notably *Paropsis* spp., is a significant management problem in stands of some commercial eucalypt species.
Source: Bulman, 2014.

Table 3.5: Forest area affected by possums (000 hectares) (2013)

	Forest area (000 ha)	Percentage of total area
Plantation forest	140	8
Indigenous forest	6 704	81

Sources: Bellingham et al, 2013; D Brown, Department of Conservation (unpubl); Bulman, 2014; MacLeod et al, 2012.

control method, especially over terrain with limited ground access. Aerial 1080 operations covered approximately 432 000 hectares of land in 2012.

Possums are present in indigenous forests throughout the North, South and Stewart Islands although the impact from possum browsing in indigenous forests varies across the range of New Zealand forest types. A range of biotic and abiotic factors also affects browsing patterns in forests that may predispose some plant communities to possum damage. Browsing occurs in highly preferred canopy and sub-canopy species and high densities of possums can result in defoliation and death of individual trees subject to browsing.

Brushtail possum.

Understanding the distribution, abundance and impact of possums in New Zealand indigenous forests is clearly fundamental to effective control of the pest. This has improved greatly since the establishment of the Land Use and Carbon Analysis System (LUCAS) permanent plot network in 2005 and the recent implementation of the Department of Conservation's Biodiversity Monitoring and Reporting System (BMRS) (see also Indicator 1.3.b). Two measures are used in identifying pest levels. 'Occupancy' is the proportion of sampling locations occupied by the species and 'relative abundance' refers to the number of a species present relative to all species at a site. In 2013, possums occupied 81 percent of indigenous forest on public conservation land with an overall relative abundance of 4.5 percent (Bellingham et al, 2013).

Results from the BMRS show that possums are less abundant in beech than in non-beech forests. Abundance, but not occupancy, was statistically lower in national parks compared with other conservation lands. Possum abundances were considerably lower than previous estimates both nationally and in low-altitude forests. The reason for this is not immediately obvious, but may result from earlier estimates focusing on sites where possums were known to be present, and the use of different methods for estimating

Table 3.6: Total area (forest and non-forest) of public conservation land under sustained possum control management and areas under targeted possum control treatment in any one year

Year ended 30 June	2009	2010	2011	2012	2013
Sustained control (000 ha)	1 100	1 024	1 080	1 024	1 011
Annual targeted treatment (000 ha)	188	285	224	235	184

Source: Department of Conservation, 2013.

abundance. The highest abundances were found in North Island and Stewart Island forests.

The aim of pest control is to reduce both occupancy and relative abundance of the pest species to the point where the relative abundances of favoured native species (at a site) are showing signs of recovery. The success of controls can be gauged by measuring these changes, although such monitoring is challenging at the extensive scale required for the pest population across New Zealand indigenous forests. Nevertheless, it is anticipated that measurements of the percentage change in the relative abundance over time, indicating the effectiveness of controls, will be available in a forthcoming reporting cycle. (Refer also to discussion under Indicator 1.3.b.)

Trends in the size distributions of canopy and sub-canopy tree species were evaluated on public conservation land between the periods 2002–2007 and 2009–2012 (MacLeod et al, 2012). These data show that kāmahi, New Zealand's most common tree and a preferred browse species for possums (and also for introduced ungulates), is continuing to regenerate on public conservation land (MacLeod et al, 2012) (see also indicator 1.3.b).

In the past 15 years, possum control efforts have significantly increased in extent and intensity. Possum control measures in the Department of Conservation-administered public conservation estate (forested and non-forest land) include: sustained possum control, which increased from 669 000 hectares in 2000 to a peak of 1 100 000 hectares in 2009, and control treatments in specific targeted areas (see Table 3.6).

Vertebrate invasive pests – ungulates

Many species of ungulate have established wild populations in New Zealand (King, 2005): feral goats *(Capra hircus)*, red deer *(Cervus elaphus scoticus)*, wapiti *(C. elaphus nelsoni)*, white-tailed deer *(Odocoileus virginianus)*, sambar deer *(Rusa unicolor)*, sika deer *(C. nippon)*, rusa deer *(R. timorensis)*, fallow deer *(Dama dama)*, Himalayan tahr *(Hemitragus jemlahicus)*, alpine chamois *(Rupicapra rupicapra)*, feral sheep *(Ovis aries)* and feral cattle *(Bos taurus)*. These ungulates can alter the growth and survival rates of plants by browsing and trampling, which leads to the replacement of preferred, browse-intolerant plant species by less preferred or avoided species (Forsyth et al, 2010).

Ungulates are commonly present in New Zealand forests. As with possums, measuring and monitoring occupancy and relative abundance are the keys to ungulate control. The BMRS (Allen et al, 2009; Bellingham et al, 2013; MacLeod et al, 2012) indicated that, in 2012 and 2013, wild deer and/or feral goats occupied 75 percent of indigenous forest on public conservation land (Table 3.7), but were mostly present at low abundances relative to the high abundances observed in the 1950s to 1970s. Occupancy and relative abundances of deer and/or feral goats were higher on Stewart Island and the North Island than the South Island. BMRS data show that ungulates were statistically less abundant in beech than in non-beech forests. Occupancy and abundance did not differ between national parks and other conservation lands.

Table 3.7: Indigenous forest area affected by introduced ungulates

Disturbance	Indigenous forest area (000 ha)	% of total indigenous forest
Disturbance by ungulates	6 207	75

Sources: Bellingham et al, 2013; MacLeod et al, 2012.

Table 3.8: Total area (forest and non-forest) of public conservation land under sustained feral goat and deer control by the Department of Conservation

Year ended 30 June	2009	2010	2011	2012	2013
Feral goat control area (000 ha)	2 389	2 185	2 221	2 357	2 311
Deer control area (000 ha)	769	721	732	732	550

Source: Department of Conservation, 2013.

Observations in ungulate exclosure plots, measuring 20 by 20 metres, indicate that:

- selective browsing favours an increase of some browse-resistant, or tolerant, species in the understorey on some sites, and more generally across the national ungulate exclosure system;
- ungulate impacts are less significant in mature than disturbed forest stands.

Control operations for deer and feral goat (Table 3.8), and possum, have significantly reduced abundance levels. Together with sustained hunting, they have enabled favoured browse species such as kāmahi to regain adequate regeneration levels.

Effects of mustelids

Mustelids are members of the animal family Mustelidae, all carnivores native to the northern hemisphere. Three species of mustelids are established in New Zealand: stoats *(Mustela erminea),* weasels *(M. nivalis vulgaris)* and ferrets *(M. furo)*. These were introduced to New Zealand in the 19th century and have since established across a wide range of habitats, including into forests. Their prey includes rats and mice, but also a range of indigenous species – birds, lizards and insects. Stoats, especially, have spread to most areas in New Zealand and population increases stimulated by high numbers of rats and mice lead to subsequent predation pressure on bird species when rodent numbers decline.

Trapping and poisoning control measures are undertaken by the Department of Conservation and regional councils.

Indigenous forests affected by non-woody weed species

The assessment of weed species (vascular species exotic to specific sites) in indigenous forested sites forms part of a monitoring and reporting process covering a range of non-forested and forested sites across New Zealand undertaken by the Department of Conservation's Biodiversity Indicators Programme, which is conducted through Landcare Research. The sites are monitored as part of a systematic measurement system and reported on in the Department of Conservation's annual reports. In general, invasive weeds are more prevalent in non-forested and highly modified sites than in forested sites that are more difficult for shade-intolerant weed species to grow in (see also Indicator 1.3.b).

Forest affected by woody invasive species

Indigenous forests in protected areas could be increasingly threatened by weeds, as surrounding land uses intensify and fragmentation of the natural landscape occurs (Timmins and Williams, 1991). Howell (2008) provides a consolidated list of 328 vascular plant species present on Department of Conservation land that are considered to have detrimental effects on the conservation values of sites.

Wilding conifer spread

The term "wildings" refers to the seed-sourced natural regeneration of introduced conifer tree species (particularly pines, Douglas-fir, redwood and larch) originating from stands planted in New Zealand for a

Pine wilding spread, MacKenzie Basin, South Canterbury. Photo: Ian Platt.

variety of purposes over many years. Wilding conifers are a problem primarily in the Marlborough Sounds, the South Island high country and the central plateau of the North Island, but are also invading natural habitats in Otago and the Mackenzie Basin. Wildings can grow in dense stands. They reduce the value of managed pasture, displace native biodiversity and alter the character of the landscape.

The New Zealand Wildling Conifer Management Strategy 2015–2030

Ministry for Primary Industries, 2014b) is a non-regulatory strategy supporting collaborative action between land occupiers, researchers, regulators and communities to address the critical issues facing wilding conifer management. The Strategy has been developed in collaboration with a multi-stakeholder working group and identifies actions for key parties involved in wilding conifer management under four principles: individual and collective responsibility; cost-effective and timely action; prioritisation; and co-ordination. The overall aims of the working group are to prevent the spread of wilding conifers, to contain or eradicate established areas of wilding conifers by 2030, and to seek the following outcomes:

- key parties collaborate to minimise the negative economic, environmental and landscape impacts of wilding conifers;
- communities are aware of and taking actions for the prevention and effective management of wilding conifers;
- beneficial conifer plantings continue;
- landowners do not establish conifer plantings at high risk of spreading on spread-prone sites, and reduce or prevent spread from new and existing wilding conifer populations;
- wilding conifer management and control are timely and cost-effective.

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Indicator 3.b Area and percent of forests affected by abiotic agents (e.g. fire, storm, land clearance) beyond reference conditions

Some 63 000 hectares of planted forest area have been damaged by storm events between 1945 and 2008, and modelling of storm records is a tool to predict risk of damage.

The precise causes of physiological needle blight (PNB), considered a disturbance caused by abiotic factors, and the associated pathogen remain under investigation. PNB affected a little less than 1 percent of the total plantation forest area annually on average during 2009–2013.

In the six-year period from 2007 to 2013, wildfire incidents affected about 4000 hectares of plantation forest and about 500 hectares of indigenous forest.

Quality of information: M

Progress against indicator: ▶

Rationale

This indicator identifies the impact of abiotic processes and agents on forests. Where change due to these agents and processes occurs beyond a critical threshold, forest ecosystem health and vitality may be significantly altered and a forest's ability to recover could be reduced or lost. Monitoring and measuring the effects of these processes provide information helpful in the formulation of management strategies to mitigate risk.

NEW ZEALAND'S REPORT

Effect of wind damage on forests

Wind is the main abiotic factor affecting plantation forests in New Zealand. Records of wind damage indicate that a total of 63 000 hectares of forest were damaged over a period from 1945 to 2008. Three main storm events contributed two-thirds of the total damage over the 50-year period. Recent work on analysis of wind damage records of plantations (Moore et al, 2013) shows an average of 0.21 percent of the national net stocked area affected by wind annually, across a range of 0.98 in the most affected to 0.03 percent in the least, affected wood supply regions. By modelling wind event data, the same study estimated that 500 hectares of damage nationally would occur every five years, with a 95 percent expectation of such damage occurring between 4.5 and 6.2 years. Similarly, 1000 hectares of damage might be expected every 6.4 years, with the 95 percent expectation of this happening between 4.8 and 9.9 years. Such work assists forest owners to better understand risks of losses potentially affecting their emission liabilities under the New Zealand Emissions Trading Scheme.

Damage in indigenous forests is well reported in many anecdotal accounts of specific storm events with detail on species, size, location and local physical conditions. Where these forests occupy sites prone to stormy conditions, such as mountain areas, wind damage can be a common occurrence and the structure and composition of some forest types, notably beech forest on such sites, are governed by disturbance (Wardle, 1984).

Cyclone Ita in April 2014 affected an unusually extensive area of indigenous forests in the South Island's West Coast region, and caused windthrow damage across a range of forest types and geographic areas, including lowland podocarp forest. The forest area affected was assessed at 40 880 hectares in both private lands and the public conservation estate (Ministry for Primary Industries, 2014).

Forest area affected by other abiotic factors

Periodic severe seasonal needle cast of radiata pine of unknown origin has been recorded in a number of locations throughout New Zealand since the early 1980s. This has been termed physiological needle blight (PNB) and is considered a disturbance caused by abiotic factors. The disorder affects trees 15 years and older and causes foliage to turn red brown and die, while still attached to the tree. To date, the precise cause of PNB is unknown, but investigation has focused on both the mechanisms that promote the symptoms and the subsequent pathogen infection causing needle death. PNB occurs in radiata pine plantations in late winter or early spring and is associated with high water availability, in winter (in particular high mid-winter rainfall) and high canopy humidity. PNB outbreaks have often been associated with non-porous soils (Forest Biosecurity Research Council, 2006).

Mapping of field observations indicates that the incidence of PNB is relatively high in the northern part of the North Island, compared with lower incidence at sites further south. PNB incidence remains sporadic and is estimated to have affected about 15 000 hectares of planted forest per year on average in the 2009–2013 period (Bulman, personal communication, 2015).

Forest area affected by fire

Table 3.9 records the area affected by fire for planted and indigenous forests from annual fire returns provided by the National Rural Fire Authority, which gathers information on fire incidence. Controlled fire is no longer widely used as a site preparation tool in New Zealand forest management, although controlled fire is used as part of fire management training. Controlling wildfire in forests, during drought periods, remains a management issue.

Forest clearance

Information on deforestation (permanent clearance of forest) is obtained from time series mapping of land use change and through annually updated forest owner surveys of deforestation intentions; these sources therefore provide information about historical clearance as well as likely clearance in current and future years. Both these sources are primarily for assessing current and future forest carbon levels used to monitor the Government's international climate change commitments and New Zealand Emissions Trading Scheme (ETS), and also assist with future climate change policy development.

Time-series mapping (in the *New Zealand Greenhouse Gas Inventory 1990–2012* (Ministry for the Environment, 2014) and the New Zealand Land Cover Database Version 3 provide estimates of deforestation of indigenous forest over the period since January 1990. These sources indicate that annual clearance was higher prior to regulatory measures such as through the Resource Management Act 1991 and the Forests Act 1949, as well as before commitments were made under the 1991 New Zealand Forest Accord – an agreement between the forest industry and conservation groups on limiting the clearance of indigenous forests.

Deforestation in plantation forests (including both climate change policy categories of pre-1990 and post-1989 forest) increased significantly after 2002,

Table 3.9: Forest area affected by wildfires

Forest fires	Area affected by wildfires (ha)					
	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13
Plantation forest fires	1150.34	164.72	1202.51	440.76	559.35	434.51
Indigenous forest fires	23.73	283.96	78.77	29.04	31.00	56.15
TOTAL forest fires	**1174.07**	**448.68**	**1281.28**	**469.8**	**590.35**	**490.66**

Source: New Zealand Fire Service, 2013.

Table 3.10: Area of deforestation (hectares)

Forest land subcategory	1990 to 2012	2008	2009	2010	2011	2012
Pre-1990 natural forest	39 098	864	1 895	1 297	853	811
Pre-1990 planted forest	91 855	4 154	6 008	4 842	4 182	5 384
Post-1989 planted forest	20 591	965	2 501	1 082	1 092	567
TOTAL area	**151 544**	**5 983**	**10 404**	**7 221**	**6 127**	**6 762**

Source: Ministry for the Environment, 2014.

rising to a peak just before the ETS policy started in 2008. This rise was due in part to forest landowners anticipating deforestation liabilities under the ETS, the price of emission units and the relative attractiveness of alternative land uses, such as dairy farming. The *2013 annual deforestation survey* (Manley, 2014) reports that forest owners' intentions to deforest in future years (2014–2020) are scaled back slightly from the 2012 survey.

Table 3.10 lists areas deforested since 1990 and by years since 2008, using forest categories established under the Kyoto Protocol.

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Cyclone Ita storm damage to West Coast forest, April 2014. Photo: Ian Platt.

CRITERION 4:
CONSERVATION AND MAINTENANCE OF SOIL AND WATER RESOURCES

Soil and water resources underpin forest ecosystem productivity and functions. Forest ecosystems play an important role in the regulation of surface and groundwater flow and, together with associated aquatic ecosystems and clean water, are essential to the quality of human life.

The interaction of soil, water and topography influence the character and health of streams and rivers flowing through and from forests. Monitoring change in the chemical, physical and biological characteristics of soil, water and aquatic systems provides valuable information to support sustainable forest management.

Forest management activities can significantly alter forest soils, water quality and associated aquatic habitats. Inappropriate management may result in soil compaction, the loss of the soil A horizon, loss of riparian buffering capacity, increased sediment loads in streams, degradation and destruction of aquatic habitats and altered flow regimes. Change in water flow can also create an increased risk of flooding or the complete desiccation of streams. Both have harmful implications for human safety, property and economies.

Soil and water resources may be protected through the allocation of land for that purpose or through appropriate management regimes and best management practices.

Table 4.1 lists the indicators covered in this section.

Table 4.1: Indicators for Criterion 4 – quality of information and trends

Criterion 4: Conservation and maintenance of soil and water resources		Quality of information	Trend
	Protective function		
4.1.a	Area and percent of forest whose designation or land management focus is the protection of soil or water resources	L	▶
	Soil		
4.2.a	Proportion of forest management activities that meet best management practices or other relevant legislation to protect soil resources	M/H	▲
4.2.b	Area and percent of forest land with significant soil degradation	L/M	▶
	Water		
4.3.a	Proportion of forest management activities that meet best management practices, or other relevant legislation, to protect water related resources	M	▲
4.3.b	Area and percent of water bodies, or stream length, in forest areas with significant change in physical, chemical or biological properties from reference conditions	L	▶

KEY

L = low		Neutral	▶
M = medium		Positive	▲
H = high		Negative	▼

NEW ZEALAND OVERVIEW

Key achievements since 2008 are:

- the addition of further sections to the *New Zealand Environmental Code of Practice for Plantation Forestry* by the New Zealand Forest Owners Association;
- the publication by the New Zealand Forest Owners Association of the *New Zealand Forest Road Engineering Manual*;
- an increase from 55 percent to 61 percent of the plantation forest resource under Forest Stewardship Council certification;
- modest increases in the area under forest cover for the mitigation of soil erosion (under the Erosion Control Funding Programme (East Coast) and the Sustainable Land Management (Hill Country) Erosion Programme;
- the issuing by the Government of a National Policy Statement for Freshwater Management.

Natural soil erosion is a significant feature of New Zealand hill country and mountain areas. With a young and active geology, and a high storm frequency, much of this landscape is vulnerable to accelerated soil erosion through inappropriate land and forest use. About 6.7 million hectares of forests, including virtually all indigenous forests, fulfil vital water and soil protection functions. The risk or incidence of active soil erosion is moderate or higher under about 25 percent of indigenous forests and 17 percent of plantation forests. Surprisingly, land and forest management planning does not commonly embrace a specific designation for the protection of soil and water values.

The Resource Management Act 1991 (RMA) is the overarching legislation for the sustainable management of natural and physical resources. Forestry (and other land management) activities that have the potential to have significant adverse effects on soil and water values are subject to provisions of plans prepared under the RMA. Resource consents from the administering local authority may be required before certain activities can commence.

Sustainable (indigenous) forest management plans and permits under Part 3A of the Forests Act 1949 are also required to maintain the natural values of forest ecosystems.

The New Zealand Forest Owners Association published the *New Zealand Environmental Code of Practice for Plantation Forestry* in 2007, which replaces earlier codes of practice. The Association recommends that its members adhere to the principles and practices within the Code, which emphasise best management practices for soil and water quality values.

Independent third-party forest certification provides a market-driven mechanism to ensure the country has well-managed forests that protect soil and water resources. The area of forests under third-party certification continues to increase, with about 61 percent (net stocked area) of the plantation forest estate now under Forest Stewardship Council certification.

Little analysed national information is available on changes in physical, chemical or biological properties of streams in forest catchments. Substantial information is available at the regional level.

INDICATOR 4.1 PROTECTIVE FUNCTION

Indicator 4.1.a Area and percent of forest whose designation or land management focus is the protection of soil or water resources

New Zealand has significant areas of natural and accelerated soil erosion, but the designation of protection forest land is no longer applied in most management planning. Although forest land is still managed with conservation of soil and water resources as implied objectives, and sometimes as specific objectives, national data on the extent of such management are derived estimates only.

Since 2008, progress has been modest in the management of land for soil and water values through further forest establishment under the Erosion Control Funding Programme (East Coast), and initiatives under the Sustainable Land Management (Hill Country) Erosion Programme.

Quality of information: L

Progress against indicator: ▶

Rationale

The area and percent of forest designated or managed primarily for the protection and regulation of soil and water reflects the importance of these resources to society, including the trade-offs made between other uses.

NEW ZEALAND'S REPORT

The New Zealand Country Report for the Food and Agriculture Organization's Global Forest Resource Assessment (Ministry for Primary Industries, 2014) indicates 6.742 million hectares of indigenous and plantation forest have soil and water protection functions. This assumes that nearly all indigenous forests fulfil these roles, although little if any is specifically designated for this purpose.

Co-ordinated efforts to manage hill country erosion date from the early part of the 20th century. This work led to the passage of the Soil Conservation and Rivers Control Act in 1941. This Act authorised the establishment of local catchment boards, tasked with co-ordinating soil and water conservation. The boards provided financial assistance to landowners to carry out flood protection and soil conservation works. Many of these works involved tree planting programmes to stabilise slopes and reduce sediment yield.

The catchment boards were rolled into a new regional council structure in 1989 and the focus went on to providing landowners with technical information on and assistance with sustainably managing their properties. In a number of regions, some financial support continued to be available for land management plantings (such as riparian plantings along streams).

The annual cost of hill country soil erosion (mainly in pastoral use) is reported to be $100 million to $150 million. These national estimates of the cost of soil erosion and sedimentation in New Zealand are based on Krausse et al (2001), who estimated the order-of-magnitude average annual cost to be $127 million.

Patterson and Cole (1999, 2013) have looked at the total economic value of New Zealand's land-based ecosystems and the services they provide. In examining forest ecosystems, they valued erosion control at $2092 million, second only to the production of raw materials. In particular, they found that indigenous forests "play a critical role in maintaining soils and preventing sediment loss on land that is often steep and unstable" (Patterson and Cole, 2013, p 503).

Indigenous forests

Much of the indigenous forest on the mountain and hill country of New Zealand has historically been referred to as "protection forest". This reflects the naturally unstable nature of the terrain, and also the important roles the forest vegetation plays in reducing soil erosion and maintaining water values.

McKelvey (1995) identified 4.3 million hectares (69 percent) of indigenous forests as being protection forests. This area comprised 1.68 million hectares of upland forest and 2.62 million hectares of lowland forest. All upland forest was considered important for the protection of soil and water values.

These forests are considered to have a strong slope-stabilising influence with low-intensity storms. However, natural erosion processes coupled with high-intensity/low-frequency storm events may initiate mass movements on steep, forested slopes (McKelvey, 1995).

The Forests Act 1949 specifically recognised the use of state forest land for soil and water conservation, and a forest zoning system that evolved in the 1970s had a specific soil and water protection category. Since the management of state indigenous forests was transferred from the disestablished New Zealand Forest Service to the (then new) Department of Conservation in 1987, these forests have been managed "…for conservation purposes…" under section 6(a) of the Conservation Act 1987. The term "protection forest" is not now commonly used in forest management planning.

The Conservation Act 1987 interpretes conservation as including protection of natural resources such as forest vegetation, so the roles the vegetation performs in protecting soil and water resources are maintained.

Some indigenous forested catchments are also managed for the supply of domestic drinking water – for example, Wainuiomata catchment in Wellington and the Hunua Ranges in Auckland.

Plantation forests

Plantation forests have also been established for soil and water conservation purposes, although most of the land involved is not formally designated as such.

This includes the planting of Aupouri, Woodhill, Santoft and Bottle Lake forests to stabilise sand dunes. The total area of coastal sand dune planting is estimated to be 67 000 hectares, nearly all of which occurred prior to 1990.

More recently, 42 000 hectares of forests have been established through planting or reversion under the government's Erosion Control Funding Programme (East Coast) (ECFP, formerly the East Coast Forestry Project) for the primary purpose of soil conservation. Some 26 percent of the land on the East Coast is susceptible to severe soil erosion.

The ECFP was established in 1992 to control erosion on the worst eroding or erosion-prone land in this district, and is administered under the Forestry (East Coast) Grants Regulations 1992. It targets 60 000 hectares of the lands at greatest risk, plus immediate surrounding areas. The government provides financial grants for establishing effective tree cover through planting, or encourages natural reversion to indigenous forest.

The ECFP was reviewed in 2011 and 2012. Subsequent changes seek to make landowner participation in the ECFP easier, to remove the requirement for a covenant to be registered against the land title, and to streamline grant payments.

The Sustainable Land Management (Hill Country) Erosion Programme was established by the government in 2007. It supports projects helping hill country farmers treat erosion-prone land and implement sustainable management practices. The total hill country land area at risk of erosion is about 1.14 million hectares, with 300 000 hectares having a severe to extreme risk. Soil conservation initiatives under this programme, including afforestation, are co-ordinated by regional councils who can apply for funding from an annual pool of $2.2 million.

These programmes recognise that avoiding erosion has significant, long-term benefits beyond the productive capacity of New Zealand's pastoral and forest lands. In particular, they improve water quality and protect the "built environment" in rural and urban communities (such as bridges, roads, water supplies and flood banks).

In establishing and managing forests individual land owners make decisions around the focus of their land management. Much of the forest on Māori owned land is managed to protect the whenua (land) for future generations so intrinsically incorporates soil and water conservation in the management objectives.

The economic value of reduced erosion was calculated by Barry et al (2012). They found that afforestation using radiata pine trees on marginal lands in the Gisborne region may provide an avoided erosion benefit in excess of NZ $1000 per hectare in perpetuity. The benefits could be even higher for marginal lands in Gisborne that have steeper slopes (Yao et al, 2013).

(See also Indicator 6.1.c.)

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INDICATOR 4.2 SOIL

Indicator 4.2.a Proportion of forest management activities that meet best management practices or other relevant legislation to protect soil resources

New Zealand has legislative mechanisms, through the Resource Management Act 1991 and the Forests Act 1949, that address activities that may have adverse effects on soil resources. All commercial forest management must meet the requirements of these Acts. The *New Zealand Environmental Code of Practice for Plantation Forestry* and *New Zealand Forest Road Engineering Manual* also address the mitigation of impacts from forestry operations on soils and are widely promoted by forestry associations. About 61 percent of the plantation forest estate has international Forest Stewardship Council certification, and national certification schemes are being progressed.

Since 2008, new sections have been included in the *New Zealand Environmental Code of Practice,* and the *New Zealand Forest Road Engineering Manual* has been published.

Quality of information: M/H

Progress against indicator: ▲

Rationale

The indicator provides information about the extent to which soil resource protection, legislation and best management practices have been identified and integrated into forest management activities. Inappropriate activity may result in the loss of soil nutrients, forest productivity and other ecosystem services that soils provide.

NEW ZEALAND'S REPORT

In addition to legislative and regulatory requirements relating to soil resources, standards and guidelines for indigenous forestry, an environmental code of practice for plantation forestry, and forest certification schemes are in operation.

Resource Management Act 1991

All forest management activities that may adversely affect the soil are subject to the requirements of the Resource Management Act 1991 (RMA). Proposals that will result in disturbances or changes to soil-related resources will usually require a resource consent to be granted by the appropriate local authority. Resource consents commonly specify a number of conditions that must be met in undertaking forestry (or other) activities.

The RMA approach to environmental management centres on the ideas of sustainable management and the integrated management of resources. Regional and district plans are prepared by 78 regional, district and city councils, to assist them to carry out their functions under the RMA. These plans deal with issues relating to soil disturbance through activities such as earthworks, cultivation and removal of vegetation.

Regional councils collect and hold a large amount of soil resource information, the extent of which has not been assessed for this report. Their substantial resources are used for monitoring, planning and reporting activities that relate to soil resources at the sub-national level.

Forests Act 1949

Part 3A of the Forests Act 1949 focuses on privately owned indigenous forests. It promotes the principle of sustainable management by allowing a level of timber harvest that provides for the management of natural (non-timber) values. Landowners and forest managers seeking approvals for sustainable forest management plans and permits on private land must comply with Part 3A of the Act. The Act is administered by the Ministry for Primary Industries (MPI) and contains requirements relating to soil values.

The fifth edition of MPI's *Standards and Guidelines for the Sustainable Management of Indigenous Forests* was published in 2013. It reflects the statutory requirements under Part 3A of the Act and includes a criterion and standards section with indicators relating to soil quality. These cover the siting and construction of earthworks to minimise soil disturbance, and minimising soil compaction and the erosive effects of machine use.

Environmental Code of Practice and Road Engineering Manual

Codes of practice focus on promoting sound management practices and are particularly important for soil conservation. In 2007, the New Zealand Forest Owners Association (NZFOA) published Part 1: Best Environmental Management Practices of the *New Zealand Environmental Code of Practice for Plantation Forestry*. This code replaced the 1993 *New Zealand Forestry Code of Practice*.

Four more parts have subsequently been included in the *New Zealand Environmental Code of Practice*:

- Part 2: Recognising environmental values;
- Part 3: Planning for good environmental outcomes;
- Part 4: Resources and references;
- Part 5: Training.

The Code is a practical means of helping forest planners, contractors and operators to accomplish required levels of environmental performance, consistent with good health and safety and financial performance and the community and regulatory expectations that they face. Soil conservation and quality values and issues are covered in most of the Best Environmental Practices and, in particular, for earthworks, harvesting and mechanical land preparation.

In 2011, NZFOA published the *New Zealand Forest Road Engineering Manual*. The objective of the Manual is to ensure that roads, water crossings and related infrastructure in plantation forests are fit for purpose and are designed and constructed to meet high environmental standards.

Members of the NZFOA and the New Zealand Farm Forestry Association own or manage more than 85 percent of the country's plantation forests. Both organisations strongly endorse the *New Zealand Environmental Code of Practice* and *New Zealand Forest Road Engineering Manual* for their applicability to all forest owners throughout New Zealand, and recommend that their members adhere to the principles and practices.

Forest certification

Forest certification schemes recognise good forest management, including safeguarding soil and water resources.

Most large-scale forest owners in New Zealand have international Forest Stewardship Council (FSC) certification. This provides a third-party guarantee that the products come from forests that have been managed in accordance with FSC principles and criteria.

In FSC terms, this verifies that the forest products come from responsibly-managed forests. Principles 9 and 10 and their associated criteria include the requirements to control erosion of vulnerable soils and slopes, manage infrastructure development, transport activities and silviculture so soils are protected, and manage harvesting of timber so that environmental values (including soils) are protected.

The gross forest area under FSC certification is 1.499 million hectares, of which 1.054 million hectares are productive forest areas (61 percent of the plantation forest estate). This includes 12 000 hectares of indigenous forest managed under Part 3A of the Forests Act 1949.

A New Zealand standard is being prepared with the expectation that FSC endorsement will be sought when it is completed.

Standards New Zealand published standard NZS AS 4708:2014 Sustainable Forest Management in May 2014. It is expected that endorsement under the Programme for Endorsement of Forest Certification will be sought for this standard.

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Pinus radiata plantations, Wairau Valley, Marlborough. Photo: Ian Platt.

Indicator 4.2.b Area and percent of forest land with significant soil degradation

National data on all aspects of soil degradation are not available. About 25 percent of indigenous forests and 16 percent of plantation forests are located on land with moderate or higher incidences of soil erosion. Disturbance or displacement through erosion can cause nutrient loss in soils. Physical soil damage through compaction can result from the concentrated use of heavy machinery. An environmental code of practice addresses these issues and is widely applied.

The area of forest land with significant soil degradation is likely to have remained similar to the area that existed in 2008.

Quality of information: L/M

Progress against indicator: ▶

Rationale

The indicator provides information on the extent of significant soil degradation in forests likely to affect productivity, hydrology, ecosystem processes or social and cultural benefits. This indicator is primarily concerned with degradation caused directly or indirectly by human activity.

NEW ZEALAND'S REPORT

Considerable information is available on the soil erosion component of soil degradation, but not for other aspects of this issue.

Much of the New Zealand landscape is mountainous or hilly, undergoing uplift, and subject to high-intensity rainfalls. As many areas are underlain by soft, erodible materials (such as recent marine deposits), natural rates of soil erosion are high.

Before human settlement, the extensive indigenous forest land cover provided protection for the soil mantle, except during extreme rainfalls. With much of this indigenous forest cleared, parts of the country are prone to mass-movement soil-erosion processes, particularly in the East Coast of the North Island. Across the country, about 10 percent of the land area is classified as severely erodible.

The remaining indigenous forests often continue to fulfil critical soil conservation roles, mostly unaffected by human activities. However, the introduction of invasive animal pest species in the 19th and early 20th centuries, particularly possums and deer, has impacted on the health and regenerative capacity of some forest types. Hence these animal populations are likely to have some influence on the soil conservation role provided by these forests, even though they are subjected to control operations.

The Ministry for the Environment administers national environmental reporting, although many of the data are collected by other agencies. An Environmental Snapshot report on soil health in 2010 summarises the results from sampling 740 sites between 1995 and 2009 under productive land uses, including plantation forestry. Seven soil measures were monitored, providing information about organic reserves, fertility, acidity and the physical status of the soils. About 60 percent of plantation forestry sites sampled did not meet all target ranges for soil health. For key soil measures:

- 8 percent of the sites did not meet the target range for organic reserves;
- 33 percent of the sites did not meet the target range for fertility;
- 48 percent of the sites did not meet the target range for physical status.

However, much of the plantation forest estate has been established on eroding and erosion-prone sites, some of which have been subject to soil degradation.

Soil erosion

A broad indication of the levels of soil erosion for land under forest cover in New Zealand can be derived from the New Zealand Land Resource Inventory (LRI) and the New Zealand Land Cover Database (see Table 4.2).

Soil erosion peaks and sedimentation may occur during harvesting operations in plantation forests,

Table 4.2: Soil erosion area and percent by forest type

Degree of erosion	INDIGENOUS FOREST		PLANTATION FOREST	
	Area affected (000 ha)	Percentage affected	Area affected (000 ha)	Percentage affected
Unclassified	110	2	1	<1
Negligible	1 337	19	693	34
Slight	3 778	54	988	49
Moderate	1 404	20	274	14
Severe	268	4	46	2
Very severe	51	1	11	1
Extreme	14	<1	3	<1
TOTAL LRI areas	**6 962**		**2 016**	

Sources: Landcare Research, 2014; Ministry for the Environment, 2014.

often due to associated earthworks (the construction of roads and tracks). Earthworks are addressed by the *New Zealand Environmental Code of Practice for Plantation Forestry.* They are commonly subject to provisions of local government plans prepared under the Resource Management Act 1991 (see Indicator 4.2.a). The period between harvesting and the re-establishment of good vegetation cover and root networks may also see elevated levels of soil erosion.

Very little harvesting occurs in indigenous forests. However, where harvesting is undertaken, it concerns single trees, small groups of trees or small coupes under the sustainable forest management requirements of the Forests Act 1949, and often by helicopter.

New Zealand Empirical Erosion Model

Scientists from the Sustainable Land Use Research Initiative developed the New Zealand Empirical Erosion Model (NZeem®), which predicts mean annual sediment yield from a given catchment based on annual rainfall, type of terrain and percentage of woody vegetation cover. The model can calculate the likely extent of erosion under different types of land cover. This will enable prioritising soil conservation work and defining those areas that would benefit from tree cover.

Nutrient supply

Disturbance or displacement through soil erosion can cause nutrient loss. Although there is no evidence in New Zealand that successive harvests cause severe decrease in soil nutrient supply, an early classification by Hunter et al (1988) suggested some soils will be less able to maintain nutrient supply than others.

Large-scale plantation forest managers commonly monitor nutrient levels through foliage and/or soil analyses. Fertilisers are applied where nutrient deficiencies would adversely affect tree growth, and to maintain long-term productivity.

Soil compaction

The major cause of soil compaction on forested sites is the concentrated use of heavy machinery (for example, on landings for harvesting operations), particularly when soil moisture levels are high. This issue is also addressed under the *New Zealand Environmental Code of Practice for Plantation Forestry* with guidance notes provided on how to mitigate soil compaction.

No national data on soil compaction under forested land are available.

Government sustainable land management initiatives

Several sustainable land management initiatives supported by government are designed to address soil erosion through forest establishment. These include the Erosion Control Funding Programme (East Coast) (formerly the East Coast Forestry Project), and the Sustainable Land Management (Hill Country) Erosion Programme.

The Permanent Forest Sink Initiative focuses on carbon sequestration and storage, but some of the afforestation is likely to be on eroding land. While not specifically implemented for soil erosion control, this is likely to be a secondary benefit.

Sources of information

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Beech-podocarp forest, Aorere River, Golden Bay. Photo: Ian Platt.

INDICATOR 4.3 WATER

Indicator 4.3.a Proportion of forest management activities that meet best management practices, or other relevant legislation, to protect water related resources

The New Zealand Government issued a National Policy Statement for Freshwater Management in 2011 and amendments in 2014 that provide direction to local government on the management of water resources.

Legislative mechanisms through the Resource Management Act 1991 and the Forests Act 1949 relate to activities that may affect riparian zones, and water quality and quantity. The area of plantation forest certified by the Forest Stewardship Council has increased to 61 percent of the estate.

Since 2008, in addition to the National Policy Statement, further sections have been included in the *New Zealand Environmental Code of Practice for Plantation Forestry* and a revised edition of the *Standards and Guidelines for the Sustainable Management of Indigenous Forests* has been published. Both publications address the protection of water resources.

Quality of information: M

Progress against indicator: ▲

Rationale

This indicator provides information about the extent to which water resources have been identified and safeguarded during forest management. This indicator is primarily concerned with activities that may affect riparian zones, water quality, quantity and flow rather than the designation of land for water-related conservation. The protection of water resources and associated forest and aquatic ecosystems is vital for the human populations dependent on them.

NEW ZEALAND'S REPORT

New Zealand manages its water resources in accordance with the Resource Management Act 1991 (RMA). In addition to the legislative requirements relating to water resources, there are standards and guidelines for indigenous forestry, an environmental code of practice for plantation forestry, and forest certification schemes.

Resource Management Act 1991

A National Policy Statement for Freshwater Management was issued by the Government under the RMA in 2011, and amended in 2014.

The National Policy Statement directs regional councils to consider specific matters (including the setting of objectives, policies and rules) about fresh water when they are developing regional plans for fresh water. The councils are required to gather water quality and quantity information on water bodies to assess their current state and decide the water quality objective for each value communities chose based on economic, social, cultural and environmental impacts on those communities.

All forest management activities that may affect riparian zones, and water quality, quantity and flow are subject to the requirements of the RMA. Local authority plans prepared under the RMA deal with issues relating to water quality and quantity, and may include rules relating to riparian areas, set-backs for plantation forestry, requirements for stream and river crossings, the classification of rivers and streams according to their values and requirements for water monitoring.

The discussion on the RMA under Indicator 4.2.a is also relevant to the protection of water resources.

Forests Act 1949

Landowners and forest managers seeking approvals for sustainable forest management plans and permits on privately owned indigenous forest land must comply with Part 3A of the Forests Act 1949. The Act is administered by the Ministry for Primary Industries (MPI), which considers water values in their processes.

The fifth edition of MPI's *Standards and Guidelines for the Sustainable Management of Indigenous Forests* was published in 2013. The Standards and Guidelines reflect the statutory requirements under Part 3A of the Forests Act 1949 and include a criterion and standards with indicators relating to water quality. These include the protection of permanent stream beds and stream margins.

Environmental Code of Practice and Forest Road Engineering Manual

Indicator 4.2.a discusses the *New Zealand Environmental Code of Practice for Plantation Forestry* and the *New Zealand Forest Road Engineering Manual*. Water quality values and issues are covered in most of the Best Environmental Management Practices under the Code and through the information in the Manual.

With respect to riparian management, the *New Zealand Environmental Code of Practice* states that a minimum setback from planting of 5 metres is generally recognised as appropriate for small, permanently flowing streams, while wider widths are often established on the margins of wetlands and geothermal areas or adjacent to larger streams and rivers.

Forest certification

Most large-scale plantation forest owners in New Zealand have international Forest Stewardship Council (FSC) certification. The area certified accounts for 61 percent of the plantation forest estate. Certification provides an independent and credible guarantee that the products come from forests that have been managed in accordance with FSC Principles and Criteria. In FSC terms, this certification verifies that the forest products come from responsibly managed forests.

FSC Principles 6, 9 and 10 all include criteria that relate to the management of water resources.

See Indicator 4.2.a for data on the area of forests with FSC certification, the preparation of a New Zealand standard for FSC endorsement, and the expectation that endorsement under the Programme for Endorsement of Forest Certification will be sought for standard NZS AS 4708:2014 Sustainable Forest Management.

Sources of information

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Indicator 4.3.b Area and percent of water bodies, or stream length, in forest areas with significant change in physical, chemical or biological properties from reference conditions

At the national level, New Zealand has no river quality monitoring by land use cover, and no substantive information available on changes in physical, chemical or biological properties of streams in forest areas. Monitoring is undertaken on a regional basis. The quality of water from forest catchments is generally considered to be high. For plantation forests, the most significant measured changes to water quality have been increases in suspended sediment.

Since 2008, the national level information available on the properties of streams flowing through forested land has changed little.

Quality of information: L

Progress against indicator: ▶

Rationale

This indicator provides information relating to water quality in forests. Significant changes in the physical, chemical or biological properties of water in forest lakes, rivers and streams may reveal the extent to which management activities or natural events are affecting water quality. Maintaining water quality is important for human use and consumption and to support healthy forest and aquatic ecosystems. Where water quality is being adversely affected by human activity, forest management practices may be adapted to protect water values.

NEW ZEALAND'S REPORT

No detailed quantitative national information is available to identify changes in physical, chemical or biological properties of water bodies that flow through New Zealand's forest lands.

The Ministry for the Environment (2013) reports that river condition indicators monitored nationally (but not by land use) were either stable or improving at most sites. The exception was nitrate concentrations that were increasing in about a quarter of the sites.

The National River Water Quality Network consists of 77 sites on 35 rivers distributed across New Zealand. Monitoring a range of physical and chemical variables has been undertaken since 1989. National trends for the period 1989 to 2007 (but not by land use) showed no significant change in water temperature and percentage of dissolved oxygen, but significant increases in visual clarity, dissolved reactive phosphorus, total phosphorus, oxidised nitrogen and total nitrogen.

Davies-Colley (2013) notes that, compared with Europe, North America and Asia, river water quality in New Zealand is "fairly good", although conditions vary greatly from place to place depending on land use. The author also notes that:

- water quality is very good in rivers draining conservation lands (most of which have indigenous vegetation cover);
- rivers draining plantation forests sometimes approach the quality of rivers in indigenous vegetation cover, although periodic harvest operations can mobilise fine sediment.

Larned et al (2004) assessed water quality at the national level in low-elevation streams by land cover types. Pair-wise comparisons indicated that:

- nitrogen oxide, ammonium and *Escherichia coli* concentrations were significantly lower, and clarity was significantly higher, in indigenous and plantation forest classes compared with urban and pastoral classes;
- differences between indigenous and plantation forest classes were not statistically significant for any parameters;
- the median *E. coli* concentration in indigenous forest streams, and conductivity in plantation forest streams, exceeded the guideline values.

The majority of indigenous forests are located in higher-altitude catchments, and most properties of their water bodies have not been significantly affected by human activities. However, the historical introduction of browsing animal pests has adversely impacted on the health of some forests, leading to accelerated soil erosion and sedimentation in streams (O'Loughlin, 2005).

For water bodies in plantation forests, the most serious changes that have been measured in water quality are increases in suspended sediment concentration. These increases are associated with the construction of forest roads, tracks and landings for harvesting; accelerated landsliding; and other forms of erosion after harvesting from steep, unstable slopes (Fahey et al, 2003 in O'Loughlin, 2005).

An analysis of the River Environment Classification (Ministry for the Environment, 2014), and the Land Resource Inventory (Landcare Research, 2014), enables estimates to be made of the distances of rivers flowing across forested land areas against the degree of surrounding land soil erosion. This provides one indication of the potential for sedimentation (see Table 4.3).

At the sub-national level, regional councils collect and hold a large amount of water resource information. This substantial resource is used for monitoring, planning and reporting activities (including forestry) that relate to water resources. Land and Water Aotearoa has used models to estimate nutrient concentrations for different land uses based on data collected from hundreds of regional monitoring sites over the five years to 2012.

Sources of information

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LAWA – Land Air Water Aotearoa (2014). **http://www.lawa.org.nz/**. Accessed 3 July 2014.

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Table 4.3: Distance of rivers within forested areas by degree of surrounding land erosion (kilometres)

Degree of erosion	Indigenous forest		Plantation forest	
	Kilometres	Percent	Kilometres	Percent
Negligible	23 215	26	8 955	43
Slight	47 663	53	8 620	41
Moderate	16 049	18	2522	12
Severe	2 855	3	462	2
Very severe	475	1	153	1
Extreme	217	<1	89	<1
TOTAL stream distance	**90 474**		**20 801**	

Note: The River Environment Classification and the Land Resource Inventory have not been subject to significant updating since the *2009 NZ Country Report.* Consequently Table 4.3 is the same as the corresponding table in the previous report.

Sources: Landcare Research, 2014; Ministry for the Environment, 2014.

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O'Loughlin, CL (2005). Forestry and hydrology. In Colley, M (ed) *Forestry handbook* (4th edition). New Zealand Institute of Forestry (Inc); Christchurch.

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Fiordland, New Zealand.

CRITERION 5:

MAINTENANCE OF FOREST CONTRIBUTION TO GLOBAL CARBON CYCLES

Forests are renewable and one of the largest terrestrial reservoirs of biomass and soil carbon. They have an important role in global carbon cycles as sinks and sources of carbon. Carbon stocks in forests include above ground biomass, below ground biomass, dead and decaying organic matter and soil carbon. Carbon is also stored in wood products.

The biosphere has a significant influence on the chemical composition of the atmosphere. Vegetation draws carbon dioxide (CO_2) from the atmosphere, through photosynthesis, and returns it through respiration and the decay of organic matter. The interchange between the biosphere and atmosphere is large; approximately a seventh of total atmospheric CO_2 passes into vegetation each year.

Global climate change could have significant impacts on the structure, distribution, productivity and health of temperate and boreal forests as well as impacts on forest carbon stocks and fluxes, and the prevalence of forest fires, disease and insect outbreaks, and storm damages.

Forest management practices also affect the carbon cycle and fluxes as well. Deforestation has a negative impact, but management activities that maintain and enhance the carbon stored in forests and forest products over the medium to long term can help to mitigate atmospheric carbon dioxide levels. In addition, biomass from forests (usually wood waste) can be used as a substitute for fossil fuels, thereby reducing their use and displacing greenhouse gas emissions[28].

Change in the global carbon cycle and associated climate change will have major impacts on human wellbeing, especially rural communities and indigenous peoples dependent directly on the natural environment

Table 5.1 lists the indicators covered in this section.

Table 5.1: Indicators for Criterion 5 – quality of information and trends

Criterion 5: Maintenance of forest contribution to global carbon cycles		Quality of information	Trend
5.a	Total forest ecosystem carbon pools and fluxes	H	▲
5.b	Total forest product carbon pools and fluxes	M	▶
5.c	Avoided fossil fuel carbon emissions by using forest biomass for energy	M	▲

28 As the carbon is removed from the atmosphere as the plantation tree grows, emissions from the use of wood as a fuel are balanced over the lifetime of the tree grown.

KEY

L = low	Neutral	▶
M = medium	Positive	▲
H = high	Negative	▼

NEW ZEALAND OVERVIEW

Since 1990 the carbon stock in New Zealand's forests has increased from 3071 million tonnes to a total of 3298 million tonnes in 2012: 2844 million tonnes of carbon in natural forests and 454 million tonnes in the planted production estate.

While still developing data to report on harvested wood product pools, it is possible to infer changes by looking at current domestic production of the key products since 2008:

- carbon in wood being converted into paper declined 13 percent, sawn wood declined 6 percent, and panels declined 5 percent;
- production in 2014 remained 76 percent higher than in 1990;
- woody biomass remained about 7 percent of New Zealand's primary energy in 2013 but energy supply increased by 44 percent to 57.83 petajoules since 2008;
- this has reduced emissions from fossil fuels by approximately 4 million tonnes of CO_2 equivalent, if woody biomass displaced coal.


East coast, New Zealand.

Indicator 5.a Total forest ecosystem carbon pools and fluxes

From 2014 New Zealand started using the Land Use and Carbon Analysis System (LUCAS) for reporting carbon pools and fluxes in all forests. Forest carbon stocks increased from 3071 million tonnes of carbon in 1990 to 3298 million tonnes in 2012. Of this total, 2844 million tonnes of carbon were in indigenous forests and 454 million tonnes were in the plantation production estate.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator provides information about the total amount of carbon stored in forest ecosystems. It also describes changes, fluxes or flows in carbon between forests and the atmosphere. A better understanding of these processes will aid the development of appropriate responses to the effects of climate change.

NEW ZEALAND'S REPORT

Estimation methodology

Carbon stocks in New Zealand forests are estimated based on three pools defined in the *Good Practice Guidance for Land Use, Land-use Change and Forestry* (IPCC, 2003):

- alive biomass (above ground biomass, below ground biomass);
- dead organic matter (coarse woody debris, fine woody debris and litter);
- soils.

The New Zealand data are being collected through the Land Use and Carbon Analysis System (LUCAS), a robust and comprehensive system for data gathering, management, analysis and reporting that is appropriate for reporting on the land use, land use change and forestry sector under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Data collection methodologies have been designed to provide unbiased carbon estimates at the national scale, with methods supported by relevant scientific research.

Analysis of the data will provide nationally applicable values for carbon stock and stock change for the three carbon pools, and the key different forest types (indigenous forest versus forests planted for timber purposes, and forests established prior to 1990 and those established after 1989). It also provides information on non-forest land uses.

The areas under different land uses and land use change are based on three wall-to-wall land use maps derived from satellite imagery at nominal mapping dates of 1 January 1990, 1 January 2008 and 31 December 2012. The forest carbon inventory involves the use of plots located on a systematic grid across New Zealand (8-kilometre grid for pre-1990 forests and 4-kilometre grid for post-1989 forests). Recent and historic plots for soil carbon measurement have been established in different land uses.

Plantation forests

New Zealand's exotic plantation forest estate is intensively managed for production forestry, with rapid-growing genotypes selected and enhanced for optimum growth. In 2012, exotic plantation forests covered approximately 2.1 million hectares (gross area) – around 7.8 per cent of New Zealand's total land area. This also includes areas not managed for timber supply; for instance, areas planted for erosion control.

In addition to changes in carbon stock that result from the plantation forest growing into maturity, and their subsequent harvest, land use change is an important driver of the forest carbon stocks. After 2000, New Zealand experienced deforestation in some of its plantation forests (those that were on highly productive agricultural land). This has resulted in a decline in net forest area and a marginal decline in carbon stock when these areas are not replanted (relative to the carbon stock if they had been replanted). Overall, sequestered carbon remains high and increasing.

It is projected that from 2013 onwards, harvesting areas will continue to increase, and around 2020, plantation forest carbon stocks will decline in the short term as the large areas of forests planted (or replanted) in the 1980s and 1990s approach harvestable age. It is expected that these stocks will recover once the forests are replanted. This cyclical change in forest carbon stock is characteristic of New Zealand's non-even age class structure across the whole estate.

A negative number for soil carbon in the post-1989 forests shows that the soil carbon pool under forests is less than that under grassland. It takes 20 years after the conversion for the carbon to stabilise.

Indigenous forest

In 2012 natural forests in New Zealand covered over 7.84 million hectares (as described in Ministry for the Environment, 2014), around 29.1 percent of the land area. This forest is a mix of tall forests and areas of regenerating forests and shrubland that meet the greenhouse gas definition of forest areas (1 hectare in size, over 30 percent canopy cover and 5 metres at maturity)[29]. On average, tall forests that existed prior to 1990 average 253.14 tonnes of carbon per hectare in all biomass pools while shrubland averages 84.88 tonnes of carbon per hectare in all biomass pools (that is, excluding soil).

The long-term change in the carbon stocks within New Zealand's natural forests is less certain primarily due to the difficulty in gathering historical data, and in projecting the recovery of the forests from previous disturbance and the maximum carbon stock that will be reached, which is closely correlated with the species in the mature forests.

29 This total is slightly different than for the natural forest area discussed elsewhere within this report due to slight differences in measurement purposes and definitions of 'forest', which may, for example, include or exclude regeneration of natural forests after 1990.

Sources of information

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Table 5.2: Estimates of the carbon stock in forests at 31 December (million tonnes carbon)

	1990	1995	2000	2005	2010	2012
Indigenous forest						
Living biomass	1 466	1 487	1 507	1 528	1 549	1 557
Dead organic matter	326	327	328	330	331	331
Soil	956	955	955	955	955	955
Total	**2 747**	**2 769**	**2 791**	**2 813**	**2 835**	**2 844**
Pre-1990 plantations						
Living biomass	110	136	153	162	172	170
Dead organic matter	25	32	35	37	39	41
Soil	188	186	184	183	183	183
Total	**324**	**353**	**372**	**382**	**394**	**393**
Post-1989 plantations						
Living biomass	0	0	8	23	47	59
Dead organic matter	0	0	2	8	10	10
Soil	0	–1	–2	–5	–7	–8
Total	**0**	**0**	**8**	**27**	**50**	**61**
ALL FORESTS	**3 071**	**3 122**	**3 170**	**3 222**	**3 279**	**3 298**

Note: Values shown to no decimal places.
Sources: Based on data from Ministry for the Environment, 2014, and unpublished and developing outputs from New Zealand's LUCAS.

and Kyoto Protocol. http://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/sixth-national-communication_20131220%5B1%5D.pdf Accessed 9 Jul 2015

Ministry for the Environment (2014). *New Zealand's greenhouse gas inventory 1990–2012*. Ministry for the Environment; Wellington. http://unfccc.int/files/national_reports/annex_i_ghg_inventories/national_inventories_submissions/application/zip/nzl-2014-nir-11apr.zip. Accessed 26 May 2015.

Further reading

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Doubtful Sound, Fiordland.

Indicator 5.b Total forest product carbon pools and fluxes

Under the UNFCCC, in April 2015 New Zealand will report emissions and sinks from harvested wood products (HWP). The timing of this *Montreal Process report* means the data to project the HWP stock of wood sourced from New Zealand's forests are still being developed. However, it is possible to infer changes to the HWP pools in New Zealand, and from New Zealand harvested wood that is exported:

- between 2008 and 2014 harvested volume increased 38 percent, with the bulk of this increase in export logs[30];
- carbon in wood being converted into paper declined 13 percent;
- carbon in wood being converted into sawn wood declined 6 percent;
- carbon in wood being converted into panels declined 5 percent;
- production in 2014 remained 76 percent higher than in 1990.

Quality of information: M

Progress against indicator: ▶

Rationale

This indicator provides information on the role that forest products play in storing, cycling and releasing carbon. Forest products delay the release of carbon into the atmosphere and are more sustainable than products with manufacturing processes that have significant carbon footprints.

30 Year ending 31 March http://www.mpi.govt.nz/Portals/0/Documents/news-resources/statistics/forestry/logs/annual-roundwood-removals.xls

NEW ZEALAND'S REPORT

The UNFCCC has agreed that parties will report the changes in the harvested wood product pool. New Zealand's LUCAS programme has begun to assess the suitability of data to support reporting using the alternative HWP methodologies. In the Agriculture, Forestry and Other Land Uses volume of the revised Intergovernmental Panel on Climate Change (IPCC) guidelines for greenhouse gas inventories (IPCC, 2006), Chapter 4 describes four methodologies for including HWP reporting in national greenhouse gas inventories.

The HWP approaches outlined in the 2006 IPCC guidelines share a common approach of dividing the harvest wood into different product categories based on their lifetimes. All approaches include domestically grown and consumed wood products; they differ in terms of the treatment of imported and exported wood products.

To provide an indication of the carbon that New Zealand can confirm is going into HWP, a proxy measure based on domestically processed wood and the IPCC categories of wood product is provided.

The approach used here loosely approximates the production approach in the IPCC guidelines. Differences include the exclusion of exported roundwood and the disaggregation of the solid wood category into sawn timber and panels. The approach estimates only HWP production and does not provide stock or stock change in the HWP pool. New Zealand is currently developing its HWP reporting methods and full HWP reporting will be provided in the 2013 National Inventory Report (2015 submission). Once New Zealand's HWP reporting methods are complete, it is expected that carbon stock in the HWP pool will increase from 1990 onwards.

As Figure 5.1 shows, domestic processing of harvested wood into short-lived products (paper) has remained relatively static since 1990. In contrast, longer-lived products have increased substantially since 1990, although they have declined since 2005. It is believed that this more recent decline has been driven by relatively high production costs and the high New Zealand dollar, combined with the rationalisation of older, smaller mills.

The fate of New Zealand's exported roundwood is more difficult to determine. While New Zealand's roundwood export has significantly increased since 1990 (from about 17 percent to about 56 percent of the harvest volume), uncertainty exists about the ultimate products these logs are processed into. Work is under way to improve this information: as part of both product traceability work and also for climate change reporting. Therefore export roundwood is excluded from these HWP estimates.

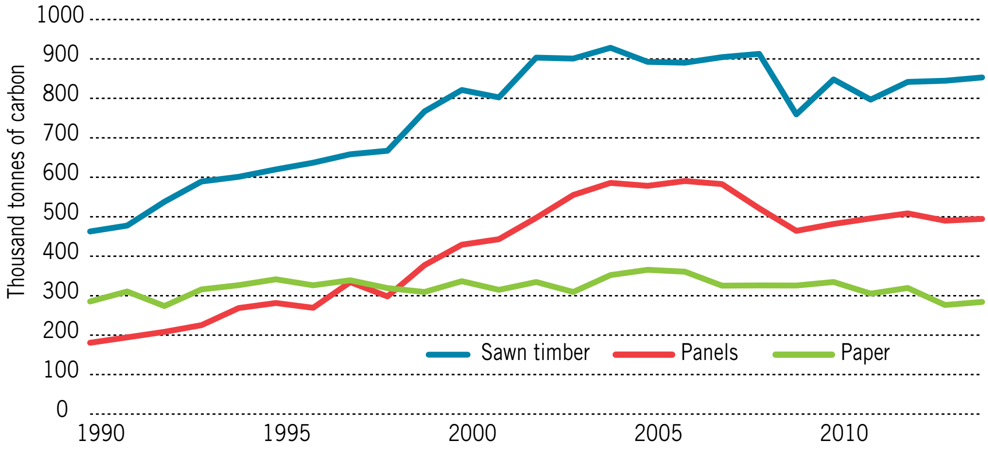
Sources of information

Food and Agriculture Organization (2014). *FAOStat: FAO statistical databases*. Food and Agriculture Organization of the United Nations; Rome. **http://faostat3.fao.org/download/F/FO/E** (modified to enhance data continuity). Accessed 26 May 2015.

Ministry for Primary Industries (2014). *Situation and Outlook for Primary Industries 2014*. **http://mpi.govt.nz/about-mpi/corporate-publications/**. Accessed 9 July 2015.

Intergovernmental Panel on Climate Change (2006). *2006 IPCC guidelines for national greenhouse gas inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston, HS; Buendia, I; Miwa, K; Ngara, T; Tanabe, K (eds). Institute for Global Environmental Strategies; Japan.

Figure 5.1: Carbon in New Zealand–produced wood processed into the three main wood product categories



Source: Derived from Food and Agriculture Organization, 2014.

Indicator 5.c Avoided fossil fuel carbon emissions by using forest biomass for energy

Woody biomass remains a constant proportion of New Zealand's primary energy but has increased in its energy supplied:

- about 7 percent of the country's primary energy comes from forest biomass, a proportion that has remained since the 2008 report;
- this figure represents 57.83 petajoules, a 44 percent increase since 2008;
- this has reduced emissions from fossil fuels by about 4 million tonnes of CO_2 equivalent, if woody biomass has displaced coals.

Quality of information: M

Progress against indicator: ▲

Rationale

This indicator provides information about the amount of energy produced from forest biomass and the extent to which it offsets the need to burn fossil fuels, thereby benefiting the global carbon budget and lowering carbon emissions.

NEW ZEALAND'S REPORT

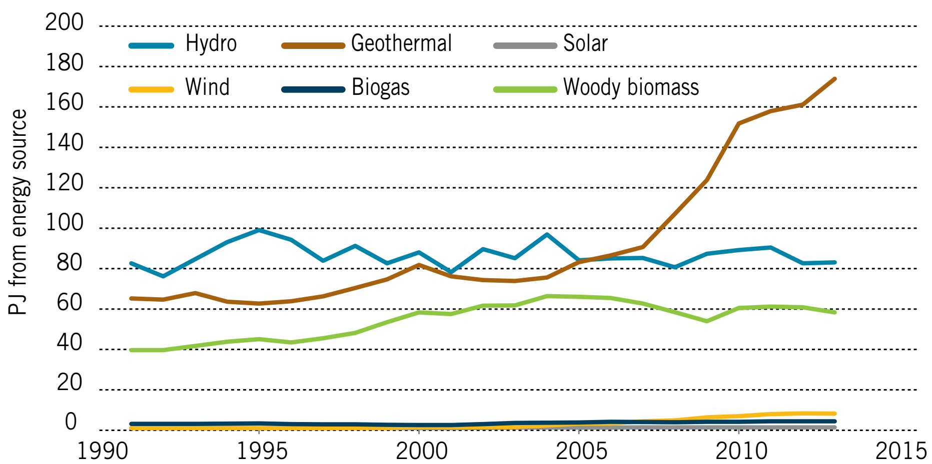
Forest biomass plays a relatively small role in New Zealand's consumer energy supply. While the total energy provided in 2013 has increased by about 44 percent since 2008, strong increases in supply from other sources have meant the percentage of national supply from wood has remained relatively stable at around 7 percent.

Of the 57.8 petajoules of energy supplied from wood, around 4.9 petajoules is used in cogeneration, around 45.6 petajoules in industrial uses and around 7.4 petajoules in residential properties, primarily for heating.

Biomass, usually wood waste, is also supplemented by fossil fuels such as coal and gas. The use of biomass for process heat and electricity generation also has the advantage of reducing waste disposal costs while utilising a renewable resource. Co-firing is used to improve boiler performance when using low-quality primary fuels. In 2013, the Census reported that over 36 percent of New Zealand households use wood to heat their homes.

The use of biomass can be considered as avoiding use of fossil fuels, thereby benefiting the national carbon budget and lowering carbon emissions. However,

Figure 5.2: Energy supply from biomass and other key renewables to the New Zealand's energy supply since 1991



Sources: Ministry of Business, Innovation and Employment, 2014 (Table 2); Ministry of Business, Innovation and Employment, undated: http://www.med.govt.nz/sectorsindustries/energy/energy-modelling/publications/energy-innew-zealand-2014 there are some complexities in calculating avoided emissions. The biomass energy could be replaced by renewable sources (geothermal, wind and hydro) or fossil fuels, hence avoided emission depends on the choice of the energy source.

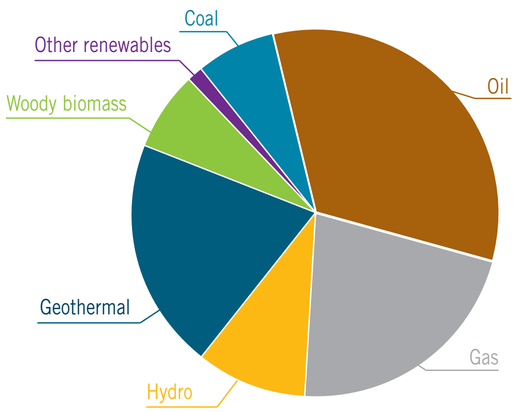
If it is considered that all the current biomass energy used in industrial processes (45.6 petajoules in 2013) was replacing coal, the avoided emission would be about 4 million tonnes of CO_2 equivalent, using an average emission factor of 89.4 kilotonnes of CO_2 equivalent per petajoule.

Sources of information

Ministry of Business, Innovation and Employment (2014). *Energy in New Zealand 2014*. http://www.med.govt.nz/sectors-industries/energy/energy-modelling/publications/energy-in-new-zealand. Accessed 26 May 2015.

Ministry of Business, Innovation and Employment (undated). *Energy in New Zealand: renewables data tables*. http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/data/renewables.xls. Accessed 26 May 2015.

Figure 5.3: Breakdown of the New Zealand's consumer energy supply in 2013



Source: Ministry of Business, Innovation and Employment, 2014 (adapted from Table B2).

Central North Island forests.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CRITERION 6:
MAINTENANCE AND ENHANCEMENT OF LONG-TERM MULTIPLE SOCIO-ECONOMIC BENEFITS TO MEET THE NEEDS OF SOCIETY

Forests provide a wide variety of social, cultural and economic goods, services and benefits that contribute to meeting the needs of society. Forests are not distributed uniformly throughout the country but for a number of regions and people who live in them forests and forestry is already the significant or major source of income, livelihood and wellbeing. For a number of other regions and communities forestry is an increasingly important source of local wealth and economic activity. Information on the production and consumption of forest products, investment and employment in the forest sector, forest-based recreation and tourism, and other social and cultural forest values illustrate the many benefits forests provide.

Table 6.1 lists the indicators covered in this section.

Table 6.1: Indicators for Criterion 6 – quality of information and trends

Criterion 6: Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of society		Quality of information	Trend
6.1.a	Value and volume of wood and wood products production, including primary and secondary processing	H	▲
6.1.b	Value of non-wood forest products produced or collected	L	▲
6.1 c	Revenue from forest-based environmental services	L/M	▲
6.1 d	Total and per capita consumption of wood and wood products in roundwood equivalents	M/H	►
6.1 e	Total and per capita consumption of non-wood forest products	L	►
6.1 f	Value and volume in roundwood equivalents of exports and imports of wood products	H	▲
6.1 g	Value of exports and imports of non-wood forest products	L/M	►
6.1 h	Exports as a share of wood and wood products production, and imports as a share of wood and wood products consumption	M	▲ / ►
6.1 i	Recovery or recycling of forest products as a percent of total forest products consumption	L/M	▼ / ►
	Investment in the forest sector		
6.2 a	Value of capital investment and annual expenditure in forest management, wood and non-wood forest products industries, forest-based environmental services, recreation and tourism	L/M	►
6.2 b	Annual investment and expenditure in forest-related research, extension and development, and education	M/L	►
	Employment and community needs		
6.3 a	Employment in the forest sector	H	▼
6.3 b	Average wage rates, annual average income and annual injury rates in major forest employment categories	H	wages ▲ injury rates ▼
6.3 c	Resilience of forest-dependent communities	L/M	►
6.3 d	Area and percent of forests used for subsistence purposes	L	►
6.3.e	Distribution of revenues derived from forest management	L	▲

Criterion 6: Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of society		Quality of information	Trend
	Recreation and tourism		
6.4.a	Area and percent of forests available and/or managed for public recreation and tourism	M	▲
6.4.b	Number, type, and geographic distribution of visits attributed to recreation and tourism and related to facilities available	H	▲
	Cultural, social and spiritual needs and values		
6.5.a	Area and percent of forests managed primarily to protect the range of cultural, social and spiritual needs and values	M	▲
6.5.b	The importance of forests to people	M	▶

KEY

L = low	Neutral	▶
M = medium	Positive	▲
H = high	Negative	▼

NEW ZEALAND OVERVIEW

Key findings are:

- Since 2008, there has been little overall change to the "quality" of the available statistical information for reporting against Criterion 6.
- Harvest levels are now 50 percent higher than in 2008, and, as a result, there are upwards trends for a number of the variables, notably those associated with roundwood exports, the share of exports in production, the economic importance of forestry and incomes associated with forestry.
- A notable fact is that virtually all of the increase in harvest has been associated with log exports. Sawn timber and pulp production remain at levels similar to 2008, while paper production is now lower than in 2008.
- Reflecting the growth in harvest, the capital stock in forestry and logging has increased, that associated with solid wood processing remains at levels similar to 2008, while the capital associated with the paper industry has fallen.
- New Zealand remains a relatively high per capita wood user. With relatively slow population growth, and no substantive new use for wood, trends relating to local use of wood products have remained relatively unchanged both in total and per capita terms.
- Sector employment has continued to decline, reflecting increasing labour productivity. The improving injury rates noted in the 2008 report have failed to continue, and the current injury rate is unacceptably high.
- The importance and appreciation of forestry for environmental, recreational, tourism cultural and social purposes have continued to grow. More research is being undertaken to attempt to value these aspects, but at this time quantification of these various values can still only be described as variable.

Forest values

New Zealand's forests are well recognised for a range of natural, cultural, social and economic values, although the relative importance of each value and mixes of values vary with the nature and location of the forests. Māori have strong cultural, spiritual and economic connections with forests and forestry.

The area of tall indigenous forest land in the Crown-owned conservation estate increased from 4.9 million hectares in 2000 to 5.0 million hectares in 2008, and to 5.2 million hectares in 2014 (Earl, 2014). There is, in addition, a further 0.4 million hectares of regenerating indigenous forest administered by the Department of Conservation (DOC) in the public conservation lands. The purpose of management of both the tall and regenerating forest land by DOC is to maintain the intrinsic values.

Commercial forest industries

New Zealand has high quality time series of statistical datasets for the commercial production of wood, processed wood products and trade in wood products. These statistical series now apply essentially to plantation forests, despite indigenous forests accounting for nearly 80 percent of the total estate. Wood harvested from New Zealand's indigenous forests accounts for less than 0.1 percent of the total commercial harvest.

From 2002 to 2008, roundwood removals hovered around 20 million cubic metres per year. The volumes and quantities of processed wood products similarly showed modest increases and decreases over this period, in accordance with market conditions. During the 2002 to 2008 period, log exports fluctuated between 25 percent and 40 percent of total harvest, but typically accounted for about a third of total harvest. Since 2008, both the harvest and the importance of the export log trade, particularly trade with China, have grown dramatically. For the year ended March 2014, the total harvest was 30.3 million cubic metres per year (153 percent of that in 2008). Log exports for the year (17.1 million cubic metres) were 56 percent of the total harvest, and the increase in log exports between 2008 and 2014 (11.1 million cubic metres) was slightly greater than the 10.6 million cubic metre increase in total harvest over this period. As implied by these numbers, the volume of processed products, and specifically the amount of newsprint now produced, is less than in 2008. For most other wood products, current production levels are similar to those recorded in 2008.

Apparent annual domestic consumption of wood and wood products between 2007 and 2014 ranged from 6.7 million cubic metres to just over 9 million cubic metres (roundwood equivalent) per year. Peak consumption over this period (9.02 million cubic metres) occurred in 2008, just before the global financial crisis. The lowest level of consumption (6.74 million cubic metres) was in 2010 (March year). With the gradual improvement of the New Zealand economy since that time, and with rebuilding in Christchurch since the February 2011 earthquake, total consumption has returned to a level of 8.9 million cubic metres per annum (March year 2014). Over the period, annual imports of wood and wood products (in roundwood equivalents) have comprised 30 percent to 38 percent of apparent domestic consumption (assuming all imports are consumed domestically).

At present, nearly 80 percent of the harvested volume is exported as logs or processed wood products. Exports of wood and wood products are worth $5.2 billion (10.5 percent of total merchandise exports) and have increased significantly since 2008 ($3.2 billion), with a 50 percent increase in harvest and a 185 percent increase in the volume of log exports. Over the same period (2008 to 2014), the annual value of imports remained virtually unchanged at $1.5 billion.

Although the commercial forest industries are a significant employer in many regions, and a major employer in a few, the six years between 2007 and 2013 saw a 14.6 percent decrease in direct forestry and first-stage processing employment (from 20 389 to 17 415). Average hourly earnings in both the forest and wood product manufacturing sectors are below the national average, but the gap has narrowed over the past four years, particularly for forestry workers. Average hourly earnings in forestry are currently 84 percent of the national average. For wood product manufacturing, the figure is 85 percent.

Injury prevention and reduction is a critical issue for the sector and for New Zealand's workplace regulators. The injury claim rate for the primary sector (which includes agriculture and fishing as well as forestry) is more than twice the national average, and the forest industry has seen a rise in fatalities in the past few years (reversing a downward trend in the figures from the 1990s and early 2000s). In January 2014, the industry commissioned an independent forestry safety review to identify the causes and factors contributing to the fatalities and rate of serious injury occurring within the sector (*Independent Forestry Safety Review,* 2014). Changes proposed by the Health and Safety Reform Bill, where people conducting a business, task or project (undertaking) will share and own the same duties as the people on the ground, are likely to increase the focus of all parties on health and safety within the forest industries.

With the exception of paper (and paperboard), limited progress has been made in the recycling of wood products. About 30 percent of domestic consumption of paper and paperboard is recycled. Significant volumes of waste timber and other wood products go to landfills.

Non-wood forest products

The economic benefit that New Zealand derives from the forest estate is not just confined to timber. The indigenous and plantation forests are significant attractions for the $23.8 billion tourism and recreation industry, and there is reasonable data on this sector. For other non-wood forest products industries, data are generally limited in their development, often regional in focus and not always specifically forest based, for example, the mānuka honey industry. Because of the small scale (and diversity) of most of these activities, up-to-date information on production, consumption and trade for many non-wood forest products is difficult to obtain.

Environmental services

Forests provide environmental services that support sustainable resource management; such roles are increasingly being acknowledged from parts of the New Zealand community. At the national level carbon sequestration is a key environmental services that are provided by forests. While at the local level water quality and mitigating soil erosion are possibly the most recognised environmental services that forests provide for New Zealand. Two regionally focused government-funded schemes provide grants for tree planting for this purpose: the Erosion Control Funding Programme (East Coast) (previously the East Coast Forestry Project) and the Sustainable Land Management Hill Country Erosion Programme. The New Zealand Emissions Trading Scheme (to be reviewed in late 2015) and the Permanent Forest Sink Initiative provide carbon credits to forest owners for carbon sequestration. These credits can be sold.

Research and development

Total expenditure on research and development (R&D) is difficult to assess because of the number of research providers, the diversity of funding sources and the challenge in defining what is true research expenditure, as opposed to something else such as publicity or marketing. There is also a question of what percentage of any research that is not simply pure forestry, but that does have an acknowledged potential forestry component, should be regarded as being forestry related.

These challenges acknowledged, central government is still clearly the principal source of R&D funding, with the Ministry of Business, Innovation and Employment (MBIE) being the agency that manages and co-ordinates the allocation of the bulk of government research funding. MBIE is also the agency charged with monitoring the effectiveness of public sector investment. A quarter of government R&D expenditure supports the primary industries, which include forestry. Government invested $789.6 million for science and innovation for the 2013/14 year, of which $197.4 million is the estimate of the primary sector's share of this funding. Nearly 18 percent of this, or $35.5 million, is estimated to be directly forest research-related funding. This in turn means forestry research funding represents about 4.5 percent of the science and innovation budget.

In addition, research in areas such as transport, industrial production and energy, which together represent another 30 percent of all government R&D expenditure, has associated benefits to forestry.

Despite the focus on government, not all R&D expenditure is government funded. Research funding from the forest growers levy is managed and directed by the Forest Growers Levy Trust, a statutorily endorsed forest industry organisation, while individual forestry-related businesses also undertake or commission research specifically tailored to their own interests and needs.

Sources of information

Earl, R (2014.) Personal communication. Department of Conservation; Wellington.

Independent Forestry Safety Review (2014). *Factors influencing health and safety in the forestry sector – public consultation document*. Independent Forestry Safety Review; Wellington.

INDICATOR 6.1 PRODUCTION AND CONSUMPTION

These indicators provide information on the contribution of wood and non-wood products and environmental services to national economies. The value, volume and revenues associated with domestic production and consumption of forest products and services, including through international trade, demonstrates the type and magnitude of the contribution of forests to domestic economies. They also provide information about market conditions relevant to forest management and the forest sector.

Indicator 6.1.a Value and volume of wood and wood products production, including primary and secondary processing

New Zealand has readily available, high quality time series of statistical data on the production and trade of harvested wood and wood products. The annual values and volumes of wood and wood products vary with market conditions. National accounts provide information on the industries' financial contributions to the country's economy.

Quality of information: H

Progress against indicator: ▲

Rationale

This indicator provides information on the value and volume of wood and wood products at various stages of processing. The value and volume of wood products reflects one aspect of the importance of forests and wood processing sector to the domestic economy.

NEW ZEALAND'S REPORT

New Zealand can estimate the contribution from commercial forest industries in terms of value to the economy or to New Zealand's gross domestic product (GDP) through the "Forestry and logging" and "Wood and paper products" production groups in the New Zealand System of National Accounts. The units of value are New Zealand dollars for the relevant year, or (for a time series) constant 1995/96 prices. The value added through downstream processing is estimated and/or captured as the contribution to GDP of the production groups "Wood and wood products" and two-thirds of the value of the "Paper, printing and publishing" group.

Table 6.2 illustrates the type of data that are available for value estimates, in this example, in constant 1995/96 prices. This means the changes in the value shown reflect changes in the volume of output.

Table 6.2: Forest industries' contribution to GDP (2006–2014) expressed in 1995/96 prices ($ million calendar year)

Industry group	Forestry and logging		Wood and paper products		GDP
Year	$ million	% of GDP	$ million	% of GDP	
2006	1 144	1	2 518	2	133 854
2007	1 214	1	2 485	2	137 592
2008	1 238	1	2 472	2	141 560
2009	1 177	1	2 196	2	138 841
2010	1 298	1	2 285	2	138 690
2011	1 423	1	2 403	2	141 208
2012	1 459	1	2 415	2	144 596
2013	1 535	1	2 313	2	147 917

Note: GDP = gross domestic product.
Source: Statistics New Zealand, 2014.

A similar table in dollars for the year would reflect the value changes due to both price and output quantity changes. The volumes of output from forests (roundwood removals) are provided in Table 6.3, and outputs from the sawmilling, panel products, pulp and paper, and log and chip export industries are provided in Table 6.4.

More detailed data, both quarterly and annual, relating to production of major forestry products are available on the websites of the Ministry for Primary Industries or Statistics New Zealand – see **www.mpi.govt.nz** or **www.statsnz.govt.nz.**

Sources of information

Ministry for Primary Industries (2014). *Forestry: forestry production and trade statistics detail the production, trade, and other forestry activities in New Zealand*. **http://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/forestry/**. Accessed 5 May 2015.

Statistics New Zealand (2014). *Gross domestic product by industry*. **www.stats.govt.nz/browse_for_stats/economic_indicators/GDP/GrossDomesticProduct_HOTPDec13qtr.aspx**. Accessed 5 May 2015.

Table 6.3: Estimated roundwood removals from New Zealand forests (000 cubic metres of roundwood) (2005–2014)

Year ended March	Indigenous forest total	Plantation forests							Total removals
		Saw logs	Peeler logs	Small logs	Pulp logs	Export chip	Export logs	Plantation total	
2005	27	8 013	1 169	1 486	3 286	199	5 123	19 277	19 303
2006	23	7 641	1 120	1 479	3 234	261	5 067	18 802	18 825
2007	18	7 768	1 198	1 409	3 284	265	5 973	19 897	19 915
2008	18	7 839	1 204	1 290	3 492	363	6 199	20 388	20 406
2009	16	6 519	1 084	1 184	3 119	293	6 648	18 847	18 863
2010	14	6 675	784	1 180	3 461	276	9 567	21 944	21 958
2011	17	7 172	1 156	1 028	3 681	317	11 679	25 033	25 050
2012	16	6 937	1 215	1 254	3 582	451	12 531	25 971	25 987
2013	15	7 169	1 075	1 278	3 495	363	14 678	28 057	28 072
2014	22	7 322	1 077	1 234	3 433	256	17 083	30 405	30 427

Source: Ministry for Primary Industries, 2014.

Table 6.4: Annual production volumes: quantities by forest industries (2005–2014)

Year ended March	Sawn timber (000 m^3)	Panel products (000 m^3)	Pulp (000 air dried tonnes)	Paper and paperboard (000 tonnes)	Log and chip exports (000 m^3 roundwood equivalent
2005	4 392	2 179	1 587	921	5 323
2006	4 235	2 214	1 561	941	5 328
2007	4 301	2 203	1 529	872	6 238
2008	4 340	1 939	1 546	871	6 562
2009	3 609	1 716	1 511	870	6 942
2010	3 695	1 521	1 537	897	9 843
2011	3 971	1 873	1 590	930	11 997
2012	3 840	1 947	1 555	859	12 938
2013	3 968	1 880	1 495	825	15 014
2014	4 057	1 880	1 468	749	17 339

Source: Ministry for Primary Industries, 2014.

Indicator 6.1.b Value of non-wood forest products produced or collected

The economic benefits that New Zealand derives from the forest estate are not confined to timber production. New Zealand's indigenous and plantation forests are important components of the $23.8 billion tourism and recreation industry. Nature-based tourism activities are among the principal attractions for overseas visitors, and an increasing number of communities are coming to rely on the employment generated by this sector.

A number of small to medium scale industries also rely upon the forest estate. These include the beekeeping industry, which produces several monofloral honeys based upon tree species; the game hunting and trapping industry; and the sphagnum moss collection industry. While these industries are not major employers at the national scale, they are important for supporting economic activity within local communities.

Quality of information: L

Progress against indicator: ▲

Rationale

This indicator provides information on the value of non-wood forest products. The collection, processing and use of non-wood forest products are important dimensions of the economic value of forests. In some countries, non-wood forest products are vital to the livelihoods and lifestyles of indigenous and other rural communities.

NEW ZEALAND'S REPORT

Timber production is just one of the economic benefits that New Zealand derives from its indigenous and plantation forest. The 10.1 million hectare forest estate is a significant component of New Zealand's tourism industry. The tourism industry is one of the economic drivers of the economy, particularly in rural and more remote areas. The industry directly contributed $8.3 billion (or 4.0 percent) to gross domestic product (GDP) in the March 2014 year and a further $6.5 billion of indirect value added (equal to 3.2 percent of GDP)[31]. At an employment level, the tourism industry directly employed 4.7 percent of the working population in the March 2014 year (Statistics New Zealand, 2014). This equated to 94 100 full-time equivalent (FTE) positions.

Another industry with a strong reliance on New Zealand's forests and bush lands is apiculture. The forest estate is an important source of pollen and nectar for apiarists. Several monofloral honeys are sourced from forest and bush lands. Honey exports have grown strongly over the past decade, and this has generated increased interest in the opportunities provided by the forest estate.

31 The gross domestic product figures calculate the value added contributed by tourism (directly and indirectly). The figures exclude imports sold to tourists.

New Zealand's indigenous and plantation forests have also been used over the past century for commercial game and trophy hunting, possum trapping (for fur and skins) and sphagnum moss collection. These activities employ relatively small numbers but can be important in local communities. A range of medicinal herbs and berries have traditionally been collected by Māori and the early European settlers. These resources have mainly been gathered for personal use, but are attracting increasing commercial interest for health and skin-care products. For the future, research and commercial trials are under way on the establishment of secondary crops in plantation estates (such as mycorrhizal mushrooms). The intention is to diversify production and improve the economic returns from forestry.

Value of recreational tourism

> Natural attractions are widely regarded as New Zealand's key draw-card for international visitors… Nature-based tourism ranges from high impact adventure activities such as jet boating, skydiving and mountain climbing to more relaxing activities such as bush walking, wild life and scenic tours. (Ministry of Tourism, August, 2009, p 1).

In 2009, the Ministry of Tourism[32] estimated that around 70 percent of international visitors participated in at least one nature-based tourist activity, while the "propensity for domestic tourists was lower at around 22%, owing to a higher proportion of visitors being on business or visiting friends and relatives" (Ministry of Tourism, August 2009, p 1). Nature-based activities that attracted between 200 000 and 500 000 overseas visitors in 2008 included short and half-day bush walks, glacier walks, trekking, visiting national parks and lakes, scenic drives and geothermal attractions.

Total tourism and recreational spending amounted to $23.8 billion in the March 2014 year, of which international visitors contributed $10.3 billion and domestic visitors $13.4 billion. Total tourism expenditure increased 77 percent (in nominal terms) in the 15 years from 1999. In 1999, tourism expenditure stood at $13.4 billion. This figure increased steadily during the early 2000s and reached $22.1 billion in 2008. (Statistics New Zealand, 2014).

The growth in tourism expenditure over the past 15 years has been driven by overseas visitor numbers. Short-stay visitor numbers have climbed 81 percent over this period, from 1.52 million in the March 1999 year to 2.75 million in the March 2014 year, as shown in Figure 6.1 (Statistics New Zealand, Infoshare, 2014).

32 The Ministry of Tourism is now part of the Ministry of Business, Innovation and Employment.

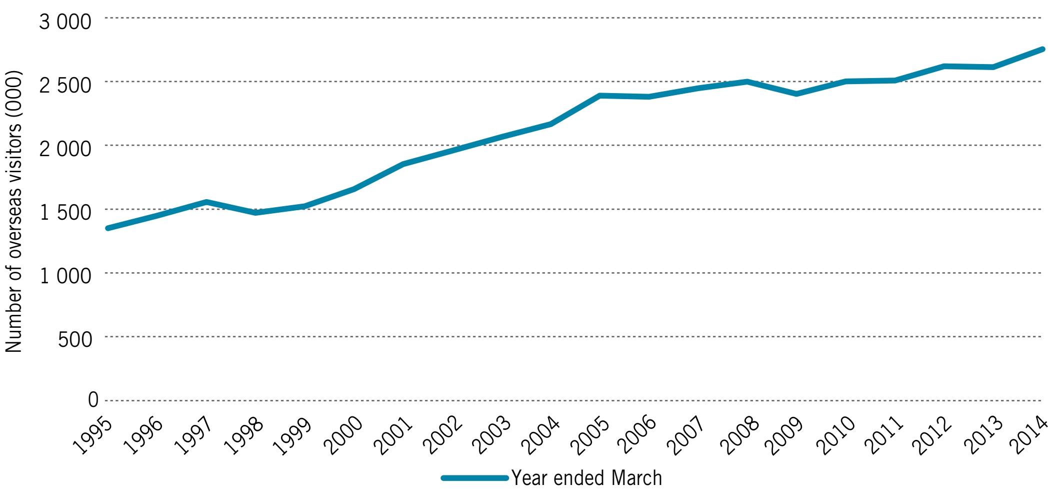
Direct employment in tourism was estimated to be 94 100 FTEs, in the March 2014 year. Another 72 700 FTEs were generated through indirect activities. (Statistics New Zealand, 2014, p 33).

The importance of recreational tourism can be seen particularly in regions such as the West Coast of the South Island that continue to rely heavily on their natural resources. The region has extensive areas of indigenous forest, which have been incorporated into the conservation estate. A study by the Department of Conservation (DOC) found that the economic activities associated with the public conservation estate contributed "15 percent of the 12,341 full-time job equivalents in the region in 2003, 13 percent of total household income, and more than 10 percent of total gross output" (Department of Conservation, 2006, p 7). Most of these activities are related to tourism and recreation, followed by mining and farming. The activities are mainly conducted by third parties through a formal concession system. This system enables DOC to monitor the use of the West Coast's natural resources and ensure they are being managed in a sustainable manner. In 2003, there were 682 third-party concessions on the West Coast for non-mining activities. The economic activity on conservation lands generated value-added of $117.7 million in 2003 and total output of $221.6 million (Department of Conservation, 2006).

Honey production and related products

As discussed in indicators 2.e and 6.1.g, the forest estate is an important source of pollen and

Figure 6.1: Overseas visitor arrivals to New Zealand (1996–2014)



Source: Statistics New Zealand, Infoshare, 2014 nectar for apiarists. Several indigenous tree species have been identified as having favourable traits for honey production, and a range of monofloral honeys have been developed. These include mānuka *(Leptospermum scoparium),* southern rātā *(Metrosideros umbellata)* and tāwari *(Ixerba brexiodes)*. Mānuka honey is particularly favoured as it contains a number of natural compounds with recognised antibacterial properties, which enable it to be used in medical dressings and for treating burns.

Nationally, New Zealand produced 17 825 tonnes of honey in the 2012/13 season (Ministry for Primary Industries, 2013). Estimating the proportion of honey derived from forests and pasture species would be difficult because apiarists frequently move their hives into forested areas or locate them on the bush line in early spring, so they can access nutrients from the bush. Indigenous forests provide the hives with an early season nectar flow that is critical for building up bee colonies.

Honey exports have been growing progressively over the past decade and reached 8000 tonnes in the 2012/13 season. As discussed in Indicator 6.1.g, the value of honey exports was $170.5 million in the December 2013 year. The industry also produces a range of secondary products, for both the domestic and export market. These include: beeswax, live bees and queen bees.

Possum fibre and related products

The past 15 years has seen renewed commercial interest in the trapping of the Australian brushtailed possum *(Trichosurus vulpecula)*. Originally introduced with the objective of building a fur trade in New Zealand, the possum population expanded rapidly (due to a lack of predators) and is now estimated to be 30.3 million (Warburton et al, 2009). The species is a significant threat to New Zealand's native flora and fauna.

The revival in trapping stems from consumer interest in the inherent thermal qualities of possum fibre and new manufacturing techniques that enable possum fibre to be blended with merino wool, to create a light-weight, high-quality yarn.

As discussed in Indicator 2.e and 6.1.g, this fibre blend has become an established part of the yarn and high-quality fashion industry. In 2008, the merino–possum yarn and fashion sector was estimated to be worth $50 to $70 million per annum, and a 2010 estimate put turnover at $100 million per annum (Adams, 2010; Warburton, 2008).

A small trade in fur skins continues and there is also interest in possum meat as a high-quality pet food.

Game meat

Commercial and private hunters have sourced game meat from New Zealand's forested areas for more than a century. As outlined in Indicator 2.e, commercial hunters harvested between 10 000 and 30 000 feral deer per annum during the 1990s and the early 2000s. Numbers fell away in 2002 and 2003, with a fall in venison prices and a tightening of export controls. Commercial hunting remains at relatively low levels and could be described as a niche industry. In 2012, four processing companies handled most of the feral deer that were commercially hunted.

Recreational hunting remains a significant activity. Research by Lincoln University estimates that "there are in the order of 40,000 or more game hunters, who spend about 1.3 million days per year hunting" (Kerr, 2012, p 3).

Guided hunting

New Zealand has developed an international reputation as a destination for game hunting. The industry has developed over the past 20-to-25 years, and now includes a number of game estates and reserves (large fenced areas of indigenous forest, non-forest trees and vegetation and open grasslands), where selected stock are introduced. Game estates can be well over 2000 hectares in size, and are comparable to open range hunting. Hunters are attracted by New Zealand's wilderness experiences and the range of species that can be hunted. These include chamois, red and sika deer, tahr and wapiti.

All of these species have been introduced over the past 150 years and have established in New Zealand's forest and conservation lands.

> The costs of hunting on a game estate vary depending on the client's aspirations. It can range from $200 [NZ] for a hind to $10 000 [NZ] for a top trophy, with the average being $2000 to $3000 (Orman, 2006, pp 8–9).

Earnings from the game estate and guided hunting industry were estimated to be worth $15 million to $20 million per annum in the 2000 to 2005 period (Earl, 2001; McKinnon, 2006). More recent estimates of earnings are in the vicinity of $25 million per annum. In 2013, the Game Animal Council Act established the Game Animal Council, which has a range of functions in relation to game animals including the improvement of hunting opportunities and setting minimum standards for hunting guides and estates.

In addition to commercial game hunting, New Zealand receives substantial numbers of visitors who hunt with friends and family, or who arrange their own hunting permits. While these visitors are not recorded in the game industry financial estimates, they do contribute to local economic activity through expenditure on accommodation and other services.

Sphagnum moss collection

A regionally important activity for the West Coast of the South Island has been the collection of sphagnum moss *(Sphagnum cristatum)* (see Indicator 2.e). A large percentage of this crop is exported to Japan and Southeast Asia, where the principal customers are orchid growers. Exports during the 1990s ranged between $13 million and $18 million per annum but have declined in the past decade. Exports fell to $9 million in the June 2007 year and have been in the range of $3.9 million to $4.5 million since 2011 (Plant and Food Research, 2013).

Future crops

Several innovative research and investment efforts are under way to commercialise the extraction of native plant extracts for food ingredients, medicinal purposes and skin-care products, and to extend the range of secondary crops that can be grown within the forest estate. Indicator 2.e provides details on the prospects for these new opportunities.

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Indicator 6.1.c Revenue from forest-based environmental services

New Zealand's forests provide a broad range of environmental services that benefit both local communities and the national economy. These services include erosion mitigation, the filtering of nutrients, the protection and enhancement of biodiversity, carbon sequestration and recreational health benefits. While New Zealanders place a high priority on these services, they have generally been treated as free or public goods. The exceptions to this have been targeted initiatives for catchment management (for erosion and flood protection) and the introduction of the New Zealand Emissions Trading Scheme (which provides tradable carbon credits).

Within New Zealand, debate is growing on environmental services (frequently referred to as ecosystem services) and how New Zealand can maintain its natural capital through policy actions and initiatives. This dialogue has been supported by an increasing body of research on the value of non-market services from New Zealand's natural resources and the primary sector. This work is increasing community and political awareness of these issues, particularly in the context of soil and water management.

Quality of information: L/M

Progress against indicator: ▲

Rationale

This indicator provides information about forest-based environmental services for which markets and revenues are emerging or currently exist. Revenues from forest-based environmental services can be an important component of the economic value of forests.

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Mitigation of soil erosion

> The benefits provided by erosion control are a key ecosystem service in New Zealand because of the widespread occurrence of many different forms of erosion. (Basher, 2013, p 363)

New Zealand has naturally high rates of erosion, which are compounded by extreme weather events. "Hill country erosion is estimated to cost New Zealand between $100 and $150 million per year" (Dominati and MacKay, 2013, p 1) through lost production, damage to infrastructure and sedimentation. One of the most effective measures for maintaining soil cover and fertility on properties is to utilise forest and shrub cover.

> Storm damage surveys since 1970 show that the area of soil eroded by storms is consistently less where forest is planted, scrub is allowed to revert or bush is retained, than under pasture. Reductions are mostly in the range of 50% to 90%. (Blaschke et al, 2008, p 63)

Erosion management has been a public policy issue for over 80 years, and there have been several programmes to support landowners to modify their land use practices (particularly on hill country properties). Regional councils have continued this work and are engaging with landowners and communities in vulnerable catchments. Central government has put in place several targeted programmes for erosion control:

- The Erosion Control Funding Programme (ECFP) (previously the East Coast Forestry Project) was initiated in 1992. The programme targets severely eroded properties with high sediment yields in the Gisborne (East Coast) region of the North Island. The ECFP uses grants to establish plantations and wide spaced plantings and encourage the reversion of land to indigenous forest. In 2014, about 42 000 hectares have been treated.
- The Sustainable Land Management Hill Country Erosion Programme was introduced in 2006/07. This initiative is a partnership between central government and regional councils to support hill country farmers in treating soil erosion through sustainable land management practices. Management tools include whole farm plans, the use of forestry or wide spaced plantings and land

retirement (through natural reversion to indigenous forest).

These programmes recognise that avoiding erosion has significant, long-term benefits for the productive capacity of New Zealand's pastoral and forest lands, through improving water quality and protecting the "built environment" in rural and urban communities. (See Indicator 4.1.a.)

Carbon sequestration and emissions trading

The Government operates the New Zealand Emissions Trading Scheme (ETS) to help meet its international climate change obligations and help reduce New Zealand's net greenhouse gas emissions to below business-as-usual levels. The key sectors of the economy are being progressively brought into the scheme, and market mechanisms set the price of tradable carbon units.

The forestry sector entered the ETS in January 2008, and owners of post-1989 forests (on eligible land) have been able to register their holdings and account for changes in the carbon stocks of their forests since this date. The ETS recognises the ability of forests to sequester carbon dioxide from the atmosphere and store it in branches, tree trunks, leaves, roots and the soil. At the time of harvest, owners repay an equivalent number of units to the carbon that has been lost through harvesting.

This mechanism recognises the important role that new forests (those established after 1989) play in sequestering carbon (and offsetting emissions in other sectors). These forests are around a third of the current plantation estate, and future plantings will add to this total. While the forest owner has to repay the carbon credits, they may gain cash flow by trading carbon credits throughout the rotation. This additional revenue has operational advantages (in terms of matching expenditure to income) and reduces the effective holding costs of investors. Managing carbon sequestration credits accrued in multi-aged forests also enables forest owners to balance harvesting emissions with sequestration gains in younger stands, adding real value to forest holdings.

In the initial years of the scheme, trading saw a carbon price of around $20.00 per New Zealand unit tonne of carbon dioxide equivalent). However, over the past three years (2012–2014), there has been significant price volatility and a decline in overall price. As of mid-2014, the price of a New Zealand unit was around NZ$4.00.

Research undertaken by Patterson and Cole (2013) ranked climate change regulation as the third most valuable ecosystem function performed by forests in New Zealand.

Other initiatives

In 1977, the Government established the Queen Elizabeth II National Trust to protect significant natural and cultural features on private land, using open space covenants. The Trust acts as a perpetual trustee to ensure the covenanted areas remain protected. These areas include wildlife habitats, remnants of natural forest, cultural sites and grasslands. The Trust provides legal and management assistance to landowners in establishing the covenanted areas. Financial assistance may also be available to partially fund fencing costs and similar work. As at 30 June 2014, 180 845 hectares were protected through 4350 registered or approved covenants.

In 2007, the Government approved the Afforestation Grant Scheme (AGS), which ran for five years (from 2008/09). The AGS was part of the Government's package of climate change initiatives and had the twin objectives of increasing carbon sequestration and enhancing land use sustainability. The criteria for assessing applications had a weighting towards applications that could show tangible benefits for soil conservation, improved water quality and enhanced biodiversity. The AGS was of particular benefit to hill country farmers, who were seeking to use plantings as both an economic investment and as a tool to manage soil and water issues.

Environmental services: A developing area of public debate

The role of environmental services is emerging as an important planning and policy issue in New Zealand. Government agencies, such as the Department of Conservation and Ministry for the Environment, are taking on board the need to accurately assess New Zealand's natural capital, and to develop valuation methods that can measure non-market goods and services.

> The first steps in preventing further decline in ecosystems (and the services they provide) are to recognise that they have economic values, and to attempt to measure at least some of

> them. Armed with this information, the Department [of Conservation] hopes to make better-informed conservation decisions, and increase public awareness of what is at stake… (Department of Conservation, 2006, p 19)

The development of base-line environmental data is occurring at both a local and national level, with councils, government agencies and key industry groups exploring methodologies for valuing the benefits of ecosystems. In recent years, choice modelling and contingent valuation methods have been used to value biodiversity, water quality enhancement and recreational values. The direction of this analysis is illustrated in a 2006 study of the water supply services provided by the 22 000 hectare Te Papanui Conservation Park, near Dunedin in the South Island.

> In approaching a valuation of Te Papanui's water supply, Butcher Partners Ltd asked this question: if the water supply were suddenly removed, how much would it cost the biggest users to get water from somewhere else?
>
> The resulting value of the water supply was $11 million a year (in 2005 dollars) to provide water for Dunedin residents, hydro-electricity generators in the region, and to irrigate the fields of Taieri farmers. This figure equates to a one-off payment in 2005 of $136 million. (Department of Conservation, 2006, p 13)

The need for this type of work is also being recognised by commercial enterprises and community organisations. Several project assessments have been undertaken in recent years that have incorporated non-market environmental services as part of their analysis. As the New Zealand public becomes more familiar with this type of assessment, environmental values are likely to play a larger role in negotiations on resource management issues.

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Indicator 6.1.d Total and per capita consumption of wood and wood products in roundwood equivalents

Consumption of wood products is estimated using import, exports and production data. Total apparent consumption, and apparent consumption per 1000 capita, have been slowly trending down, with minor year-on-year variation during the period from 2007 to 2012 reflecting general economic conditions applying at the time. For 2014, the total consumption and consumption per 1000 capita increased to 8.9 million and 1975 cubic metres respectively.

Quality of information: M/H

Progress against indicator: ▶

Rationale

This indicator provides information on consumption, including consumption per capita, of wood and wood products. It provides an indication of trends and changes in wood usage within New Zealand and illustrates one aspect of society's dependence on forests as a source of raw materials.

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The indicator can be interpreted as apparent domestic consumption of various and/or all wood and wood products. Conceptually, this is measured as: Apparent domestic consumption = reported production + (reported imports – exports) + changes in stocks. (It should be noted that, in general, in the New Zealand reporting, no allowance is made for stock changes.)

Consumption per 1000 capita equals apparent gross domestic consumption in the reference period divided by estimated mean population (in 1000s) for the same reference period. Table 6.5 provides figures for 2004 to 2014 for domestic consumption of roundwood.

Apparent domestic consumption and per capita consumption data are available for a range of wood and wood products. The products for which MPI reports apparent consumption are: roundwood, sawn timber, wood pulp, paper and paperboard, plywood, particleboard and fibreboard. An example of the available time series information (for sawn timber) is given in Table 6.6.

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Table 6.5: Estimated domestic consumption of roundwood (2004–2014)

Year ended March	Mean NZ[1] population (000)	Production (000m³)	Imports[2] (000 m³)	Exports[3] (000 m³)	Total apparent consumption (000 m³)	Apparent consumption per 000 capita (m³)	Consumption per 000 capita (5-year moving average) (m³)
2004	4 045	20 910	2 330	14 590	8 650	2 138	2 024
2005	4 101	19 333	2 410	13 458	8 254	2 020	2 045
2006	4 148	18 896	2 507	13 616	7 787	1 877	2 016
2007	4 198	19 974	2 478	13 979	8 473	2 018	2 026
2008[4]	4 241	20 481	2 755	14 213	9 023	2 127	2 036
2009[4]	4 281	18 937	2 373	14 434	6 876	1 606	1 930
2010[4]	4 332	22 042	2 153	17 460	6 735	1 555	1 837
2011	4 381	25 131	2 437	19 796	7 772	1 774	1 816
2012[4]	4 415	26 070	2 469	20 707	7 832	1 774	1 767
2013[4]	4 444	28 164	2 377	22 970	7 570	1 704	1 682
2014	4 489	30 258	3 384	24 776	8 866	1 975	1 756

Notes: 1. Estimated resident populations from 2001–06 have been revised in light of results from the 2006 Census.
2. Imports do not take account of the use of sawmill residues in the country of origin.
3. Exports are adjusted to net roundwood to account for the use of sawmill residues.
4. Includes an estimate – newsprint exports estimated because data withheld by Statistics New Zealand for confidentiality reasons.
5. This table updates Table D8 of New Zealand Forestry Statistics 2000, Ministry of Agriculture and Forestry (2001).
6. No account is taken of changes in stock levels.

Source: Ministry for Primary Industries, 2014a.

Table 6.6: Estimated production, imports, exports and consumption of sawn timber (2004–2014)

Year ended March	Mean NZ population (000)	Production (000 m³)	Imports (000 m³)	Exports (000 m³)	Total apparent consumption (000 m³)	Annual consumption per 000 capita (m³)	Consumption per 000 capita (5-year moving average) (m³)
2004	4 045	4 222	42	1 624	2 640	653	627
2005	4 101	4 409	50	1 847	2 612	637	627
2006	4 148	4 273	58	1 818	2 512	606	626
2007	4 198	4 333	51	1 938	2 446	583	627
2008	4 241	4 382	56	1 771	2 666	629	621
2009	4 281	3 651	42	1 739	1 953	456	582
2010	4 332	3 742	38	1 916	1 864	430	541
2011	4 381	4 016	41	2 053	2 004	457	511
2012	4 415	3 886	44	1 928	1 994	452	485
2013	4 444	4 019	44	2 117	1 946	426	447
2014	4 489	3 936	325	2 024	2 238	498	455

Notes: See under Table 6.5.

Source: Ministry for Primary Industries, 2014b.

Indicator 6.1.e Total and per capita consumption of non-wood forest products

New Zealand's forest estate provides opportunities for game meat, possum fur, honey and herbs, but the harvest levels are limited and there is a low reliance on this resource by individuals and households.

The hunting of feral deer, goats and pigs is a popular past time for a section of the community, but the meat represents only a small proportion of the protein intake of the New Zealand population. Households have some reliance on the forest estate for honey. On average, New Zealanders consume about 1 kilogram of honey per annum. New Zealand's forests were traditionally used by the Māori population as a source of berries, herbs and nuts. Some harvesting of berries and herbs continues. The harvest levels are considered to be small, although interest in the use of traditional foods and medicines, for private and commercial use, is growing.

The forest estate supports a small sphagnum moss industry but most of this harvest is destined for overseas markets rather than domestic consumption. This is also the case for the possum trapping industry. The fur and skins are used in high-value fashion garments, which are primarily exported or sold to international visitors. A recently developed merino–possum yarn is generating increased domestic interest in possum fibre, and it is becoming common to see these garments in local retail stores.

Quality of information: L

Progress against indicator: ▶

Rationale

This indicator provides information on the consumption of non-wood forest products. The quantity of non-wood products consumed illustrates society's dependence on forests as a source of these products.

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Limited statistical information exists on the consumption of non-wood forest products in New Zealand, particularly game meat and wild foods, as they are normally harvested for personal use.

> Whilst [the New Zealand Food Safety Authority] is reasonably confident that it knows the range of wild foods that are harvested, there is a lack of reliable and up to date information on harvesting activities. (NZFSA, 2007, p 15).

Some secondary information is available through hunting organisations, nutritional studies and the companies that process game meat and wild foods. This information indicates that wild foods are a small component of most New Zealanders diet. In saying this, it is important to recognise that, for a section of the Māori population, the collection of wild foods (from the forest and marine environment) continues to be a high priority.

Game meat consumption

The principal game animals harvested in New Zealand are deer, goats (including chamois and tahr), pigs and rabbits. Each of these species was introduced to New Zealand for their meat and hides. They have become established across the country, and their grazing patterns pose a threat to the natural ecosystems in which they now roam.

Of the seven deer species established in New Zealand, red deer are the most commonly hunted, followed by Sika deer and fallow deer. A limited number of surveys have been conducted on the number of deer harvested by recreational hunters. Work in the early 1990s estimated that the annual harvest (using ground-based hunting techniques) was roughly 50 000 head per annum (NZFSA, 2005). Anecdotal evidence from the New Zealand Deerstalkers' Association indicates that "90% of what is hunted ends up on the table" (NZFSA, 2007, p 16). Only a small percentage of the carcasses brought out by recreational hunters are sold.

Commercial harvesting of deer from conservation lands and the forest estate was discussed in Indicator 2.e. In 2012, four processing companies handled most of the feral deer that were commercially hunted.

A significant proportion of the annual cull of feral goats is for pest control rather than human consumption. Past surveys indicate there are several hundred thousand feral goats, and that they thrive in scrub-covered hill country on both conservation and private farm land (NZFSA, 2005). The browsing habits of feral goats pose a risk to indigenous plants and forest undergrowth (Department of Conservation, 2006). No recent studies have been undertaken on the number of feral goats culled annually. An assessment in the early 1990s estimated that 68 500 were culled over one season (57 000 by private hunters and the remainder by government hunters) (NZFSA, 2005). Two of the favoured hunting species, chamois and tahr,[33] have a combined harvest of nearly 2000 to 3000 per annum. They are mainly hunted for trophy heads rather than food consumption (Fraser, 2000; NZFSA, 2005).

Feral pigs "inhabit forest and scrublands, and are prevalent on rough hill-country farmland", covering around 34 percent to 37 percent of New Zealand (NZFSA, 2005, p 26). Most of the feral pigs are harvested from private farmland and plantation forests (Fraser, 2000; TBfree New Zealand, 2013). The annual cull was estimated by Nugget (1992 in NZFSA, 2005) to be roughly 100 000 per annum.

Data on game meat consumption is limited and mostly dated:

- Venison was reported to be consumed by 0.4 percent of respondents in the 1997 National Nutrition Survey, but data did not differentiate between game and farmed venison (NZFSA, 2005).
- The 1997 National Nutrition Survey contains no records representing consumption of goat, tahr or chamois (NZFSA, 2005).
- While the National Nutrition Survey found that 38 percent of the population consume pork during any 24-hour period there was no data on what proportion was derived from feral pigs (NZFSA, 2005).

Consumption of honey

New Zealand's honey production has averaged 12 524 tonnes a year over the 2008 to 2013 period (9267 tonnes per annum over 2001–07). Domestic consumption is estimated to be 5000 tonnes to 6000 tonnes per annum. The additional volume is exported, principally to the United Kingdom, Hong Kong/China, Australia and Singapore (Coriolis Limited, 2012; HortResearch, 2007; Plant and Food Research, 2013). The apiculture industry also produces beeswax, pollen and propolis (a resin marketed for its health benefits).

As discussed in Indicator 2e, the industry has seen steady production growth over the past decade, driven by strong international demand particularly for mānuka honey. Hive numbers have increased since 2005/06, and the number of registered beekeepers has grown over the 2009–2013 period (Ministry for Primary Industries, 2013). The industry has become a significant exporter, and the principal companies are some of New Zealand's most innovative, with research into the medicinal and pharmaceutical properties associated with honey.

The 1997 National Nutrition Survey found that the average consumption of honey was around 1.06 kilograms per person per year (NZFSA, 2005). As discussed previously, the statistics collected on honey production do not differentiate between the pollen and nectar sources, such as white clover or indigenous stands of mānuka. This would be a complicated exercise, as hives can be located in a variety of pasture and bush situations during a single season.

Possum fibre and associated products

The Australian brushtailed possum (*Trichosurus vulpecula*) was introduced to New Zealand in an effort to establish a commercial trapping industry. The first recorded shipment of possum pelts occurred in 1921. The market for pelts has been variable and driven by overseas trends in the fashion industry, the public view of fur products and the preference of international buyers. During periods of depressed pelt prices, the quantity of skins exported fell below 500 000, while in peak years (when returns were sufficient to provide a reasonable living for trappers) it exceeded 3 million. The negative image of fur in the 1980s and 1990s saw demand fall away.

The renewed interest in possum fur over the past 15 years has been driven by the development of a new fibre blend (incorporating possum and merino fibres) and local companies taking more control of processing

33 Tahr numbers are managed under Department of Conservation operational control plans.

and garment development. A description of the recent changes in the industry has been provided in Indicator 2.e. While the level of domestic processing has increased, the industry still depends on the export market to sell much of the yarn and final fashion garments. Blended possum and merino products are increasingly seen in New Zealand retail outlets. The blended fibre is used in products such as gloves, scarves and hats, which emphasise its heat-retention properties.

There has been limited use of possums as a game meat, because the animal can be a carrier of the tuberculosis vector and has been implicated in the spread of the disease to farm animals such as cattle and deer. Ongoing efforts by TBfree New Zealand and the Department of Conservation have been successful in reducing the infected population and enabling specific areas to be declared disease free. Possum meat is being used mainly in the production of pet food. The industry is in the initial stages of development, and the demand is coming more from the export market than local consumer interest.

Berry, herb and nut consumption

Berries, herbs and nuts were traditionally harvested by Māori as a component of their diet. Information is not collected on customary harvest levels (NZFSA, 2005).

Sphagnum moss usage

The sphagnum moss industry is export focused, with most of the harvest being supplied to overseas customers. (See Indicator 2.e.)

Whitebait harvesting

Whitebait is the generic term for the juvenile form of five fish species from the *Galaxiidae* family. The Māori population traditionally caught whitebait, and it has become one of New Zealand's aquatic delicacies. The harvesting of whitebait is controlled by the Department of Conservation and is limited to a short season in spring (about three months). Whitebait can be found in many of New Zealand's major rivers and streams, but its presence has generally declined in areas of extensive pasture land (that were drained in previous generations).

Intact forested catchments, with their higher water quality, continue to be a major source of whitebait. One of the best known areas for whitebait is South Westland (on the West Coast of the South Island), where most of the streams have their source within the conservation estate.

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Indicator 6.1.f Value and volume in roundwood equivalents of exports and imports of wood products

Forestry is the third-largest export earner for New Zealand, with merchandise trade exports for the June 2014 year valued at NZ$5.2 billion. In roundwood equivalent terms, nearly 82 percent of current harvested volume (25.2 million cubic metres) is exported either as logs or as processed product. Imports of wood and wood-based products are worth around $1.5 billion and, based on the product mix, contain the equivalent of 3.4 million cubic metres of roundwood.

Quality of information: H

Progress against indicator: ▲

Rationale

The indicator provides information about the value and volume of a country's exports and imports in wood products and their contribution to the domestic economy. International trade in wood products may be a significant factor in the management, commercial use and economic value of forests.

NEW ZEALAND'S REPORT

Roundwood removals (currently about 30 million cubic metres per year) far exceed New Zealand's domestic consumption of wood products (see Indicator 6.1.d). At present, in excess of 56 percent of the annual harvest (over 17 million cubic metres) is exported as logs and, in total, over 80 percent (nearly 82 percent for the June 2014 year) of the harvest volume is exported either as logs or processed product. The 44 percent of harvest that is not directly exported as logs is currently processed into a range of products for both domestic and export markets. While for the processed products the split between domestic consumption and export varies depending on the specific product, across all processed products around half of the total volume (in roundwood equivalent terms) is exported.

New Zealand has good statistical datasets covering the trade of forestry products. The annual values and volumes of these exports from 2008 to 2014 (June year) are provided in figures 6.2A and 6.2C.

New Zealand imports a little less than NZ$1.5 billion of wood products per year. The values and volumes of these imports are provided in figures 6.2B and 6.2D.

The four graphs show the main features of New Zealand's international trade in forest products over the past 14 years; falling export volumes (as roundwood equivalents) and export returns between 2001 and 2008, principally because of reduced volumes of log exports. This period of decline in log exports is then followed by a period of dramatic growth in both the volume and per unit value of log exports, about a compound 12 percent per annum increase in volume and a similar compounded increase in the per unit value, between 2008 and 2014. As a result of this, between 2008 and 2014, the sector's export earnings increased from $3.2 billion to $5.2 billion. Virtually all of the change in forestry's export fortunes over this six-year period is due to log exports. The annual volumes and the values of processed product exports (sawn timber, wood pulp, paper, panel and "other" products) have been virtually constant and unchanging throughout the 14-year period.

Imports for the first four years (2001 to 2004) saw an increase in the volume and value associated with growth in paper imports. That, in turn, reflects a static local paper industry that has increasingly been focused on producing a limited number of paper grades. From 2004 to 2013, imports in volume terms were relatively static at about 2.5 million cubic metres of roundwood equivalent per annum. During this period, there was a small upward trend in the total value of imports, reflecting growth in the unit value of "other" forest products imports.

The 2014 year has seen an increase in imports in volume and value terms. This increase is associated with imports of sawn timber and panels and is possibly associated with the ongoing rebuild of Christchurch following the earthquake damage in 2010/2011. Despite the recent growth in the volume (roundwood equivalents) of sawn timber imports, sawn timber is not a big component of overall imports. Paper and panel products typically account for over 85 percent to 90 percent of the roundwood equivalent volume of imports, with paper and "other" products accounting for about 90 percent of the value. In roundwood terms, the volume of imports is only 14 percent to 20 percent of the volume of exports, while in value terms imports are 18 percent to 28 percent of the value of exports.

Source of information

Ministry for Primary Industries (2014) *Forestry: forestry production and trade statistics detail the production, trade, and other forestry activities in New Zealand*. **http://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/forestry/**. Accessed 5 May 2015.

Figures 6.2.A, 6.2.B, 6.2.C and 6.2.D – Values and volumes of exports and imports of wood products

Figure 6.2.A: Value (actual NZ$000) of New Zealand exports of wood products

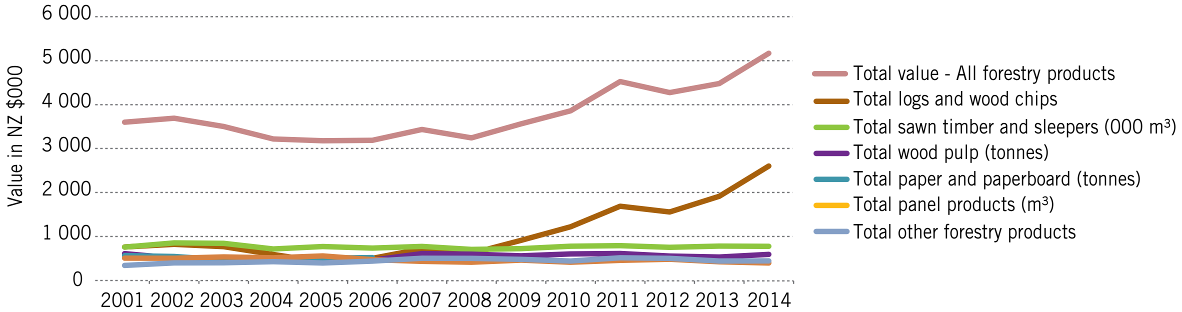


Figure 6.2.B: Value (actual NZ$000) of New Zealand imports of wood products

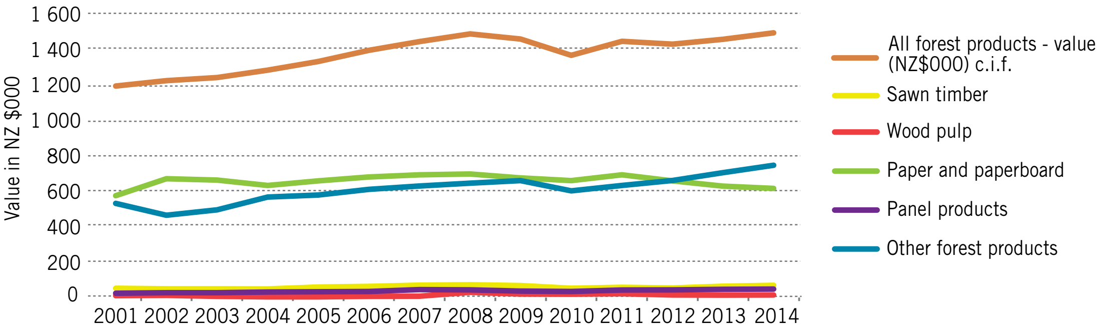


Figure 6.2.C: Volume (in roundwood equivalent 000 m³)) of New Zealand exports of wood products

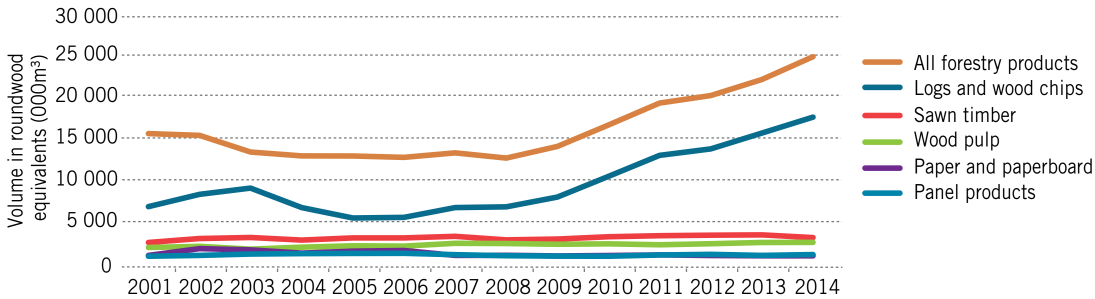
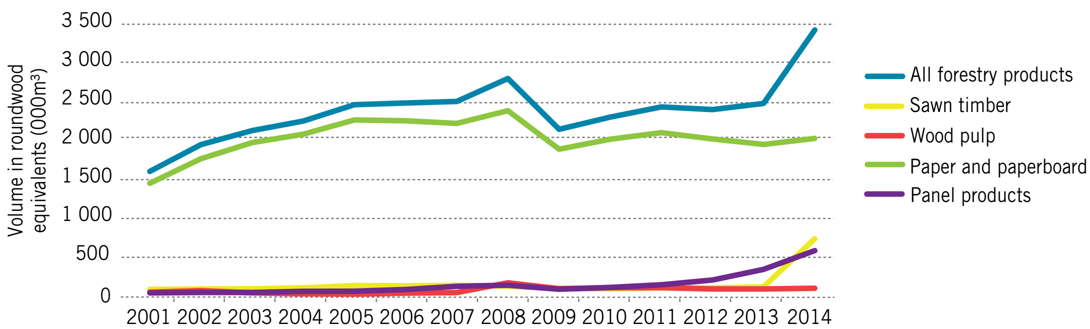


Figure 6.2.D: Volume (in roundwood equivalent 000 m³) of New Zealand imports of wood products



Indicator 6.1.g Value of exports and imports of non-wood forest products

New Zealand exports a limited range of non-wood forest products. The principal categories of exports are natural honey ($170 million), live bees ($4.4 million), sphagnum moss ($4.0 million) and fashion garments made from a blend of possum fibre and merino wool.

Non-wood forest products can also be found in a range of processed goods, including food flavourings and skin-care products (derived from plant extracts), and medical applications (sourced from natural products such as mānuka honey).

Imports of non-wood forest products are minimal. Only small quantities of natural resins, fur-skins and honey are imported each year.

Quality of information: L/M

Progress against indicator: ▶

Rationale

This indicator provides information about the value of a country's exports and imports of non-wood products and their contribution to the domestic economy. International trade in non-wood products may be a significant factor in the management, commercial use and economic value of forests.

NEW ZEALAND'S REPORT

In the 2013 calendar year, New Zealand's two-way merchandise trade (imports and exports) amounted to NZ$96.4 billion.[34] Non-wood forest products made up nearly 0.25 percent of this total.

Honey (and bee product) exports and imports

As discussed in indicators 2.e and 6.1.b, apiarists use both the forest estate and forest margins as sources of pollen and nectar.

The value of natural honey exports (in nominal terms) has increased from $27 million to $170.5 million between 2003 and 2013 (December year figures[35]), while imports over the same period have been less than $1.2 million per annum (with a low of $24 000). The export figures do not differentiate between pasture- and forest-based honeys, and in some cases they draw on both nectar sources.

The increase in honey exports has been driven by strong international demand (particularly for high-quality honeys), the growing reputation of mānuka honey and increasing demand from China. Chinese demand has grown, particularly since the introduction of the New Zealand–China Free Trade Agreement. The volume of honey exported in retail packs has increased significantly since 2007, while bulk honey exports have been declining over the past five years. The upturn in export demand has meant that "New Zealand suppliers have been able to invest more in the value-added component of their business" (Ministry for Primary Industries, 2013, p 4).

In addition to natural honey exports, apiarists supply overseas customers with live bees, beeswax and pollen. The export value of live bees and beeswax in the 2013 calendar year was $6.4 million. Imports of beeswax stood at just $80 000 and there were no imports of bees (Statistics New Zealand, 2014b).

These figures do not include situations where honey and honey extracts are used in the production of value-added products, such as cooking ingredients, pharmaceuticals or medical applications. One of New Zealand's monofloral honeys (based on mānuka) is gaining an international reputation as an antibacterial substance. Long-term research has been undertaken on the level of antibacterial activity in mānuka honey, and several commercial products have been developed and are now being exported.

34 This figure includes all merchandise trade in the December 2013 year. Merchandise trade covers exports and imports of goods that alter the nation's stock of material resources.

35 "Free on Board" export value – the value of goods at New Zealand ports before export (source: Statistics New Zealand, 2014b).

Possum fibre

The past 15 years have seen growing commercial interest in the fibre of the Australian brushtailed possum *(Trichosurus vulpecula)* for yarn manufacturing and the production of fashion garments. This interest is based on the thermal properties of the fibre and recent advances in yarn manufacturing, which have enabled it to be blended with merino to create a light-weight but high-quality yarn for clothing and textile production. The interest in possum fibre is helping to underpin the trapping industry and supports efforts to control possum numbers in New Zealand's forests.

The 2008 country report noted that the blending of possum fur and merino had become an established part of the New Zealand yarn industry and that the total value of the sector was estimated to be worth "in the order of $50 to $70 million per annum" (Warburton, 2008, p 8). More recent figures estimate the sector to have a turnover of around $100 million annually (Adams, 2010).

The growth in the sector has been supported by both domestic and overseas demand. Overseas visitors to New Zealand have been major purchasers of possum–merino products, such as jerseys and scarves. These purchases are recorded as domestic sales and are not included in the export figures. Blended yarns and textiles are being exported to a range of overseas customers and countries, with particular interest from China. Because these products are in a semi-processed or processed state, the trade database records the finished product rather than the raw material. This prevents an accurate estimate of possum-fibre exports.

Possum skins and pet food

The trade in possum skins saw progressive growth in the early to mid-2000s, with export activity increasing from $0.5 million dollars in the 2002 calendar year to $2.2 million in 2007 and $2.3 million in 2008. Export activity dropped during the global economic crisis with returns falling to only a few hundred thousand dollars in recent years. Imports of possum skins are negligible.

Previous reports have commented on the potential for developing export pet-food lines based on possum meat. Interest in this opportunity continues, and niche product lines have been developed. Separate figures are not available for the export of possum-derived pet food.

Sphagnum moss exports

The sphagnum moss industry has a strong focus on the export market, with a significant share of production going to customers in Japan and Southeast Asia (see indicators 2.e and 6.1.b). The major customers for sphagnum moss *(Sphagnum cristatum)* are orchid growers, as the moss can hold twenty times its own weight in water. Sphagnum moss also has medicinal uses, as it is a naturally sterile substance.

Export returns were between $13 million and $18 million during the 1990s and the early 2000s. Returns have declined over the past decade and have been between $3.9 million and $4.5 million since 2011 (Plant and Food Research, 2013). Part of this decline relates to the high value of the New Zealand dollar and competition from other Pacific Rim producers.

New Zealand imports only small quantities of mosses and lichens.

Foliage and live plant exports

New Zealand has a developing trade in the export of foliage, cut flowers and plants. Native plants have a small role in these exports. New Zealand has several species of *Pittosporum* that are valued for their

foliage by flower arrangers. Between $1.6 million and $1.8 million per annum of *Pittosporum* foliage was exported over the past four years (Plant and Food Research, 2013).

Other traded products

There is increasing interest in the use of native plant extracts in skin-care and medicinal products. Research is ongoing in this area, and several companies are working to develop overseas markets for these new product lines. Separate trade data is not available on these exports.

New Zealand has a small trade in natural gums and resins, a proportion of which are derived from forest and bush lands.

Sources of information

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Indicator 6.1.h Exports as a share of wood and wood products production, and imports as a share of wood and wood products consumption

As of 2014, over 80 percent of the annual volume of wood harvest in New Zealand is exported either as logs (over 56 percent of harvest) or in the form of locally processed wood products (sawn timber, pulp and paper, panel products) that is then exported. The wood material required to produce the wood products imported by New Zealand in the year to June 2014 was equivalent to around 11 percent of the domestically harvested volume.

Quality of information: M

Progress against indicator: ▲/▶

Rationale

This indicator provides information on the relative importance of international trade in wood and wood products to domestic production and consumption. Wood and wood product exports can be a significant source of revenue for domestic economies. Imports may supplement or substitute for production from domestic forest sources.

NEW ZEALAND'S REPORT

New Zealand has a well-managed sustainable plantation forest estate of some 2.1 million hectares (gross) – the net figure is 1.7 million hectares. The extent of the commercial forest resource, the typical growth rates (cubic metres per hectare per annum) and the size of the New Zealand population (estimated to be 4.5 million as of May 2014), mean domestic demand accounts for less than 20 percent of total current production (see Indicator 6.1.d).

The country is highly dependent on international trade, and most of New Zealand's wood harvest is destined for overseas markets. Wood and wood products are the third-largest export industry in New Zealand. Over the 2007–14 period, revenue from wood and wood product exports, which were worth $3.2 billion a year in 2007 and $5.2 billion a year in 2014, accounts for between 8 percent and 10 percent of the country's merchandise exports (depending on the year and the value of other exports).

For the 2014 (June) year, the total harvest was 30.6 million cubic metres of which 25.2 million cubic metres (in roundwood equivalents) were exported as logs, poles, lumber, panel products, joinery, furniture, pulp, paper and other miscellaneous forest products.

New Zealand imports wood and wood products to meet some of its domestic requirements. In 2007, the product imported represented nearly 2.5 million cubic metres (in roundwood equivalents). For 2008, imported product was equivalent to 2.8 million cubic metres (roundwood equivalents). With the global financial crisis, this dropped to 2.1 million cubic metres for 2009. Imports then stabilised at around 2.4 million cubic metres per annum for the next four years. However, 2014 saw an increase in the level (roundwood equivalents) from 2.4 million to 3.4 million, despite the fact that local harvest in 2014 was almost 50 percent higher than in 2007 and total domestic consumption 10 percent lower (with apparent consumption per capita 14 percent lower than in 2007). Furniture, paper and paperboard are the main imported items.

In 2007, New Zealand's estimated domestic consumption was 8.4 million cubic metres. Per capita consumption was just over 2 cubic metres in that year and 2.1 cubic metres in 2008 (see Table 6.7). With the global financial crisis, per capita consumption dropped to 70 percent of that previously applying, and, since 2010, per capita consumption has slowly inched up around 1.7 cubic metres to 1.8 cubic metres per annum in the 2011–13 period. For 2014, per capita consumption increased significantly to 1.975 cubic metres per capita per annum – which is almost back to the levels applying before the global financial crisis.

Imports currently account for 30 percent of the volume of total consumption. An example of the type of information available for exports (and imports) is provided in Table 6.8.

Note that, since 2007, the values of paper and paperboard exports have been suppressed to comply with the confidentiality rules applied by Statistic New Zealand.

Sources of information

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Table 6.7: Estimated New Zealand production, imports, exports and apparent consumption of roundwood (2007–2014)

Year ended March	Mean NZ population (000)	Production (000 m³)	Imports (000 m³)	Exports roundwood equivalent (000 m³)	Total apparent consumption (000 m³)	Apparent consumption per 1000 capita (m³)
2007	4 198	19 974	2 478	13 979	8 473	2 018
2008	4 241	20 481	2 755	14 213^E	9 023	2 127
2009	4 281	18 937	2 373	14 434^E	6 876	1 606
2010	4 332	22 042	2 153	17 460^E	6 735	1 555
2011	4 381	25 131	2 437	19 956^E	7 772	1 774
2012	4 415	26 070	2 469	20 859^E	7 832	1 774
2013	4 444	28 164	2 377	22 970^E	7 570	1 704
2014	4 489	30 258	3 384	24 776^E	8 866	1 975

Note: E = estimate.
Source: Ministry for Primary Industries, 2014a.

Table 6.8: Exports of forestry products from New Zealand, years ended 30 June 2007 to 30 June 2014

Forestry products in roundwood equivalents (000 m^3)	2007		2008		2009		2010		2011		2012		2013		2014	
	Quantity	Value (NZ$000)	Quantity	Value (NZ$000)	Quantity	Value (NZ$000)	Quantity	Value NZ$000	Quantity	Value NZ$000	Quantity	Value NZ$000	Quantity	Value NZ$000	Quantity	Value NZ$000
Logs and wood chips	7 026	729 057	7 109	626 882	8 294	922 294	10 778	1 230 527	13 309	1 697 226	14 083	1 566 540	15 982	1 921 393	17 912	2 609 544
Sawn timber	3 557	783 402	3 139	716 289	3 234	733 035	3 515	789 268	3 640	801 559	3 703	762 976	3 741	792 359	3 416	786 888
Wood pulp	2 715	621 785	2 698	608 726	2 607	569 587	2 662	613 758	2 540	622 219	2 674	565 040	2 818	544 051	2 838	603 682
Paper and paperboard	1 269		1 279		1 209		1258		1 332		1 260		1 219		1 221	
Panel products	1 350	443 973	1 230	424 136	1 179	472 808	1 163	425 655	1 314	468 273	1 395	493 771	1269	435 987	1 360	406 669
Other forestry products		516 525		513 312		490 872		453 251		524 310		512 942		452 522		455 252
TOTAL VALUE	**13 610**	**3 440 200**	**12 984**	**3 249 023**	**14 379**	**3 566 708**	**16 963**	**3 862 311**	**19 603**	**4 526 843**	**20 500**	**4 277 596**	**22 429**	**4 483 808**	**25 183**	**5 169 497**
Total NZ merchandise trade		**33 301 308**		**38 453 309**		**41 011 193**		**38 995 831**		**44 234 328**		**44 892 891**		**44 112 959**		**49 398 765**
Forestry products – exports as a percentage of total merchandise exports		10.33		8.45		8.70		9.99		10.23		9.53		10.16		10.46

Source: Ministry for Primary Industries, 2014b.

Indicator 6.1.i Recovery or recycling of forest products as a percent of total forest products consumption

With the exception of paper, New Zealand has made limited progress in the recycling of wood products. Significant volumes continue to go to landfills. The recycling (or safe disposal) of preservative-treated timber is an issue New Zealand must address.

Quality of information: L/M

Progress against indicator: ▼/▶

Rationale

This indicator provides information on the extent to which forest products are recycled or recovered. Recycled and recovered products are an important source of wood fibre for many industries and may compete with, or substitute for, harvested wood. Such products can help meet the demand for forest products without increasing harvest levels.

NEW ZEALAND'S REPORT

Paper is the major forest product that is recycled in New Zealand and the only product for which recycling statistics are available. The annual tonnage of waste paper used in local manufacturing of paper and paperboard has been relatively static, but when coupled with the waste paper that has been recovered and exported, overall recovery of paper has been gradually increasing (see Table 6.9).

The total production of paper and paperboard for the year ended March 2014 was 749 314 tonnes. Based on the usage of waste paper in Table 6.10, the recycled component of production is around 30 percent. Total domestic consumption of paper is roughly 870 000 tonnes annually (Ministry for Primary Industries, 2014).

Little progress has been made in the recycling of waste timber and wood products (other than paper), with significant volumes going to landfills. In 2004, timber accounted for 14 percent of the then estimated 3.2 million tonnes of solid waste that went to landfills. This does not include waste disposal to cleanfill, construction and demolition waste landfill sites, or dedicated industrial waste landfills (Ministry for the Environment, 2007). More recent information indicates that timber still comprises at least 11 percent of the levied (nearly) 2.5 million tonnes nationally of solid wastes that are land filled annually.

Coping with numerous types of wood products, and finding reliable recycling suppliers, has presented problems to establishing recycling operations (InWood, 2005). Preservative-treated timber presents a new recycling (or disposal) issue for New Zealand, as the first significant volumes are beginning to reach the end of their (theoretical) life cycle.

Table 6.9: Waste paper exported or used for local paper and paperboard manufacturing (2006–2013)

Year ended December	Waste & scrap paper & paperboard exported (tonnes)	Waste paper used in local paper & paperboard manufacture (tonnes)
2006	242 299	222 062
2007	253 957	240 330
2008	261 309	260 064
2009	242 611	264 693
2010	240 300	245 456
2011	261 386	240 430
2012	255 419	241 308
2013	212 646	226 883

Source: Bartley, 2014.

A small and growing market has developed for the use of recycled indigenous timbers. These timbers are mainly recovered from the demolition of older buildings and houses constructed during the period when indigenous forests were the principal source of timber. The recycled timber is used in furniture manufacturing and (to a limited degree) in the construction of new houses.

Consumer demand for healthy living environments, along with regulatory demands for chemical free building products, is driving Scion's wood preservation team to develop bio-based alternatives to chemical wood preservatives.

In 2008, New Zealand passed into law the Waste Minimisation Act. This Act established a waste disposal levy that has been applied since July 2009 to waste disposed at disposal facilities. The levy has two purposes:

- to raise revenue for promoting and achieving waste minimisation;
- to increase the cost of waste disposal to recognise that disposal imposes costs on the environment, society and the economy.

The levy is currently set at $10 plus goods and services tax per tonne and generates a net income of nearly $25 million per annum. Half of this money goes to territorial authorities (allocated proportionally to their share of the population), to help them with minimising waste in their area. The remaining levy money (minus administration costs) is put into a fund to support waste minimisation activities around New Zealand.

Sources of information

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Marlborough Sounds, top of the South Island.

INDICATOR 6.2 INVESTMENT IN THE FOREST SECTOR

These indicators provide information on long-term and annual expenditures to enhance forest management, forest-based enterprises, and the knowledge and skills of people who are engaged in the forest sector. Maintaining and enhancing the long-term multiple socio-economic benefits derived from forests depends in part on investment in the forest sector, including both long-term capital investments and annual operating expenditures.

Indicator 6.2.a Value of capital investment and annual expenditure in forest management, wood and non-wood forest product industries, forest-based environmental services and recreation and tourism

Expenditure by the commercial forest industries is influenced by market conditions. These, both domestically and internationally, can only be described as being "challenging" in recent years. The dramatic growth in wood harvest in recent years (shown in Indicator 6.1.a) has been accompanied by a significant increase in investment in harvesting and transportation, but not in local processing (see Indicator 6.1.f and figures 6.2.a and 6.2b). Expenditure on forestry and logging in 2012 was 30 percent higher than in 2008. Expenditure in the pulp and paper subsector in 2012 was also a higher (7 percent) than in 2008, but investment spending in solid wood processing expenditure was at a high point in 2008, but in 2012, it was 10 percent lower. For non-wood forest products and the provision of environmental services, information on expenditure exists for some specific projects only.

After allowing for inflation, expenditure by the Government on all forestry-related activities is estimated to have been relatively static in real terms between 2005 and 2014.

Quality of information: L/M

Progress against indicator: ▶

Rationale

This indicator quantifies investment and expenditure in developing, maintaining and obtaining goods and services from forests. Maintaining and enhancing forests and their benefits often depends on regular investments in restoration, protection and management, as well as in operations, forest industries and forest-based environmental services. When the capacity to protect, manage and use forests is eroded through lack of funding, the benefits that forests provide may decline or be lost.

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Systematic information and estimates are available on the capital stock annual expenditure (and revenue) for the commercial (plantation) forest sector and for expenditure by the Crown and private sector on several specific forestry-related issues.

Expenditure on non-wood forest product industries, forest-based environmental services, recreation and tourism information collection is less systematic than is the case with the pure commercial material. Information that is collected and tagged as being forestry related frequently relates to specific (and possibly time limited) projects. There is significant and ongoing Crown expenditure, for example, in pest control and/or biosecurity, most notably by the Department of Conservation (DOC) but also by MPI and Ministry of Business, Innovation and Employment (MBIE), which affects the long-term environmental services of both forest and other lands where the forest-based component of that expenditure is not clearly separated and identified.

Commercial forest management and wood-based products

Both capital investment and annual expenditure by commercial forestry enterprises are influenced by market conditions. Estimates of net capital stock and total expenditure to 2012 for the major industry categories are provided in tables 6.10 and 6.11.

The detailed breakdown given in Table 6.10 is currently only available to 2012, while the expenditure data (Table 6.11) is only to 2013. The broader gross domestic product (GDP) measure (output less intermediate consumption) is available for forestry and logging and for the combined wood and paper products manufacturing for 2012 and 2013. These numbers indicate a continuation of the trends evident in Table 6.10 – growing forestry and logging output and a relatively stable net contribution from local wood-based manufacturing.

These results are consistent with an increasing capital stock in the forestry and logging subgroup, relatively stable capital stocks in wood product manufacturing,

Table 6.10: Net capital stock and gross domestic product measures ($ million) by ANZSIC06[1] industry groups (March year)

Year	Net capital stock[2]			Output			Intermediate consumption		
	Forestry & logging	Wood product manuf	Pulp, paper & converted paper prod manuf	Forestry & logging	Wood product manuf	Pulp, paper & converted paper prod manuf	Forestry & logging	Wood product manuf	Pulp, paper & converted paper prod manuf
2008	1 249	2 269	1 992	2 413	4 911	2 983	1 513	3 455	2 125
2009	1 359	2 310	1 883	2 743	4 206	3 036	1 847	3 110	2 368
2010	1 477	2 296	1 730	3 143	4 082	3 130	2 016	2 854	2 310
2011	1 574	2 188	1 590	3 607	4 482	3 256	2 271	3 106	2 422
2012	1 712	2 101	1 594	3 587	4 290	3 180	2 440	3 025	2 430

Notes: 1. ANZSIC = Australian and New Zealand Standard Industrial Classification.
2. Chain-volume series expressed in 2009/10 prices.
Source: Statistics New Zealand, 2014a (tables 1 & 3).

Table 6.11: Total expenditure ($ million) by relevant ANZSIC[1] group

ANZSIC group	2008	2010	2011[2]	2012[2]	2013[2]
Forestry and logging	2 522	2 778	2 967	3 284	3 359
Wood product manufacturing	4 852	4 187	4 544	4 414	4 446
Pulp, paper and converted paper product manufacturing	3 013	3 205	3 263	3 234	3 424

Notes: 1. ANZSIC = Australian and New Zealand Standard Industrial Classification.
2. These figures are provisional.
Source: Statistics New Zealand, 2014b.

and a possible slow decline in the capital stocks associated with paper manufacturing (although there has been a recent $60 million investment in upgrading tissue manufacturing plus investment in refurbishing one pulp mill). This result is in line with the increase in harvest and the growth of the export log trade rather than growth in manufactured timber exports, as evident in Indicator 6.1.a.

For wood product, and paper and paper product manufacturing, all investment and expenditure is from private enterprises. Central and local government own about 5 percent of the plantation forest resource, so a small component of the expenditure under forestry and logging is from public sources.

For forestry and logging, the growth in expenditure over the period is accounted for by the levels of harvest, which grew from 20.4 million cubic metres in 2008 to 30.3 million cubic metres in 2014 (years ending 31 March).

Crown forestry

For 2005, forestry-related operational expenditure and transfer payments by New Zealand's two principal government agencies with forestry responsibilities, DOC and the then Ministry of Agriculture and Forestry (now the Ministry for Primary Industries), were estimated as being $221 million. The forestry-related component of these two agencies' expenditure has grown to a projected $270 million for the coming (2014/15) year (The Treasury, 2014 a,b).

Other expenditure is carried out by both agencies (but particularly DOC) and some other agencies that is intended to maintain and enhance environmental and recreational services in general, for example, pest control. This expenditure can be undertaken on forestry lands but is not specifically tagged as forest expenditure.

Under the Conservation Act 1987, all Crown land in New Zealand designated for conservation and protection is managed by DOC. The land area involved (about 8.8 million hectares – Earl, 2014) represents over 30 percent of the country's land mass, the bulk of which is classified as indigenous forest land. DOC has an annual appropriation in excess of $440 million to manage all its lands, and a portion of this expenditure should be counted as part of state forestry spending (The Treasury, 2014a).

Non-wood forest products

The non-wood forest products industry is not well developed in New Zealand, and little information is available on investment or total income potential. The main recognised products, in commercial terms, are game meat (feral deer and pigs), pelts, sphagnum moss and honey. In addition, small quantities of berries and fungi are harvested annually, along with plant extracts for medicinal remedies and healthcare products (see indicators 2.e and 6.1.b).

This summary does not do justice to the wide range of species and products harvested both commercially and non-commercially. Nor does it indicate the economic impact many non-wood products could potentially make. For example, recent research that attempted to scope the ginseng industry potential in the central North Island concluded not only that the product adds a layer of possibilities for standard commercial forestry, but over half of the 450 000 hectares of plantation forests in the central North Island have suitable environmental and geophysical conditions to grow wild simulated ginseng. That potentially offers a large and significant benefit for New Zealand's economy, because the analysis also indicated that adding ginseng could double profitability compared with forestry alone, returning an additional 154 percent to 188 percent value per hectare of plantation forest (Scion, 2013).

Another example of ongoing research with positive environmental effects and potentially significant economic impacts is the "High-performance Mānuka Plantation" programme. Mānuka honey was worth $75 million to the New Zealand economy in 2010. This research programme, which is jointly funded by industry ($1.49 million) and the Crown ($1.4 million), aims to convert lower quality land to mānuka plantations, principally for honey production. Conversion is likely to have positive environmental effects in terms of land stabilisation and reduced erosion. It also has the potential to increase honey income from the 2010 figure of $75 million per annum to around $1200 million by 2027. To date, Crown expenditure on this project is $379 000, and private sector funding has been comparable (Ministry for Primary Industries, 2015).

Environmental services

All forests provide environmental services of differing types and to differing degrees. For New Zealand, the primary environmental services include maintenance of biodiversity, soil conservation, maintenance of water quality, carbon sequestration and storage, and landscape values. Environmental, recreational and tourism services are the main output of indigenous forests under DOC management.

Environmental services, at least as far as the commercial plantation estate is concerned, are only components of, or secondary benefits from, broader forest management objectives. Given that over half of all the New Zealand plantation forest area is Forest Stewardship Council-certified and that certification requires management incorporating environmental values, there is specifically recognised environmental spending associated with over half of all the plantation estate. Unfortunately, good, systematic information on total financial expenditure for any specific environmental service clearly tagged to being purely "forestry" related and on a national basis, is not readily available. Expenditure on a few specific initiatives is addressed below.

The Erosion Control Funding Programme (ECFP) (previously the East Coast Forestry Project) is a government-tendered grant scheme that has been in operation since 1992 (first plantings occurred in 1993). Its aim is to help mitigate severe soil erosion in the East Coast region of the North Island through forest establishment, using poplar and willow treatments and indigenous (native) regeneration. Since 1992, landowners have used the fund to treat soil erosion on 42 000 hectares.

Nearly $26 million remains available in the ECFP until 2020, after which no new applications will be accepted. Some funding will still be available for final maintenance payments available until 2028 when the ECFP is due to expire. The remaining money is sufficient to treat around another 12 000 hectares to 25 000 hectares.

The New Zealand Emissions Trading Scheme (ETS) allows owners of post-1989 forest on eligible land to freely choose to participate in the ETS, take responsibility for managing carbon stock changes on that land and earn carbon credits where the carbon stock increases (see Indicator 6.1.c).

Recreation and tourism

The management of recreational opportunities by DOC in 2013/14 cost $137.95 million (Department of Conservation, 2013), and the 2014/15 expenditure is budgeted at $144.9 million (The Treasury, 2014a). In 2001/02, the provision of recreational opportunities and management of visitor and public information services by DOC accounted for $60.6 million.

Plantation forests are commonly available for restricted recreational activities, with a few forests having high levels of use.

Despite the lack of comprehensive data on expenditure on recreation in plantation forests, several papers (for example, Yao et al, 2013; Clough, 2013; and Patterson and Cole, 2013) in a recent national assessment of ecosystem services in New Zealand indicate significant recreational benefits arising from a small sub-set of plantation forests. DOC's annual report for the year ended June 2013 indicates current expenditure is maintaining the recreational and tourism value of the estate it administers (Department of Conservation, 2013).

The recent book *Ecosystem Services in New Zealand* (Dymond, 2013) indicates not only significant recreational and tourism values for the indigenous estate but that those for the plantation estate are also significant. For example, Yao et al, 2013, report two studies of recreation benefits in Whakarewarewa Forest (an exotic plantation forest) worth $9 million and $28 million per annum respectively. (These recreational values exceed the value of the annual wood production from this forest.)

The importance of better measures of the non-market values is well illustrated in the Dymond (2013) publication, which indicates that the worth of values not measured and accounted for by the System of National Accounts significantly exceeds the worth of the commercial values captured by this system.

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Further reading

Department of Conservation. **http://www.doc.govt.nz**

Ministry for Primary Industries. **http://www.mpi.govt.nz**

Indicator 6.2.b Annual investment and expenditure in forest-related research, extension and development, and education

In New Zealand, there are numerous research consortiums, research providers and industry arrangements, although most government agencies are organised by functional groupings rather than around a specific sector or industry. This means it is a challenge putting a firm and precise value on the forest component of any government expenditure.

Since the last report, in 2008, the data indicate that there has been a slight decrease (in real terms) in clearly identified purely forestry-related research expenditure. However, during this period, overall research expenditure has increased significantly as has expenditure on a growing number of collaborative, multi-disciplinary research projects that either have some forestry component and/or involvement of researchers from an institution with a forestry orientation (see Scion, 2014). Expenditure has also increased on training and obtaining skills that will likely be required if the sector is to fulfil its perceived potential.

Quality of information: M/L

Progress against indicator: ▶

Rationale

This indicator provides information on annual investment and expenditure in forest-related research, extension and development, and education. Research underpins scientific understanding, including the ability to practise improved forest management and develop and apply new technologies. Education, including extension activities, increases public awareness of the multiple benefits provided by forests.

NEW ZEALAND'S REPORT

Research and development funding

In New Zealand, the principal source of research and development (R&D) funding is central government. Over the three years from 2005/06 to 2007/08, the average vote to Research, Science and Technology was $642 million. In the three years from 2011/12 to 2013/14, expenditure averaged $779.1 million, while the 2014 Budget figure for 2014/15 year is $966.6 million.

MBIE is the agency that manages and co-ordinates the allocation of the bulk of research funding and monitors the effectiveness of the public sector investment. Using information from the *Draft National Statement of Science Investment 2014–2024* (Ministry of Business, Innovation and Employment, 2014), Table 6.12 gives an approximate split of current government research spending by "driver" or proposer of the research. It also provides a summary of the agencies involved in supplying the Government funding and associated with oversight of the expenditure of the Government research and development money in a particular category.

Table 6.12: Estimated government forestry research funding

Use of research funding directed by:	Percentage of overall funding spent in this area	Funding administered by:
Researcher	20	Tertiary Education Commission, Royal Society of New Zealand
Sector research organisation	50	Ministry of Business, Innovation and Employment, Health Research Council
Industry	25	Ministry of Business, Innovation and Employment, Ministry for Primary Industries, Callaghan Innovation
Funding for international, infrastructure, science in society and so on	5	Ministry of Business, Innovation and Employment

Source: Derived from MBIE, 2014.

Table 6.13 gives an estimate of the proportion of voted government science funding that is invested in forestry.

The projected government science investment profile over the next 10 years (to 2023/24) peaks at around $1456 million in 2015/16, followed by a reduction to a relatively stable $1350 million to $1374 million per annum over the following seven years (The Treasury, 2014). Virtually all of the reduction in forecast government science funding is due to projected changes to two funding areas. The first is a reduction in MBIE funding of sector-specific research (a forecast reduction in funding of around $30 million per annum from a high of $218 million per annum to $189 million per annum in 2023/24). The second is a $60 million per annum reduction in government funding of Callaghan Innovation. This latter reduction should, in terms of government-funded forest research, have a relatively limited impact. The former (reduced MBIE sector research funding) could potentially impact on the level of forestry research, as indicated in Table 6.13. Even allowing for this, forestry is still likely to represent between 4 percent and 5 percent of total government research.

Historically, government science investment has been heavily focused on the primary sector and, in 2013, nearly 20 percent of government R&D was allocated to agriculture or forestry. Over 10 percent of the country's research effort was directed towards environmental research, some of which supports the primary sectors by exploring matters such as sustainable land use. Additionally, at least 2 percent of the 24 percent attributed to university funding is also attributable to research related to primary industries.

Overall, it is likely that, in some form, well over a quarter of government R&D expenditure supports primary industries, including forestry (The Treasury 2014). Finally, while not all research in areas such as transport, industrial production, energy and general advancement of knowledge (in total over 30 percent of all government R&D) is necessarily relevant to forestry, the potential is clearly there for forestry to benefit in some cases.

The forestry sector's own contribution to R&D funding is difficult to calculate, due to the numerous research consortiums and research provider and industry arrangements. In many instances, there are also significant in-kind contributions to research programmes.

Forest growers levy

This levy illustrates the difficulties in isolating and defining forest-related research, extension and development expenditures. The levy was grower driven and resulted from a vote for approval by growers.

The forest growers' levy came into force on 1 January 2014 and is paid on logs harvested from New Zealand plantation forests. Forest owners are primarily responsible for payment, which is made to the Forest Growers Levy Trust (FGLT). The FGLT sets the levy rate and is responsible for overseeing spending of the money raised. For the 2014 calendar year, the levy rate is set at 27 cents per tonne of harvested wood material (excluding non-commercial domestic firewood).

The FGLT is able to strike different levy rates for future years, but after five years (and again after every subsequent five-year period) all growers must vote on

Table 6.13: Estimated government forestry research funding ($000)

	2009/10	2010/11	2011/12	2012/13	2013/14
Government Appropriation Science and Innovation	721 618	770 085	756 694	790 974	789 588
Estimated primary sector research funding	180 404	192 521	189 200	197 500	197 397
Estimated forestry research funding	28 865	33 113	34 051	35 550	35 531
Forestry percentage of estimated primary sector research	16	17.2	18	18	18
Forestry as percentage of Vote Science and Innovation	4	4.3	4.5	4.5	4.5

Source: MBIE, 2014.

whether or not they wish to continue with a levy. At this, and all subsequent five yearly votes, at least 80 percent of those voting, by number and by harvest volume, need to vote in favour for the levy to continue. (The system is designed to avoid the risk of a few large owners being able to dictate outcomes that are not acceptable to a much larger number of smaller growers.)

The general purposes for which the FGLT may spend the levy are:

- research and development;
- forest biosecurity;
- the National Forest Health Surveillance Scheme;
- health, safety and education;
- supporting implementation of the Wood Council of New Zealand's Strategic Action Plan;
- facilitation of industry collaboration on issues of general concern, for example, health and safety;
- generic industry and product promotion;
- information dissemination;
- representing the interests of forest owners and the industry;
- administration costs.

The levy is not to be spent on any commercial or trading activities. With the current harvest level, it should raise around $8.2 million to be spent on the identified functional areas. Most of these are clearly the type of forest-related research, extension, development and education covered by Indicator 6.2.a. Some expenditure, for example, possibly that on supporting the Wood Council of New Zealand's Strategic Action Plan (Woodco, 2012), facilitating industry collaboration, generic promotion, representing the interests of owners and industry and administration, should possibly be excluded as not strictly related to Indicator 6.2.a.

Primary Growth Partnership

The Primary Growth Partnership (PGP) is a government–industry initiative investing in significant and/or transformational programmes of primary sector research and innovation. The aim is to boost the productivity and profitability of the sectors delivering a significant increase in longer-term economic growth and sustainability.

PGP programmes are business-led and market-driven innovation proposals working along the primary sector's value chains. PGP is managed by the Ministry for Primary Industries and is open to any entity, including firms, industry bodies, private research organisations, individuals, Crown research institutes and local government businesses. PGP investments cover education and skills development, R&D, product development, commercialisation, commercial development and technology transfer. While most PGP proposals contain a significant science component, the PGP is not mainly a science fund.

The ClimbMAX harvester is a steep slope harvesting machine, felling and bunching trees on slopes up to 45 degrees.

Table 6.14: Revenue sources for Competenz (2012–2013)

Revenue	2012 $000	Percentage	2013 $000	Percentage
Government revenue	18 940	61.7	12 967	66.5
Other income	11 723	38.3	6 638	34.5
TOTAL	**30 663**	**100**	**19 495**	**100**

Source: Competenz, 2013.

One of the goals in creating the PGP was to encourage more private investment in primary sector research and development. Core to the idea of the partnership approach is matched funding by industry, which must contribute at least 50 percent of any programme's funding.

As of April 2014, total government funding paid to programmes already under way (including three forestry programmes) was $99.9 million. In 2014, the total committed investment in PGP proposals over the duration of the established programmes is $708 million. This figure includes $333 million of Crown funding. Three forestry programmes (described below) represent 3.2 percent of the total investment. A mānuka honey project, represents another 2 percent of the total, as mānuka is a valuable non-wood forest product. Again, this highlights the challenge in identifying value add forestry-related research investment.

The Steepland Harvesting programme aims to reduce steepland harvesting costs by 25 percent; grow harvest machinery manufacture in New Zealand to future-proof the sector; and make harvesting jobs safer. The centrepiece of this programme is the development of a steep-slope, feller–buncher machine which can operate safely and efficiently on steep slopes without endangering workers. Government and industry have committed $3 million each over 6 years from 2010.

The Stakeholders in Methyl Bromide Reduction (STIMBR) programme researched sustainable and effective alternative phytosanitary and biosecurity treatments for the fumigant methyl bromide. Methyl bromide is an ozone depleting substance, though its continued use for quarantine and phytosanitary treatments is allowed. It is used for New Zealand logs and other primary sector exported products. The STIMBR programme ended on 30 June 2014. The total programme funding was $2.65 million, with $1.19 million from government.

The Stump to Pump PGP programme investigated how to generate more value from forestry waste by converting it to liquid biofuels. This feasibility study into the commercial viability of a biofuels business using radiata pine residues was a comprehensive and rigorous assessment of all key aspects from feedstock characteristics and availability, to design and technical viability of a test plant, to fuel distribution and logistics. The programme provided the partners with a significant amount of technical understanding around the potential to produce biofuels from forestry waste. The total programme funding was $3.62 million, with $1.81 million from government.

Sustainable Farming Fund

The Sustainable Farming Fund (SFF) invests in farmer, grower and forester led and aquaculture projects that deliver economic, environmental and social benefits to New Zealand's primary industries. Funding was up to $8 million a year. Examples of forestry projects include establishing the best silvicultural practices for adding value to new durable eucalypt plantations; an investigation of the potential of redwoods and eucalypts by investigating timber quality, durability and growth strains; and initiatives to support the national wilding conifer strategy.

Education and training

Over the 2011–2014 period significant structural change has occurred in the industry training sector. At the start of 2011, 38 sector or industry-based industry training organisations (ITOs) were servicing ongoing industry training needs. Forestry establishment, harvesting, solid-wood processing, wood panels, forest health, and pulp and paper production were under the Forest Industries Training and Education Council (FITEC). By January 2014, mergers (including that of FITEC with Competenz[36] in 2012) among these ITOs had reduced their number to 12 larger organisations that are multi-sector or multi-trade focused.

36 Competenz is a multi-sector industry training organisation.

In 2013, there were 5253 forestry and wood manufacturing trainees registered with Competenz.

At university level, forestry education throughout the period 2011–2014 period continued to be based at the University of Canterbury's School of Forestry. Graduate numbers from the university (forestry and forest engineering degrees) over the past few years ranged from 14 to 20 per annum (average 18) (New Zealand Forest Owners Association, 2009–2013).

Achieving the goals outlined in the Wood Council of New Zealand's 2012 Strategic Action Plan will require a larger forestry workforce, increased education and training, with the focus being on engineering, building and business rather than forestry (Grimmond et al, 2014).

In 2013, total funding for Competenz was $19.5 million (see Table 6.14). Government funding was around two-thirds of this with other sources (industry in the main) providing the last third. Of the 21 292 learners, a quarter were enrolled in either a forestry or wood manufacturing course. The split between forestry and wood manufacturing was around one-quarter wood manufacturing and three-quarters forestry.

Funding for the University of Canterbury degree courses in forestry science and forest engineering totalled $3.5 million in 2014 ($2.2 million in 2007) (Manley, 2014).

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INDICATOR 6.3 EMPLOYMENT AND COMMUNITY NEEDS

Forest-based and forest-related employment is a useful measure of the social and economic importance of forests at the national and local level. Wage and income rates and injury rates are indicators of employment quality. Communities whose economies are concentrated in forest industries, or who rely on forests for subsistence purposes, may be vulnerable to the short or long-term effects of economic or policy changes in the forest sector. These indicators provide information on levels and quality of forest employment, community resilience to change, use of forests for subsistence purposes, and the distribution of revenues from forests.

Indicator 6.3.a Employment in the forest sector

Forest management and timber processing are seen as one of the drivers of regional economic activity in New Zealand. The sector is a significant employer in its own right and underpins economic activity in several regional towns and centres. The sector also has significant downstream employment in further processing and support services, such as transportation, furniture manufacturing and timber wholesaling. The wide geographical spread of the forest estate means employment opportunities exist in nearly all districts. These opportunities include not only operational activities in the forest or mill but also positions in marketing, accounting and management. Employment activity has declined over the past decade, due to a combination of increasing productivity, restructuring within the sector and changes in market and foreign exchange conditions. Longer term, the potential exists for additional employment opportunities as the plantings of the 1990s mature and new uses for timber fibre are commercialised.

Quality of information: H

Progress against indicator: ▼

Rationale

This indicator provides information on the level of direct and indirect employment in the forest sector. Employment is a widely understood measure of economic, social and community wellbeing.

NEW ZEALAND'S REPORT

The forestry sector has been a significant contributor to employment and economic activity in New Zealand since the mid-19th century. The modern picture of the sector is of a diversified industry, with employment opportunities ranging from logging and sawmilling through to laminated veneer, pulp and paper manufacturing, energy production and research on bio-material applications.

In 2002 nine regions had over a thousand workers directly employed in forestry management, harvesting or first-stage processing (Table 6.15). While the level of forestry employment has declined over the past decade, the sector remains a significant employer across the country.

The central North Island has the largest number of workers employed in forestry and first-stage timber processing. The region had 37.6 percent of direct forestry employment in 2013 (as shown in Table 6.15). This concentration of employment reflects the distribution of mature forests and processing capacity. The central North Island was the focus of the initial round of plantation plantings in the 1920s and 1930s.

The New Zealand Forest Service sought to broaden the distribution of plantings in the decades following the Second World War, with the establishment of new plantations in regions such as Northland, Nelson/ Marlborough and Otago/ Southland. Private investors also took on a larger role in forestry development during this period. A noticeable development was the growth in small, farm forestry plantings. These plantings have created a geographically dispersed estate. The maturing of these plantings from the

1990s has enabled regional harvest rates to be sustainably increased over the past 20 years.

The increase in regional harvest activity led to a period of new investment in processing facilities during the 1990s and the early part of this century. This generated employment growth across the country. In the case of Otago/Southland, the combined region experienced 3.6 percent annual growth in full-time employment between 1994 and 2003, which was "over three times the regional annual average growth rate in FTE [full-time equivalent] employment of 1.1% p. a. [per annum]" (Business and Economic Research Limited, 2005). The growth in regional harvest volumes generated additional employment across the country.

In looking at forestry employment activity, it is important to examine not only direct employment but also indirect and induced workforce activity. In the Otago/Southland region:

> …the indirect and induced impacts of the sector generate[d] a further 3,047 FTEs [full-time equivalents] and $214 million in real GDP [gross domestic product] elsewhere in the region. In broad terms every one FTE employed in the sector generates a further 1.3 FTEs elsewhere in the region (Business and Economic Research Limited, 2005, p 17).

A similar study in the Marlborough district found that:

> …including indirect and induced effects, the forest industry generated $170 million in regional GDP [gross domestic product] and employed 1,090 FTEs [full-time equivalents] in the year ending March 2007. (Business and Economic Research Limited, 2008, p 24)

Recent trends in employment activity

Over the past 10 years, the forestry sector has seen a decline in employment activity (see Tables 6.16 and 6.17). This has been due to improvements in productivity, along with market and exchange rate conditions. The sawmilling and processing sectors have experienced tight margins over several years (for both domestic and export markets). This has led to a number of mill closures and initiatives to improve mill throughput and productivity. The rise in the log harvest over the past four years has stabilised the employment levels in forestry and logging.

Between 2002 and 2013, the workforce engaged in forestry and first-stage processing has declined by around 30 percent (as shown in Table 6.15 and Table 6.16). All 10 wood supply regions have seen a reduction in employment activity. The central North Island has seen the largest fall, with the "employee count" declining by 3977 or 38 percent.

The downturn in new planting at the beginning of the century, and tight economic conditions, had a significant impact on the number of workers employed in nursery operations, site preparation, planting and silviculture (that is, support services). This segment

Table 6.15: Regional distribution of employment in forestry and first-stage processing (February totals)

Region	Employees 2002	Percentage	Employees 2007	Percentage	Employees 2013	Percentage
Northland	2 300	9.3	1 962	9.6	1 679	9.7
Auckland	1 847	7.4	1 500	7.3	1 426	8.2
Central North Island	10 500	42.3	7 891	38.6	6 523	37.6
East Coast	1 010	4.1	810	4.0	800	4.6
Hawke's Bay	1 112	4.5	1 083	5.3	1 046	6.0
Southern North Island	2 100	8.5	1 870	9.1	1 410	8.1
Nelson/Marlborough	1 913	7.7	1 857	9.1	1 616	9.3
West Coast	620	2.5	450	2.2	316	1.8
Canterbury	1 457	5.9	1 418	6.9	1 196	6.9
Otago/Southland	1 993	8.0	1 627	7.9	1 351	7.8
NATIONAL TOTAL	**24 852**		**20 389**		**17 363**	

Notes: 1. The figures are based upon "employee count" (that is, a head count of all salary and wage earners for the February month). The "full-time equivalent" count was discontinued in 2003 and replaced with the "employee count" in 2004.
2. Employment figures are rounded and discrepancies may occur in compounded figures.
3. The 2013 data incorporate the changes to the Auckland region in 2010.
4. Percentages may not add to 100 due to rounding.

Source: Ministry for Primary Industries, 2013.

Table 6.16: Employment in forestry and first-stage processing (2002–2013)

ANZSIC code 2006 (1996)	Description of activity	2002	2007	2012	2013	Percentage change (2002-13)
A030100 (A030100)	Forestry	980	550	740	730	–25.5
A030200 (A030200)	Logging	4 590	3 610	3 960	3 970	–13.5
A051000 (A030300)	Forestry support services (services to forestry)	3 860	2 310	2 310	2 210	–42.8
C141100 (C231100)	Log sawmilling	7 430	6 750	5 130	5 020	–33.2
C141200 (C231200)	Wood chipping	30	9	30	25	–16.7
C141300 (C231300)	Timber re-sawing and dressing	1 760	2 200	1 740	1 800	2.3
C149300 (C232100)	Veneer and plywood manufacturing (plywood and veneer manufacturing)	1 800	1 730	1 230	1 220	–32.2
C149400 (C232200)	Reconstituted wood product manufacturing (fabricated wood manufacture)	1 340	1 140	800	760	–43.3
C151000 (C233100)	Pulp, paper and paperboard manufacturing	3 040	2 090	1 770	1 680	–44.7
Forestry and first-stage processing		**24 852**	**20 389**	**17 710**	**17 415**	**–29.9**
Total labour force as at March quarter (3)		**1 980 200**	**2 238 000**	**2 402 100**	**2 395 600**	**21.0**

Table 6.17: Employment in industries associated with forestry (2002–2013)

ANZSIC code 2006 (1996)	Description of activity	2002	2007	2012	2013	Percentage change (2002-13)
C149200 (C232300)	Wooden structural fitting and component manufacturing (wooden structural component manufacturing)	4 510	6 140	4 650	4 730	4.9
C149900 (C232900)	Other wood product manufacturing (wood product manufacturing (n.e.c))	2 130	2 130	1 860	1 760	–17.4
C251100 (C292100)	Wooden furniture and upholstered seat manufacturing	6 370	5 630	3 640	3 440	–46.0
C152100 (C233200 and C233300)	Corrugated paperboard and paper container manufacturing (solid paperboard container manufacturing and corrugated paperboard container manufacturing)	1990	1 880	1 480	1 410	–29.1
C152200 (C233400)	Paper bag manufacturing (paper bag and sack manufacturing)	230	190	80	70	–69.6

Notes to Tables 6.16 and 6.17

1. The figures are based on "employee count" (that is, a head count of all salary and wage earners for the February month).
2. Employment figures are rounded and discrepancies may occur in compounded figures.
3. The total labour force figures are derived from the Household labour Force Survey, Statistics New Zealand.
4. ANZSIC = Australian and New Zealand standard industrial classification.
5. n.e.c = not elsewhere classified.

Source: Ministry for Primary Industries, 2013.

of the industry declined by 1550 workers between 2002 and 2007. The workforce has stabilised in more recent years.

The numbers employed in logging are determined by the annual harvest and improvements in productivity (particularly on steeper slopes). Harvest volumes in 2007 were nearly 5 percent lower than in 2002, due to exchange rate and market conditions. Employment numbers experienced a sharp decrease (nearly 1000), as contractors sought to reduce costs by adopting new technology and systems to increase employee productivity. Employment levels have increased by nearly 10 percent from the 2007 low, due to the rise in harvest volumes over the past four years.

Employment in log preparation and sawmilling has fallen by 33 percent since 2002. The decrease has been felt particularly since 2008, with domestic and international markets affected by the global economic downturn. Tight margins, a fall-off in demand from major overseas markets and more recently higher log input prices have seen restructuring and further efforts to improve productivity in the sector. The sector has seen several mill closures over recent years.

The re-sawing and dressing segment of the industry (for example, floorboards, mouldings and kiln dried timber) experienced a 25 percent increase in employment between 2002 and 2007 and absorbed a proportion of the employment that was lost from sawmilling. This employment trend has been reversed over the past five years (due to the factors listed previously) and employment numbers are on par with 2002.

Ongoing rationalisation in the pulp, paper and paperboard industry has seen employment numbers decline by 43 percent since 2002.

A sample of the downstream manufacturing activities associated with the forestry sector is shown in Table 6.17. One of the growth areas for employment in the early 2000s was the structural component industry, which includes the manufacturing of wooden structural fittings, wooden components for prefabricated wooden buildings, wooden door frames, roof trusses and the like. Between 2002 and 2007, the industry experienced positive growth of 36 percent (1630 workers). In line with the wider sector, the structural component industry experienced difficult market conditions post 2008 and this led to a period of restructuring and job losses.

The furniture industry has traditionally been a significant employer of skilled cabinet makers and

wood machinists, producing for both the domestic and export market. This industry has experienced a decline in employment of 46 percent (2930 workers) since 2002. This is attributed to a combination of increased imports of furniture and a higher New Zealand exchange rate.

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Indicator 6.3.b Average wage rates, annual average income and annual injury rates in major forest employment categories

Nationally, New Zealand workers recorded an inflation adjusted 2.6 percent increase in average hourly earnings between 2010 and 2014 (March quarter figures). In nominal terms, the increase was 11.4 percent. Earnings in both the forestry and wood product manufacturing sectors increased at rates above the national average. In the case of forestry workers, the rise in inflation-adjusted hourly earnings was 15.7 percent, with a significant proportion of this increase occurring in the past two years, due to the rise in harvest volumes and increased labour demand. The wood product manufacturing sector saw hourly earnings increase by an average of 4.2 percent in real terms.

Average hourly earnings in both sectors sit below the national average, but the gap has narrowed over the past four years, particularly for forestry workers. Average hourly earnings in forestry now sit at 84 percent of the national average and 85 percent for wood product manufacturing.

Injury prevention and reduction are critical issues for the forest industry and New Zealand's workplace regulators. The injury claim rate for the primary sector (which includes agriculture and fishing) is more than twice the national average; and 2013 saw a rise in fatalities (reversing a historical downward trend in the 1990s and 2000s).

In response, the industry is working closely with WorkSafe New Zealand and the Accident Compensation Corporation to identify and mitigate the highest risk tasks, and adopt injury prevention and monitoring initiatives. A strong emphasis is placed on recording incidents, to enable companies to learn from past experiences. WorkSafe New Zealand has committed additional resources to addressing injury rates in the industry and is being proactive in assessments and monitoring. The industry commissioned an independent forestry safety review in January 2014 to identify the causes and contributing factors to the rate of serious injury and fatalities occurring within the sector (see Independent Forestry Safety Review, 2014).

Quality of information: H

Progress against indicator: wages ▲ injury rates ▼

Rationale

This indicator provides information on average wage, income and injury rates. These are important aspects of employment quality and the economic value of forests and forest-related employment to communities.

NEW ZEALAND'S REPORT

Average earnings in the forestry and timber processing industries

Moderate growth has occurred in hourly earnings in New Zealand since the previous report. Total hourly earnings increased in nominal terms by an average of $2.90 per hour or 11.5 percent over the 2010 to 2014 period (March year figures), and in real terms by 2.6 percent (adjusted for inflation). This growth has occurred against the back drop of a recovering international economy, improving domestic activity and gains in productivity. Unemployment levels increased in the period following the 2008 global economic crisis, but there is now positive momentum in the job market, leading to labour and skill shortages in several areas.

Wage growth has not been consistent across the board, as every industry has its own set of drivers and constraints. In the case of the log trade, sustained demand from China (and other Asian markets) has resulted in increased harvest volumes and prices over the past four years. This has produced increased demand for logging contractors and associated services. While improving log prices have favoured growers and logging contractors, they have raised input costs for the timber processing sector. The processing sector has also been squeezed by the relatively high New Zealand dollar and constrained demand in key markets for sawn and remanufactured timber.

Average hourly earnings for workers in the forestry and timber processing industries can be tracked over time, using data from New Zealand's Quarterly Employment Survey (Statistics New Zealand, 2014). This survey is managed by Statistics New Zealand and provides quarterly estimates of changes in average hourly earnings (pre-tax); average hours of paid work and the number of filled jobs. The survey covers around 18 000 business locations throughout New Zealand.

Table 6.18 provides average total hourly earnings for workers in the forestry and the wood product manufacturing sectors. The wage data are provided in both nominal and inflation adjusted terms. Workers in the forestry sector have seen strong growth in earnings over the past two years. This rise has substantially exceeded the New Zealand average. Total hourly earnings (which include overtime) increased in nominal terms by $4.83 per hour, or 25.7 percent, between 2010 and 2014. When adjusted for inflation, forestry workers experienced a 15.7 percent increase in real earnings. As discussed previously, the strong growth in export activity over recent years has increased demand for contractors and harvesting gangs and pushed up wage rates. This demand is highly dependent on key markets, such as China. Periods of reduced demand in China can reduce this wage pressure, as seen since the second quarter of 2014.

Earnings in the wood product manufacturing sector increased in nominal terms by $2.79 per hour, or 13.2 percent, between 2010 and 2014. The increase in real terms was 4.2 percent. Wood product manufacturing is a skilled activity, and processors are competing for labour with other sectors of the economy (in particular, other manufacturers and the construction industry). This demand for labour keeps pressure on wage rates.

Both sectors have seen their hourly earnings move closer to the national average. The change has been particularly noticeable in the forestry sector where average hourly earnings have increased from 74 percent to 84 percent of the national average since 2010. The increase for wood product manufacturing has been from 84 percent to 85 percent of the national average.

Average hours of work

The Quarterly Employment Survey provides another important indicator of worker welfare – the average number of paid hours worked by employees. Nationally, the New Zealand labour force worked an average of 38.75 hours a week in the March 2014 quarter. This total included nearly one hour of overtime. Looking at the 2010 to 2014 period, the average working week has changed only marginally.

For the forestry sector, the average number of paid

Table 6.18: Average total hourly earnings for the forestry and timber processing industries

	Forestry industry (A03)	
March year	Average total hourly earnings (nominal figures)	Average total hourly earnings (adjusted to March 2010 figures)
2010	18.80	18.80
2011	20.68	19.80
2012	19.48	18.36
2013	21.36	19.94
2014	23.63	21.75
	Wood product manufacturing (C14)	
March year	**Average total hourly earnings (nominal figures)**	**Average total hourly earnings (adjusted to March 2010 figures)**
2010	21.17	21.17
2011	21.11	20.21
2012	22.02	20.75
2013	23.99	22.42
2014	23.96	22.05

Notes: 1. "Average total hourly earnings" is equal to "total earnings" (ordinary time plus overtime) divided by "total hours" (ordinary time plus overtime).
2. Figures adjusted using the Consumers Price Index (all groups).
Source: Statistics New Zealand (Quarterly Employment Survey), 2014.

hours worked each week has fluctuated over the past four years, between 37.5 hours and 42.5 hours. This fluctuation reflects varying demand for harvesting services, the availability of crews (particularly new crews coming on stream) and the location of sites.

The average working week for employees in the wood product manufacturing sector is within a narrower band of 38.8 hours to 41.4 hours of paid labour. Part of this variability relates to the level of overtime occurring within the industry.

Overview of the New Zealand occupational health and safety system

New Zealand operates a national accident and injury prevention scheme, which provides cover for all residents and temporary visitors. The scheme covers workplace, sporting and household injuries. The scheme was introduced in 1974 and is administered by the Accident Compensation Corporation (ACC), a Crown agency. Those suffering injuries are entitled to free emergency care, subsidised or free ongoing medical care, compensation for lost earnings and assistance with rehabilitation. In the 2012/13 year, ACC received 1.7 million sporting, household, road and work claims. Of the 178 000 work claims, 1439 were from the forestry sector (Accident Compensation Corporation, 2013).

As well as supporting the injured, ACC has a strong focus on injury prevention and mitigation. In 2014, it introduced a Cross-government Injury Prevention Work Plan, to improve co-ordination with stakeholders and target programmes on priority areas. ACC has developed a range of resources to improve safety practices in the forestry sector and to up-skill contractors and staff. These include training and supervision resources, tools to improve operational and workplace practices and material on the identification of hazards. In the June 2013 year, ACC spent close to $22.4 million on injury prevention schemes, in association with employers, sporting bodies and the like (Accident Compensation Corporation, 2013).

The monitoring and assessment of workplace health and safety was reorganised in late 2013, with the establishment of a stand-alone Crown entity, WorkSafe New Zealand.[37] WorkSafe has a combination of compliance, education and promotion roles. Inspectors from WorkSafe will carry out around 12 500 proactive workplace assessments in 2014 and at least 1000 onsite investigations to assess compliance with the regulations, the need for enforcement or to identify potential causes of harm in the workplace. Alongside these compliance activities, WorkSafe New Zealand is working with industry to improve operational practices and promote dialogue on safety matters (through guidance, education and collaborative initiatives). WorkSafe New Zealand works with several government organisations to ensure workplace practices meet legislative and regulatory standards. These include the New Zealand Police, Maritime New Zealand, Civil Aviation Authority and the New Zealand Transport Agency.

WorkSafe New Zealand has committed additional resources to addressing injury (and fatality) rates in the forestry sector and is being more proactive in assessments and monitoring safety compliance. Between August 2013 and April 2014, it undertook 235 worksite inspections of forestry crews involved in breaking out. Of these inspections, 95 percent were proactive assessments and 5 percent were reactive workplace investigations.

> While many crews are performing well or working hard to meet safety standards, a concerning number are facing challenges... Approximately 50 percent of workplace forestry visits carried out during the breaking out[38] phase have resulted in enforcement activity (i.e. formal warning or notices issued for non-compliance). (WorkSafe New Zealand, 2014a, p6)

Workplace safety in the forestry sector

The forestry working environment can have a high degree of natural risk, due to terrain, slope and climatic conditions. Slope is a particular issue in New Zealand, with a significant proportion of forests located on steeper sites, which cannot be traversed by mechanical harvesting equipment.

> The work requires considerable physicality and technical skill from workers operating where the terrain and working conditions can be difficult.

37 WorkSafe New Zealand assumed the health and safety functions previously carried out by the Ministry of Business, Innovation and Employment and its predecessor the Department of Labour. WorkSafe New Zealand also carries out new functions under the WorkSafe New Zealand Act 2013.

38 Breaking out is the first part of the extraction phase from the felling site. It includes selecting and hooking up the tree stems to be extracted using wire rope or chain

> Plantation forest blocks in New Zealand are often on difficult land... [that]... is frequently steep and can sometime[s] be unstable. (Independent Forestry Safety Review, 2014, p11)

Site preparation, earthworks and harvesting also bring with them operational risks related to the use of heavy machinery and the felling and extraction of logs.

The industry recognises the challenges of the New Zealand forest environment and has been working to ensure that safe operating practices are followed and lessons are learnt from accidents. The focus has been on both reducing operational risks, through improved procedures, training and support, and mitigating the effects of natural conditions. An important issue is the level of manual tree felling due to slope and terrain conditions. The industry (in collaboration with the Government[39]) has a six-year project under way to research innovative harvesting technologies that will improve worker safety and productivity on steeper sites.

Work-related injury claims for forestry accidents are recorded as part of the larger "Agriculture, forestry and fishing" industry category. In 2012, ACC received an average of 201 injury claims for every 1000 full-time equivalent (FTEs) employees in this category. Nearly 90 percent of all claims received by ACC were for one or two visits to a health professional. This reflects the nature of the injuries being recorded. Nationally, 42 percent of all claims involved sprains and strains. A 2008 report by the Centre for Human Factors and Ergonomics showed similar figures for the timber processing sector. "Around 43% of all claims were musculoskeletal disorders, followed by lacerations/puncture/sting, accounting for 22% of all claims" (Ashby and Tappin, 2008, p 1). A relatively small percentage of injuries led to entitlement claims for rehabilitation or weekly compensation. In the agriculture, forestry and fishing industry, an average of 27 entitlement claims per 1000 FTEs were received in the 2008 to 2013 period (Statistics New Zealand, 2013).

The rate of injury claims by workers in these three primary sectors was more than twice the national average.

> The overall rate of injury claims was 93 claims for every 1,000 full-time equivalent employees... Entitlement payments were given in 11 percent (19,000) of all work-related claims. (Statistics New Zealand, 2013, pp 1–2)

In comparison with other sectors, the agriculture, forestry and fishing industry has the highest incidence of injury and entitlement claims on an FTE basis.

Detailed forestry sector data are available for serious harm and fatal incidents, which are notified to WorkSafe New Zealand. The data for the 2008 to 2013 period are shown in Table 6.19. Since 2008, the number of serious harm injuries has fluctuated between 161 and 188 per year. Over this same period, the annual harvest increased by 40 percent, from 20.4 million cubic metres to 28 million cubic metres. Fatal incidents in the forestry sector have reversed a downward trend in the 1990s and the early 2000s, with a spike over the past two years.

> On a per worker basis the forestry sector had the highest rate of fatalities over the last five years.

39 A six-year "Steepland Harvesting Project" started in 2010, under the Government's Primary Growth Partnership.

Table 6.19: Work-related forestry and logging[1] fatalities and serious harm notifications (2008–2013)

Calendar year	Fatal notifications	Serious harm notifications (including fatal)
2008	4	179
2009	5	161
2010	4	170
2011	3	182
2012	6	188
2013	10	Not available[2]

Notes: 1. The figures include the sub-categories of "Forestry support services" and "Services to forestry".
2. Provisional figures for the six months to June 2013 recorded 87 serious harm notifications.
Source: WorkSafe New Zealand, 2013, WorkSafe New Zealand, 2015.

> Tree felling and breaking out are the two highest risk tasks in forestry, with 52% of fatalities attributable to felling, and 31% to breaking-out over the last three years" (WorkSafe New Zealand, 2014a, p 4)

The increase in fatal incidents has led to an industry review of safety and the implementation of new initiatives by WorkSafe New Zealand and other agencies. These initiatives are discussed in the following section. WorkSafe New Zealand has found that while "there is [generally] a strong commitment to safety systems and rules" across the industry, the outcomes on the ground are not meeting industry and community expectations (WorkSafe New Zealand, 2014a, p 3). The priorities for WorkSafe New Zealand are to continue building industry-wide acceptance of responsibility for workplace safety, addressing the main activities that are causing injury and death and supporting the key managers in the supply chain (particularly contractors and crew bosses).

Initiatives to improve forestry workplace safety

In 1984, a national database on logging injuries was established. Companies voluntarily reported the details of injuries sustained, days of work lost and near-miss events. The Accident Reporting Scheme was an important tool for undertaking research on injuries and monitoring the long-term success of prevention measures. Work undertaken by the "Centre for Human Factors and Ergonomics (COHFE) show[ed] the number of lost time injuries per million cubic metres of wood harvested decreased from 23.2 in 1990, to 5.8 in 2002" (New Zealand Forest Owners Association, 2003, p 5). These figures are particularly noteworthy, because the downward trend occurred during a time of increasing harvest volumes and a general move into more difficult terrain.

In 2005, the New Zealand Forest Owners Association, with the support of ACC, launched a web-based Incident Reporting Information System (IRIS). This is an interactive database that enables companies (and the industry as a whole) to benchmark their health and safety performance. The database contains a substantial quantity of information on close calls, which can be used to reinforce (or refine) workplace practices. Periodic improvements have been made to the system (such as a fully searchable library of Safety Alerts), to help owners to avoid similar events.

In 2010, the Department of Labour,[40] in a partnership with ACC and the New Zealand Forest Owners Association, put in place an action plan to address the high injury rate in the forestry sector. The action plan identified tree felling and breaking out as the priority areas for intervention, and the partners have worked with the wider industry to build capability and knowledge in these areas. As a result of the plan of action, the Forest Industries Training and Education Council (now part of Competenz) increased the availability of health and safety training, and a new certification process for breaking out has been introduced. Initiatives were also developed to increase the "culture" of safety within companies and the workforce and to update the Approved Code of Practice for Forestry Operations.

With the establishment of WorkSafe New Zealand, additional resources have been committed to the inspection of forestry operations and the enforcement of safety regulations. WorkSafe New Zealand has increased the number of dedicated inspectors along with identifying new tools and resources for improving education and compliance.

In January 2014, the New Zealand Forest Owners Association, the Forest Industry Contractors Association and the New Zealand Farm Forestry Association initiated an independent forestry safety review to identify the causes and contributing factors to the high rate of serious injury and fatalities occurring in the forestry sector (Independent Forestry Safety Review, 2014). The review team had a broad mandate to look across the sector and its supply chains. This included the regulatory framework, contractual arrangements, working conditions, skills of workers and managers, work practices and equipment. At the time of preparing this report the review team had undertaken extensive consultation and was assessing the findings of submissions.

40 The predecessor organisation to WorkSafe New Zealand.

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Indicator 6.3.c Resilience of forest-dependent communities

The forestry and timber processing industries are important components of regional economic activity, but there are relatively few communities where the sector is the major employer. In most regions, forestry occurs in conjunction with pastoral production and other forms of economic activity, such as tourism and primary sector processing. Nationally, forestry and timber processing accounted for less than 1.4 percent of enterprise employment in 2013.[41] Even in New Zealand's major forestry and timber processing regions (Bay of Plenty, Gisborne, Northland, Tasman and Waikato), the figure was between 3.5 percent and 6.4 percent of enterprise employment.

New Zealand's forestry and timber processing communities have seen significant change over the past 25 years, with the:

- corporatisation and sale of the Crown's commercial forests and processing assets;
- drive to improve productivity and performance (leading to the replacement of labour with capital and technology);
- periods of low log and timber prices, which have seen the closure and restructuring of businesses.

These challenges have seen downward pressure on local employment activity and the loss of key personnel from businesses and districts. Communities have responded by identifying new employment opportunities (often associated with the natural environment, such as tourist tracks) or by putting in place infrastructure to attract new forms of industry. The adjustment process can be a difficult path for communities, with the loss of population and services. Successfully attracting new industry normally involves the community working closely with local and central government agencies.

Quality of information: L/M

Progress against indicator: ▶

Rationale

This indicator provides information on the extent to which communities are dependent on forests for their wellbeing, livelihoods, subsistence, quality of life or cultural identity and are able to respond and adapt to social and economic change.

41 This figure includes direct employment in forestry and sawmilling (ANZSIC 06 codes A03, A051 and C141), along with "Other wood product manufacturing" (C149) and "Pulp, paper and converted paper product manufacturing" (C15). This estimate is drawn from the New Zealand Business Demography Statistics, an annual assessment compiled by Statistics New Zealand of economically active enterprises (with a turnover of more than NZ$30 000 (for goods and services tax purposes)).

NEW ZEALAND'S REPORT

The forestry sector contributes at many levels to the economic and social wellbeing of towns and communities throughout New Zealand. The sector has been described as one of the drivers of regional economic activity, because the industry generates significant downstream employment in transportation, retailing and public administration (principally education and health). Modelling by Business and Economic Research Limited (2005; 2008) indicates that this downstream activity can equal or exceed the direct contribution of the industry.[42] A 2013 economic assessment of forestry in the Gisborne (Tairawhiti) region concluded that forestry and related activities generated:

> …direct revenue of $234 million with approximately $94 million paid out as salaries and wages to Gisborne residents. The associated multiplier of 2.7 suggests a regional economic impact of approximately $631 million. (Institute for Business Research, 2013, p 9).

42 Downstream activity includes indirect and induced economic activity and employment.

One of the characteristics of the forestry sector is the dispersed nature of employment opportunities. Every district in New Zealand (apart from the Chatham Islands) has positions in forestry, logging or downstream wood product manufacturing and processing.[43] This availability of employment is important for attracting families to communities (particularly younger families), and ensuring that local services and community organisations continue to be well supported (for example, sporting clubs and voluntary emergency services, such as the fire brigade). The forestry sector also brings to communities critical skills in management and administration. Management skills are important in smaller communities to guide decision making and foster local leadership.

> Forestry plays a key role in communities such as Gisborne–Tairawhiti, by building economic resilience in rural communities, diversifying economic activity, providing new skills and attracting new and younger workers. (Institute for Business Research, 2013, p 8)

Forestry and timber processing are normally one of several primary sector activities undertaken in rural communities. There are "few rural communities in New Zealand [that] are totally dependent on a single resource sector" (Taylor Baines and Associates, 1999, p 11). Forestry normally sits alongside pastoral production and other primary sector industries, including viticulture, cropping, fishing and mining. This diversity in economic activity provides communities with a more even (and secure) growth trajectory.

The communities with a heavy reliance on forestry and timber processing generally fall into one of three categories:

- communities that were originally established around the harvesting and processing of indigenous timber milling and have made the transition to plantation forestry;
- servicing centres that provide logistical services for forest management and processing (such as transport operators);
- communities that have developed around the maturing exotic plantations established by the then New Zealand Forest Service and private investors since the 1920s.

Māori relationship with the lands and forests of New Zealand

New Zealand's indigenous forests historically provided Māori with a range of basic needs. Forests were a source of food, medicinal herbs and materials for handicrafts and weaving. Communities also harvested selected trees for settlement construction and canoes (waka). Customary practices evolved over the centuries to ensure that forest resources were maintained for future generations and not over-utilised.

> Traditionally, there was a specific custom for the taking or use of any material for basic living, such as food, shelter or clothing. For any of these, a formal ceremony took place. This is [still] valid today for many Māori. A recent occasion involved a ceremony to mark the removal of a tree for the construction of a waka (canoe) by the people of the Taitokerau. (Forest Industries Training and Education Council, undated)

With European settlement, and the introduction of commercial farming and horticulture, Māori reliance on forests for their subsistence needs diminished. Small quantities of food and medicinal herbs continue to be collected by individuals and families. The hunting of feral deer, goats and pigs by individuals and families remains a social and recreational activity for a section of the Māori population. Hunting and commercial trapping provides a livelihood for a small proportion of the Māori and European population. In recent years, there has been growing commercial interest in a number of the herbs and remedies that were traditionally sourced from New Zealand's natural forests (see Indicator 2.e).

Indigenous forests

Māori continue to identify closely with their traditional lands and forests. Of the 1.2 million hectares of privately owned indigenous forest, Māori (through tribal incorporations and trusts) manage more than 400 000 hectares (Miller et al, 2005).[44]

> Currently there are approximately 50,000 hectares of indigenous forest being managed

43 The 2013 New Zealand Business Demography Statistics recorded employment in one or more of the following employment categories in all territorial authorities, apart from the Chatham Islands: A03 (Forestry and logging), A051 (Forestry support services), C141 (Log sawmilling and timber dressing), C149 (Other wood product manufacturing) and C15 (Pulp, paper and converted paper product manufacturing).

44 Almost 80 percent of New Zealand's indigenous forests are now managed by the Crown for conservation purposes.

> under nearly 50 [sustainable forest] management plans, with an allowable annual harvest of 78,000 m^3 standing volume... Approximately 250,000 hectares of indigenous forests have the potential to be sustainably managed. (Ministry for Primary Industries, undated)

Several Māori incorporations have taken the lead in developing sustainable forest management (SFM) plans for their land holdings (under Part 3A of the Forests Act 1949). SFM plans provide for a sustainable annual harvest and detail the protection and management of the forest (including pest control, the regeneration of tree species and areas to be set aside). The allowable harvest is calculated for each species and is within the rate of stand and species replacement.

Māori owners of indigenous forest are also taking initiatives to expand the economic opportunities for indigenous timber species. Research initiatives have looked at marketing and supply chain conditions for species such as beech and tawa. Alongside this work have been initiatives to improve the growth modelling of production species, to improve the technical data behind sustainable harvesting. These initiatives have generally been in association with government funding providers, research agencies and other investors in the indigenous timber industry.

Plantation forests

Māori participation in commercial forestry is significant, through employment, training and land ownership. In a 2012 assessment, the Forest Industries Training and Education Council estimated that 32 percent of the forestry and wood processing labour force was Māori, compared with an average of 12.2 percent across all industries (Forest Industries Training and Education Council, 2012). A similar percentage of Māori were involved in training for forest management, harvesting and timber processing.

The forestry sector has provided an important source of employment for Māori over the past two-to-three generations. The sector has helped to maintain economic activity in rural centres and provided a platform for new Māori enterprises, from silviculture contracting through to harvesting and transport operations.

> The use of independent contractors offers Māori workers opportunities to develop as small business owners, perhaps not so small when a mechanised operation has several million dollars of equipment (Goulding, 2014, p 2).

The availability of forestry employment has also enabled Māori to maintain their association with the land. "Cultural and spiritual links with the land need to be nurtured, and an opportunity to work on the land helps to facilitate this" (Thorp, 2014, p 6).

Māori are playing an increasingly important role in both the ownership of forest land and the management of the forest estate.

In a November 2000 survey, the then Ministry of Agriculture and Forestry estimated that 238 000 hectares of Māori-owned land was in plantation forestry, but only 10 percent of this estate was directly managed by Māori (Miller, et al, 2005). Most of these plantings had been developed through lease agreements (with the Crown or private forestry companies) and were being managed by external parties. This situation has been steadily changing, with Māori incorporations and trusts assuming direct responsibility and management as leases expire. This reflects the growing aspirations of Māori owners to more directly manage their assets.

The settlement of historical Treaty of Waitangi claims is continuing to increase Māori involvement in commercial forestry.

> In total, there are currently around 420,000 hectares of plantation forests on Māori land. By the end of the Treaty claims process this may increase to around 680,000 hectares, or 40 percent of the country's plantation estate. Māori currently own around 80,000 hectares of plantations of which two entities own half... (Thorp, 2014, p 3)

Forestry as a proportion of enterprise employment

The number of communities with a moderate-to-high reliance on forestry, logging and timber processing is relatively small. This can be seen by reviewing recent enterprise employment data. In the February 2013 year, 17 400 people were engaged in forestry and first-stage timber processing. When wood product manufacturing and paperboard production are included, this figure rises to 26 700 people (Ministry for Primary Industries, 2013a). Nationally, this represents less than 1.4 percent of enterprise employment.

The regional distribution of forestry and timber processing employment is largely aligned to the location of the resource. The Bay of Plenty, Gisborne, Northland, Tasman and Waikato regions all have forestry employment levels 1.5 to 4 times the national average (from 2.3 percent to 6.4 percent of the employee count). The Auckland region has an employment level half the national average (0.7 percent of workers), but in absolute terms it is one of the higher employment areas, particularly in wood and paper product manufacturing.

The level of community reliance upon forestry can be seen by looking at the Bay of Plenty region, in the central North Island. While the region employs around a third of the national workforce for forestry and first-stage timber processing, the industry makes up just 4.1 percent of paid employees in the region (Statistics New Zealand, 2014). A breakdown of the region, by area unit,[45] reveals that 98 of the 129 area units[46] (76 percent) had less than 5 percent of their employee count in forestry and timber processing. Only nine of the 129 area units had more than 15 percent of employees in these categories, and just three units had over 33 percent. The area units with the highest rates of forestry employment were those with service communities established during the 1950s and 1960s to meet the labour needs of the maturing exotic forests in the central North Island (along with their associated processing facilities).

An example of one of these centres is the township of Kawerau, in eastern Bay of Plenty. The township was constructed to house the workforce for an integrated sawmill and pulp and paper facility. More than 50 years later, Kawerau still depends heavily upon the mill and its associated industries.

Structural pressures on forestry communities

New Zealand's forestry communities have faced several economic challenges over the past generation, which they have weathered with varying degrees of success. The main developments in this period have been:

- the phasing out of indigenous logging on the Crown estate;
- the corporatisation, and subsequent sale, of the Crown's commercial forests and processing assets;
- the centralisation of public and private services;
- increased technology adoption to improve productivity and competitiveness; and
- periods of low log and timber prices, which have seen the closure and restructuring of businesses.

Reduction in the indigenous timber harvest

The phasing out of indigenous logging from the Crown estate, and the requirement for private landowners to harvest on a sustainable basis,[47] has seen the indigenous harvest progressively decline, from just over 1 million cubic metres of roundwood in 1970 to 15 000 cubic metres in the March 2013 year (Ministry for Primary Industries, 2013b). The decline in indigenous log supplies led to extensive restructuring in this part of industry, from the 1970s through until the turn of the century.

In areas where mills were in close proximity to maturing plantations, there were opportunities to upgrade facilities to process radiata pine. Investors have tended to prefer mill conversions over the development of "greenfield" facilities, as the sites are already designated for industrial activity. This can save considerable time and expense in obtaining planning consents. The move to exotic timber processing has helped to safeguard jobs and, in certain cases, been the springboard for expansion, particularly in the area of further processing.

Where mills have not been able to move into exotic processing or secure sufficient supplies of indigenous timber from sustainably managed blocks, there have been redundancies and mill closures. The response of these communities to plant closures, or to the downsizing of operations, has not been uniform, but there have been several common themes.

The communities, supported by their district councils,[48] have normally undertaken scoping projects to identify alternative employment opportunities

45 Area units are aggregations of mesh blocks with unique names. They are non-administrative areas intermediate between mesh blocks and territorial authorities. Area units must either define or aggregate to define urban areas, rural centres, statistical areas, territorial authorities and regional councils. Each area unit must be a single geographic entity with a unique name.

46 The New Zealand Business Demography Statistics were designed to provide high-quality national-level data. The data frame has limitations at a sub-national level, and the results should be seen as indicative.

47 Sustainable harvesting of indigenous timber from private holdings was introduced through a 1993 amendment to the Forests Act 1949.

48 This support is frequently provided through a development board or community trust.

for their communities. In the case of the Tuatapere community (in western Southland), the Southland District Council helped in developing a concept plan for the township, which built on its heritage sites (Houghton et al, 1996). As a consequence of this report, community funds were invested in developing a major walking track, which has encouraged investment in accommodation and associated tourism and craft activities.

These plans have generally focused on using the historical values of the community and developing tourism activities associated with the natural environment. Communities are also exploring the utilisation of their forested areas for non-timber products, such as honey production, game trophy hunting and wilderness tours. The adjustment communities go through after the closure of a mill can be difficult for individuals and families. The skills of silviculture and processing workers are not necessarily compatible with the new initiatives being developed. Consequently, younger workers have frequently migrated in search of new positions, while older employees have taken early retirement or accepted lesser-skilled positions.

For the wider community, the loss of forestry revenue (through wages and service purchasing) has normally led to a period of economic uncertainty. This persists while new ventures are explored and developed. In the case of tourism bush walks, the planning and development of a track and supporting facilities can take several years.

Corporatisation and centralisation of government services

Another economic challenge for these communities was the corporatisation of the Government's plantation estate, which represented 49 percent of all exotic plantings in 1990. In 1984, these holdings were placed on a purely commercial footing, and. in 1987, were formed into a corporate entity. This led to a rationalisation of staffing, with a number of district offices closing, the contracting out of services and key management functions being centralised. The subsequent sale of the Crown's forestry cutting rights to private investors led to a further rationalisation of management functions.

At a community level, the loss of forestry staff (particularly specialised and highly skilled workers) impacted on leadership roles within these towns and districts. Forestry staff had provided important skill sets for a range of community organisations (for example, accounting and secretarial knowledge). The loss of these skills affected the social and cultural life of these communities (particularly at a sporting and volunteer service level).

In this same period, rural communities were experiencing a loss of services through government corporatisation and private businesses rationalising their business networks (including postal outlets, bank branches and stock and station stores). These developments had significant economic and social ramifications for communities with a heavy reliance on forestry employment. As the forestry and service sector workforce was scaled back, the spending power in these communities declined. Falling disposable incomes had a direct flow-on effect for retail and commercial activity.

> Both the retail sector and other business firms in Murupara were seriously affected by the reduction of the workforces of Tasman Forestry and NZFS [New Zealand Forest Service]... (McClintock and Taylor, 1999, p 31)

> The reduction in employment opportunities impacted particularly on unskilled, older workers, who "do not have the technical skills to work the new technology..." (Taylor Baines and Associates, 1999, p 6).

Productivity and pricing pressures

The heavy dependence of the forestry and timber processing industries on the international market has created an underlying pressure to improve productivity and performance, to maintain the competitiveness of the New Zealand industry against other Pacific Rim countries. Fluctuations in the New Zealand exchange rate, and periods of low commodity prices for logs, sawn timber and other forestry products, have added to the pressure.

The drive for improved productivity can be seen in both processing and forest management. In the sawmilling sector, larger operators have been steadily moving to higher productivity (and capacity) systems, with scanner optimisation, bin sorters and mechanised stacking processes. The drive for improved efficiency has been seen particularly in the pulp manufacturing industry. The major plants have seen successive rounds of investment over the past 30 years, to achieve production and productivity gains, while lowering unit costs of production. At the harvesting level, improvements in felling and extraction systems have progressively improved the productivity of workers, with a consequential reduction in the labour inputs required.

> The major forestry companies and smaller business units have sought to maintain their profitability by investing in more capital-intensive technology, reorganising their work practices, and reducing the size of their workforces. (McClintock and Taylor, 1999, p 31)

Managerial restructuring has also been seen, with plantation companies merging districts and centralising marketing, harvest planning and technical functions.

These improvements in productivity are maintaining the competeviness of the industry, but they have generally been reducing the labour requirements for forestry and processing operations. This has affected the immediate communities that service these operations. The communities experience a progressive loss of forestry employment over a number of years or decades. This has been seen in communities such as Kawerau, Tokoroa and Murupara in the central North Island.

This employment trend has been moderated in districts with increasing harvest volumes and where processing companies have added additional capacity

or manufacturing activities. As discussed previously, several affected communities (supported by their district councils) have undertaken initiatives to strengthen and diversify their local economies. The initiatives in the central North Island have focused "on adding value to timber by further processing" (McClintock and Taylor, 1999, p 32) or encouraging activities that support the forestry sector. The Kawerau District Council has established a light industrial park, which has attracted businesses that provide support services to the local mill. This initiative has also been successful in attracting business activities from outside of the forestry sector.

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Indicator 6.3.d Area and percent of forests used for subsistence purposes

No communities rely on forests for subsistence purposes in New Zealand, but for some individuals and families the supply of fuel (firewood) and opportunities to hunt deer and pigs for food are important. Traditional Māori medicine uses indigenous plant species.

Quality of information: L

Progress against indicator: ▶

Rationale

This indicator provides information on the extent to which indigenous and other communities rely on forests as a source of basic commodities, such as food, fuel, shelter and medicinal plants. The practice of forest-based subsistence reflects the dependence of rural communities and individuals on forests for essential resources and may be closely linked to cultural identity and quality of life.

NEW ZEALAND'S REPORT

For centuries, Māori made extensive use of the indigenous forest resource for the supply of food, fuel, shelter, clothing and medicinal products. The resource use involved traditional processes of selection, access and removal – requiring the observance of rituals and ceremonies (see Indicator 6.3.c).

No communities rely on forests for subsistence purposes. Nevertheless, the supply of food (for example, meat from wild pigs and deer) and fuel (firewood) from both indigenous and plantation forests are important for some individuals and families, particularly in more remote locations (King et al, 2013). Forests and forestry are important sources of heat energy for the domestic sector. Wood-based fuels account for 7 percent (57.8 petajoules (PJs)) of the country's primary energy supply (Ministry of Business Innovation and Employment, 2013). The main user of wood fuels is the wood processing sector, and the decision to use wood fuel is strictly a commercial one. However, wood fuel also accounts for a little less than half of all the energy used in domestic heating (Isaacs et al, 2006), and a portion of the fuel used in this way is obtained outside the monetised part of the economy.

Traditional Māori medicine (rongoa Māori) involves spiritual healing and the use of herbs from indigenous plants, including tree species. Rongoa Māori is still practised, and scientific studies have supported some of the information about the medicinal use of plants. There is a growing interest in rongoa Māori, and several educational institutions now offer National Certificate of Educational Achievement (NCEA) courses in this field.

The use of the indigenous forest resource by Māori is closely linked to their culture and values. Traditional Māori attitudes to the land, sky, rivers, lakes and seas and the creatures that live in them are based on their knowledge and beliefs about the beginnings of the world.

A revival of interest in community knowledge of the indigenous forest and its fauna and flora is taking place. Māori take wood for carving, vegetable materials for weaving, and feathers of indigenous birds and other materials for traditional purposes. No data are available to indicate the extent to which these uses of forests are undertaken, but in a national context they are limited.

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Manuka tree.

Indicator 6.3.e Distribution of revenues derived from forest management

Information is available on revenues generated by the commercial forest industries and received by government forest agencies. For forest industries in various forms of domestic and overseas private ownership, little information is available on how their revenues are distributed back to communities.

Quality of information: L

Progress against indicator: ▲

Rationale

This indicator provides information about the flow and distribution of revenues from forest services, management and use back into forest-based communities, wider society and the forest sector. The distribution of those revenues provides information on the extent to which forest-based communities, the forest sector and the wider society share in the economic benefits generated by forests.

NEW ZEALAND'S REPORT

As for Indicator 6.2.a on investment and expenditure, information is available on annual revenue for the commercial forest industries and for revenue received by government. Information is not readily available on revenue from the production of non-wood products or for environmental services from New Zealand's forests.

Commercial forest management and wood-based products

Annual income received by commercial forestry enterprises is influenced by market conditions. Estimates of total income for 2012 and 2006 for major industry categories are provided in Table 6.20.

For "Wood product manufacturing" and "Paper and paper product manufacturing", the income received is all by private enterprises: the group description covers a range of listed and privately owned international and domestic companies.

No information is available on the distribution of profits or dividends. In 2006, some $1241 million was paid in salaries and wages to employees and working proprietors; in 2012, salaries and wages were $1240 million. Purchase and other operating expenses increased from $5129 million in 2006 to $5748 million in 2012 (Statistics New Zealand, 2013). The relatively small change to either compensation of employees or to operating expenses for wood and paper product manufacturing over this five-year period is consistent with the fact that there was little growth to output from either over this period.

For forestry and logging, ownership covers a broad range of overseas-owned timber investment management organisations (TIMOs), listed and privately owned international companies, privately owned domestic companies, partnerships, joint ventures, private investors and central and local government agencies. Again, no data are available on the distribution of profits and dividends, other than from central government owned forests (see below). For salaries and wages to employees and working proprietors, $239 million was paid in 2006 compared with $278 million in 2012. There was

Table 6.20: Total output in 2006 and 2012 financial years by ANZSIC[1] 06 categories ($ million)

ANZSIC category	2006	2012
Forestry and logging	2 810	3 774
Wood product manufacturing	4 627	4 504
Pulp paper and converted paper product manufacturing	2 752	3 337

Note 1: ANZSIC = Australian and New Zealand Standard Industrial Classification.
Source: Statistics New Zealand, 2013.

significant growth in this grouping over the period with intermediate consumption increasing from $1621 million in 2006 to $2425 million in 2012.

State forestry

Crown Forestry (a unit within MPI, but with a significant commercial function), administers the Crown's interest in forestry leases on Māori land, residual Crown forest and other forestry assets. Consistent with government policy, Crown Forestry also seeks opportunities for the Crown to sell its interest in these assets, and works with the Office of Treaty Settlements to resolve Treaty of Waitangi claims over the Crown forestry assets it administers.

Crown Forestry's commercial forestry business will deliver estimated revenues of $115.9 million with expenditure of $96.6 million during 2013/14. Trading surpluses are projected to remain reasonably steady (over $10 million) until about 2020. On the basis of net stocked area, Crown Forestry is currently the seventh largest forest owner in New Zealand.

All Crown Forestry net revenues (after paying whatever contractual obligations are owed to other parties) are paid to the Crown accounts.

The Department of Conservation (DOC) administers the conservation estate, including 5.5 million hectares of indigenous forest and small areas of inherited plantations from which periodic revenues are obtained.

DOC's major source of commercial income is from licences and royalties paid by concessioners operating in the conservation estate and from partnering with businesses. Engagement of the commercial sector in conservation is increasing, with businesses entering new partnerships with DOC and building on established relationships (Department of Conservation, 2013). Total revenue from all concessions and partnerships was only $17.1 million (2011/12) and $18.6 million (2012/13). Reported trends in DOC's financial activity in the 2014 Budget (The Treasury, 2014) indicate that concession and partnership revenue is likely to remain around this level at least until 2017/18 (The Treasury, 2014).

Environmental services

Most environmental services generate little revenue and data are limited.

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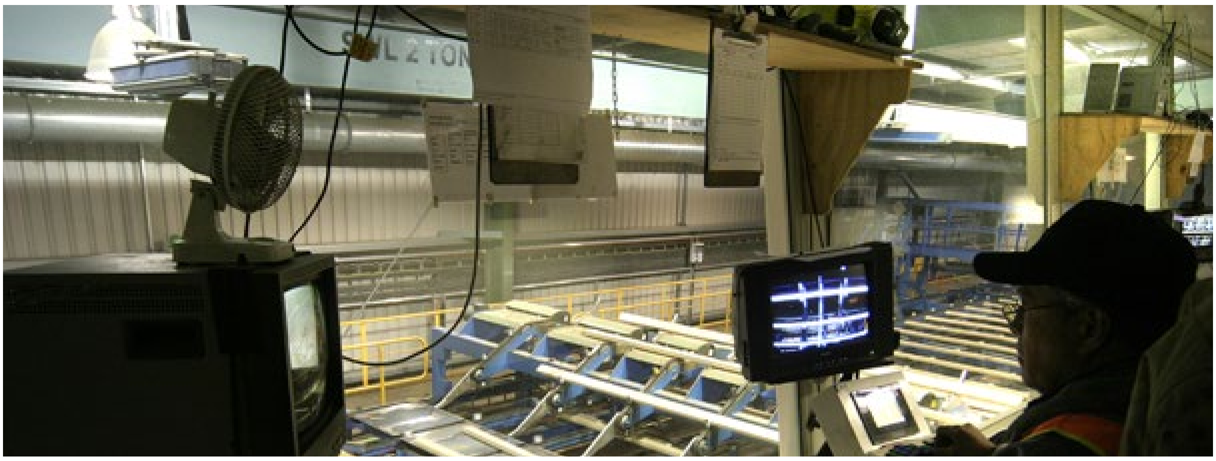

INDICATOR 6.4 RECREATION AND TOURISM

Forests have long been used as a place for recreation and other leisure activities. The location and accessibility of forests and the availability of recreational facilities are important to forest-based recreation and tourism. Levels of use are an indication of the extent to which forests are valued by society for these uses.

Indicator 6.4.a Area and percent of forests available and/or managed for public recreation and tourism

Fostering the recreational use of New Zealand's conservation lands (both indigenous forests and grasslands) is one of the principal roles performed by the Department of Conservation (DOC). DOC manages nearly 80 percent of New Zealand's indigenous forests and provides recreational opportunities for all ability and fitness levels. In the 2012/13 year, nearly 43 percent of DOC's total expenditure was devoted to maintaining and developing recreational facilities. This included maintaining 14 000 kilometres of tracks and nearly 1000 huts. The nature of this investment has been changing over time, with DOC tailoring facilities to changing public demands, such as mountain-biking tracks and extreme sport facilities.

Private interests have the opportunity to provide recreational activities within the conservation estate through a formal concession system. These activities include ski fields, guiding and boating operations.

New Zealand's larger plantation companies also provide opportunities for public access, allowing people to undertake activities ranging from hunting and horse trekking to scientific research. Access is normally via a permit system. This enables forestry operations to continue in conjunction with recreational activities.

Quality of information: M

Progress against indicator: ▲

Rationale

This indicator provides information on the area and extent of forests available and/or managed for recreation and tourism activities. The availability and management of forests for these activities is a reflection of society's recognition of the value of forests for recreation and tourism.

NEW ZEALAND'S REPORT

New Zealand's forests, rivers and alpine areas are viewed internationally as offering high-quality adventure and wilderness experiences. The value of these areas (for recreation and conservation) has been recognised for more than a century, and progressive steps have been taken to ensure they are maintained for future generations. New Zealand's first national park, the 79 500 hectare Tongariro National Park, was established in 1887, and three years later the Milford Track in Fiordland was opened. The Milford Track has developed an international reputation amongst wilderness seekers; and the wider Fiordland–South Westland region (Te Waipounamu) has been designated a World Heritage Area.

Nearly 33 percent of New Zealand's land area is formally protected for conservation and recreational purposes (8.8 million hectares out of 26.8 million hectares). Indigenous forests make up a significant proportion of this area. Of the 8.0 million hectares of tall and regenerating indigenous forests, 5.5 million hectares (69 percent) are legally protected for conservation. This is primarily Crown land, but also includes private property that is protected through covenants and other mechanisms.

The protection of New Zealand's natural resources is an ongoing process. In 2002, New Zealand's 14th national park was established, the 157 000 hectare Rakiura National Park on Stewart Island. A recent development has been the establishment of a network of conservation parks in the South Island high country.

The parks protect distinctive areas of biodiversity and provide increased access to the recreational opportunities of the high country.

> The Eyre Mountains/Taka Rā Haka Conservation Park provides unique opportunities for visitors to enjoy a back-country experience in a remote setting… Tramping and climbing options are plentiful within the park and trout fishing opportunities can be found in the rivers on the park boundaries. Hunting, four wheel driving, mountain biking, horse riding, picnicking and camping are also popular options in this remote and scenic landscape. (Department of Conservation, 2007b)

The principal pieces of legislation governing the management of New Zealand's protected lands (the National Parks Act 1980 and Conservation Act 1987) seek to balance the demands of conservation and recreation. Section 4(2)(e) of the National Parks Act 1980 and section 6(d) of the Conservation Act 1987 seek to foster public access and recreation, where activities are not inconsistent with the protection of ecological values and preservation of natural features. The Walking Access Commission, established in 2008, seeks to provide the New Zealand public with free and enduring walking access to the outdoors (including the coastline, lakes and rivers). The Commission provides leadership on walking access issues, and works to resolve disputes on access, as well as negotiate new walking access.

In addition to this legislative commitment, the New Zealand Government has allocated significant resourcing to the maintenance and promotion of recreation and educational facilities in the conservation estate.

Tramping in sub-alpine shrubland, Ruahine Mountains.
Photo: Alan Reid.

> In 2002, the Government [announced] a 10-year $349 million programme of work to replace, upgrade and maintain recreation facilities. In the first four years, the additional funds accelerated capital asset replacement, particularly of huts, structures, toilets and roadside facilities for day visitors. Highlights include 42 new backcountry huts since 2002. (Department of Conservation, 2007a)

In the 2012/13 financial year, $138 million was spent on managing recreational opportunities. This represented around 43 percent of DOC's total expenditure of $273 million. This expenditure was used to maintain 13 144 structures, 14 000 kilometres of tracks and 967 huts (Department of Conservation, 2013a).

The types of facilities and services provided by DOC have been changing, in line with visitor preferences. For example, DOC has made a significant investment over the past 15 to 20 years in the development of mountain-biking tracks and facilities for extreme sports.

In 2013, DOC released its 2013 to 2017 *Statement of Intent*. In this document, DOC assessed the changing nature of its visitor profile and identified key outputs to encourage greater participation in outdoor recreation. These outputs include:

- developing icon sites to support the growth in domestic and international visitors;
- developing gateway destinations to grow recreation in the outdoors;
- managing locally treasured destinations to increase community connections; and
- enhancing the backcountry network to attract a wider range of visitors (Department of Conservation, 2013d).

In determining the area available for recreation and tourism, it is important to recognise that activities such as hunting, orienteering and mountain biking are not confined to public conservation lands. The majority of New Zealand's commercial forest owners operate permit systems that allow varying degrees of access to their properties. The permit will detail the type of activity that can be undertaken, the forestry blocks that can be accessed and any restrictions on times and the routes to be used. The permit system enables forestry companies to continue their normal operations while safely allowing a degree of public access. Some of these recreational activities can have positive benefits for the forestry companies. Recreational hunting for wild deer, pigs and goats, along with the trapping of possums, helps the plantation companies in controlling pest numbers.

The diversity of activities undertaken in the commercial estate can be seen in the permit data of companies such as Blakely Pacific Limited (2007). The recreational activities permitted in its South Island forests include: hunting, cycling, walking, horse trekking and vehicle club access. The growing co-operation between forestry companies and recreational groups can be seen in another Blakely Pacific example. In 2011/12, the company worked with local community groups to re-establish one of the walking tracks in Herbert Forest (North Otago). The track system through Herbert Forest is seen as a significant resource for the local community.

> All of the walking tracks traverse through mature native podocarp forest remnants, the scale of which are rare in the North Otago area. (Blakely Pacific Limited, 2012)

A number of New Zealand's commercial forests have developed into significant tourist attractions in their own right. These forests were generally established by the New Zealand Forest Service (a former state-owned agency). The Forest Service created walkways and supporting facilities in key locations (particularly tourist areas). Most of these facilities have been maintained with the sale of these forests to private interests.

The 5700-hectare Whakarewarewa Forest, near Rotorua, is an important example of a commercial forest that has become a significant recreational resource for local and international visitors. The forest has a network of paths for walkers and joggers; mountain-bike and motorbike tracks; picnic areas and a visitor centre. The forest is managed by Kaingaroa Timberlands,[49] and attracts an estimated 282 000 recreational visits per year (APR Consultants, 2007). In a similar vein, Naseby Forest in Central Otago has gained a national reputation for its mountain-bike tracks. The forest is owned by Ernslaw One Limited, which has supported the recreational development of the forest.

49 Kaingaroa Timberlands manages the forest estate and the land is in Māori ownership. The Redwoods Grove in Whakarewarewa Forest is managed by the Rotorua District Council.

Further examples include the walking and mountain-bike tracks developed around Dunedin by City Forests Limited and the extensive recreational facilities in Woodhill Forest, west of Auckland. Woodhill Forest has grown into a popular recreational resource for the Auckland population, with walking, biking, horse riding and off-road opportunities, as well commercial recreational activities.

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Indicator 6.4.b Number, type, and geographic distribution of visits attributed to recreation and tourism and related to facilities available

New Zealand's indigenous forests and wilderness areas have been attracting visitors for more than 150 years and they now play a central role in the country's domestic and international tourism scene. Nearly 48 percent of New Zealanders (aged over 18) visited public conservation lands in 2012/13, and an estimated 77 percent of international visitors undertook one or more walking, hiking or trekking experiences while they were in the country (June 2013 figures).

The Department of Conservation actively promotes the use of the conservation estate for recreational purposes and has moved to a demand-driven management approach, so it can respond more effectively to domestic and overseas visitor needs.

One of the principal attractions of New Zealand for international visitors is the chance to experience wilderness activities, such as hiking, kayaking and hunting.

Quality of information: H

Progress against indicator: ▲

Rationale

This indicator provides a measure of the level and type of recreation and tourism use in forests. The number and geographic distribution of visits and the facilities available reflect the extent to which people participate in forest-based leisure activities and the importance of forests for recreation and tourism.

NEW ZEALAND'S REPORT

New Zealand's indigenous forests and conservation areas are generally seen as the cornerstone of the country's tourism industry. Domestic and international visitors are drawn by the opportunities to explore wilderness areas and to undertake a range of outdoor adventure pursuits. Providing access to these areas has required long-term investment by central and local government in establishing high-quality walkways, tracks and supporting tourist facilities. In more recent decades, the private sector has taken a larger role in providing recreational facilities and in developing new forms of adventure activity.

> Nature-based tourism ranges from high impact adventure activities such as jet boating, skydiving and mountain climbing to more relaxing activities such as bush walking, wildlife and scenic tours and boat cruises. (Market Economics Limited, 2008, p 1)

The extensive network of tracks that visitors now enjoy has been progressively developed since the late 19th century. The internationally known Milford Track was one of the first to be opened in 1890. The network of tracks was given a major boost in the 1950s and 1960s, when the then New Zealand Forest Service established a system of backcountry tracks and huts, in both conservation and production forests. These tracks opened up the backcountry for recreational and commercial hunters. This was followed in the 1970s and 1980s by a range of government initiatives to upgrade amenities to encourage greater domestic and international use of the conservation estate. New Zealand's focus on wilderness and adventure experiences brings with it a higher level of risk than other forms of tourism. In recognition of this, resources are devoted to the provision of search and rescue, and emergency care services.

When considering the recreation and tourism opportunities associated with New Zealand's forests, it is important not to overlook the role of New Zealand's 1.7 million hectares of commercial plantations. The recreational facilities in these forests are not normally as developed as those in the conservation estate, but they can provide valuable opportunities for bush walks, fishing and hunting. As discussed in Indicator 6.4.a, a number of the long-established commercial forests provide nationally important facilities, such as mountain biking and orienteering tracks.

Visitor trends

New Zealand's indigenous forests have been attracting visitors for more than 150 years. As early as the 1840s, guidebooks were promoting the unique flora and fauna of the country and the opportunities for wilderness experiences. Organised tours soon followed, along with the development of recreational facilities. The establishment of the Hermitage Hotel in 1884 (at the base of Aoraki/Mount Cook) was an early example of this development. The hotel provided a base for guided alpine walks and climbing.

Visitor numbers have grown as the cost of travel (and travel times) has decreased. Large areas of rural New Zealand were opened up to travellers in the 1950s through to the 1970s, with the sealing of district roads. This was coupled with increasing vehicle ownership and the previously mentioned upgrading of the track network. An important development was the advent of long-distance air travel to New Zealand. This enabled New Zealand to become a mass tourism destination. In the mid-1950s, fewer than 100 000 visitors arrived annually. For the year ending December 2013, visitor numbers stood at 2.72 million (Statistics New Zealand, 2014), an 11 percent increase on the 2008 report figure.

The past 10 years have seen a growing recognition that attracting visitors to New Zealand's natural features requires a stronger focus on visitor requirements.

> In order to increase participation, DOC [Department of Conservation] is moving from a supply-based asset management approach to being a demand-driven organisation. This will enable DOC to respond to the recreation needs of New Zealanders and those visiting this country, both now and as demand changes. (Department of Conservation, 2013a)

DOC has also put a strong emphasis on raising public awareness of the conservation estate and the recreational opportunities that are available to individuals and families.

Public use of the conservation estate has risen since the last report. In 2007/08, DOC estimated that 39 percent of adult New Zealanders visited the conservation estate (reserves, national parks and water areas). This increased to 50 percent in 2011/12 and fell back marginally to 48 percent in 2012/13 Department of Conservation 2013c).

Monitoring visitor numbers

Visitor numbers are monitored by DOC and the Ministry of Business, Innovation and Employment through visitor survey programmes. These programmes provide information on the major activities undertaken by domestic and international visitors, such as the number of visits to national parks, tracks and scenic reserves. This helps DOC (and the wider tourism industry) to plan for future demand and identify where natural resources may be under pressure. The data enable DOC to put in place initiatives to:

- meet current and potential visitor needs (with changing demographics and leisure preferences);
- prioritise investment at destinations that have high levels of current or emerging demand; and
- focus development on gateway and iconic sites (Department of Conservation, 2013b)

The visitor estimates produced by DOC are for the entire conservation estate. A separate analysis is not available for indigenous forests, because most reserves combine areas of forest with open grassland, tussock and bush. The International Visitor Survey, managed by the Ministry of Business, Innovation and Employment, asks about visits to specific national parks, but most of the questions, such as walking, overnight trekking and cycling are not specific to a locality.

Table 6.21: Main activity undertaken by New Zealanders during their most recent visit to public conservation land (2010–13)

Main activity	2010/11 (%)	2011/12 (%)	2012/13 (%)
Short walks	29	35	31
Day walks	12	10	16
Camping	4	5	4

Source: Department of Conservation, 2013c, p 52.

Domestic visitors

The latest survey of visitor numbers by DOC found that 48 percent of adult New Zealanders (1.6 million) had visited the conservation estate in 2012/13, and 23 percent of adult New Zealanders had visited a national park (0.8 million).

The principal activity visitors undertake is a short walk, lasting a few minutes to half a day. DOC has placed a high priority on developing short walks for public recreation. The walks have been developed as part of heritage and iconic attractions and are in areas of high visitor use or adjacent to major transport routes.

The relative importance of short walks compared with other activities is shown in Table 6.21. DOC asked visitors the main reason for their last visit to the estate. While the survey numbers vary from year to year, short walks were rated as the major reason in 29 percent to 35 percent of cases (Department of Conservation, 2013c).

Day walks were the principal activity undertaken by 10 percent to 16 percent of survey respondents over the past three years. They are available in most districts, and DOC provides a range of tracks to cater for visitors of varying ability (from easy walking to strenuous). The day-walk tracks range from reserves on the urban fringe to high country parks. Day visitors are generally seeking natural settings for walking, sightseeing, fishing or climbing. One of the more widely known day trips is the Tongariro Crossing in the central North Island. This seven- to eight-hour high-terrain walk attracts over 70 000 visitors a year (Minister of Conservation, 2013).

Camping was the main reason for visiting the conservation estate for between 4 percent and 5 percent of survey respondents. Camping is normally undertaken in conjunction with other recreational activities, such as hiking, hunting and climbing. The camping opportunities range from single, overnight stays in easily accessible sites through to extended high country tracks that can take between three and six days to complete (for example, Routeburn Track – three days, Milford Track – four days and Heaphy Track – four-to-six days). Backcountry fishing and hunting expeditions can last for significantly longer periods.

Of the visitors who stay overnight at campsites or in huts, just over 40 percent are classed as "backcountry adventurers". This group of visitors is seeking the traditional bush or high country experience. They use the more remote tracks and the group includes hunters.

Over the 2010 to 2013 period, 14 percent of adult New Zealanders (0.5 million) stayed in a DOC hut or lodge. The equivalent figures for campsites were 22 percent for basic sites, 18 percent for standard sites and 11 percent for serviced sites. DOC is working to encourage greater use of these facilities and has set five-year targets to steadily increase visitor numbers (Department of Conservation, 2013c).

International visitors

Overseas visitors to New Zealand have increased by 81 percent from 1997 to 2013 (from 1.497 million arrivals to 2.717 million). This growth in visitor numbers has led to a substantial rise in the use of New Zealand's indigenous forests and conservation areas by travellers, as shown in national park data (Table 6.22) below.

The national park data show that overseas visitors are exploring a range of geographical locations, rather than concentrating on one or two particular areas.

Table 6.22: International visitor numbers to selected national parks (1997–2012)

Calendar year	Paparoa (West Coast of the South Island)	Abel Tasman (Upper wSouth Island)	Tongariro (Central North Island)	Aoraki/Mt Cook (Central South Island)	Fiordland (Southern South Island)	Westland (West Coast of the South Island)
1997	11 700	28 800	32 100	154 300	196 100	205 500
2002	44 400	57 900	55 100	158 100	273 000	280 900
2007	97 400	110 700	97 800	172 700	439 900	376 700
2012	114 200	95 300	114 000	155 700	338 700	288 800
Change from 1997 to 2012 (%)	876	231	255	0.9	73	41

Source: Department of Conservation, 2014.

Table 6.23: Nature-based tourism activities undertaken by international and domestic tourists (2008)

Activity	International Occasions	Domestic Occasions
Scenic drive	445 000	582 000
Glacier (walk/view)	325 000	66 000
Sightseeing tour (land)	249 000	352 000
Bush walk (half hour)	248 000	603 000
Bush walk (half day)	225 000	292 000
Trekking/tramping	201 000	315 000

Source: Ministry of Tourism, 2009.

This is reflected in the fact that New Zealand's iconic alpine park (Aoraki/Mount Cook) has seen only a marginal rise in overseas visitor numbers since 1997 (1 percent). The more recently established Paparoa National Park, on the West Coast of the South Island, experienced the greatest percentage gain, with visitor numbers rising 876 percent (from 11 700 to 114 200) between 1997 and 2012.

The weak state of the international economy since 2008 has altered New Zealand's tourist flows, with reductions in long-stay tourists from the United Kingdom and the United States, and increased short-stay arrivals from Australia and China. The shorter trip length has meant that tourists are more restricted in the areas they can visit. This is reflected in the 2012 visitor numbers for parks such as Westland and Fiordland, which require several days to visit (Department of Conservation, 2014).

The principal activities associated with New Zealand's conservation lands are shown in Table 6.23. The activities undertaken by international visitors span a wide spectrum, from strenuous wilderness treks through to passive forms of recreation (such as scenic drives). In addition to this list, 116 000 international visitors undertook fishing and 147 000 kayaking and rafting in 2008 (Ministry of Tourism, 2009). These results show that New Zealand's forests, rivers and alpine landscapes are seen internationally as important tourist destinations, and that visitors travel to the country to undertake a broad range of recreational activities.

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INDICATOR 6.5 CULTURAL, SOCIAL AND SPIRITUAL NEEDS AND VALUES

People and communities, in both rural and urban areas, have a variety of social, cultural and spiritual connections to forests, based on traditions, experiences, beliefs, and other factors. Among them, the spiritual and cultural connections of indigenous people to forests often form part of their identity and livelihood. These values may be deeply held and influence people's attitudes and perspectives towards forests and how they are managed. These indicators provide information on the extent to which cultural, social, and spiritual needs and values exist and are recognized by society.

Indicator 6.5.a Area and percent of forests managed primarily to protect the range of cultural, social and spiritual needs and values

The area of forest land managed by the Department of Conservation (DOC) has increased from 4.9 million hectares in 2000 to 5.5 million hectares in 2014. DOC, in total, has management responsibility for 8.5 million hectares of legally protected lands. All of DOC's lands are managed for conservation purposes under the Conservation Act 1987 and other legislation such as the National Parks Act 1980. Management of DOC's forest land recognises its natural and cultural values. The Resource Management Act 1991 recognises and provides for the relationship of Māori and their culture and traditions in resource management planning by all levels of government.

Quality of information: M

Progress against indicator: ▲

Rationale

This indicator measures the extent of forests managed primarily for their cultural, social and spiritual values to people and communities, including indigenous communities and others with strong ties to forests. The protection of forests to meet such needs and values is a reflection of the extent to which they are recognised by society.

NEW ZEALAND'S REPORT

DOC manages land and forests under the Conservation Act 1987 and other Acts, and under a range of classifications such as national parks, conservation parks, stewardship areas, scenic and other reserves, and wildlife refuges. Under the Conservation Act 1987, all land is managed for conservation purposes. Conservation is interpreted as:

> ...the preservation and protection of natural and historic resources for the purpose of maintaining their intrinsic values, providing for their appreciation and recreational enjoyment by the public, and safeguarding the options of future generations. (Section 2, Conservation Act 1987)

DOC consults with Māori and the community about policy, management plans and operations (see Indicator 7.1.a) that relate to land managed under the Conservation Act 1987. Customary use of traditional materials and indigenous species on conservation land may be authorised under various provisions of the Act.

Under the National Parks Act 1980, national parks are to be preserved as far as possible in their natural state.

In 2014, a new model of management for the conservation estate has come into being with the passage of legislation to give substance to the Treaty of Waitangi settlement claim of Ngai Tūhoe. The Te Urewera–Tūhoe Bill provides for Te Urewera (one of the national parks) to be established as a legal identity with its own intrinsic values, and vests the current national park land in that identity. A new Board will be the primary decision maker for Te Urewera and is charged with governing the land to strengthen the connection between Tūhoe and Te Urewera, preserve its ecosystems and biodiversity and provide for ongoing public use and recreation. The inaugural Board has eight members, four appointed by the Government and four by Tūhoe Te Uru Taumatu (the Tūhoe governance entity). The Board is to select its own chair from among the Tūhoe appointees and, along with the Government and Tūhoe, will work to seek biosphere status from the United Nations Educational, Scientific and Cultural Organization (UNESCO) for Te Urewera.

DOC is also increasing business partnerships and community involvement through community-led projects to support conservation management (see Indicator 7.5.a).

Many private organisations are actively involved in conservation and environmental issues in New Zealand. These vary from local clubs concerned with the protection or restoration of the local environment, to national and international groups concerned with preserving the environment for its ecological, scientific, recreational or scenic values.

As an example, the Royal Forest and Bird Protection Society owns nearly 40 reserves around New Zealand, totalling more than 1000 hectares (Royal Forest and Bird Protection Society of New Zealand, undated).

The protection of important cultural sites, particularly wāhi tapu sites,[50] in the management of plantation forests is provided for through statutory planning processes under the Resource Management Act 1991 (see Indicator 7.1.a). Social values are not generally accorded primary recognition in plantation forest management, though with third-party certification placing emphasis on social values, their incorporation in forest management is increasing.

Management of Māori-owned plantation forests, and of plantation forests on Māori-leased land, commonly gives recognition to Māori customary values.

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50 Sacred or sites of special cultural significance to local Maori.

Indicator 6.5.b The importance of forests to people

Forests are well recognised for a range of natural, cultural, social and economic values. The importance of particular values and mixes of values varies with the nature and location of the forests and with the focus of the group being surveyed. While legislation and policy have largely ended the debate over the protection of natural values of indigenous forests, New Zealand society remains divided on the ability to interact with indigenous ecosystems in sustainable ways.

Quality of information: M

Progress against indicator: ▶

Rationale

This indicator provides information on the range of values that communities and individuals hold for forests. These values shape the way people view forests, including their behaviours and attitudes to all aspects of forest management.

NEW ZEALAND'S REPORT

New Zealanders recognise a wide range of values associated with both indigenous and plantation forests. Most prominent are:

- biodiversity at the species and ecosystem levels, and the ability of ecosystems to function in a healthy state;
- the productive capacity of forests for timber, employment and economic contributions – largely, but not entirely, related to plantation forests;
- access to non-polluted drinking water catchments and waterways;
- the contributions forests make to soil conservation and carbon sinks;
- freedom of access to a variety of passive and active recreational pursuits;
- intrinsic values and their contribution to people's health and wellbeing;
- wild animal recovery and the cultural harvest of plant species;
- landscape features and their contribution to the identity of areas.

These values are based on a review by Barnard et al (2006) who concluded that forest management practices across public and private tenures account for the values inconsistently. Many are "public" values, such as biodiversity, landscape and water quality. Consequently, forest management on publicly and privately owned land attracts considerable public interest.

The purpose of management of publicly owned indigenous forests under the Conservation Act 1987 is to maintain their intrinsic values (see Indicator 6.5.a).

Sustainable forest management of privately owned indigenous forests under Part 3A of the Forests Act 1949 requires the management of the forest land in a way that maintains the ability of the forest to continue to provide a full range of products and amenities in perpetuity, while retaining the forest's natural values. The passing of this legislation in 1993, and the decision by government to halt harvesting from publicly owned indigenous forest from 2002, ended much of the debate over the protection of the natural values of indigenous forests.

Plantation forests are recognised for their commercial value in the production of wood and processed wood products, and for employment. They also contribute to sustainable economic development, to carbon sequestration and storage, and enable the setting aside of indigenous forests from commercial wood production.

New Zealand's forests are highly valued for recreational purposes including tramping (trekking), bushwalking, camping, wildlife appreciation, photography, mountain biking and hunting (see Indicator 6.4.b). They are also widely used for community activities and school educational visits.

This recognition of the values of forest ecosystems, both indigenous and plantation, is obvious in several chapters in the book *New Zealand ecosystem services* (Dymond, 2013).

Māori have strong cultural, spiritual and commercial connections to forests and forestry. They are connected spiritually and culturally with indigenous forests as a resource for food, medicines, building materials, shelter, clothing, implements and handicrafts (Harmsworth and Awatere, 2013). Māori involvement in plantation forestry is steadily increasing and provides an option for the protection of Māori lands, employment and economic benefits.

In the management of plantation forests, Māori have historically adhered to the basic customary principles and beliefs that form Māori customary law. In managing the Māori lease plantation forests of Lake Taupo and Lake Rotoaira, the first three objectives of each lease require the:

- maintenance of soil stability and prevention of erosion to protect the streams, rivers and lakes;
- protection of wildlife and fish habitat;
- protection of wāhi tapu (sacred or sites of special cultural significance of locala Māori) on the lands.

The Parliamentary Commissioner for the Environment's 2002 report *Weaving resilience into our working lands* identifies the clash of values over what New Zealand should do with indigenous plants growing, or planted, on privately owned land. The report states:

> At the core of the debate regarding the future roles of native plants on private land is a fundamental difference of view concerning the ability of New Zealanders to interact with indigenous ecosystems in ecologically sustainable ways. There is an inherent tension in human efforts to manage natural resources. This tension is most immediately evident in the conflicts between values of utilisation and protection, between monetary returns and ecological constraints. The inability of New Zealanders to reconcile these conflicts has created a significant split in the purposes for which we manage land …
>
> As illustrated, land management in New Zealand can be characterised by a dichotomy [sic] between:
> - nature and culture (society)
> - public and private
> - indigenous and exotic
> - conservation and production
> - protection and exploitation.
>
> (Parliamentary Commissioner for the Environment, 2002, pp 15–16)

This indicates that New Zealand society is divided on how well the values of indigenous vegetation are appreciated, and questions whether the nation has yet developed the ability to manage indigenous resources for productive purposes, while protecting their natural values.

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CRITERION 7:
LEGAL, INSTITUTIONAL AND ECONOMIC FRAMEWORK FOR FOREST CONSERVATION AND SUSTAINABLE MANAGEMENT

Criterion Seven relates to the overall economic, legal, institutional, and policy environment of a country. This Criterion provides a context for the consideration of Criteria One to Six.

Legislation, institutional capacity and economic arrangements, with associated policy measures at both national and sub-national levels, create an enabling environment for the sustainable management of forests. Reporting against these indicators contributes to raising public and political awareness of issues affecting forests and builds support for their sustainable management.

Table 7.1 lists the indicators covered in this section.

Table 7.1: Indicators for Criterion 7 – quality of information and trends

Criterion 7: Legal, institutional and economic framework for forest conservation and sustainable management		Quality of information	Trend
7.1.a	Legislation and policies supporting the sustainable management of forests	H	Neutral
7.1.b	Cross-sectoral policy and programme co-ordination	H	Neutral
7.2.a	Taxation and other economic strategies that affect sustainable management of forests	H	Neutral
7.3.a	Clarity and security of land and resource tenure and property rights	H	Positive
7.3.b	Enforcement of laws related to forests	H	Neutral
7.4.a	Programmes, services and other resources supporting the sustainable management of forests	H	Neutral
7.4.b	Development and application of research and technologies for the sustainable management of forests	H	Positive
7.5.a	Partnerships to promote the sustainable management of forests	H	Positive
7.5.b	Public participation and conflict resolution in forest-related decision making	M	Positive
7.5.c	Monitoring, assessment and reporting on progress towards sustainable management of forests	M/H	Positive

KEY

L = low — Neutral ▶

M = medium — Positive ▲

H = high — Negative ▼

NEW ZEALAND OVERVIEW

Key initiatives since 2008 are the:

- introduction to Parliament of the Environmental Reporting Bill to provide a national-level environmental reporting system;
- introduction of the New Zealand Emissions Trading Scheme to address greenhouse gas emissions and removals;
- publication of the National Infrastructure Plan 2011 and the 2012–15 National Land Transport Programme;
- review by WorkSafe New Zealand in to safety in the forest industry;
- introduction of a forest growers levy to fund a variety of plantation forest industry-good initiatives;
- release of version 4 of the national Land Cover Database.

Legal framework

The Treaty of Waitangi is the foundation legal document that enshrines the partnership between New Zealand's indigenous Māori people and the Crown, and recognises the rights of Māori. Its principles are recognised in key resource management legislation.

The Resource Management Act 1991 (RMA) is the primary legislation for the statutory management planning of land, air and water resources. The purpose of the RMA is to promote the sustainable management of natural and physical resources while (amongst other things) avoiding, remedying or mitigating adverse effects of activities on the environment. Much of the responsibility for implementation of the RMA has been devolved to local government (regional, district and city councils), principally through the development of a range of policy statements and plans.

New Zealand has a well established and robust legal framework for the identification and protection of property rights, particularly through the Property Law Act 1952 and the RMA.

Biosecurity is an important issue for New Zealand, as the country is free of many overseas forest (and other) pests and diseases. With increasing trade and travel elevating the risks of incursions, a strong biosecurity system is crucial. This is delivered under the Biosecurity Act 1993, with the system focused on risk reduction, readiness, response and recovery.

Public participation is provided for in:

- legislative Bills progressed through a Parliamentary select committee process that provides for public participation, with the exception of those Bills requiring urgency;
- the development of local authority policy statements and plans under the RMA.

For members of the public to have effective input to legislative and planning processes, access to good information is essential. A variety of forestry information is available (see below under Institutional framework). The Official Information Act 1982 and Local Government Official Information and Meetings Act 1987 operate on the principle that government information shall be made available unless there is good reason for withholding it.

The Parliamentary Commissioner for the Environment is an independent Officer of Parliament under the Environment Act 1986 with wide powers to investigate, report and make recommendations to Parliament on any environmental matter. The Parliamentary Commissioner for the Environment can also investigate and advise public authorities on the effectiveness of environmental management.

At the forest level, the Conservation Act 1987 requires the Department of Conservation (DOC) to develop conservation management strategies for the integrated management of natural and historic resources, including the Crown-owned indigenous forests. Sustainable forest management plans and permits are required under the Forests Act 1949 where timber is harvested from privately owned indigenous forests.

Forestry, resource management and biosecurity legislation and regulations are enforced by specialist staff from central and local government, as well as by honorary rangers for the conservation forest estate. The legislation includes penalties for offences that provide for fines and imprisonment, while the RMA also provides for enforcement orders and abatement notices.

Dispute resolution mechanisms include arbitration, mediation, the Small Claims Tribunal and the courts.

Policy framework

Governments over the past two decades have taken a cross-sector or landscape approach to resource management. Current approaches seek to manage adverse effects on the environment, while balancing sustainable resource use. The legislative and economic frameworks mean investment is largely market driven.

The RMA delivers resource management planning at central, regional and district government levels that directly affects many forestry activities.

Conservation management strategies cover the Crown-owned indigenous forest conservation estate, and more detailed conservation management plans may be prepared. About 84 000 hectares of privately owned indigenous forest are under registered sustainable forest management plans or permits (see indicators 2.a and 2.d). Large-scale plantation forest owners also undertake estate, forest and/or operational levels of planning.

Institutional framework

Well-developed road, rail, port and energy infrastructure networks generally serve the needs of the forest industries. Central and local government operate the public road network, and central government purchased the assets of the national rail operator in 2008. Overseas trade relies heavily on sea transport, and New Zealand is served by 13 commercial ports with significant volumes of forestry exports and/or imports. Central government strategies are in place to provide for the continuing development of this infrastructure.

New Zealand has several Crown Research Institutes, universities, private companies and individuals providing forestry or forestry-related research. For the indigenous forest estate, the research is focused on biodiversity and the management of introduced pests. Research on sustainable plantation forest management is extensive and wide ranging.

New Zealand has well-developed systems of forestry training and education, delivered through Competenz (an industry training organisation), polytechnics, universities and private training providers.

DOC is increasing business partnerships and community involvement through community-led projects. DOC also engages with the public through visitor centres, volunteer programmes, conservation projects, annual events, educational resources, discussion documents, surveys and access to website-based resources.

Comprehensive statistical databases are available that describe the plantation forest estate, the production of, and trade in, wood and wood products. Forecasts of plantation forest wood availability are prepared about every five years. The reliability of this information is supported by the generally strong commitment of forest owners and processors of wood products to provide detailed statistical information.

Information on the extent and physical attributes of indigenous forests is being strengthened as a result of international climate change reporting requirements and the use of satellite imagery. These requirements, and the application of revised survey methods and the auditing of a percentage of the monitoring on conservation estate land, are raising the reliability of data available for the indigenous forest estate.

Economic framework

The main forms of taxation that affect forestry are company and income tax, and goods and services tax. The taxation regime applying to commercial forestry has been stable since 1991, when significant changes were made to the income tax legislation applying to forestry. The taxation rate for businesses in New Zealand decreased from 30 percent to 28 percent in 2011, while the goods and services tax increased from 12.5 percent to 15 percent in 2010.

Investment in commercial forestry is influenced by a range of business and market-related factors. The New Zealand Government is supportive of foreign investment. The Overseas Investment Act 2005 regulates overseas acquisitions of New Zealand land and significant business assets.

The New Zealand economy is highly dependent on international trade of primary products, with forestry the third-highest export earner. New Zealand operates a relatively open trade policy and actively engages in trade liberalisation. Over recent years, it has become a party to several regional bilateral and plurilateral trade agreements.

Indicator 7.1.a Legislation and policies supporting the sustainable management of forests

New Zealand has a well established and robust legal framework supporting the sustainable management of resources, including forests. It includes the Resource Management Act 1991 (RMA), Conservation Act 1987, Forests Act 1949 and Biosecurity Act 1993. The Treaty of Waitangi recognises the rights of Māori and their partnership with the Crown.

An indigenous forest policy established in 1991 resulted in the sustainable (indigenous) forest management provisions of the Forests Act 1949.

Since 2008, amendments have been made to the Resource Management Act 1991 and further amendments are before Parliament.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator provides information on legislation and policies, including regulation and programmes, which govern and guide forest management, operations and use. Legislation and policies designed to conserve and improve forest functions and values are prerequisite to achieving the sustainable management of forests.

NEW ZEALAND'S REPORT

Treaty of Waitangi

The Treaty of Waitangi was signed in 1840 and is the foundation legal document that recognises the rights of Māori in New Zealand and their partnership with the Crown. Its principles (see **http://www.justice.govt.nz/tribunals/waitangi-tribunal**) are provided for in many pieces of legislation, including the RMA[51] and Conservation Act 1987.

The Waitangi Tribunal is the judicial body that considers claims from Māori who believe that they are prejudiced by government action inconsistent with the Treaty of Waitangi. The Tribunal was established by the Treaty of Waitangi Act 1975. It is a permanent commission of inquiry, charged with making recommendations on claims brought by Māori relating to acts or omissions of the Crown that breach the promises made in the Treaty of Waitangi (see **http://www.justice.govt.nz/tribunals/waitangi-tribunal/the-claims-process**). Many claims relate to the return of resources held by the Crown. Land subject to a claim has its title annotated accordingly so that the claim is not affected should the land be sold.

Resource Management Act 1991

The RMA is the primary legislation for statutory resource management planning, having brought together laws governing land, air and water resources.

The RMA has been under review since 2008 to simplify and streamline planning processes. The second phase of amendments is currently under consideration through the Resource Management Reform Bill 2012.

The purpose of the RMA (section 5) is "...to promote the sustainable management of natural and physical resources". Sustainable management is described in (section 5(2)) as:

> ...managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—
>
> a. sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
>
> b. safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and

51 Under section 6(e) of the Resource Management Act 1991, the relationship of Māori with their ancestral lands, water, sites and treasured resources is a matter of national importance, to be recognised and provided for by all who exercise functions under that Act. The principles of the Treaty of Waitangi must also be taken into account in managing the use, development and protection of natural and physical resources (section 8).

c. avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Matters of national importance are also identified in the RMA (section 6) and these must be recognised and provided for by those parties implementing the legislation. They currently include the:

- protection of outstanding natural features and landscapes from inappropriate subdivision, use and development;
- protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna;
- relationship of Māori and their culture and traditions with their ancestral lands, water, sites, wāhi tapu[52], and other taonga[53];
- protection of historic heritage from inappropriate subdivision, use and development;
- protection of recognised customary activities.

Other matters that those implementing the legislation must currently have regard to (section 7) include:

- kaitiakitanga;[54]
- the ethic of stewardship;
- the maintenance and enhancement of amenity values;
- intrinsic values of ecosystems;
- maintenance and enhancement of the quality of the environment.

Amendments being considered propose to delete some matters in sections 6 and 7, add new matters, and merge into one list matters of national importance. Also proposed is a new section 7 that will set expectations of best-practice approaches to resource management decisions.

Central government has devolved much of the responsibility for resource management planning and policy making to local government through the RMA. Every regional council must have a regional policy statement with which regional and district plans must be consistent. Such statements provide an overview of the resource management issues of the region, as well as policies and methods to achieve integrated management of the natural and physical resources of the whole region. Regional and district plans help councils carry out their functions in order to achieve the purpose of the RMA. All policy statements, and regional and district plans, must be reviewed every 10 years.

To provide direction to local government, central government can prepare national policy statements (such as the Proposed National Policy Statement on Indigenous Biodiversity, New Zealand Coastal Policy Statement 2010, and National Policy Statement for Freshwater Management 2014) and national environmental standards.

District and regional councils have taken differing planning approaches to manage plantation forestry activities under the RMA. This differing treatment of forestry activities is being addressed under a proposed National Environmental Standard for Plantation Forestry. The standard is being developed jointly with industry, councils and environmental non-government organisations. It is proposed that it will cover the key plantation forestry activities including harvesting and earthworks, and it is intended to improve certainty for forest owners.

Local Government Act 2002

The Local Government Act 2002 requires regional, district and city councils to develop community outcomes and translate these into long-term community plans. These are 10-year strategic planning documents covering all functions of local government. They do not override the provisions of RMA plans but are expected to inform the preparation of plans prepared under the RMA.

Biosecurity Act 1993

Central and regional government agencies administer functions under the Biosecurity Act 1993. The Act provides a framework to manage pests and unwanted organisms in New Zealand along a continuum from pre-border activities through to incursion response and long-term control and containment. The work is led and co-ordinated by the Ministry for Primary Industries.

An effective biosecurity system is crucial to protect the environment, the economy and human health. New Zealand's biosecurity system is based on the Biosecurity Act 1993 and on four basic steps that reduce the potential or actual impact of a new and unwanted organism:

52 Wāhi tapu means land of special spiritual, cultural or historical tribal significance.

53 Taonga means a treasure.

54 Kaitiakitanga means the exercise of guardianship by Māori in relation to natural and physical resources.

- risk reduction involves identifying, analysing and eliminating or mitigating risks (offshore and border biosecurity measures);
- readiness is about preparedness for future events;
- response involves actions taken after an incursion event;
- recovery comprises the co-ordinated mid- and long-term efforts to restore or mitigate the social, economic, natural and built environments.

Forest biosecurity is strengthened through collaboration with the sector and other stakeholders. Particularly relevant are the Forest Biosecurity Consultative Committee, the Surveillance Incursion Response Working Group and the Forest Research Biosecurity Council.

Conservation Act 1987

The Conservation Act 1987 requires the Department of Conservation (DOC) to manage for conservation purposes, all land, and all other natural and historic resources held under the Act. This includes about 5.5 million hectares of indigenous forest. Section 2 of the Act defines conservation as:

> …the preservation and protection of natural and historic resources for the purpose of maintaining their intrinsic values, providing for their appreciation and recreational enjoyment by the public, and safeguarding the options of future generations.

The Act requires DOC to develop conservation management strategies in accordance with the legislation under which it operates. The purpose of these strategies is to implement general policies and establish objectives for the integrated management of natural and historic resources managed by DOC, and for recreation, tourism and other conservation purposes. For areas where there are high levels of activity or complexity that cannot be satisfactorily dealt with by a conservation management strategy, a more detailed conservation management plan may be prepared.

A conservation management plan must be prepared under the National Parks Act 1980 for each national park, and be reviewed at least every 10 years. Under the Act, national parks shall be preserved as far as possible in their natural state.

Forests Act 1949

An amendment in 1993 introduced Part 3A (provisions relating to indigenous forests) to the Forests Act 1949. Part 3A requires sustainable forest management plans or permits approved by the Ministry for Primary Industries for the commercial harvesting of timber from most privately owned indigenous forest, the registration of all sawmills processing indigenous timber, and controls the export of indigenous timber.

The purpose of Part 3A is to promote the sustainable management of indigenous forest land. Sustainable forest management is defined (section 7) as:

> …the management of an area of indigenous forest land in a way that maintains the ability of the forest growing on that land to continue to provide a full range of products and amenities in perpetuity while retaining the forest's natural values.

Independent Officers of Parliament

The Parliamentary Commissioner for the Environment (PCE) is an independent Officer of Parliament under the Environment Act 1986. The PCE aims to maintain and improve the quality of New Zealand's environment, with a focus on sustainability. The PCE has wide powers to investigate, to report findings and to make recommendations to Parliament on any matter where the environment may be, or has been, adversely affected. The Parliamentary Commissioner investigates and advises public authorities on the effectiveness of environmental planning and management.

Under the Ombudsmen Act 1975, an Ombudsman can investigate any decision, recommendation or action affecting any person or body of people undertaken by public service departments. An Ombudsman may report and make recommendations on complaints.

Policies

Government policy approach to primary sector management is cross-sector or landscape-based, with a focus on balancing environmental and economic outcomes. Government seeks to manage adverse effects on the environment while ensuring resource use is sustainable. This cross-sector and effects-based approach to resource management means a forestry policy is not considered appropriate by the Government[55]. Investment decisions are largely market driven. These frameworks can result in land use change among primary sectors, including some conversion of plantation forest to pastoral farming where farming is more profitable.

The Wood Council of New Zealand's Strategic Action Plan (WoodCo, 2012) has a target to more than double forest and wood product exports to $12 billion by 2022. Government and industry are working jointly to realise the potential of engineered wood products to add value to the forestry industry, and to contribute to growing the value of the country's forestry exports.

A Conservation General Policy and allied General Policy for National Parks are operative and guide the conservation of New Zealand's natural and historic heritage.

A 1990 National Indigenous Forest Policy provides the basis for the Part 3A provisions of the Forests Act 1949 that control the harvesting and milling of timber from privately owned indigenous forests (sustainable forest management). An amendment to this policy resulted in the cessation of all harvesting from indigenous forests on Crown-owned land in 2002, with the exception of 12 000 hectares. Cyclone Ita caused widespread wind-throw in indigenous forests on the West Coast in 2014, and recovery of some of these trees over a five-year period has been enabled.

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55 A sector project to develop a forestry policy was initiated in 2014.

Indicator 7.1.b Cross-sectoral policy and programme co-ordination

Sustainable resource management in New Zealand seeks to balance the adverse effects on the environment, while ensuring the sustainable use of resources. The Resource Management Act 1991 focuses on the integrated management of natural and physical resources.

The legislative and economic frameworks mean that investment decisions are largely market driven.

From 2008, the New Zealand Emissions Trading Scheme has been operative across most sectors of the economy to address greenhouse gas emissions and removals.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator provides information on the extent to which policies and programmes are coordinated across sectors to support the sustainable management of forests. Non-forest sector land use and development decisions may have a significant impact on forests and their use. Cross-sector coordination of forest and non-forest related policies and programmes can promote improved forest management by helping to minimise adverse impacts and by strengthening the ability of countries to respond to national and global issues.

NEW ZEALAND'S REPORT

Sector policies and programmes

Government policy approach to primary sector management is cross-sector or landscape-based, with a focus on balancing environmental and economic outcomes. Government seeks to manage adverse effects on the environment while ensuring resource use is sustainable. This cross-sector and effects-based approach to resource management means a forestry policy is not considered appropriate by the Government. Investment decisions are largely market driven. These frameworks can result in some land use change among primary sectors, including conversion of plantation forest to pastoral farming where farming is more profitable.

The sustainable management of natural resources, and the sectors they support, is addressed during the development and review of regional policy statements and regional and district plans under the Resource Management Act 1991 (RMA). The RMA has a strong focus on the "integrated management" of the natural and physical resources of a region or district.

The procedures for preparing policy statements and plans incorporate formal (as set out in the legislation) and informal consultation processes. Public submissions must be called for during the drafting of policy statements and plans. Consultation with affected parties may also be required before resource consents for specific activities are granted or declined. Any submitter who is not satisfied with a council's decision may appeal to the Environment Court, and then to the High Court (on points of law).

The RMA requires the Minister for the Environment to monitor the effect and implementation of the legislation. The Act also requires every regional and district council to monitor the state of the whole or any part of the environment of its region or district. It does so to the extent that is appropriate to enable the local authority to carry out its functions effectively under the Act. Regional and district councils are also required to respond to complaints and, where necessary, take enforcement action. Such action may include infringement and abatement notices, enforcement orders and prosecutions (see Indicator 7.3.b).

Non-forest sector land use

The clearance of forest and development of pastoral agriculture by early settlers has resulted in significant areas of land with moderate to severe, actual or potential, soil erosion. Reforestation and other soil erosion mitigation measures are needed. The current cost of purchasing much of this land does not reflect its sustainable use (for example, few regulatory land use controls exist on soil erosion) and is an impediment to the establishment of new plantation forests or regeneration to indigenous forests. Policies to address wider environmental impacts (e.g. nutrient limits) or allocate environmental goods (e.g. water) can also impact land use-options, though the affect this has on forests is ambiguous.

Responding to national and global issues

The New Zealand Emissions Trading Scheme (ETS) is the primary mechanism for the country to reduce greenhouse gas emissions and meet international commitments. It puts a price on emissions from most sectors of the economy and a value on carbon sequestration and storage to change behaviours through a market mechanism. For the past three years (2012–2014), the value of New Zealand Units (carbon credits) traded under the ETS has reflected the low international price and has provided little incentive for tree planting. (See also indicators 6.1.c and 6.2.a.)

The establishment of substantial areas of plantation forests during the 1990s that are maturing, sequestering and storing carbon has enabled New Zealand to offset its greenhouse gas emissions from other sectors of the economy, for example, agriculture and transport.

New Zealand's strategy for implementing the Convention on Biological Diversity is outlined in the New Zealand Biodiversity Strategy. The Department of Conservation co-ordinates implementation of this strategy. The international reporting period 2009–2013 is covered in New Zealand's Fifth National Report to the United Nations Convention on Biological Diversity, which provides information on the nature and extent of implementation and progress towards the 2020 Aichi Biodiversity Targets.

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Indigenous forest remnants and poplar/willow erosion control planting on farmland, East Coast of the North Island.
Photo: Alan Reid.

Indicator 7.2.a Taxation and other economic strategies that affect sustainable management of forests

The commercial forestry taxation regime has been stable since 1991. The goods and services tax increased from 12.5 percent to 15 percent in 2010, while the general company income tax rate was reduced from 30 percent to 28 percent in 2011.

The New Zealand Government is open to foreign investment, and regulations are liberal by international standards. The Overseas Investment Act 2005 regulates overseas acquisitions in New Zealand land and significant business assets.

New Zealand has a liberal trade policy and engages in trade liberalisation forums. It is a party to several regional bilateral and plurilateral trade agreements.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator provides information on the economic strategies that affect the sustainable management of forests. Government policies and strategies on investment, taxation and trade may influence both forest management and the level of long term investment in forestry.

NEW ZEALAND'S REPORT

Taxation

The main forms of taxation that affect forestry are income tax and goods and services tax (GST). The income tax rate for all companies in New Zealand was reduced from 30 percent to 28 percent from 1 April 2011 and applies to net income after allowable deductions.

The current income tax regime for forestry has applied since 1991. For taxation purposes, expenditure by a forestry business falls within three categories:

- capital expenditure that is never deducted and depreciated for tax purposes, for example, land purchase;
- expenses of a capital nature expended on an asset with a limited life, for example, construction of fences, roads and firebreaks; these can be depreciated against income from any source;
- costs directly related to the tree crop or incurred in the maintenance of the forestry business, for example, for planting, tending, pest control and overheads; these are deductible in the year incurred from income from any source.

When standing timber is sold in conjunction with land or other assets, the portion of the sales value assigned to the tree crop is treated as part of the seller's assessable income for taxation purposes. The purchaser needs to record the part of the sale price that is immature timber and is able to claim this as a deduction on the eventual sale of that timber.

All personal income, other than most capital gains, is taxed at varying rates that depend on the level of income (with the highest rate being 33 percent).

GST is a value-added tax that applies to goods and services supplied by GST-registered people. The GST rate was increased from 12.5 percent to 15 percent on 1 October 2010.

Investment

The New Zealand Government is open to foreign investment. Regulations governing foreign investment are liberal by international standards, with targeted investment restrictions in only a few areas of critical interest.

Historically secure property rights, an independent, transparent and efficient legal system and lack of corruption, all favour long-term investment in the New Zealand forest industries. General factors that influence investment decisions in forest growing and wood processing include:

- operating costs, capital costs, size of margins and the return on capital;
- availability of labour with the required skills;

- taxation regimes;
- environmental legislation and performance requirements;
- infrastructure.

Investment in the forest growing and wood processing industries can be made in several ways, giving flexibility for investors. Mechanisms include:
- direct investment, such as through the purchase of land, forestry cutting rights or processing facilities;
- joint ventures facilitated through the Forestry Rights Registration Act 1983;
- shares in forestry companies;
- investment companies;
- partnerships.

Foreign direct investment
The Overseas Investment Office administers the New Zealand Government's foreign investment policies, the Overseas Investment Act 2005 and the Overseas Investment Regulations 2005. The Act regulates the acquisition by oversees entities of 25 percent or more ownership or control of interests in significant business assets, and sensitive New Zealand land, which includes:
- non-urban land greater than 5 hectares;
- land on identified offshore islands greater than 0.4 of a hectare;
- land greater than 0.4 of a hectare that is held for conservation purposes under the Conservation Act 1987;
- land greater than 0.4 of a hectare subject to a heritage order;
- registered historic places, historic areas, wāhi tapu (sacred or sites of special cultural significance to local Māori) or wāhi tapu areas.

Consent to acquire sensitive land is only granted if the transaction will, or is likely to, benefit New Zealand, or the relevant overseas person intends to reside in New Zealand indefinitely.

Significant business assets arise where the value of the assets exceeds $100 million.

The Act identifies criteria for consents for overseas investments in land and in significant business assets.

There are no restrictions on the movement of funds into or out of New Zealand, or on repatriation of profits. No additional performance measures are imposed on foreign-owned enterprises.

Trade
Trade is critical to New Zealand's economy, with exports contributing about 30 percent to gross domestic product (GDP). Primary products (agriculture, fisheries, forestry) contributed 73 percent of the value of all merchandise exports, and forestry products contributed 10.3 percent in the year ended December 2013 (Statistics New Zealand, 2014).

New Zealand operates a relatively open trade policy, having removed trade-distorting subsidies on primary products, and is promoting similar liberalisation in international trade.

Historically, forest products have not been subject to the same sensitivities in trade as agricultural products, but restrictions include:
- tariff escalation, where tariffs rise in line with the amount of added-value processing of a traded product;
- non-tariff barriers that include a variety of trade restricting measures imposed by trading countries, such as biosecurity or product certification measures.

Forest products trade has increasingly been subject to requirements related to meeting environmental and social standards under several certification schemes, including chain of custody arrangements and third party audited certification. These measures are also aiming to provide assurances on the legality of timber management, harvest and associated trade.

Regional bilateral and plurilateral agreements
New Zealand is party to a number of regional bilateral and plurilateral agreements, and is negotiating further agreements. In general, these promote trade liberalisation and economic development. Agreements include those outlined below.

Asia–Pacific Economic Cooperation (APEC)
APEC, of which New Zealand is a foundation member, is a co-operative agreement that promotes trade liberalisation, facilitation and economic development. Fourteen of New Zealand's top 20 export markets are APEC members. For the 2013 calendar year, the value of New Zealand's total merchandise trade with APEC members was NZ$68.5 billion, representing 73 percent of New Zealand's total two-way goods trade (Statistics New Zealand, 2014).

APEC leaders agreed in 2010 to enhance co-operation to address concerns with illegal logging and associated trade. In 2011, APEC Ministers Responsible for Trade instructed officials to establish an Experts Group on Illegal Logging and Associated Trade (EGILAT) to:

- promote trade in legally harvested forest products;
- combat illegal logging and associated trade; and
- build capacity.

ASEAN, Australia and New Zealand Free Trade Agreement (AANZFTA)

AANZFTA was signed by New Zealand, Australian and ASEAN Trade Ministers in February 2009. The Agreement entered into force on 1 January 2010 for Australia, Brunei, Myanmar, Malaysia, New Zealand, Singapore, the Philippines and Viet Nam. It entered into force for Thailand on 12 March 2010 and Lao People's Democratic Republic and Cambodia on 1 January and 4 January 2011 respectively. It will enter into force for Indonesia after it has notified completion of its internal ratification procedures. Tariffs on key forest products will be eliminated at various points between 2010 and 2020.

Australia–New Zealand Closer Economic Relations Trade Agreement (ANZCERTA)

Under ANZCERTA, all forestry trade between the two countries is free of tariffs. The Investment Protocol to the New Zealand–Australia Closer Economic Relations Trade Agreement was signed by New Zealand and Australia in February 2011 and entered into force on 1 March 2013. The Protocol maintains the status of closer economic relations as the highest quality free trade agreement that New Zealand or Australia has with any trading partner, widely recognised as the most comprehensive bilateral free trade agreement in the world.

Trans-Pacific Strategic Economic Partnership Agreement (Trans-Pacific Agreement or TPA, formerly P4)

The TPA was signed by New Zealand, Chile and Singapore on 18 July 2005, and by Brunei on 2 August 2005. A binding Environment Co-operation Agreement and a binding Labour Co-operation Memorandum of Understanding were signed concurrently. All forest products-related trade under the TPA is tariff free.

Trans-Pacific Partnership (TPP)

The TPP has developed from the expansion of the TPA and aims to create a regional free trade agreement involving 12 Asia Pacific countries: Australia, Brunei Darussalam, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, the United States and Viet Nam. Negotiations under the TPP include an ambition for free trade for forest products.

New Zealand and China Free Trade Agreement

The New Zealand–China Free Trade Agreement (FTA) was signed in April 2008 and entered into force on 1 October 2008. Under the FTA, the current tariff for logs, sawn timber and wood pulp is zero. These products represent 97 percent of New Zealand forest product exports to China (year ended December 2013) (Global Trade Information Services Inc, undated). The FTA binds these existing favourable conditions.

The agreement also secured immediate tariff elimination on a limited number of engineered wood products where tariffs were either 4 percent or 7.5 percent. The products include: wooden frames for painting, windows, French windows and their frames; pallets; tool and brush handles; and specific types of plywood, fibreboard and laminated panels. Paper and paperboard products with tariffs of either 5 percent or 7.5 percent, and other types of engineered wood products with tariffs of 4 percent or 7.5 percent, are excluded from tariff elimination. In total, these products account for 2.5 percent of current exports to China (year ended December 2013) (Global Trade Information Services Inc, undated).

Pacific Agreement on Closer Economic Relations (PACER)

New Zealand has ratified the PACER, which entered into force in 2002. PACER guides future trade relations in the Pacific region, and provides for the free trade agreement in goods among Pacific Island countries (the Pacific Island Countries Trade Agreement) now being implemented and later likely to be extended to services. PACER also provides for the development of a free trade agreement among the Forum Island Countries (FIC) and Australia and New Zealand, commonly referred to as PACER Plus. PACER Plus will supersede the South Pacific Regional Trade and Economic Co-operation Agreement (SPARTECA), under which Australia and New Zealand currently provide non-reciprocal duty-free access for

FICs to their markets. For most products, including all forest products, SPARTECA entails duty-free access and this will be carried over into the new PACER Plus agreement.

New Zealand–Korea Free Trade Agreement

Negotiations have been completed on the New Zealand–Korea FTA, which will be signed in 2015. The FTA will eliminate tariffs and duties on exports, and facilitate industry co-operation between the countries.

World Trade Organization (WTO)

New Zealand is committed to the WTO, by ensuring its border protection operations and technical standards and regulations are consistent with the *WTO Agreement on Sanitary and Phytosanitary Measures* and the *WTO Agreement on Technical Barriers to Trade*.

Domestic policy

New Zealand does not restrict export of wood products (including logs) sourced from plantation forests. However, under the sustainable indigenous forest management provisions of the Forests Act 1949, export of logs and woodchips, and sawn timber for most indigenous species, is prohibited. No restrictions are in place on the export of finished products manufactured from indigenous timbers. These restrictions reflect the Government's goal of ensuring that the limited supply of slow-growing and valuable indigenous timber species is directed to high-value local finished products.

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Indicator 7.3.a Clarity and security of land and resource tenure and property rights

New Zealand's property transfer system has been in place for 140 years and provides a secure, transparent system for protecting the rights of individual and multiple owners. The system is defined in legislation, and there is a well-established compensation regime for public works.

The system provides a high degree of certainty for landowners and prospective purchasers (both domestic and international). This certainty has been a significant factor in New Zealand attracting ongoing forestry investment over the past 20 years, both in the form of new planting and the acquisition of existing land and forest assets.

An important element in assessing the strength of property rights is the level of corruption within a country, as this can add to the cost of carrying out business. In international assessments, New Zealand is perceived as having a low incidence of corruption. In 2013, New Zealand and Denmark were ranked as the least corrupt countries in two international surveys.

Quality of information: H

Progress against indicator: ▲

Rationale

This indicator provides information on land, forest and resource tenure, laws and rights. Clear title identifies rights and responsibilities under the law with respect to land and resources, while due process ensures that these rights can be protected or disputed. Lack of clear ownership or due process may hinder the active engagement of stakeholders in the sustainable management of forests, or leave forests vulnerable to illegal or unsustainable use.

NEW ZEALAND'S REPORT

New Zealand's legal and administrative systems for the protection of private property rest on the "English-law traditions of strict protection of property rights in land and interests in land" (Boast and Quigley, 2011, p 131). These systems have been progressively developed since the mid-18th century and successive governments have worked to provide landowners with certainty of tenure and legal redress in the event of contractual arrangements not being met. The current system is seen internationally as providing:

- a secure system of property rights;
- a fair and efficient judicial redress; and
- an efficient administrative system (with a low incidence of corruption) (Ministry of Agriculture and Forestry, 2009).

A stable and secure system of property rights (for both physical and intellectual property) encourages long-term investment, and borrowing for intensification or expansion. This has been seen across New Zealand's primary industries, where investment in management systems, genetics and human capital has produced ongoing gains in production and productivity. This certainty of investment has been a major factor in New Zealand's primary producers remaining competitive on the international stage and building their market presence in new and emerging products. In each case, owners had the assurance that they could loan against their property rights to improve production or enter into agreements to lease or manage properties.

New Zealand's reputation for secure property rights has been a crucial element in attracting overseas investors and skilled labour. Both of these resources are scarce internationally, and they are becoming increasingly mobile. Investors look for certainty of property rights and an ability for arbitration and redress, when investigating opportunities outside of their home jurisdiction. These legal rights can sway the balance when companies examine countries with similar resource attributes. This point has been expressed by a number of overseas investors who purchased forestry rights or land in New Zealand during the 1990s and early part of this century.

Registering private property rights

Land registration in New Zealand is based upon the Torrens system, which records transfers (and other dealings involving the land) and provides a secure form of title. The system was introduced in

New Zealand through the Land Transfer Act 1870.

> The system amounts essentially to a state guarantee of title to holders of estates in land as defined by surveys... (Boast and Quigley, 2011, p 131)

The system provides for guaranteed certificates of title, along with a low cost and efficient method of conveyancing.

The basis of the system has remained consistent over the past 140 years.

> The few amendments which have emerged over the years have generally been of an amelioratory nature and have only changed the mechanics of the Act in accordance with modern practices without departing from its basic principles. (McLintock, 2009)

In recent years, the system has evolved to include the electronic lodgement and registration of documents.

The current legislation governing land registration is the Land Transfer Act 1952 and the Land Transfer Regulations 2002. These statutory instruments are administered by Land Information New Zealand (LINZ), a government department. LINZ has oversight of the system and checks that all documents meet the legal requirements (including cadastral survey standards).

The Registrar-General of Land, based within LINZ, develops standards and sets an assurance programme for the land registration system (Land Information New Zealand, undated(b)).

Compensation for public works

New Zealand has "a strong and well-developed law of compensation for public works" (Boast and Quigley, 2011, p 129). Land required for public works can only be acquired in accordance with the Public Works Act 1981, and:

> ...provides for the payment of compensation for losses arising from the acquisition of the land by the Crown. Entitlement to compensation is set out in Part V of the Act. Section 60(1) provides that affected landowners are entitled to 'full compensation' so that they are left in a no better or worse position, than they were before the public work commenced. (Land Information New Zealand, undated(a))

Redress for property and contractual disputes

Disputes over property rights and contractual arrangements are addressed through negotiation, mediation and the courts system.

Civil disputes on property matters are frequently worked through by direct negotiation or mediation between the parties.

> The courts encourage resolution of disputes by the parties, and it is a requirement of many civil proceedings in the District Court that the parties first attend a judicial settlement conference before a trial is allocated. (Chapman Tripp, 2013, p 44).

A negotiated resolution can occur at any time during a case, but this most regularly takes place before formal proceedings.

> Civil disputes may also be resolved by private arbitration, pursuant to the Arbitration Act 1996... Some contracts provide for arbitration in the event of a dispute, but parties may also agree to arbitrate after a dispute has arisen. (Chapman Tripp, 2013, p 44).

The New Zealand courts system has evolved over the past 170 years, and includes a system of general courts and specialist tribunals. A Disputes Tribunal handles minor contractual claims (less than $15 000, or $20 000 if all parties agree), while claims of less than $200 000 are normally handled by the District Courts. Complex claims of over $200 000 are managed by the High Court. There is generally one right of appeal, from the District Court to High Court, or the High Court to the Court of Appeal. "Second appeals require the leave of either the court appealed from or the court appealed to. All appeals to the Supreme Court require the leave of that Court" (Chapman Tripp, 2013, p 42).

Special tribunals include the Environment Court, which has civil and criminal jurisdiction over environmental matters covered by the Resource Management Act 1991. "Appeals against Environment Court decisions on questions of law can be taken on to the High Court and the Court of Appeal" (Ministry for Primary Industries and the New Zealand Forestry Industry, 2013, p 10).

Business environment

> Internationally, New Zealand is viewed as one of the world's least corrupt countries to operate in ... [and] ... a number of forestry companies have stated this as a key factor in investing in New Zealand. (Ministry of Agriculture and Forestry, 2009, p 67)

For a new business or investor, a low incidence of corruption provides greater operating certainty and an assurance of secure property and intellectual rights. Corruption adds to the bottom-line cost of undertaking business in a country, from informal payments through to additional inspections and the expectation of free goods and services.

International assessments of corruption by Transparency International and World Audit both found a low incidence (or perceived incidence) of corruption in New Zealand. In their 2013 assessments, both organisations ranked New Zealand and Denmark as the least corrupt countries in which to operate. New Zealand's low incidence of corruption stems from several inter-related factors, including no history of informal payments, an independent judicial system, freedom of the press and a strong commitment to the rule of law.

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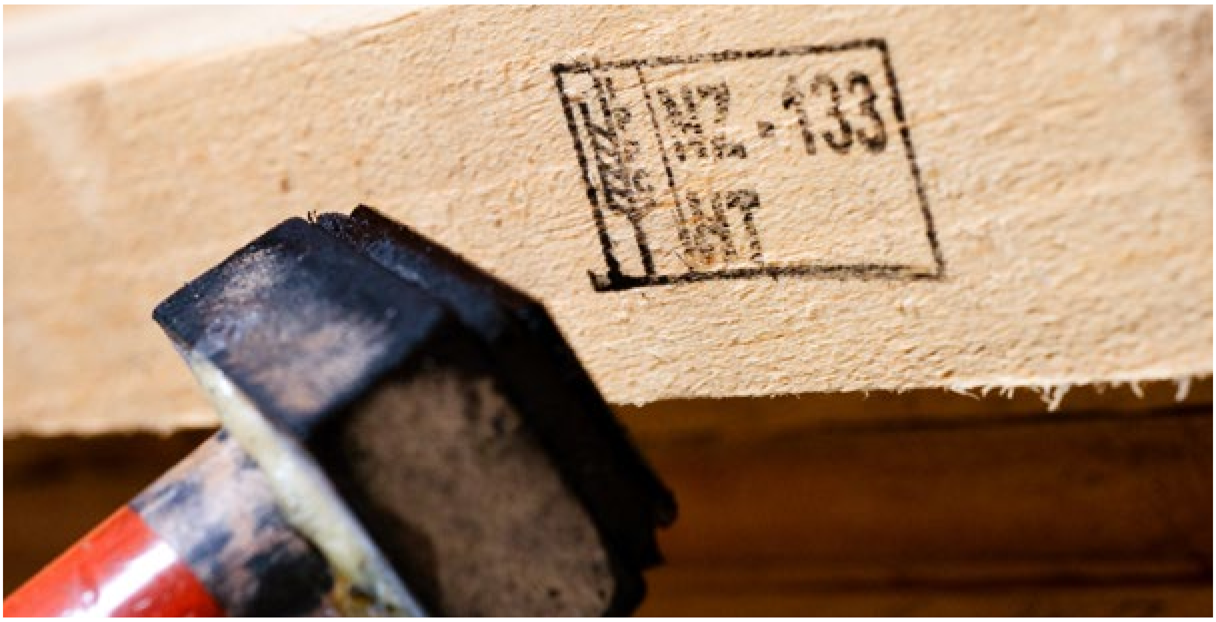

Indicator 7.3.b Enforcement of laws related to forests

Compliance with forest-related legislation is encouraged through education in the first instance. Abatement notices and enforcement orders can be used under the Resource Management Act 1991. Where offending occurs, the laws are rigorously enforced through prosecutions. Financial penalties are provided for under relevant legislation, including the Forests Act, as is imprisonment for some offences under the Conservation Act 1987, Biosecurity Act 1993 and Resource Management Act 1991.

Enforcement of forest laws continues to be a high priority for government agencies.

Quality of information: H

Progress against indicator:

Rationale

This indicator provides information on the extent to which forest- related laws and regulations are enforced. The ability to successfully prosecute offenders is essential in combating harmful activities that may threaten forests and their sustainable management (e.g. illegal forest conversion and illegal logging).

NEW ZEALAND'S REPORT

Laws and regulations are enforced both by central and local government agencies.

Department of Conservation

Voluntary compliance is the aim of the Department of Conservation (DOC), but it also recognises that awareness of offences and penalties can act as a useful deterrent to offending. Compliance is encouraged by effective education and making information readily available. DOC has the options of legal compliance and enforcement to protect and preserve conservation values. These powers are derived under the legislation it administers.

The compliance and law enforcement system is based on complete integration, and the powers exercised across the various Acts are similar. The estate administered by DOC's compliance and law enforcement-warranted officers relevant to Indicator 7.3.b consists of:

- reserves (including wildlife protected areas) in a marine or terrestrial setting;
- national parks (some, such as Fiordland and Abel Tasman, are both in a marine and a terrestrial context);
- conservation areas.

DOC generally undertakes its own enforcement work because:

- the operations frequently occur in remote locations where it is not practical to call in the police;
- specialist knowledge and skills are often needed for conservation enforcement work, in terms of understanding both the legislation and the assets and values it manages;
- staff often need to act quickly to apprehend an offender or prevent the offence from causing major environmental effects.

Currently, DOC uses legal powers of warranted officers to:

- intervene to stop offending (and prevent further damage);
- investigate or apprehend people believed to have committed an offence;
- stop transportation devices;
- enter vehicles, ships or aircraft used in breach of the Conservation Act 1987, or believed to be so used;
- search land, huts, tents, caravans, other buildings (not permanent residences) and transportation devices;
- seize products illegally taken and things being used, or intended to be used, in breach of the Conservation Act 1987.

Warranted officers can deal with an offence they see occurring or they can investigate and collect evidence about an offence that they believe, on reasonable grounds, has been committed.

DOC has divided law enforcement into three facets. High-level officers are available to operate in a national context to deliver the chain of evidence required for serious offending, such as the taking of plants (indigenous forest) or biosecurity threats. These officers carry out planned operations in areas of high risk for DOC, or where information is received that an illegal activity is taking place.

The second level is a specific role for field staff dealing with incidents in their own locations, and submitting prosecution files.

The last level involves all staff employed by DOC: they have a role to be the eyes and ears for any offending, and to pass on information to the second level for investigation.

DOC has a written Prosecution Policy (Department of Conservation, 2013).

Honorary ranger system

DOC has functions New Zealand-wide. It is impossible to carry out its statutory role without the involvement of the community, given the scale involved. For example, in the whitebait fisheries surrounded by forests in the remote parts of New Zealand, the honorary warranted officer carries out DOC's role. Expense and time-wise, it would be impossible for full-time DOC staff with compliance roles to spend the entire season in the location. The honorary system also helps DOC with capacity to carry out its statutory function. A regular reporting obligation forms part of holding the honorary warrant.

Honorary warranted officers work in three ways:
- in teams with DOC staff in surveillance roles on planned operations;
- through advocacy and education, including publicising and promoting material relating to conservation;
- in surveillance outside normal work hours.

All honorary warranted officers undertake the same five-day compliance and law enforcement course as DOC staff. Regular refresher courses are made available, as are opportunities to be part of the yearly whole-of government cross-agency training.

Ministry for Primary Industries

The Ministry for Primary Industries enforces the Forests Act 1949 and parts of the Biosecurity Act 1993. Enforcement includes bringing prosecutions against those who contravene the Acts and their regulations.

Forests Act 1949

Part 3A of the Forests Act applies to most of the privately owned indigenous forests. The number of prosecutions under this Act (generally brought for illegal harvesting of indigenous timber) has been low in recent years. This reflects an efficient control system of sawmill registration, improved understanding by forest owners of the provisions of the Act and ongoing monitoring by the Ministry for Primary Industries (MPI). In isolated areas, however, smaller scale offences can be difficult to detect.

In 2011, MPI prosecuted the largest over-harvest of indigenous timber since the sustainable forest management provisions were enacted in 1993. The defendant harvested 588 cubic metres, while the permitted volume was 373 cubic metres. Fines totalling $134 000 were imposed and the timber was forfeited to the Crown.

Biosecurity Act 1993

MPI has a specialist enforcement team with powers of prosecution for breaches of the Biosecurity Act 1993. Penalties for offences against the provisions of the Act vary according to the nature of the offence. For an individual person, penalties range up to imprisonment for a term not exceeding five years, a fine not exceeding $100 000, or both. In the case of a corporation, the penalties involve fines of up to $200 000.

New Zealand is relatively free of major pests and diseases owing to its geographic isolation, and effective biosecurity processes from pre- to post-border are important. Incoming passengers and freight are checked for the presence of items that could be carrying dangerous pests and diseases. The maximum penalty for knowingly making a false declaration about possessing such items is a fine of up to $100 000, or imprisonment for up to five years. An instant fine of $400 is levied on anyone who completes a declaration card incorrectly or forgets to declare items.

Local government

Local government (regional, district and city councils) primarily implements the Resource Management Act 1991 (RMA) (see Indicator 7.1.a).

Under section 314 of the RMA, enforcement orders can be sought by a council or any person from the Environment Court that:

> …require a person to cease, or prohibit a person

from commencing, anything done or to be done by, or on behalf of, that person that:

– contravenes or is likely to contravene the Act, any regulations, a rule in a plan, a resource consent, or certain other provisions;

– is, or is likely to be, noxious, dangerous, offensive, or objectionable to an extent that it has or is likely to have an adverse effect on the environment.

Enforcement orders can also require a person to do something that is considered necessary to ensure compliance with the Act, any regulations, a rule in a plan, a resource consent and certain other provisions, and to avoid, remedy or mitigate adverse effects on the environment caused by, or on behalf of, that person.

An authorised enforcement officer can serve an abatement notice under the RMA on any person for a similar range of circumstances as outlined above. An abatement notice is a warning to the recipient that (s)he is contravening, or is likely to contravene, the provisions of the RMA.

Penalties for offences vary, depending on their nature. For any person they extend to imprisonment for up to two years or a fine not exceeding $300 000, and where the offence is a continuing one, a fine not exceeding $10 000 for every day that the offence continues.

Regional pest management strategies for plant and animal pests are drawn up and administered by local government under the Biosecurity Act 1993. If a land occupier fails to comply with any rule in a strategy, the relevant regional council may require the landowner to undertake specified actions to address the situation. Failure to comply with a legal direction can result in the regional council entering onto the land to carry out the work itself, and subsequently recovering actual and reasonable costs from the landowner.

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Indicator 7.4.a Programmes, services and other resources supporting the sustainable management of forests

New Zealand has well developed road, rail, port and energy infrastructure networks to support the forest industry. A National Infrastructure Plan, published in 2011, and the 2012–15 National Land Transport Programme provide strategies for continuing development of these services.

Financial services are provided by a range of organisations and are regulated by the Financial Markets Authority and the Reserve Bank of New Zealand. The New Zealand Qualifications Authority ensures qualifications are robust.

Safety in forestry, particularly associated with harvesting, has become a prominent issue with a major review being undertaken in 2014 by WorkSafe New Zealand.

Quality of information: H

Progress against indicator: ▶

Rationale

This indicator provides information on the capacity of both government and private organisations to deliver programmes and services to maintain and develop infrastructure and to access the financial and human resources necessary to support the sustainable management of forests.

NEW ZEALAND'S REPORT

A range of programmes and services exist that support infrastructure, financial and human resources.

Infrastructure

New Zealand has physical infrastructure networks to support a broad range of activities, including the forest industry. Trucks transport 92 percent of New Zealand's total freight by weight, with 6 percent going by rail and 2 percent by coastal shipping. There are 91 000 kilometres of roads, 4000 kilometres of rail track, a number of sea ports (including 13 that import or export forest products), 28 regional and seven international airports. In the energy sector, most electricity is from renewable sources, including hydro, geothermal, wind and wood residues. The importance and capacity of the telecommunications sector continue to grow (New Zealand Government, 2011a).

In general, the transport infrastructure is well developed and able to meet current demands. There are some issues and specific localities where economic and population growth place pressure on aspects of the infrastructure.

The Government published the *National Infrastructure Plan 2011* to ensure that New Zealand has the infrastructure to support economic growth aspirations (New Zealand Government, 2011b). The Plan has a 20-year vision and a programme of work led by the National Infrastructure Unit (based within The Treasury). The Unit releases an annual *National State of Infrastructure Report* outlining progress in implementing the Plan and looking at the opportunities and challenges that lie ahead

Road infrastructure

Central and local government fund and operate the public road network, which is the largest capital investment in New Zealand's transport system.

The 2012–15 National Land Transport Programme is a planning and investment partnership between the New Zealand Transport Agency and local authorities, giving effect to the Government's transport priorities. The Programme involves $12.28 billion of investment in the country's land transport system over the three-year period (New Zealand Transport Agency, 2012).

New Zealand has an extensive roading network, with a total length of 90 783 kilometres of formed road. Major roads, known as state highways, and local authority roads (the secondary network) each account for about 18 billion vehicle kilometres per year.

It has been estimated that the movement of forestry goods within New Zealand totalled 37.3 million tonnes of logs and timber products in 2012. When average transport distances are taken into account, the movement of logs and wood products in New Zealand accounted for 4.6 billion tonne-kilometres. This is 18 percent of total road tonne-kilometres, and well ahead of other commodity groups. Milk and dairy products accounted for 2.5 billion tonne-kilometres in the same year (Ministry of Transport, 2014). The capacity of some local authorities to meet requirements from increases in harvested wood volumes will present a challenge in the future.

In 2010, the Government allowed heavier (greater than 44 tonnes gross mass) and longer (exceeding 20 or 22 metres) vehicles to operate over selected routes subject to specified conditions. Trials indicated that productivity could increase by 10 percent to 20 percent, trip numbers could reduce by 16 percent and fuel use by 20 percent. This is an important initiative for the transportation of logs, but infrastructure issues, particularly bridge strength, have limited route availability for the use of these high productivity motor vehicles (Road Transport Forum New Zealand, 2010).

Another initiative, 50MAX, is a new generation of 50-tonne vehicles that have one more axle (nine) than conventional 44-tonne vehicles, spreading the load and resulting in no additional wear on roads per tonne of freight.

Rail infrastructure

Railway infrastructure in New Zealand includes about 4000 kilometres of narrow-gauge track. While rail only transports a small proportion of New Zealand's freight (6 percent by weight and 15 percent by tonne per kilometres), the freight load is predicted to double by 2040 (New Zealand Government, 2011b).

Logs, pulp, sawn timber and panel products are carried by rail to domestic destinations and export ports. Most pulp and paper is hauled by rail, but trucks dominate the market for hauling logs, lumber and wood chips. The limited transport distances and double-handling requirements constrain the use of rail in many regions.

The Government purchased the assets of the national rail operator in 2008, with the national rail system now operated by KiwiRail (a state-owned enterprise). The Government's main rail focus is the KiwiRail Turnaround Plan, which seeks to make KiwiRail a financially sustainable rail freight business.

The Turnaround Plan requires $4.6 billion of investment over 10 years, most of which will come from KiwiRail's cash flows. The Government has committed in principle $750 million for three years (New Zealand Government, 2011b).

Sea port infrastructure

Sea ports move 99 percent by volume of New Zealand's total exports. There are 13 commercial ports with significant volumes of forestry exports or imports. They are owned or majority owned by local government, with ownership in five ports partially privatised. Most forest product exporting ports are focusing on improving log storage and covered storage facilities for processed forest products.

In the year ended March 2014, 56 percent of New Zealand's harvested logs were exported. This is a significant increase from 30 percent recorded for the year ended March 2008, and has been driven by strong demand for logs from China. Sawn timber, panel products and pulp and paper are also exported (Ministry for Primary Industries, 2014).

Central government's focus is on improving public information on maritime and freight transport to support more informed decision-making. Initial work includes the Freight Information Gathering System, which will provide better information on international and domestic freight flows through New Zealand ports. The Government is also focusing on how port productivity can be improved.

Maritime New Zealand is the Crown entity with responsibilities for standards development, seafarer qualifications and licensing, oil spill prevention and response, search and rescue, inspection of ships, port and ship security, vessel safety, accident investigation and aids to navigation.

Energy infrastructure

New Zealand has over 200 power stations generating electricity, 18 natural gas fields, 18 oil fields and one oil refinery processing imported crude oil.

The New Zealand Energy Strategy 2011–2021 sets the strategic direction for the energy sector and the role energy will play in the New Zealand economy. It sets out four priority areas:

- diverse resource development;
- environmental responsibility;
- efficient use of energy;
- secure and affordable energy (Ministry of Economic Development, 2011).

The National Infrastructure Plan 2011 focuses on the infrastructure required to extract, store and distribute energy (New Zealand Government, 2011b).

In 2013 and 2014, the Government partially privatised three of the five major electricity generating companies. (The two others are privately owned.)

New Zealand's Total Primary Energy Supply (TPES) for use in the country has increased by an average of 1.9 percent per year since 2008. Oil accounts for 33 percent of the TPES, gas 21 percent and geothermal energy 19 percent (Ministry of Business, Innovation & Employment, 2013).

Renewable energy made up 37 percent of the TPES in 2012, the third-highest contribution in Organisation for Economic Co-operation and Development countries. This results from the high levels of hydro and geothermal energy used for electricity generation. Woody biomass and geothermal are the major sources of direct-use heat, with the forest industry being the major user of woody biomass.

New Zealand generated 164 petajoules (PJs) of electricity in 2012 with 73 percent coming from renewable sources. A flat demand outlook means major new investment in electricity generation is not expected before 2020.

Financial services

Financial (or economic) services are provided by a broad range of organisations, including banks, credit card companies, finance companies, credit unions, insurance companies, accountancy companies, stock brokerages and investment funds.

Financial markets are regulated by the:

- Financial Markets Authority which enforces securities, financial reporting and company law as they apply to financial services and securities markets, and regulates securities exchanges, financial advisers and brokers, trustees and issuers;
- Reserve Bank of New Zealand which holds prudential powers over the banking sector, including finance companies and credit unions.

The Serious Fraud Office is responsible for complex or serious fraud investigation and prosecutions.

The Commerce Commission is an independent Crown entity responsible for enforcing laws relating to competition, fair trading and consumer credit.

Human resources

Most forestry sector organisations recognise the importance of developing and maintaining a high level of education and skill in their workforces. Commercial forest industries face the challenge of balancing the retention of skilled staff and contractors with maintaining viability and reducing employment levels during periods of depressed demand for wood products.

Training includes formally structured, nationally recognised qualifications, in-house training programmes, and training for community-based organisations.

New Zealand Qualifications Authority

The New Zealand Qualifications Authority ensures that New Zealand qualifications are valued as credible and robust, both nationally and internationally.

The New Zealand Qualifications Framework involves 10 qualification levels that depend on the complexity of learning. The levels cover senior secondary school education, certificates, diplomas, Bachelor's degrees, postgraduate diplomas and certificates, Master's degrees and doctorates. Certificate courses cover a variety of topics relevant to the management of both the commercial plantation forest and indigenous conservation forest estates.

University programmes

The New Zealand School of Forestry at the University of Canterbury offers the only professional forestry degree programmes in New Zealand. These are:

- Bachelor of Forestry Science;
- Bachelor of Forest Engineering;
- Postgraduate Diploma in Forestry;
- Master of Forestry Science;
- Doctorate in Forestry.

Lincoln University also offers a range of forestry courses. Other universities provide undergraduate and postgraduate programmes associated with resource management, environmental sciences, sustainability and the environment, engineering and recreation, leisure and tourism.

Polytechnics

The Department of Forestry and Resource Management at the Waiariki Institute of Technology is the largest vocational forestry training centre in New Zealand. It offers qualifications in:

- forestry operations;
- forest management;
- wood manufacturing;
- occupational health and safety.

Two other polytechnics offer more restricted forestry training.

Workplace training

Competenz facilitates workplace training to build skills and add value to an organisation. It services a variety of industries and provides forest silviculture and harvesting training. (See Indicator 6.2.b.)

Health and safety

WorkSafe New Zealand is New Zealand's health and safety regulator that works with employers, employees and others to:

- educate about workplace health and safety responsibilities;
- engage in making changes that reduce the chances of harm;
- enhance workplace health and safety legislation.

The forest industry has an Approved Code of Practice for Safety and Health in Forest Operations, last updated in December 2012 by the Ministry of Business, Innovation and Employment. It is currently subject to further review.

The Health and Safety Reform Bill is currently before Parliament. When passed, it will replace the Health and Safety in Employment Act 1992.

WorkSafe New Zealand has expressed concern about safety compliance and the high rates of injury and death in the New Zealand logging industry. Ten deaths occurred during 2013. A major safety review was announced in January 2014 by the forest industry in liaison with WorkSafe New Zealand. An independent panel is examining the health and safety structure and culture of the forest industry, and reviewing health and safety education and training.

In 2014, WorkSafe New Zealand also produced best practice guidelines on safe manual tree felling. (See also Indicator 6.3.b.)

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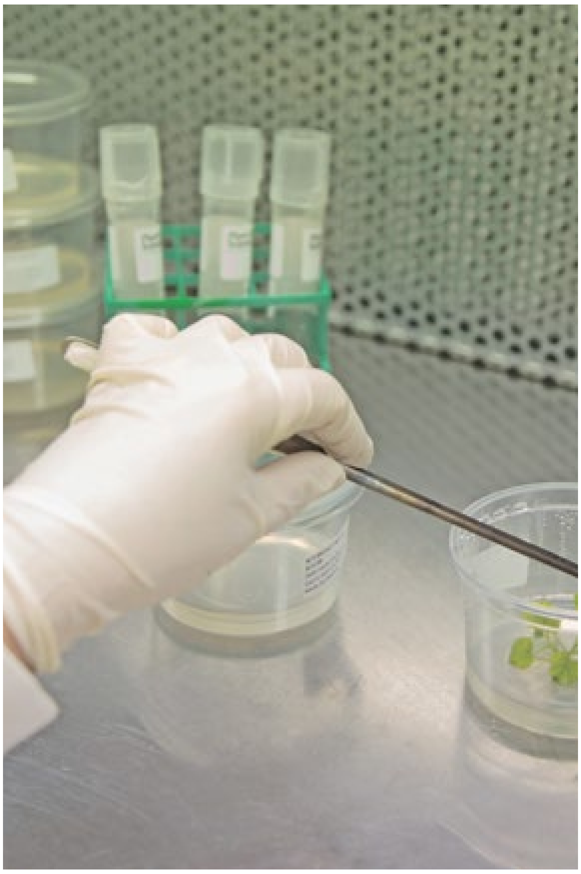

Indicator 7.4.b Development and application of research and technologies for the sustainable management of forests

New Zealand has a long history of high-quality forest research involving Crown Research Institutes and universities. Research and technologies for sustainable plantation forest management are extensive and continue to be developed. For the indigenous conservation estate, research is focused on biodiversity and management of threats from introduced pests.

New government initiatives that include forestry research are the National Science Challenges for collaborative mission-led research, the Primary Growth Partnership to encourage more private investment in research and development, and the Sustainable Farming Fund to support communities of interest to undertake research and extension projects.

Quality of information: H

Progress against indicator: ▲

Rationale

This indicator provides information on the capacity to develop and incorporate new science, research, and technologies into forest management. Continuous improvement in the depth and extent of knowledge and its application will help ensure advances in the sustainable management of forests.

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In May 2014, the Government released a *Draft National Statement of Science Investment 2014–2024*, and sought feedback on the proposed direction for, and contribution of, science investment in New Zealand. The *Draft National Statement* notes that the Government's investment in 2015/16 will be $1.5 billion, allocated through:

- collaborative mechanisms, including the National Science Challenges;
- contestable mechanisms, such as the Ministry of Business, Innovation and Employment administered sector-specific research funds;
- institutional funds, such as the Crown Research Institute core funding;
- business-led mechanisms, such as the Primary Growth Partnership (Ministry of Business, Innovation and Employment, 2014).

The 10 new National Science Challenges are mission-led programmes of work undertaken by collaborations of different researchers, organisations, end-users and business. They include:

- **Our Land and Water** – enhancing primary sector production and productivity while maintaining and improving land and water quality for future generations.
- **New Zealand's Biological Heritage** – protecting and managing biodiversity, improving biosecurity, and enhancing resilience to harmful organisms.
- **Science for Technical Innovation** – enhancing the capacity of New Zealand to use physical and engineering sciences for economic growth.

The introduction in 2014 of the forest growers levy is a notable initiative that, in part, provides funding for forest research (see Indicator 7.5.a).

Scion

Scion is a Crown Research Institute that specialises in research, science and technology development for the forestry, wood product and wood-derived materials and other biomaterial sectors. Its purpose is to drive innovation and growth from these sectors, to build economic value and contribute to beneficial environmental and social outcomes for New Zealand. In 2013/14, Scion received Crown funding of $17.7 million.

Under the Forest Science theme, Scion's work includes:

- forests and climate change – quantifying the role of forests in greenhouse gas mitigation, and evaluating the potential effects of climate change on the environment;
- forest biosecurity – focusing on the exclusion, eradication and effective management of risks to forests and trees posed by insect pests, pathogens and invasive weeds;

- rural fire research – providing specialist fire research expertise in rural and forest landscapes, developing the science and technology to protect life and property, and manage fire in the landscape;
- forest management – enabling forest growers to produce material that meets consumer needs in ways that are cost-effective, efficient and sustainable;
- tree improvement – advancing breeding programmes and deployment strategies for commercial tree species.

The Sustainable Design theme recognises the prominence of sustainability in government policy and in business. Work includes:

- measuring sustainable design – deploying models of resource use that enable environmental impacts to be measured and monitored so improvements can be made;
- optimising land value – developing new systems and approaches to integrated land management;
- environmental technologies – designing technologies that minimise ecosystem contamination through water recycling, energy reduction, environmental remediation, carbon recovery and conversion of wastes;
- trade and economic development – developing and applying economic forest sector models for forecasting and analysing the impacts of global policy on forest product markets and trade;
- social values – undertaking social science research within selected communities in areas such as sustainable biowastes management, rural fire and biosecurity management, and integrating the findings with environmental and economic research;
- human factors – recognising that the productivity of people is integral to sustainable economic success.

A six-year research programme, *Growing Confidence in Forestry's Future,* announced in 2013, is a major new initiative. The programme targets where improvements can be made throughout the growing cycle for current and future forests that will boost productivity under intensified management regimes, while maintaining wood quality and the quality of the environment. This will require a shift from the current low input forest management practices to precision forestry, integrating the latest advances in sensor technology, tree physiology, genetics and forest ecology, while working closely with the industry.

The programme is a joint initiative among Scion, the forest growing industry and the Ministry of Business, Innovation and Employment. It has been allocated funding of $3.75 million per year from the Ministry and $1.6 million per year from the Forest Growers Levy Trust.

Scion also provides research, science and technology to convert renewable wood and fibre to a range of products and energy. Core areas include:

- wood–plastic composites;
- wood drying;
- wood modification and preservation;
- timber engineering;
- pulp and paper;
- biotransformation;
- green chemical and biopolymers;
- bioplastics;
- liquid fuels;
- biorefinery pilot plants.

Landcare Research

Landcare Research is another Crown Research Institute with core Crown funding of $24.2 million in 2013/14. Its purpose is to drive innovation in the management of terrestrial biodiversity and land resources. In addition to research undertaken for the Department of Conservation (see below), other important forestry programmes focus on the following.

Sustainable indigenous forestry

The main challenge for sustainable indigenous forestry is to extract timber while maintaining or even enhancing the non-extractive benefits of these forests, such as biodiversity, water quality, carbon storage and cultural identity.

Studies of tree recruitment, growth and mortality in indigenous beech forests where low-impact harvesting has occurred have found that, with the correct management systems, the mortality rate for remaining trees does not increase. Beech trees grow very slowly in natural forest, and even-aged stands regenerating from felled forest tend to develop into dense thickets of saplings and pole-sized trees where competition between trees is strong and dominant trees are slow to emerge. The challenge for sustainable forestry is to balance the costs of thinning beech regeneration against the added value provided by the faster growth rates.

An improved understanding of indigenous forest regeneration in the Urewera Ranges of the central North Island is helping tāngata whenua (the indigenous people of New Zealand) restore podocarp forests that were extensively logged last century.

Physiological growth modelling

How fast forests can grow and whether they will grow faster or more slowly as climatic conditions change are important questions for current and future wood supply, and for assessing the potential of forests to sequester carbon to mitigate the effects of climate change. Past assessments using empirical modelling approaches to provide growth estimates have had limited scope and reliability.

New Zealand scientists are now using a physiologically based approach to model the wood growth and carbon storage of radiata pine. The model demonstrates that pine growth is often temperature limited, with optimal growth occurring under the highest temperatures currently found in New Zealand. With climatic warming, stands are therefore likely to grow faster in the cooler parts of the South Island. In contrast, growth is likely to be reduced in the north and in the drier regions on the east coast of both islands, where warming will likely intensify water limitations. However, even these limitations could be overcome through increasing carbon dioxide levels, provided plant responses are as strong as currently seen in experimental observations.

The work has only recently been completed so has yet to be adopted by the forest industry and policymakers. The growth estimates have been used in national-scale assessments of ecosystem services and forests. The model is being used for assessing the rate of soil–carbon changes after land use change and for modelling the growth of kānuka and mānuka stands.

School of Forestry, University of Canterbury

Research is undertaken within the following four clusters:

- **sustainable land management** – better understanding the interaction among economic use, biodiversity conservation and pest management within primary production systems, in order to sustain New Zealand's unique and endemic biodiversity;
- **forest engineering** – improving the operational performance of the New Zealand forest industry (optimising economic performance while ensuring physical feasibility and social acceptability);
- **forest variability** – understanding the reduced variability in the forest resource, which increases the risks to forest growers and processors;
- **forestry as a business** – understanding the economic value of forests managed for timber, as well as other products and services.

Department of Conservation

The Department of Conservation (DOC) has administrative and management responsibility for most of New Zealand's indigenous forest area. The primary objective of that management is biodiversity conservation, but recreation also features prominently, along with cultural and historical considerations in some areas. Research and technological developments currently focus on ecological threat management. Three broad initiatives have dominated DOC's forest science, research and technological development over the past five years. They cover carbon storage in indigenous forests, improved management of threats from introduced browsing and predatory mammals, and biodiversity inventory and monitoring.

A $1.2 million five-year research programme on the impacts of introduced ungulates and possums and their management on carbon sequestration has recently been completed for DOC by Landcare Research Ltd.

A second and major focus of DOC forest research and development is aimed at management of introduced pest mammals. Rodents, particularly ship rats *(Rattus rattus),* and stoats *(Mustela erminea)* undergo periodic population irruptions in response to masting events of the southern beech species. Without management, these events are cumulatively threatening the survival of several vertebrate species. In addition to the development of new traps, toxins and delivery systems, research effort is also focused on improving wide-scale control tools such as the aerial application of toxins targeting these animals as well as brushtailed possums *(Trichosurus vulpecula).* Besides being predators, possums are also vectors of bovine tuberculosis, as well as major defoliators and agents of stand-level dieback and canopy collapse of many indigenous tree species. Possum control with minimised non-target effects is therefore an important research and development goal.

The national Biodiversity Monitoring and Reporting System has been developed by DOC and Landcare Research Ltd over the past seven years (2007–14). The objective is a consistent approach to monitoring and reporting on the state of, and trends in, ecological integrity in terrestrial, freshwater and marine environments, but its major application to date has been to forest and non-forest lands. The whole system is designed around three "tiers", which operate at different scales with varying levels of detail and coverage.

Tier 1 monitoring samples all public conservation land, and potentially the whole of New Zealand, through regular assessment of a selection of native species and pests (including game animals) at 2500 locations (1405 are on public conservation land) 8 kilometres apart and spaced evenly across the landscape. It provides both unbiased, repeatable indicators of ecological integrity across all public conservation land and waters managed by DOC, and other national-level information collected through desktop exercises and other targeted field-based programmes.

Tier 2 monitoring involves consistent, rigorous monitoring of results and outcomes for ecosystems and species that are managed. Tier 3 monitoring involves intensive research and biodiversity measurement at a few important sites distributed throughout New Zealand. (See indicators 1.2.a and 7.5.c for further information.)

Ministry for Primary Industries

The Ministry for Primary Industries administers two programmes that offer funding for research related to the primary sectors.

The goal of the Primary Growth Partnership (PGP) is to encourage more private investment in existing and new research and development in New Zealand, which is low by Organisation for Economic Co-operation and Development standards. PGP programmes are primarily business-led and market driven innovation programmes that are jointly funded by government and industry. They focus on boosting productivity and profitability, and delivering long-term economic growth and sustainability across the primary sectors.

Of the 18 announced PGP programmes, three involve the forestry sector and total $79 million (from government and industry). They concern:

- steepland harvesting – with the focus on development of a steep-slope, feller-buncher;
- methyl bromide reduction – the aim is to reduce its use for quarantine and pre-shipment fumigation of exported forest (and horticultural) products, and eventually replace it with alternative treatments;
- forest waste to liquid fuels – investigating how to generate more value from forestry waste by converting it to liquid biofuels.

The Sustainable Farming Fund (SFF) supports "communities of interest" to undertake research and extension projects that tackle a shared problem or develop a new opportunity in the primary sectors. Most projects leverage a high proportion of other funding or in-kind support to complement the SFF grant.

Between 2010 and 2014, there were 30 forestry-related projects with SFF funding.

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Robot being developed for felling plantation forest.

Indicator 7.5.a Partnerships to promote the sustainable management of forests

Partnerships are becoming increasingly important in the management of the conservation estate. The Department of Conservation has formed a new Conservation Partnerships Group to work with a range of businesses and community groups.

For the commercial plantation forest sector, partnerships focus on research. The Forest Growers Levy Trust is a new enterprise administering a plantation forest growers' levy for a variety of industry-good initiatives.

Quality of information: H

Progress against indicator: ▲

Rationale

This indicator provides information on partnerships and their contribution to the sustainable management of forests. Partnerships may help create a shared purpose and are important tools in building capacity; leveraging financial, technical and human resources; strengthening political commitment; and in developing public support to advance the sustainable management of forests.

NEW ZEALAND'S REPORT

Partnerships are becoming increasingly important in the management of the indigenous conservation forest estate. For commercial plantation forests, the significance of partnerships lies mainly in research.

Indigenous forests

Department of Conservation

To progress priorities in conservation management, the Department of Conservation (DOC) is increasing business partnerships and community involvement through community-led projects.

To facilitate this work, a new Conservation Partnerships Group has been established within DOC. The group has partnership staff working in close to 100 offices across the country. Their work involves creating awareness and interest in conservation and exploring new conservation projects and initiatives in partnership with others. Three specialist teams focus on commercial business, community engagement and integration.

DOC relies on partnerships with the community to achieve its objectives in conservation management. These partnerships include:

- a Treaty of Waitangi partnership with Māori;
- working with regional and district councils to implement their responsibilities for biodiversity conservation in regional and district plans and coastal plans under the Resource Management Act 1991;
- working with environmental non-government organisations, trusts and other community interest groups;
- working with private landowners for the protection of natural areas through covenants and other conservation measures such as Ngā Whenua Rāhui;[56]
- working with universities and research institutions to improve knowledge and techniques of conservation;
- working with education providers to enable them to deliver conservation education programmes;
- providing and promoting opportunities for community involvement in practical conservation projects and policy development;
- joint programmes for the protection of biodiversity, such as Project Crimson, and organisations such as the Nature Heritage Fund.

Notable existing business partnerships with DOC related to the indigenous conservation forest estate involve:

- **Air New Zealand** – to promote and protect the Great Walks and preserve threatened species;
- **Dulux New Zealand** – to paint and protect

56 A contestable fund with which to negotiate the voluntary protection of indigenous forest on Māori-owned land.

backcountry huts and other recreation and historic assets, and to support the Kea Conservation Trust;
- **Genesis Energy Whio Recovery Programme** – to support the whio/blue duck recovery;
- **Kākāpō Recovery Partnership** – to support kākāpō recovery;
- **Mitre 10 Takahē Rescue** – to support the Takahē Recovery Programme;
- **Project Crimson Trust** – to plant and protect pohutukawa and rata trees throughout the country;
- **the Kiwi Trust (BNZ)** – to support kiwi conservation groups across the country.

In March 2014, the Minister of Conservation announced a Community Conservation Partnerships Fund to support the work of voluntary organisations undertaking natural heritage and recreation projects. The new fund of $26 million over four years is distributed to community organisations in annual contestable funding rounds of between $6 million and $7 million a year. It replaces the previous Biodiversity Advice Fund and Biodiversity Condition Fund of $3.6 million per year.

The Community Conservation Partnerships Fund is directed at:
- practical, on-the-ground projects that:
- maintain and restore natural heritage diversity;
- enable more people to participate and enjoy recreation in the natural environment;
- encourage more people to be involved with, and value, the benefits of conservation;
- projects that have a transformational impact on conservation growth in New Zealand.

Queen Elizabeth II National Trust, Royal Forest and Bird Protection Society of New Zealand and other organisations

The Queen Elizabeth II National Trust works with private landowners in New Zealand to protect special natural and cultural features on their land with open-space covenants. As at June 2014, there were 3934 registered covenants and 414 approved covenants, covering a land area of 180 845 hectares.

The Royal Forest and Bird Protection Society works in partnership with other environmental organisations, government agencies, businesses and community groups to achieve conservation objectives. In addition to involvement in the Kākāpō Recovery Partnership, Genesis Energy Whio Recovery Programme and the Kiwi Trust (see above), other major collaborative projects relating to indigenous forests that the Royal Forest and Bird Protection Society is involved with include:
- **High country parks** – advocating for high country parks to protect landscapes, native plants and animals;
- **Ark in the Park** – to restore the wilderness and wildlife of the Waitakere Ranges;
- **BirdLife International Community Conservation Fund** – sponsoring community projects to conserve threatened species;
- **JS Watson Conservation Trust** – sponsoring community conservation projects.

Local government is also involved with a range of forest-related partnership programmes in parts of the country.

Plantation forests

Research

It is common for Crown Research Institutes and universities to work in partnerships with other institutes and/or universities to research forestry and forestry-related topics.

Other forestry research partnerships include:
- the Radiata Pine Breeding Company – comprises 19 New Zealand and Australian forestry companies, consultants, seed and seedling suppliers, and focuses on tree improvement research;
- Solid Wood Innovation – a consortium of about 26 companies working on the increased and more efficient manufacturing of appearance-related wood products, energy efficiency and reduced water use in wood drying.

Forest Growers Levy Trust

The Forest Growers Levy Trust is an incorporated society with board members representing large-scale plantation forest owners (members with at least 1000 hectares of forest) and small-scale plantation forest owners (members with less than 1000 hectares of forest).

The Trust is responsible for the administration of a plantation forest growers levy that came into force in January 2014. The levy is imposed on logs harvested from plantation forests in New Zealand, and forest owners are primarily responsible for the payment. The initial rate of the levy (for the year ending 31 December 2014) was set by the Trust at 27 cents per tonne of harvested wood. (See Indicator 6.2.b for further information and an explanation of how the levy is spent.)

National Exotic Forest Description

The National Exotic Forest Description (NEFD) provides publicly available area-age class data by species or species groups by local authority for New Zealand's commercial plantation forests.[57]

The NEFD has been managed as a partnership between the New Zealand Forest Owners Association and the Ministry for Primary Industries (MPI) for nearly 30 years through a steering committee with representation from the two partners. The forest owners provide the forest resource information, and MPI undertakes the data collection, collation and dissemination.

Ministry for Primary Industries

MPI's mission is growing and protecting New Zealand. An important part of the approach to achieving this involves partnering with primary industries.

The Sector Partnerships and Programmes (SPP) Branch delivers MPI's non-regulatory programmes and initiatives to promote sustainable economic growth, such as Primary Growth Partnerships, the Sustainable Farming Fund and the Māori Agribusiness programme. SPP has an important role in linking government with industry and provides an entry point for stakeholders seeking access to growth-related initiatives.

The two contestable research funding programmes, the Primary Growth Partnership and Sustainable Farming Fund, enable MPI to partner research initiatives of agencies and community groups through partial funding. These programmes have been discussed under Indicator 7.4.b.

Biosecurity

Better Border Biosecurity (B3) is a multi-partner, co-operative science collaboration that researches ways to reduce the entry and establishment of new plant pests and diseases in New Zealand.

B3 is the science vehicle underpinning New Zealand's current practice, and for anticipating and informing future challenges and opportunities, for plant-based border security. It provides science-based solutions for supporting and protecting the international competitiveness of the country's export industries and protecting territorial ecosystems.

The B3 unincorporated joint venture integrates investment and expertise from five science agencies (Plant and Food Research, AgResearch, Scion, Landcare Research and the Bio-Protection Research Centre) and three end-user partners (MPI, DOC and the New Zealand Forest Owners Association).

57 See http://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/forestry/.

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Indicator 7.5.b Public participation and conflict resolution in forest-related decision making

Good information to support public participation in forest-related decision making is available for the commercial plantation sector and the conservation estate. A range of legislatively based and semi-formal mechanisms provide for public input to decision-making processes on resource management. Dispute resolution processes exist in some situations.

Forest certification has increased opportunities for community consultation in commercial forestry.

Quality of information: M

Progress against indicator: ▲

Rationale

This indicator provides information on the processes that promote public participation in forest-related decision making and reduce or resolve conflict amongst forest stakeholders. Public participation in decision making processes and conflict resolution efforts can lead to decisions that are widely accepted and result in better forest management.

NEW ZEALAND'S REPORT

Information

The Official Information Act 1982 makes official information more freely available to members of the public of New Zealand. This helps their effective participation in the making and administration of laws and policies. The main principle governing release of official information is that "…information shall be made available unless there is good reason for withholding it" (section 5). Section 6 of the Act identifies the reasons for which official information can be withheld.

A wide range of general information and data related to the New Zealand forestry sector is freely available through government departments, particularly the Ministry for Primary Industries, Department of Conservation (DOC), Ministry for the Environment and Statistics New Zealand. This helps informed public participation in decision-making processes.

Central government

National policy influencing forestry is developed by central government. In the policy development process, public consultation may be undertaken.

The New Zealand Parliamentary system has one legislative chamber, an elected House of Representatives. All legislative Bills[58] are referred to select committees (small groups of Members of Parliament) for consideration. Select committee consideration allows the public to examine and have input, through written and oral submissions, to draft legislation before it passes into law.

Local government

At regional and district levels, the Resource Management Act 1991 provides for Māori and members of the wider community to take part in planning the management of resources of their area. Examples are public consultation and input in the initial stages of preparing policy statements and plans, and submissions to local governments after the public has been notified about policy statements, plans or plan changes. Certain applications for resource consents for proposed activities with potentially adverse environmental effects must be publicly notified and allow for submissions.

Long-term council community plans are prepared under the Local Government Act 2002. Part of their purpose is to provide an opportunity for participation by the public in decision-making processes on activities that are to be undertaken by regional, district and city councils.

58 Except those considered under urgency, and Appropriation and Imprest Supply Bills.

Department of Conservation

Involving the community in caring for its heritage through education, sponsorships, awards, community involvement programmes, partnerships and events such as Conservation Week is an important part of DOC's work. Public involvement activities range from national-level initiatives to locally run community programmes.

DOC provides a range of levels of engagement for the public. Its visitor information centres provide interpretation of New Zealand's indigenous ecosystems. There are volunteer programmes and annual events such as Arbor Day. Information about New Zealand's biodiversity is also made available through mechanisms such as educational resources for schools, fact sheets, scientific papers, public discussion documents, maps and media articles. DOC's website provides access to these resources.[59] In addition, DOC supports community-initiated conservation projects, either on conservation land administered by DOC or on other land with significant conservation value.

59 See **http://www.doc.govt.nz**.

Ministry for Primary Industries

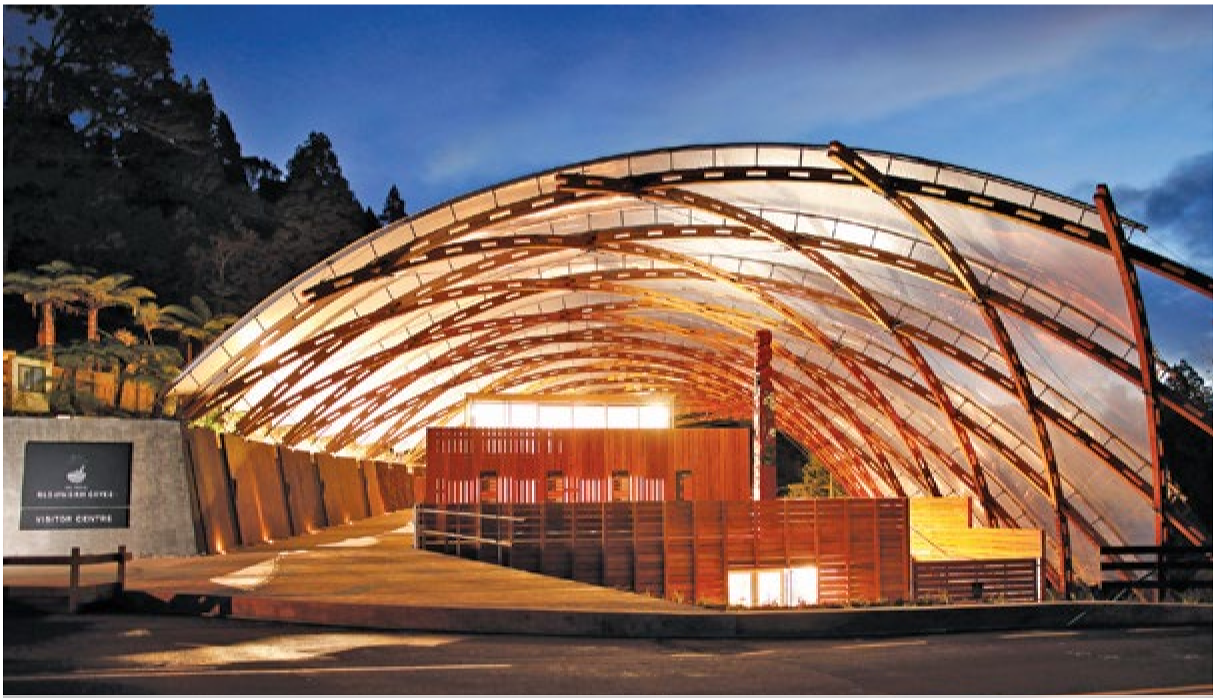
The Ministry for Primary Industries has a specific focus on the collection, collation and dissemination of information and statistical data concerning commercial plantation forests, the primary processing of wood products, and international and domestic trade of wood products. These cover quarterly and annual releases of statistics on logs and roundwood removals and on the production of sawn timber, panel products, pulp, paper and paperboard, and wood chips. The exports and imports of forest products are covered by annual releases of statistics. The information is available on the department's website.[60]

This information facilitates informed public participation in forestry issues and decision-making processes.

Commercial forest owners

More than 90 percent (by area) of the commercial forest estate is held in various forms of private ownership. About 61 percent of the total area (mostly held by large-scale forest owners) has certification

60 See **http://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/forestry**.



The Waitomo Glowworm Caves Visitors Centre: engineered timber was used to construct the curved roof.

under the Forest Stewardship Council (FSC) International Standard, and a national standard for FSC endorsement is in preparation. Another national standard (NZS AS 4708:2014 Sustainable Forest Management) was published by Standards New Zealand in May 2014, and will provide a further avenue for forest certification when auditors have been accredited. It is anticipated that endorsement of this standard will be sought under the Programme for the Endorsement of Forest Certification (PEFC).

The FSC International Standard, the standard in preparation for FSC endorsement, and NZS AS 4708:2014, all variously contain requirements for forest managers to engage on forest management matters with affected and interested stakeholders, with local communities and with indigenous peoples.

Other opportunities for public participation may occur when forest managers seek resource consents under regional and district council planning procedures.

Conflict resolution

Several conflict resolution processes are available to stakeholders and members of the public:

- judicial review can be sought for any decision, proposed decision or refusal to exercise a power of decision by the Executive of Parliament or a public body according to law;
- the Ombudsman handles complaints against government agencies and access to official information;
- legislation may include appeal procedures through the courts;
- the Disputes Tribunal deals with many types of disputes with a value of up to $15 000 (and, with agreement, up to $20 000);
- parties may agree to arbitration or mediation (professional arbitrators and mediators are available).

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Indicator 7.5.c Monitoring, assessment and reporting on progress towards sustainable management of forests

National environmental monitoring continues to evolve, driven by domestic and international concerns for the environment. Detailed statistical data from comprehensive inventory systems exist for commercial plantation forests, while data for indigenous forests are available at a lower level of detail. New Zealand reports internationally through the United Nations Food and Agriculture Organization's Global Forest Resource Assessment and the Montreal Process.

Recent initiatives include the Environmental Reporting Bill, the release of version 4 of the Land Cover Database (Landcare Research) and the progressive implementation by the Department of Conservation of the national Biodiversity Monitoring and Reporting System.

Quality of information: M/H

Progress against indicator: ▲

Rationale

This indicator provides information on the capacity to monitor, assess and report on forests. An open and transparent monitoring and reporting system that provides up-to-date and reliable forest-related information is essential for informed decision making, in generating public and political awareness of issues affecting forests and in the development of policies to underpin the sustainable management of forests.

NEW ZEALAND'S REPORT

National environmental reporting

The Ministry for the Environment (MfE) reports on the state of New Zealand's environment and provides information on the state of the air, atmosphere and climate, freshwater, land, and marine environment. MfE uses its own data and data collected from several other agencies for this reporting. These include local authorities, Crown research institutes and other government departments.

Reporting on land has been based on six national environmental indicators: land cover, land use, soil health, soil erosion risk, area of indigenous land cover and the distribution of seven selected indigenous species. These may change if the Environmental Reporting Bill, introduced into Parliament in February 2014, is passed in to law. The purpose of this Bill is to create a national-level environmental reporting system to ensure that reporting on the environment occurs on a regular basis and can be trusted by the public as independent, fair and accurate. Responsibility for environmental reporting will lie with the Secretary for the Environment and the Government Statistician: the latter to ensure reporting is at arm's length from the government of the day.

Two land classification systems are used to report on New Zealand's land, the Land Cover Database and Land Environments of New Zealand, as described below.

New Zealand Land Cover Database

The New Zealand Land Cover Database (LCDB) is a Crown-owned, digital thematic classification of land cover and land use classes. It is designed for use in geographic information systems or as printed maps.

The current version 4 of the LCDB was released in 2014 and uses 33 land cover classes. These include nine forest or shrubland categories.

Land Environments of New Zealand

Land Environments of New Zealand (LENZ) is a quantitatively based classification of the country's terrestrial environments that helps biodiversity conservation and natural resource management. It identifies climatic and landform factors likely to influence the distribution of species, and uses these to group together sites that have similar environmental conditions.

LENZ maps New Zealand's landscapes at four different levels using 20, 100, 200 or 500 environments.

Local government environmental monitoring

Local government must monitor the state of the environment for their region or district under the Resource Management Act 1991. Although reporting the results of this monitoring is not a legislative requirement, councils must make a review of the results of their monitoring available to the public at least every five years.

Forest inventories

Three national-scale forest inventories have been undertaken in New Zealand, the most recent being through the ongoing Land Use and Carbon Analysis System (LUCAS). The focus of the LUCAS forest inventories is carbon, but they also provide other metrics for different reporting purposes, for example, standing volume for the Global Forest Resources Assessment reporting. Further, the Department of Conservation's (DOC's) Biodiversity Monitoring and Reporting System is integrated into the LUCAS indigenous forest inventory. The original national forest inventory was undertaken between 1921 and 1923, and another national forest survey was conducted between 1946 and 1955.

Land Use and Carbon Analysis System

LUCAS was established in 2005 and helps New Zealand meet its international reporting requirements under the United Nations Framework Convention on Climate Change and the Kyoto Protocol. It is a cross-government programme led by MfE.

Land use data are collected for indigenous and plantation forests, and both are sub-divided between those established before 1990 and those established after 1989.

Between 2002 and 2007, a network of about 1257 permanent 20 metre by 20 metre plots was established on an 8 kilometre grid system across indigenous forests. An 8 kilometre grid system has also been used to establish permanent plots in pre-1990 plantation forests, while a 4 kilometre grid system has been used for plots in post-1989 forests. For plantation forests, airborne scanning using Light Detection and Ranging (LiDAR) is used in a double-sampling approach to increase the precision of the estimates.

The intention is to re-measure plantation forests every five years and indigenous forests every 10 years from 2014. (See Criteria 2, 3 and 5 and State of New Zealand's Forests.)

National Exotic Forest Description

The National Exotic Forest Description (NEFD) is New Zealand's commercial plantation forest resource description. It is prepared by the Ministry for Primary Industries and the New Zealand Forest Owners Association to help with resource and policy planning.

The NEFD comprises two data sets. The first is an area-age class data set with net stocked forest area by district and/or city council administrative area, year of planting, species and management regime. The second is a yield table data set with stem volume broken down into pruned, sawn and pulp logs by location, age, species and management regime.

In addition to the area-age class and yield information, data on planting, harvesting and some ancillary forest resource data are collected. NEFD forest area reports are published each year; and yield tables are published from time to time. At about five-year intervals, national and regional wood availability forecasts are prepared from the NEFD data sets.

The 31st edition of the annual NEFD report describes the plantation forest resource as at April 2014.

Other forest-related inventories

National Vegetation Survey databank

Ecologically based vegetation monitoring has been undertaken over the past 50 years or so. The resulting information has been brought together in the National Vegetation Survey (NVS) databank, the largest vegetation database in New Zealand.

The NVS is a physical archive and electronic databank containing records from about 94 000 vegetation survey plots – including data from over 19 000 permanent plots. NVS provides a unique record, spanning more than 50 years, of indigenous and exotic plants in New Zealand's terrestrial ecosystems. Broad ranges of habitats are covered, with an emphasis on indigenous forests and grasslands.

The physical archive includes plot sheets, maps and photographs from many years of vegetation surveys. Software for entering, validating and summarising data is available.

The former New Zealand Forest Service, the Department of Lands and Survey and the Botany Division of the Department of Scientific and Industrial

Research (DSIR) conducted the original surveys. Ongoing surveys and research by MfE, DOC, regional councils, universities and Landcare Research are constantly providing new data to NVS.

Data within NVS can support reporting requirements for the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, state of the environment reporting, the Resource Management Act 1991 and the Montreal Process. Historical information in NVS has significance in enabling New Zealand to address issues of current concern that were unforeseen at the time of data collection. Examples are: assessing the impact of climate change on indigenous ecosystems, the storage of carbon in indigenous ecosystems and setting restoration goals in areas since degraded.

Biodiversity Monitoring and Reporting System

DOC is progressively implementing a national system to monitor and report on New Zealand's biodiversity. The Biodiversity Monitoring and Reporting System provides DOC with comprehensive information about biodiversity on public conservation lands, and potentially across New Zealand.

The system uses indicators and measures from the New Zealand Biodiversity Assessment Framework (see Lee et al, 2005). It has three tiers of information that operate at different scales and have varying levels of detail and coverage:

- **Tier 1** is broad scale with monitoring on 1405 sites on the public conservation estate over five-year periods. (See Department of Conservation, Indicator 7.4.b, for a fuller description.) The two biodiversity indicators are the dominance of exotic weeds, pests and threats, and the mix of indigenous plants and animals. (Another 1100 sampling sites lie outside the conservation estate.)
- **Tier 2** focuses on detailed information needed to manage ecosystems and species effectively and involves consistent monitoring and reporting of results and outcomes achieved in terrestrial, freshwater and marine environments.
- **Tier 3** combines intensive research and monitoring at a few important sites to help predict and interpret national and local-scale trends, and provide the understanding needed to maintain or restore biodiversity.

Commercial forestry statistics

New Zealand has a rich set of commercial forestry statistics, some dating back to the 1920s. These statistics cover forest planting, harvesting, processing and trade in forestry products.

Ministry for Primary Industries

The Ministry for Primary Industries collects, collates and publishes forestry production and trade statistics on a quarterly basis. Annual production and trade tables are also published.

The statistics cover:

- **production** – roundwood removals from plantation and indigenous forests, and the production of sawn timber, panels, pulp, and paper and paperboard;
- **trade** – log, chip and sawn timber exports by port of loading and country of destination, and pulp and panel exports by country of destination;
- **stocks** – estimates of the quantities of sawn timber, panels and pulp and paper on processors' sites.

Since 2003 the NZ Forest Owners Association, in conjunction with MPI, has published an annual collection of key statistics on plantation forestry called *New Zealand Plantation Forestry Industry Facts and Figures*.

Statistics New Zealand

Statistics New Zealand is central government's statistics agency. It publishes a number of forestry-related statistics in addition to those published by the Ministry for Primary Industries. A core focus of Statistics New Zealand is the production of key economic and population statistics.

International reporting

Information and data from the processes identified above provide the basis for New Zealand's international forest reporting. The two principal reports are the Global Forest Resources Assessment for the United Nations Food and Agriculture Organization, and this report for the Montreal Process. Both reports are completed at around five-yearly intervals.

Other forestry-related reporting is provided to the United Nations Forum on Forests and the Convention on Biological Diversity.

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APPENDIX 1:
COMMON AND CORRESPONDING BOTANICAL NAMES

Acacia	*Acacia* spp.
Ash	*Fraxinus excelsior*
Black beech	*Fuscospora solandri*
Broom	*Cytisus scoparius*
Cypress	*Cupressus* spp.
Douglas-fir	*Pseudotsuga menziesii*
Elm	*Ulmus* spp.
Eucalypts	*Eucalyptus* spp.
Ginseng	*Panax ginseng* and *P. quinquefolium*
Gorse	*Ulex europaeus*
Hall's tōtara	*Podocarpus hallii*
Hard beech	*Fuscospora truncata*
Hawthorne	*Crateaegus* spp.
Hinau	*Elaeocarpus dentatus*
Kahikatea	*Dacrycarpus dacrydioides*
Kāmahi	*Weinmannia racemosa*
Kānuka (tea tree)	*Kunzea ericoides*
Karamu	*Coprosma robusta*
Kauri	*Agathis australis*
Kohekohe	*Dysoxylum spectabile*
Koromiko	*Hebe salicifolia*
Kotukutuku	*Fuchsia excorticata*
Makomako (wineberry)	*Aristotelia serrata*
Mangeao	*Litsea calicaris*
Mangrove	*Avicennia marina* var. *resinifera*
Mānuka (tea tree)	*Leptospermum scoparium*
Matagouri	*Discaria toumatou*
Matāi	*Prumnoptys taxifolia*
Miro	*Prumnoptys ferruginea*
Mountain beech	*Fuscospora cliffortioides*
Northern ratā	*Metrosideros robusta*
Oak	*Quercus* spp.
Pahautea	*Libocedrus bidwillii*
Pink pine	*Halocarpus biformis*
Podocarps	*Podocarpus* spp.
Pohutukawa	*Metrosideros excelsa*
Poplar	*Populus* sp.
Radiata pine	*Pinus radiata*
Red beech	*Fuscospora fusca*
Rewarewa	*Knightia excelsa*
Rimu	*Dacrydium cupressinum*
Silver beech	*Lophozonia menziesii*
Southern rātā	*Metrosideros umbellata*
Sphagnum moss	*Sphagnum cristatum*
Taraire	*Beilschmiedia tarairi*
Tawa	*Beilschmiedia tawa*
Tāwari	*Ixerba brexiodes*
Tea tree (kānuka)	*Kunzea ericoides*
Tea tree (mānuka)	*Leptospermum scoparium*
Tōtara	*Podocarpus totara*
Tree daisy	*Olearia gardneri*
Willow	*Salix* spp.
Wineberry (makomako)	*Aristotelia serrata*

APPENDIX 2:
ABBREVIATIONS USED AND THEIR MEANINGS

1080	Sodium monofluoroacetate
AANZFTA	ASEAN, Australia and New Zealand Free Trade Agreement
ACC	Accident Compensation Corporation
AFOLU	Agriculture, forestry and other land uses
AGS	Afforestation Grant Scheme
ANZCERTA	Australia–New Zealand Closer Economic Relations Trade Agreement
ANZSIC	Australian and New Zealand standard industrial classification
APEC	Asia–Pacific Economic Cooperation
BERL	Business and Economic Research Ltd
BMRS	Biodiversity Monitoring and Reporting System
B3	Better Border Biosecurity
C&I	Criteria and indicators
CO2	Carbon dioxide
COHFE	Centre for Human Factors and Ergonomics
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
DOC	Department of Conservation
DSIR	Department of Scientific and Industrial Research
ECFP	Erosion Control Funding Programme (East Coast) (formerly the East Coast Forestry Project)
ETS	Emissions Trading Scheme
FAO	United Nations Food and Agriculture Organization
FGLT	Forest Growers Levy Trust
FIC	Forum Island Countries
FITEC	Forest Industries Training and Education Council
FSC	Forest Stewardship Council
FTA	Free trade agreement
FTE	Full-time equivalent
GDP	Gross domestic product
GFC	Global financial crisis
GHG	Greenhouse gas
GST	Goods and services tax
ha	Hectares
HWP	Harvested wood products
IPCC	Intergovernmental Panel on Climate Change
IRIS	Incident Reporting Information System
ITO	Industry training organisation
IUCN	International Union for Conservation of Nature
LAWA	Land and Water Aotearoa
LCDB	Land Cover Database (versions 2, 3 and 4)
LENZ	Land Environments of New Zealand

LiDAR	Light Detection and Ranging
LINZ	Land Information New Zealand
LRI	New Zealand Land Resource Inventory
LUCAS	Land Use and Carbon Analysis System
LULUCF	Land use, land-use change and forestry
MAF	Ministry of Agriculture and Forestry (one of the ministries that became MPI)
MBIE	Ministry of Business, Innovation and Employment
MfE	Ministry for the Environment
MPI	Ministry for Primary Industries
m^3	Cubic metres
NBMRP	National Biodiversity Monitoring and Reporting Programme
NCEA	National Certificate of Educational Achievement
NEFD	National Exotic Forest Description
NIWA	National Institute of Water and Atmospheric Research
NRFA	National Rural Fire Authority
NVS	National vegetation survey
NWFP	Non-wood forest products
NZ	New Zealand
NZeem®	New Zealand empirical erosion model
NZETS	New Zealand Emissions Trading Scheme
NZFOA	New Zealand Forest Owners Association
NZFSA	New Zealand Food Safety Authority
NZQA	New Zealand Qualifications Authority
NZU	New Zealand Unit: unit of trade for the Emissions Trading Scheme, 1 NZU = 1 tonne of CO_2-equivalent emissions
OECD	Organisation for Economic Co-operation and Development
PACER	Pacific Agreement on Closer Economic Relations
PCE	Parliamentary Commissioner for the Environment
PEFC	Programme for Endorsement of Forest Certification
PGP	Primary Growth Partnership
PJ	petajoule
PNB	Physiological needle blight
PTA	*Phytophthora* taxon Agathis
R&D	Research and development
RMA	Resource Management Act 1991
SFF	Sustainable farming fund
SFM	Sustainable forest management
SPARTECA	South Pacific Regional Trade and Economic Co-operation Agreement
SPP	Sector Partnerships and Programmes Branch, Ministry for Primary Industries
spp.	Species
Tb	Bovine tuberculosis
TIMO	Timber investment management organisation

TPA	Trans-Pacific [Strategic Economic Partnership] Agreement
TPES	Total Primary Energy Supply
TPP	Trans-Pacific Partnership
UNCED	United Nations Conference on Environment and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Reaping the benefits

Science and the sustainable intensification of global agriculture

October 2009

CELEBRATE 350 YEARS

THE ROYAL SOCIETY

Cover image: From an illustration of a push-pull system for pest control, courtesy of The Gatsby Charitable Foundation. *The Quiet Revolution: Push-Pull Technology and the African Farmer*. Gatsby Charitable Foundation 2005.

Reaping the benefits: science and the sustainable intensification of global agriculture

CELEBRATE
350 YEARS

THE ROYAL SOCIETY

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Reaping the benefits: science and the sustainable intensification of global agriculture

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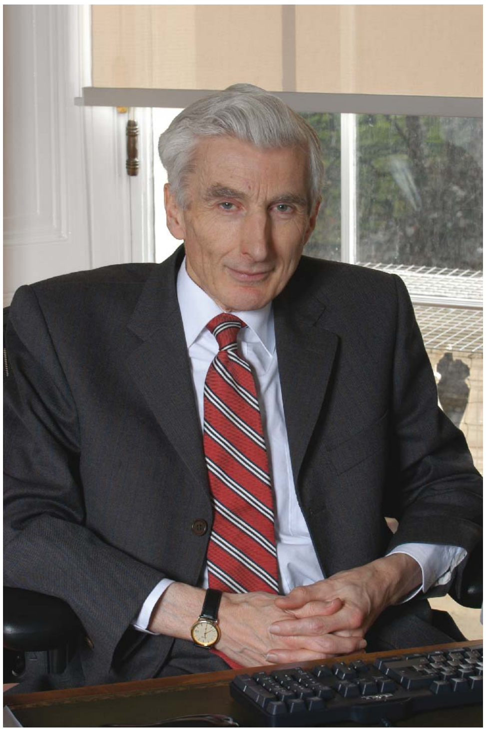

It is more than 200 years since Thomas Malthus offered his famously pessimistic prediction that the rise in human populations would outrun the growth in food supplies. But despite devastating regional famines, prognostications of mass starvation have not been fulfilled, even though the population has risen around six-fold since Malthus's time.

Nonetheless, projections for the coming decades are deeply disquieting. We are already unduly dependent on farming techniques that have harmful environmental impacts. To meet the needs of a growing population with changing consumption patterns, productivity must be enhanced, but it must be done so sustainably.

This report describes how the prudent application of recent and prospective biological advances can contribute to the 'sustainable intensification' of agriculture. It argues that a multi-pronged approach is needed. Improvements in farming practices and crop management are essential, but modern genetics must be utilised too.

There is a big gap between sophisticated UK laboratories and the reality of subsistence farming in Africa: to eliminate malnourishment requires an adequate economic and political infrastructure as well. But the message of this report is that scientific advances are necessary, even if they are not sufficient, if global food supplies are to be ensured.

Since the first 'green revolution' 50 years ago, international research institutes have made hugely valuable contributions to human welfare. UK laboratories have been at the forefront of these efforts. Their mission has never been as important as today, nor has biological knowledge ever offered such great potential. The challenge of learning how to feed the world cannot be left to the private sector: governmental support—increasingly (and gratifyingly) augmented by major charities—is crucial.

This authoritative and balanced report offers enlightening reading for all policy makers; its well judged recommendations should be heeded.

The Royal Society is grateful to all the members of the Working Group and especially to Sir David Baulcombe, its Chairman. We also acknowledge the valuable inputs from the Council's review group, and the efficient and professional support of the Society's Science Policy team. The Society would like to express special gratitude to Professor Mike Gale FRS, who died suddenly very soon after the final Working Group meeting. This report is dedicated to him and his family.

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Review Panel	
The Royal Society gratefully acknowledges the contribution of the reviewers. The review group were not asked to endorse the conclusions or recommendations of this report, nor did they see the final draft of the report before its release.	
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Summary

Food security is one of this century's key global challenges. By 2050 the world will require increased crop production in order to feed its predicted 9 billion people. This must be done in the face of changing consumption patterns, the impacts of climate change and the growing scarcity of water and land. Crop production methods will also have to sustain the environment, preserve natural resources and support livelihoods of farmers and rural populations around the world. There is a pressing need for the 'sustainable intensification' of global agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land.

Addressing the need to secure a food supply for the whole world requires an urgent international effort with a clear sense of long-term challenges and possibilities. Biological science, especially publicly funded science, must play a vital role in the sustainable intensification of food crop production. The UK has a responsibility and the capacity to take a leading role in providing a range of scientific solutions to mitigate potential food shortages. This will require significant funding of cross-disciplinary science for food security.

The constraints on food crop production are well understood, but differ widely across regions. The availability of water and good soils are major limiting factors. Significant losses in crop yields occur due to pests, diseases and weed competition. The effects of climate change will further exacerbate the stresses on crop plants, potentially leading to dramatic yield reductions. Maintaining and enhancing the diversity of crop genetic resources is vital to facilitate crop breeding and thereby enhance the resilience of food crop production.

Addressing these constraints requires technologies and approaches that are underpinned by good science. Some of these technologies build on existing knowledge, while others are completely radical approaches, drawing on genomics and high-throughput analysis.

Novel research methods have the potential to contribute to food crop production through both genetic improvement of crops and new crop and soil management practices. Genetic improvements to crops can occur through breeding or genetic modification to introduce a range of desirable traits. The application of genetic methods has the potential to refine existing crops and provide incremental improvements. These methods also have the potential to introduce radical and highly significant improvements to crops by increasing photosynthetic efficiency, reducing the need for nitrogen or other fertilisers and unlocking some of the unrealised potential of crop genomes.

The science of crop management and agricultural practice also needs to be given particular emphasis as part of a food security grand challenge. These approaches can address key constraints in existing crop varieties and can be applied widely. Current approaches to maximising production within agricultural systems are unsustainable; new methodologies that utilise all elements of the agricultural system are needed, including better soil management and enhancement and exploitation of populations of beneficial soil microbes. Agronomy, soil science and agroecology—the relevant sciences—have been neglected in recent years.

Past debates about the use of new technologies for agriculture have tended to adopt an either/or approach, emphasising the merits of particular agricultural systems or technological approaches and the downsides of others. This has been seen most obviously with respect to genetically modified (GM) crops, the use of pesticides and the arguments for and against organic modes of production. These debates have failed to acknowledge that there is no technological panacea for the global challenge of sustainable and secure global food production. There will always be trade-offs and local complexities. This report considers both new crop varieties and appropriate agroecological crop and soil management practices and adopts an inclusive approach. No techniques or technologies should be ruled out. Global agriculture demands a diversity of approaches, specific to crops, localities, cultures and other circumstances. Such diversity demands that the breadth of relevant scientific enquiry is equally diverse, and that science needs to be combined with social, economic and political perspectives.

In addition to supporting high-quality science, the UK needs to maintain and build its capacity to innovate, in collaboration with international and national research centres. UK scientists and agronomists have in the past played a leading role in disciplines relevant to agriculture, but training in agricultural sciences and related topics has recently suffered from a lack of policy attention and support. Agricultural extension services, connecting farmers with new innovations, have been similarly neglected in the UK and elsewhere. There is a major need to review the support for and provision of extension services, particularly in developing countries.

The governance of innovation for agriculture needs to maximise opportunities for increasing production, while at the same time protecting societies, economies and the environment from negative side effects. Regulatory systems need to improve their assessment of benefits. Horizon scanning will ensure proactive consideration of technological options by governments. Assessment of benefits, risks and uncertainties should be seen broadly, and should include the wider impacts of new technologies and practices on economies and societies. Public and stakeholder dialogue—with NGOs, scientists and farmers in particular—needs to be a part of all governance frameworks.

Recommendations

1. Research Councils UK (RCUK) should develop a cross-council 'grand challenge' on global food crop security as a priority. This needs to secure at least £2 billion over 10 years to make a substantial difference. We believe this will require between £50 and £100 million per year of new government money in addition to existing research spending. This long-term UK programme should bring together all research councils, the Technology Strategy Board and key central government research funders (DFID and DEFRA) and be aligned with comparable international activities in this area. It should be informed by dialogue with farmers, other stakeholders and members of the public. The following recommendations justify allocation of these funds to excellent and relevant research, research training and technology transfer.
2. UK research funders should support public sector crop breeding and genomics programmes to understand, preserve and enhance the germplasm of priority crops and train the next generation of plant breeders. International programmes in collaboration with Consultative Group on International Agricultural Research (CGIAR) centres and others in Africa and India should include millet, sorghum and rice. The top UK priority should be wheat, followed by barley, oil seed rape, potato, vegetable brassicas and other horticultural crops. Public sector support for breeding needs to emphasise longer term strategic approaches than can be expected from the private sector and develop traits from public sector research.
3. RCUK should increase support for ecosystem-based approaches, agronomy and the related sciences that underpin improved crop and soil management.
4. RCUK, and BBSRC in particular, should support long-term high-risk approaches to high-return targets in genetic improvement of crops. These targets include GM crops with improved photosynthetic efficiency or nitrogen fixation. High risk approaches might also produce GM or conventionally bred crops with reduced environmental impact because they need lower fertiliser input or could be grown as perennials. Research into conventional breeding and GM approaches to increased yield and resistance to stress and disease should also continue to be funded.
5. Universities should work with funding bodies to reverse the decline in subjects relevant to a sustainable intensification of food crop production, such as agronomy, plant physiology, pathology and general botany, soil science, environmental microbiology, weed science and entomology. We recommend that attempts by universities and funding bodies to address this skills gap look globally. Studentships and postdoctoral research positions should provide targeted subsidies to scientists in developing countries to visit the UK and work with UK researchers.
6. In order to sustain research capacity and maximise the potential for research to be utilised, crop science research funded by BBSRC, DFID and others, together or separately, should have regular calls for proposals rather than one-off grant rounds. Grants awarded in phases will allow researchers to pursue successful ideas in the field or in new countries.
7. DFID should work with the CGIAR institutes to develop new mechanisms for international research collaborations with emerging scientific bases such as in China, Brazil, India and South Africa. Through its support for CGIAR, DFID should work with research funders and UK scientists to strengthen collaborations with international researchers. The UK should work with other partner countries to prioritise global agricultural research within the forthcoming European Commission eighth framework Programme.
8. Research that links UK science with developing countries, funded by DFID, BBSRC and others, should work with farmers and extension services in target countries to make sure that benefits are captured and made accessible to poor farmers.
9. As part of the RCUK grand challenge there should be support for joint initiatives between the public sector and industry in which the explicit aim is the translation and application of previously executed basic research.
10. The UK department for Business, Innovation and Skills should review relevant intellectual property systems to ensure that patenting or varietal protection of new seed varieties does not work against poverty alleviation, farmer-led innovation or publicly funded research efforts.
11. UK government should work with EU partner countries over the next five to ten years to develop a system of regulation for new agricultural processes and products, based on shared principles.
12. DFID and DEFRA should build on the work of the Food Research Partnership to establish an independent food security advisory function. This would work openly with stakeholders to help the government put future technological options into a broad social and economic context and appraise their benefits and uncertainties alongside alternatives. It would feed into and stimulate similar international efforts at CGIAR and UN level.

1 Introduction

Summary
Food security is an urgent challenge. It is a global problem that is set to worsen with current trends of population, consumption, climate change and resource scarcity. The last 50 years have seen remarkable growth in global agricultural production, but the impact on the environment has been unsustainable. The benefits of this green revolution have also been distributed unevenly; growth in Asia and America has not been matched in Africa. Science can potentially continue to provide dramatic improvements to crop production, but it must do so sustainably. Science and technology must therefore be understood in their broader social, economic and environmental contexts. The sustainable intensification of crop production requires a clear definition of agricultural sustainability. Improvements to food crop production should aim to reduce rather than exacerbate global inequalities if they are to contribute to economic development. This report follows other recent analyses, all arguing that major improvements are needed to the way that scientific research is funded and used.

1.1 An urgent challenge

Food security will be one of this century's key global challenges. Current trends of population, food demand and climate change could lead to a global crisis in the coming decades unless action is taken now. Securing food supply for the world requires a new, concerted and immediate international effort with a clear sense of long-term challenges and possibilities. Science must play a vital role in this response. The Royal Society has chosen to assess the role of biological sciences in meeting this challenge.

Although this report offers a UK perspective, our vision is global. This report's target is not just UK food production. We are interested in the broader contribution that the UK might make to increasing food production around the world. The UK is a world leader in plant and agricultural sciences and has long combined a variety of disciplines to contribute to the fight against global food insecurity. This report offers recommendations for science and policy to enhance the contribution made by UK scientists.

In 2008, food price shocks around the world demonstrated the importance and extraordinary interdependence of global systems of food production. For many of the world's poorest people who spend a large proportion of their incomes on food, the increase in food prices had an enormous impact. Food scarcity led to riots in Morocco, Mexico, Indonesia and elsewhere. This political instability was a result of a number of short-term pressures, but it highlighted a long-term problem of food security and its impact on human well-being. Prices have since fallen, but the volatility of global markets provides a clear warning against complacency. Our report builds on the 2008 International Assessment of Agricultural Knowledge, Science and Technology for Development report's conclusion that 'Business as usual is not an option' (IAASTD 2008a).

It is now clear that global food insecurity is a chronic problem that is set to worsen (see Box 1.1).

The world population will increase up to at least the mid-21st century, and absolute demand for food will rise. Estimates of population increases over the coming decades vary, but the emerging consensus is that the world will have approximately 9 billion people by about 2050 (UN 2008). Predictions of future food demand also differ, but even the most optimistic scenarios require increases in food production of at least 50%. The demand for agricultural and food products caused by rising population and changing consumption patterns will become most acute in the next half-century.

Box 1.1 Drivers for chronic food insecurity (von Braun 2007; Conway 2009)

- Increasing population;
- Changing and converging consumption patterns;
- Increasing per capita incomes, leading to increased resource consumption;
- Growing demand for livestock products (meat and dairy), particularly those fed on grain;
- Growing demand for biofuels;
- Increasing water and land scarcity;
- Adverse impacts of climate change;
- Slowing of increases in agricultural productivity.

Climate change is also set to have a profound impact on food production (IPCC 2007a). Rising temperatures, altered rainfall patterns and more frequent extreme events will increasingly affect crop production, often in those places that are already most vulnerable (Morton 2007). Notwithstanding the potential to adapt crops to changing environments, the need to mitigate climate change will increasingly challenge conventional, resource-intensive agricultural systems which depend on chemical inputs derived from fossil fuels and contribute significantly to greenhouse gas (GHG) emissions.

John Beddington, the UK Government Chief Scientific Adviser, has used the phrase 'perfect storm' to describe the future coincidence of food, water and energy insecurity (Beddington 2009). The food component of this 'storm' is unavoidably global. Food markets are highly globalised. Countries are substantially interdependent on each other for their food supplies and will share the impacts of the global instability generated by food insecurity. Following its own assessment of worrying trends to 2050, the Food and Agricultural Organisation of the United Nations concludes that, 'the result could well be enhanced risk of persistent food insecurity for a long time to come in a number of countries in the midst of a world with adequate food supplies and the potential to produce more' (FAO 2006).

Addressing future food insecurity requires action on many fronts, across different timescales. There are systemic challenges that need addressing now, and there is a need to build resilient global agricultural systems for the next 40 years. These systems of food crop production need to be underpinned by science and technology, as has been the case for the last 150 years.

This report aims to provide a balanced assessment of the challenges to world food crop production and the range of different approaches, drawing on the biological sciences that could potentially increase the quantity and quality of crop production over the next 40 years. The application of science and technology presents new opportunities, but may also bring new side effects. The report therefore considers what research and policy action is required to predict and respond to the impacts of new agricultural products and practices.

1.2 Trends in food crop production

Over the last 50 years there has been remarkable growth in agricultural production, with increases in food production across the world. Since the advent of the green revolution in the early 1960s, gross world food production (cereals, coarse grains, roots and tubers, pulses and oil crops) has grown from 1.84 billion tonnes in 1961 to 4.38 billion tonnes in 2007 (an increase of 138%) (see Figures 1.1, 1.2 and 1.3 for a representation of major cereals, roots, tubers and oil crops). This growth has differed across continents:

Proportions of major global cereals, roots, tubers and oil crops in 2007 (Area corresponds to total production). Source: FAOSTAT (2009)

Figure 1.1. Cereals, total 2,351,396,424 tonnes.

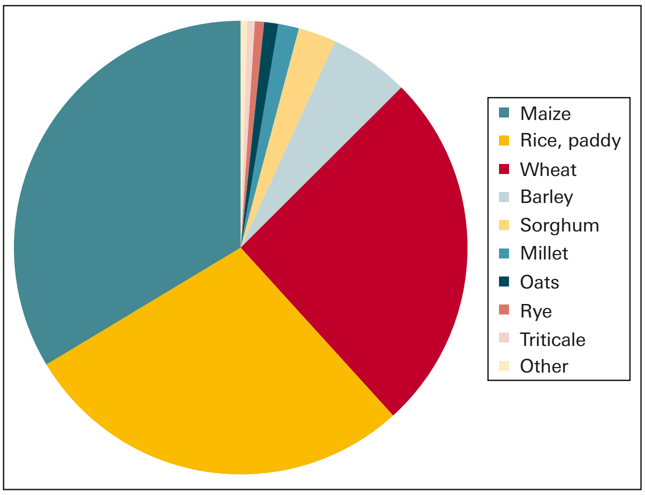


Figure 1.2. Roots and tubers, total 697,620,690 tonnes.

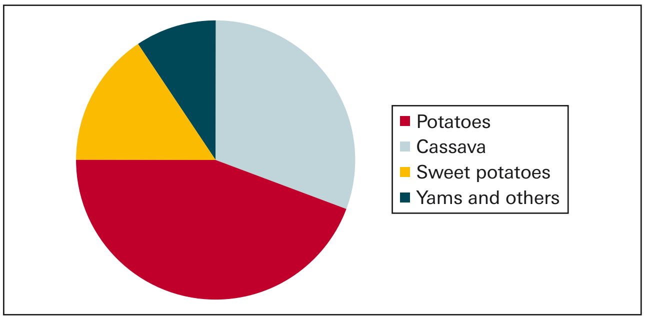
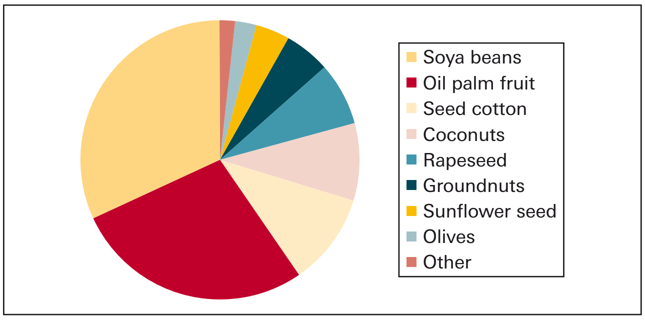


Figure 1.3. Oil crops, total 692,421,195 tonnes.



in Africa, it rose by 140%, in Latin America by almost 200%, and in Asia by 280%. The greatest increases have been in China, where a 5-fold increase occurred, mostly during the 1980s and 1990s. In industrialised countries, production started from a higher base, but still grew by 70% in Europe and doubled in the USA (FAOSTAT 2009).

Despite a substantial increase in numbers of people (from 3 billion in 1960 to 6.7 billion in 2009), per capita agricultural production has still outpaced population growth. For each person alive today, there is in theory an additional 29% more food compared with 1960. These aggregate figures again hide important regional differences. In Asia and Latin America, per capita food production increased by 98% and 61% respectively. Africa has fared less well, with food production per person falling from the 1970s and only just recovering to the 1960 level in 2005 (Figure 1.4). China has seen remarkable growth, more than trebling per capita food production over the same period (FAOSTAT 2009) (see Figure 1.5). These agricultural production gains have helped lift millions out of poverty and provided a platform for rural and urban economic growth in many parts of the world.

Beginning in the 1950s and expanding through the 1960s, agricultural development across many parts of the world saw changes in crop varietal development and input use that have come to be known as the 'green revolution'. This revolution encompassed changes to crop varieties (day-length insensitive, partitioning of carbohydrates to grain rather than straw, disease resistance), changes to agricultural practices (fertilisers, water management and pesticides) and broader social, economic and political change.

Figure 1.4. Changes in per capita agricultural production, part 1 (1961–2005).

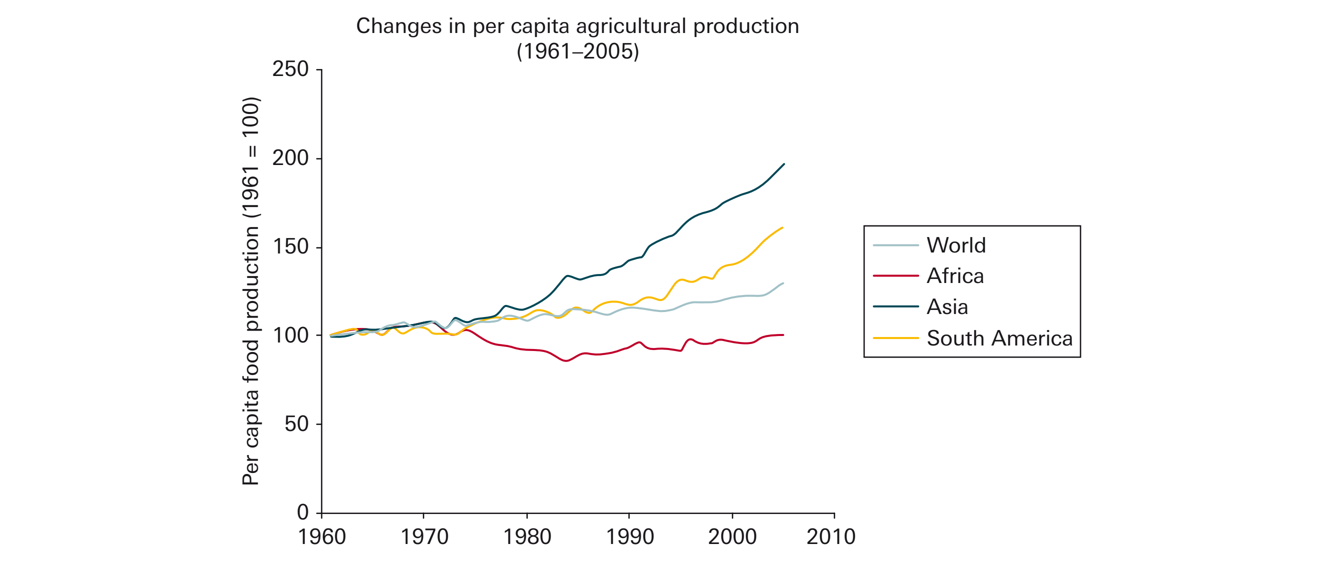
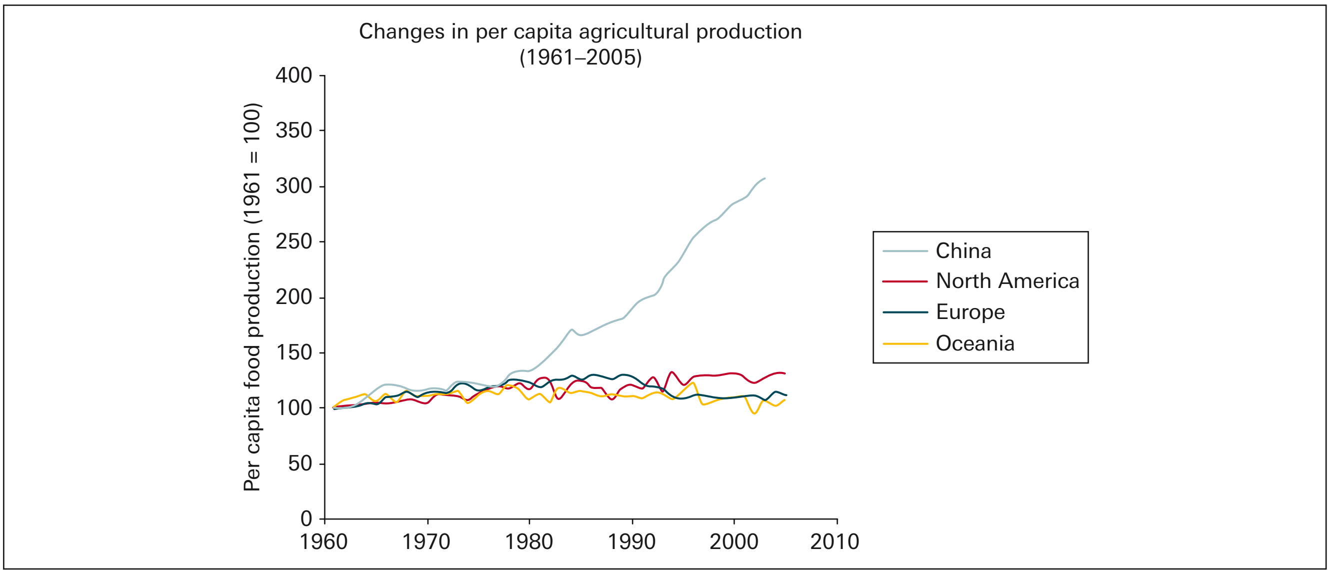


Figure 1.5. Changes in per capita agricultural production, part 2 (1961–2005).



New varieties of wheat were bred with two major genetic improvements—dwarfing (shorter stems) and resistance to stem rust. The genetic potential of these new crops was realised through changes in practice and greater use of mineral fertiliser and water. Dwarfing allowed for the increases in yield provided by nitrogen fertilisers without the crops lodging (falling over). Similar changes were made to rice varieties in Asia. New crops, new practices and new markets for inputs and outputs of agriculture helped not only with food shortages, but also with rapid economic development in a number of countries (Hossain *et al.* 2003).

The green revolution was also a revolution in the way in which research was organised. In Mexico, the International Maize and Wheat Improvement Center (CIMMYT) provided the institutional impetus for these new approaches to food production, while across Asia it came from International Rice Research Institute (IRRI), based in the Philippines. In 1971, these scientific bodies came together with others under the umbrella of the Consultative Group on International Agricultural Research (CGIAR), which continues to catalyse innovation and implement scientific advances for agriculture across the world.

The achievements of the green revolution have come at some cost. Increases in yield have been achieved without great expansion in land use, but this high-energy crop production has involved sharp increases in fertiliser, pesticide and water use, which can lead in turn to increased emissions of nitrates and pesticides into the environment and depletion of groundwater aquifers (Moss 2008) (see Figures 1.6 and 1.7). The benefits of increased yields have been distributed unevenly. The complexities of African agricultural landscapes, with mixed crops and poor access to credit, markets, seeds

Figure 1.6. World fertiliser consumption (1961–2005).

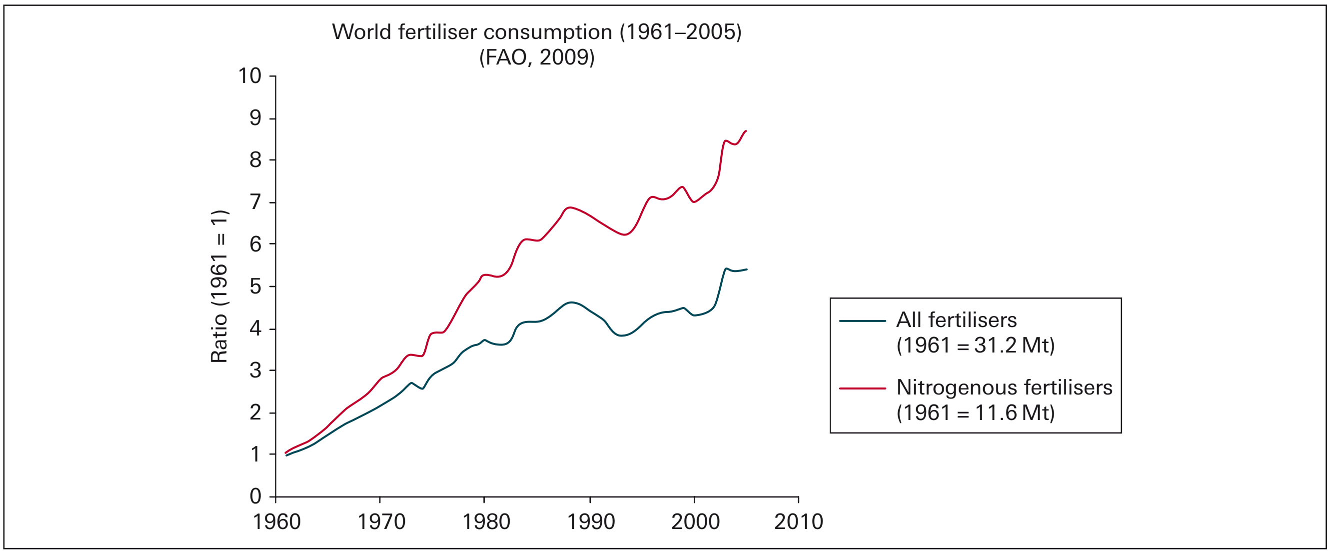
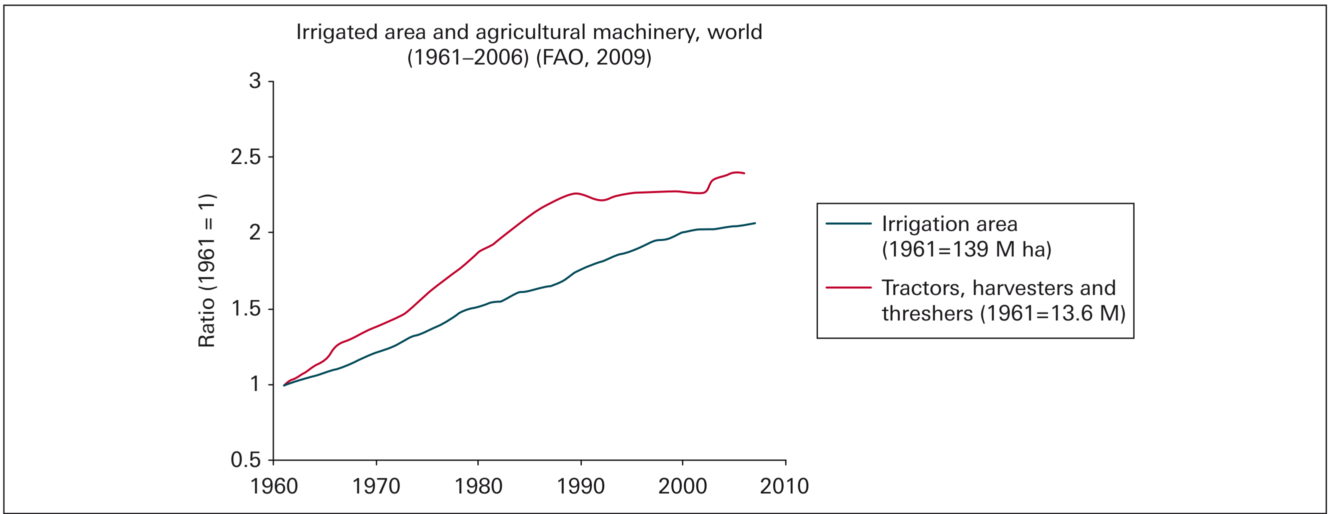


Figure 1.7. Irrigated area and agricultural machinery (1961–2006).



and fertilisers, did not suit green revolution crop varieties (Paarlberg 2006). Other social side effects of the green revolution include mechanisation replacing manual labour and worsening poverty in some rural areas (Conway 1997).

These successes and limitations of the first green revolution have led to many calls for renewed investment and collaboration directed at step changes in agricultural productivity, albeit with greater consideration of possible side effects. There have been calls for a 'greener revolution' (The Independent 2008), a 'doubly-green revolution' (Conway 1997) an 'evergreen revolution' (Swaminathan 2000), a 'blue revolution' (Annan 2000) and an 'African green revolution' (Sanchez *et al.* 2009a) which would replicate the successes of original efforts in new places, while this time being more equitable, resilient and socially and environmentally sustainable.

In 2007, the world's farmers produced 2.3 billion tonnes of grain (80% of which was wheat, rice and maize) and another 0.5 billion tonnes of roots and tubers (see Figures 1.1 and 1.2). Cereal production was 4.7% up on 2006 and 2.7 times the amount that was being produced 50 years ago (0.83 billion tonnes). However, a large proportion of this plant material is removed for livestock feed, and a growing amount for biofuel production. Since a peak of around 250 kg per person worldwide in 1995, per capita availability of cereal and roots has dropped back to near 1960s levels of around 220 kg/person of grain available for direct food use (FAOSTAT 2009). Reduced availability of these staples affects the world's poor most acutely.

The necessary changes to global agriculture are not just a matter of quantity. In addition to increasing yield, there are further challenges concerning food quality, nutritional benefit, distribution to match production with need, managing potentially adverse impacts, and reducing the environmental impact of technological change. All of these depend to a greater or lesser degree on scientific research. The green revolution was built on decades of substantial global investment in agricultural research. The outcomes of R&D can take many years to filter through to agricultural practice (Normile 2008), and it is therefore worrying that the intensity of investment in agricultural research and infrastructure has fallen in recent decades (World Bank 2008). As real food prices have fallen over time and markets have become globalised, there has been a growing complacency about food production and the global need and capacity to innovate.

1.3 Science in context

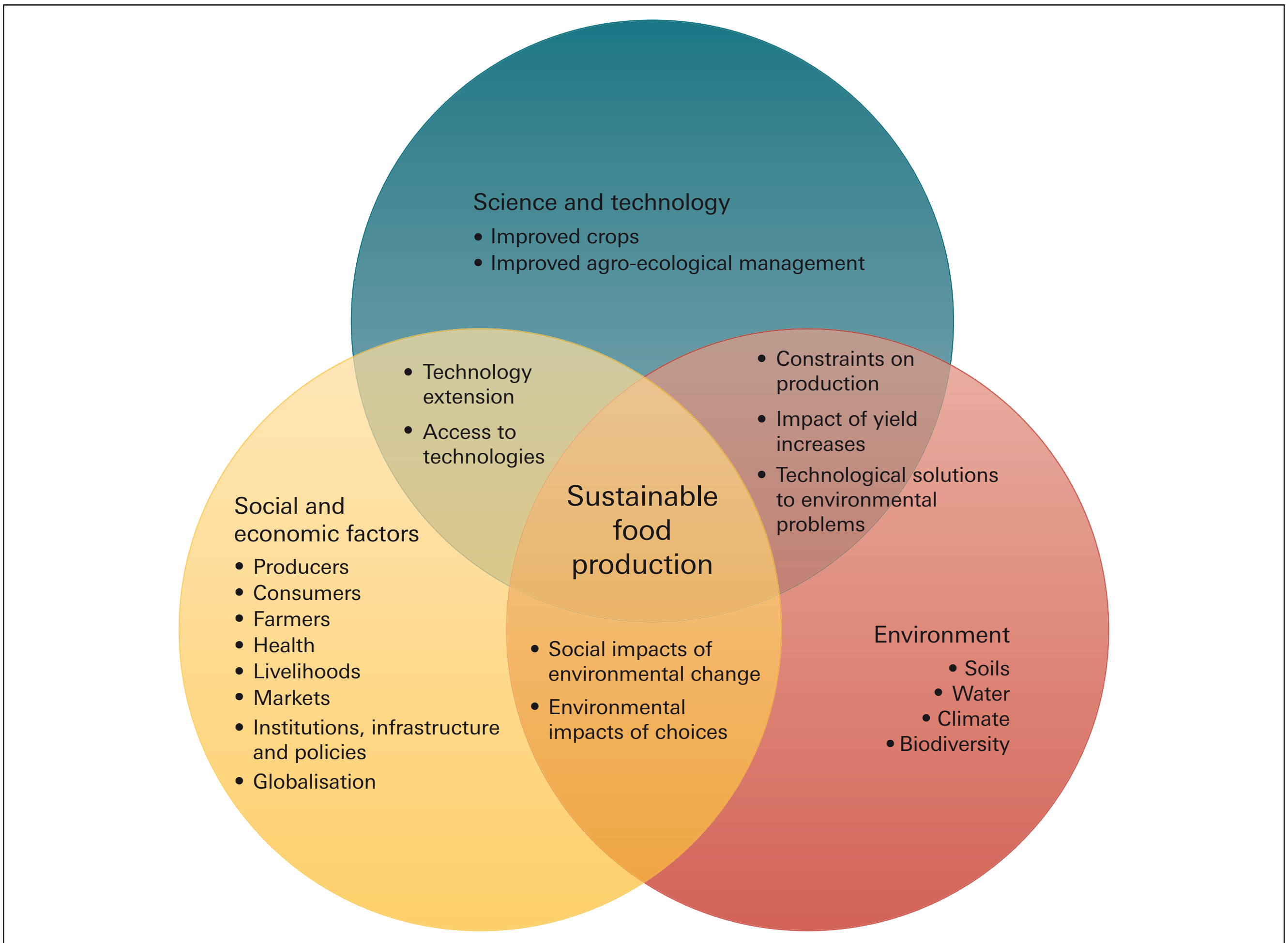
Our focus is on science and technology, but we recognise that agricultural systems rely on the interconnectedness of many different elements (IAASTD 2008). The global challenge of food security has many dimensions, only some of which are amenable to change through science and innovation. The diagram below (Figure 1.8) provides a logic for this complexity. Science necessarily interacts with social, economic and environmental systems. Improvements in food crop production may originate from scientific research, but for changes in production systems to be considered sustainable, they must take into account all three elements.

Social and economic factors, including prices for inputs and outputs, access to credit and markets, investment options, differential risks, transport costs, market control and uncertainty about market conditions constrain the options for farmers, traders and consumers. Political and policy structures such as land tenure, intellectual property law, research funding and regulation can similarly enable, encourage or constrain agriculture. All farmers except those who produce purely for subsistence experience acutely the economics of agriculture and food.

Domestic patterns of food production and consumption have become interconnected in global markets. The economics of food mean that small changes in production can lead to large fluctuations in price, especially when speculation on world markets is unconstrained. Many countries now rely on buying their food on open global food markets. But, as was demonstrated with the food price shocks, these can break down when they are most needed, when national governments seek to protect their own supplies.

Global food security is not only about producing enough food for the world's population. Questions of *access* need to run alongside those of *availability* (Ericksen 2008). Inequalities and complexities of food distribution mean that while around 1 billion people are currently malnourished, 1 billion are overweight and susceptible to diseases associated with obesity.

Figure 1.8. The complexity of agricultural systems.



As diets change, so demand for different types of food will shift radically, with large numbers of people going through a 'nutrition transition'. Increasing urbanisation and growing prosperity mean that people are more likely to adopt new diets, particularly consuming more meat, fats and refined cereals, and fewer traditional cereals, vegetables and fruit (Fitzhugh 1998; Popkin 1998; Delgado *et al.* 1999; Smil 2000a). Livestock production has increased dramatically, with a worldwide 4.4-fold increase in numbers of chickens since 1961 (to 17 billion), a 2.4-fold increase in pigs (to 9.9 billion), an 0.4–0.5-fold increase in numbers of cattle and buffalos (to 1.59 billion) and sheep and goats (to 1.96 billion) (see Figure 1.9) (Pretty 2008; FAOSTAT 2009). Some suggest that demand for livestock products will double by 2050. Already more than one-third of the world's grain is fed to domestic livestock (rising to nearly 70% in industrialised countries). As incomes rise in developing countries, so it is expected that demand for meat will tend towards the per capita consumption rates of 115 kg per year in the USA and 80 kg per year in the UK. Chinese per capita annual consumption has already increased from 4 to 54 kg in the past 50 years. On the current trajectory, livestock production will move further from extensive (pasture-based grazing) to intensive systems, placing even more demand on staple grains.

The natural environment can be seen as providing a set of benefits to agriculture (ecosystem services and organisms for biological control) and constraints (soil, water, climate, pests and diseases) that determine what can be grown, where, when and how. The primary constraints on crop production are well understood. These include biophysical factors such as radiant energy for photosynthesis (dependent on latitude), temperature (dependent on latitude and altitude), water, plant nutrients (primarily nitrogen, phosphorus and potassium), pests (vertebrates and invertebrates), diseases (bacteria, viruses and fungi), weeds (other plants) and the availability of suitable land. These constraints are the subject of Chapter 2 of this report.

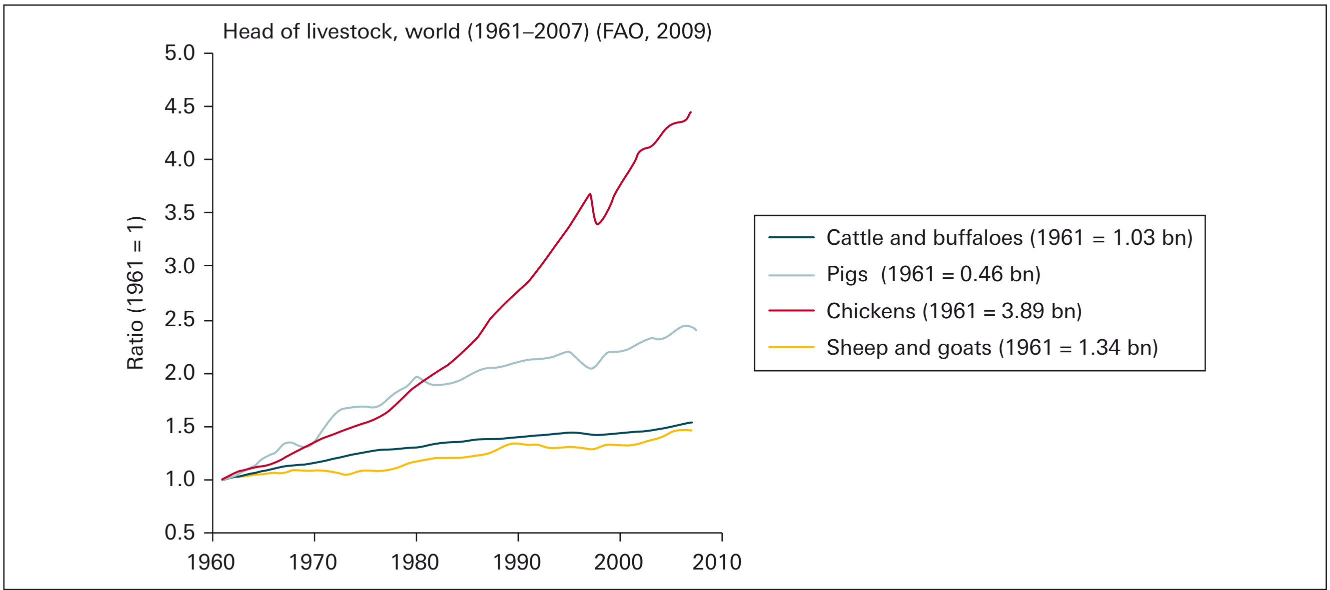
The effects of climate change on world agriculture are uncertain. Working Group 2 of the Intergovernmental Panel on Climate Change (IPCC) has estimated that global crop production will be threatened by global temperature increases of 1°C and begin to decline significantly at 3°C (Easterling *et al.* 2007). But this global picture flattens out regional variations that might bring catastrophic impacts on, for example, the drier tropical areas (Schmidhuber & Tubiello 2007). The social and economic consequences of environmental change (including changes to biodiversity and climate) will exacerbate the uncertainties faced by the world's poorest billion people.

1.4 The need for sustainable intensification

Land used for crop production has grown only slightly over the period 1961 to 2007 (total agricultural area has expanded 11% from 4.51 to 4.93 billion ha, and arable area 9% from 1.27 to 1.41 billion ha) (FAOSTAT 2009). Over the same period the human population grew from 3 to 6.7 billion (an increase of 123%). In industrialised countries, agricultural area has fallen by 3% over the same period, but has risen by 21% in developing countries. Half of the 1.4 billion ha of land used for arable crop production produces grain (approximately 700 million ha). In 1960 the area used to produce grain was 648 million ha.

Improvements to agricultural production are complicated by a number of pressures on land availability. As cities grow, they encroach on rural environments and often on high quality agricultural land (Montgomery 2007). The loss of soil globally is an increasingly serious problem (Fitter 2005). In many places, land that has previously grown food is being turned over to biofuels (Royal Society 2008a). In some countries use of land for food is prohibited by

Figure 1.9. Head of livestock (1961–2007).



protected area status. The ecosystem services provided by forests are in most cases too important to lose through their conversion to agricultural land. Following the recent food price shocks, there has been a rapid increase in demand for land in many regions as some food-importing countries have sought to secure their own food supplies. Much of this has been dominated by the private sector and foreign investors (Cotula *et al.* 2009). China, to give just one example, has successfully acquired the rights to grow palm oil on 2.8 million ha of Congolese land (The Economist 2009).

The global community faces an important choice: expand the area of agricultural land to increase gross production, or increase yields on existing agricultural land. Expanding agricultural land results in losses of vital ecosystem and biodiversity services, as well as damaging livelihoods for communities relying on these lands (Millennium Ecosystem Assessment 2005). Feedback effects are likely to elevate GHG emissions due to oxidation of carbon currently sequestered in soil, removal of carbon sinks, and increases in both nitrogen fertiliser and fossil fuel use. It is currently estimated that land-use change, primarily deforestation, is responsible for as much as 18% of global GHG emissions (IPCC 2007a; Millennium Ecosystem Assessment 2005). In this report, we argue for the sustainable intensification of global agriculture, which demands a clear definition of agricultural sustainability.

1.5 Agricultural sustainability

The concept of sustainability in the context of agricultural and food production is central to any future challenges (Pretty 2008). It incorporates four key principles:

1. Persistence: the capacity to continue to deliver desired outputs over long periods of time (human generations), thus conferring predictability;
2. Resilience: the capacity to absorb, utilise or even benefit from perturbations (shocks and stresses), and so persist without qualitative changes in structure;
3. Autarchy: the capacity to deliver desired outputs from inputs and resources (factors of production) acquired from within key system boundaries;
4. Benevolence: the capacity to produce desired outputs (food, fibre, fuel, oil) while sustaining the functioning of ecosystem services and not causing depletion of natural capital (eg minerals, biodiversity, soil, clean water).

Any system is by these principles and measures unsustainable if it depends on non-renewable inputs, cannot consistently and predictably deliver desired outputs, can only do this by requiring the cultivation of more land, and/or causes adverse and irreversible environmental impacts which threaten critical ecological functions.

The primary aim of agriculture is the efficient conversion of solar energy into various forms of chemical energy for human use. This encompasses crops grown for food, fuel, fibre and forage for animals. Agriculture involves the management of the interaction between crop genotypes or livestock breeds and their immediate agro-environment (physical and biological). The capacity to deliver from the system what is required and to be able to do this consistently over generations demands a continuity of agroecosystem functions.

As agricultural and environmental outcomes are pre-eminent objectives, sustainable agricultural systems cannot be defined by the acceptability of any particular technologies or practices. If a technology improves production without adverse ecological consequences, then it is likely to contribute to the system's sustainability. Sustainable agricultural systems are less vulnerable to shocks and stresses and also contribute to the delivery and maintenance of a range of valued public goods, such as clean water, carbon sequestration, flood protection, groundwater recharge and landscape amenity value.

A sustainable production system exhibits most of the following attributes:

1. Utilises crop varieties and livestock breeds with high productivity per externally derived input;
2. Avoids the unnecessary use of external inputs;
3. Harnesses agroecological processes such as nutrient cycling, biological nitrogen fixation, allelopathy, predation and parasitism;
4. Minimises the use of technologies or practices that have adverse impacts on the environment and human health;
5. Makes productive use of human capital in the form of knowledge and capacity to adapt and innovate and social capital to resolve common landscape-scale problems;
6. Quantifies and minimises the impacts of system management on externalities such as GHG emissions, clean water availability, carbon sequestration, conservation of biodiversity, and dispersal of pests, pathogens and weeds.

Productive and sustainable agricultural systems thus make the best use of crop varieties and livestock breeds through their agroecological or agronomic management. Science focuses on understanding and improving crop and animal genotypes as well as the conditions for agroecological management. It also seeks to improve the capacities of people and their institutions to deliver inputs, manage systems and distribute and use outputs.

1.6 Agriculture and sustainable economic development

Worldwide, agriculture accounts for 29% of global GDP and employs 65% of the workforce; 86% of rural people are involved in different aspects of the agricultural product and food chain (World Bank 2008). As well as being their livelihood, agriculture is for many people a key part of their society.

In the period from 1965 to 1985, poverty reduction across the world advanced further than in the previous two centuries (Lipton 2001). Agriculture provides a potential route to poverty alleviation for many people around the world, but the diversity of social, economic and environmental contexts means that what works to improve crop outputs and system sustainability in some places may not work in others (World Bank 2008).

To maintain such progress, agricultural systems in all parts of the world will have to make further improvements. Efforts to ensure access for poorer groups need to run alongside growth in aggregate food production. In many places, the challenge is to increase food production to solve immediate problems of hunger. In others, the focus will be more on adjustments which maintain food production whilst increasing the flow of environmental goods and services.

Sub-Saharan Africa has seen fewer productivity gains than the rest of the world. Here there is significant potential for productivity increases, but there are also real challenges that need to be overcome. In the case of African smallholder farmers, changes that improve upon current agricultural systems rather than importing a radically different set of practices tend to be more effective (Reij & Smaling 2008; Sanchez *et al.* 2009a). Linking biological science with local practices requires a clear understanding of farmers' own knowledge and innovations. There are past examples where science has seemingly offered 'solutions' to a problem but without success, because of a poor fit with local circumstances and a lack of local engagement with end-users at an early stage in the innovation process (Pretty 2002). In Burkina Faso, for example, researchers spent years developing systems of rainwater harvesting, but farmers did not adopt them. An NGO working closely with farmers has adapted simple soil and water conservation practices that have now led to significant improvements in food security and soil management (Hassame *et al.* 2000; Kaboré & Reij 2004). If agriculture continues to contribute to alleviating poverty, technologies for improving production need to be seen in their particular local social and economic contexts, as well as a broader context of public acceptance.

Past debates about the use of new technologies in food production systems have tended to adopt an either/or approach, emphasising the merits of particular agricultural systems or technological approaches and the down-sides of others. This has been seen most obviously with respect to genetically modified (GM) crops, the use of pesticides and the arguments for and against organic modes of production. The reality is that there is no technological panacea for the global challenge of sustainable and secure food production. There are always trade-offs and local complications. This report recognises that new crop varieties and appropriate agroecological practices are both needed to make the most of opportunities on all types of farms. We thus adopt an inclusive, both/and approach: no techniques or technologies should be ruled out before risks and benefits are assessed. Global agriculture demands a diversity of approaches that are specific to crops, localities, cultures and other circumstances. Such diversity demands that the breadth of relevant scientific enquiry is equally diverse, and that science needs to be combined with social, economic and political perspectives.

1.7 Other major studies

Our report follows a number of other reports and policy documents which have sought to describe and quantify the scale of the challenge of food security and food production from a variety of perspectives. Taken together, they provide a sense of likely future trends. The differences in analysis, emphasis and recommendations show the range of options available for tackling the general issue.

The most comprehensive recent analyses have been the World Bank's 2008 World Development Report and the International Assessment of Agricultural Knowledge, Science and Technology for Development, also published in 2008[1] (IAASTD 2008; World Bank 2008).

The 2008 World Development Report concluded that research and development are vital for global agriculture, and investment in R&D yields a high rate of return (43% per annum), yet it remains underfunded. The report describes significant gains from crop genetic improvement but it also identifies places, particularly Sub-Saharan Africa, where improved crop varieties have yet to make such an impact. The challenge of a growing population is compounded by new threats, such as pests, diseases and climate change, and this further indicates the need for constant research into new varieties and practices ('running to stand still'). Continued genetic improvement will be vital, but natural capital inputs to agriculture—including better soil and water management—will require new approaches too (World Bank 2008). The biggest gains from technology, the report concludes, come from combinations of improved crops and improved practices (the 'both/and' approach referred to above).

The IAASTD was sponsored by the Food and Agricultural Organisation (FAO), Global Environment Facility (GEF), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Educational Scientific and Cultural Organisation (UNESCO), the World Bank and World Health Organisation (WHO), and its 4-year process was overseen by stakeholders from

1 Many recent reviews point back to a single report: Rosegrant MW, Msangi S, Sulser T & Ringler C (2008). *Future scenarios for agriculture. Plausible futures to 2030 and key trends in agricultural growth*. International Food Policy Research Institute. This was a Working Paper submitted for consideration in the 2008 World Development Report. The data from this paper appears to have been rewritten as a background paper for the WDR but not re-published.

governments and NGOs. The report concluded that the dominant model of agriculture needs to change if it is to meet the needs of the developing world, and it must do so in the face of some major uncertainties:

1. Current social and economic inequities and political uncertainties linked to war and conflicts;
2. Uncertainties about the ability to sustainably produce and access sufficient food;
3. Uncertainties about the future of world food prices;
4. Changes in the economics of fossil-based energy use;
5. The emergence of new competitors for natural resources;
6. Increasing chronic diseases that are partially a consequence of poor nutrition and poor food quality as well as food safety;
7. Changing environmental conditions and the growing awareness of human responsibility for the threats to maintenance of essential global ecosystem services.

Their report uses the term ‘multifunctionality’ to describe the interconnectedness of agriculture with societies, economies and the environment. This should not be interpreted as meaning that every field or farm is required to deliver more than one ‘function’. But, over an agricultural landscape, the practices of land management for agricultural production need to take account of issues beyond just agricultural production. These externalities (both positive and negative) tend to be outside markets and they therefore demand particular attention in the context of system sustainability (see above) (IAASTD 2008).

The IAASTD considered a broad range of technological options for agriculture, and concluded that gains are likely to come from a mix of new applications of existing knowledge, introduction of new technologies and other non-scientific innovations in the development and implementation of appropriate economic and social policies (IAASTD 2008).

In the USA, the National Research Council has produced a report on *Emerging technologies to benefit farmers in Sub-Saharan Africa and South Asia*, exploring a range of technological options, across a range of sciences, with impacts both in the short and long term. Their report recognises the need to view these options in their social and economic context. It offers recommendations for priority research areas and wider policy needs (NRC 2008).

In the UK, there is a growing political awareness of the problem of global food security. In August 2009, the Department for Environment, Food and Rural Affairs (DEFRA) published a package of policy reports to outline the UK government’s role (DEFRA 2009c). Their focus is on UK food security, but there is a recognition that, as the Prime Minister put it, ‘The principal food security challenge for the UK is a global one’.[2] As decision makers at all levels begin to rediscover the need to think about food security, our report aims to inform the domestic and international debate, presenting the potential contribution of biological sciences.[3]

There is an emerging consensus from the various assessments produced over the past few years that the world will need to produce substantially higher yields of food for humans and livestock feed in the next half-century. However, there is no clear agreement on the exact increases required, as there are substantial uncertainties over actual numbers of people demanding food, their preferences and diets, the capacity to feed existing large numbers of hungry people, and the capacity of agricultural and natural systems themselves to produce more food.

These reports all express some optimism that the necessary increases in food production can be achieved, but opinions vary about the best way to address these challenges. Different assessments place different emphases on science, technology, markets, trade and social and political interventions. Most agree that the challenge of food security can only be met through a combination of measures across all relevant science and policy arenas. Those that focus on science and technology offer various options for improvement, but all agree that there is no simple ‘magic bullet’. Their shared conclusion is that the complacency about food availability over the last two decades has resulted in a steady erosion of investment in relevant scientific research and that this needs to change.

1.8 Further UK work

Following the *Food matters* report from the Cabinet Office (2008), The UK government’s Foresight group are conducting a major project on Global Food and Farming Futures, due to report in October 2010. The Foresight study has a broader remit than this study. Our hope is that this report will provide a useful evidence base of scientific challenges and possibilities on which Foresight can build. In addition, DEFRA is leading a National Ecosystem Assessment that will report in 2011, and this too will show the current and potential contribution of agricultural systems to environmental services.

1.9 About this report

Given the enormous complexity of systems for food production, and the uncertainties involved in developing innovations that will increase productivity without causing harm to important environmental services, our report

2 Government sets out 21st century challenges for food in the UK.’ News Release, 7 July 2008. Available online at: http://www.cabinetoffice.gov.uk/newsroom/news_releases/2008/080707_food_report.aspx.

3 Other recent assessments of global food security and the role of science include UNEP (2009) and Evans (2009).

cannot hope to do justice to the complete issue. Instead we offer a tight focus on the possible contributions of biological science and technology, while remaining aware of the context in which this science sits and the necessity of a multidisciplinary approach. There are countless aspects of food systems, such as aquaculture, livestock, consumption and supply chains that demand attention beyond the references we provide. Similarly, there are areas of expertise and technology, including social sciences, economics, climatology, engineering, chemistry and in particular the use of agrochemicals, that are relevant but beyond the scope of this report.

Debates about the role of science and technology in food production have proved contentious in the past. Our report looks at a variety of approaches, and considers their future opportunities as well as the risks, complexities and uncertainties presented through research and implementation. As well as providing a rigorous scientific assessment, we hope this report can help to start a constructive debate about the future of agriculture around the world and the contribution that might be offered by UK science.

This report's next chapter assesses the technical and environmental constraints of food crop production such as water shortages, incidence of disease and rising temperatures. Chapter 3 considers in more detail the possibilities provided by the biological sciences for addressing some of these challenges. Chapter 4 addresses the impacts—intended and unintended—of different technological approaches to agriculture, considering environmental, health and socioeconomic issues. The final chapter contains our conclusions and recommendations for policy makers.

Chapter 3 contains case studies of science and technology in different contexts to illustrate the complexity of agriculture and the necessity of specific solutions for specific problems. Our case studies tell stories of where, why and how science has made a difference to food production.

1.10 Conduct of the study

A working group chaired by Sir David Baulcombe FRS was established to undertake this study. The working group first met in July 2008 and had a further seven meetings. The full membership of the working group is given at the start of this report. The working group were shocked and saddened by the death of Professor Mike Gale FRS soon after the final meeting. This report has benefited hugely from his contributions and is dedicated to him.

In order to obtain views from a wide range of experts, a call for evidence was issued on 7 August 2008 with a closing date of 6 October 2008. Responses were received from a range of individual academics, research institutes, industry representatives and non-governmental organisations. Details of the organisations and individuals who submitted written evidence are listed at the end of the report, and the evidence is available on the Royal Society website (royalsociety.org).

An oral evidence session at the Society and an evidence-gathering workshop in India were held in October 2008. A workshop with UK-based non-governmental organisations was held in May 2009. Reports of these workshops are available on the Society's website. All this evidence informed the working group's discussions, conclusions and recommendations. We are grateful to everyone who responded to the call for evidence, participated in the workshops and submitted additional evidence.

2 Constraints on future food crop production

Summary

The constraints on food crop production and distribution differ between regions and, in particular, between industrialised and developing countries. In most areas the effects of climate change will further exacerbate the stresses on crop plants, potentially leading to catastrophic yield reductions. Fresh water availability is a major limiting factor on agricultural productivity. Improvements in the water use efficiency of plants in irrigated systems present a significant challenge, particularly in the face of climate change. Soils are another essential but non-renewable resource for food crop production. Maintenance of soil fertility, health and nutrient availability is vital. Significant losses in crop yields occur through pests, diseases and weed competition; they account for a major inefficiency of resource use (eg water, fertiliser, energy and labour). Reducing these losses represents one of the most accessible means of increasing food supplies. The need to reduce greenhouse gas emissions means that agriculture will have to become less reliant on sources of non-renewable energy derived from fossil fuels. Ensuring the diversity of crop germplasm to facilitate crop breeding in a changing climate is just one of several challenges that need to be met to ensure resilience of production.

This chapter describes the many constraints that limit the production of food crops globally including soil fertility, water availability and the incidence of pests, diseases and weeds. These constraints are variable with climate change and differ greatly between industrialised and developing countries, for social, economic and geographic reasons. In industrialised countries there is typically much better access to irrigation, chemicals for disease and pest control, synthetic fertilisers and quality seeds, which substantially account for their higher yields. Chapter 3 considers the specific biological science-based technologies that could help address these various challenges.

2.1 Climate change

Climate change will aggravate the effects on crops of stresses such as heat, drought, salinity and submergence in water (IPCC 2007b). This conclusion is starkly illustrated by Lobell *et al.* (2008), who have conducted an analysis of climate risks for crops in 12 food-insecure regions. The study identified adaptation priorities, based on statistical crop models and climate projections for 2030. Their analysis reinforces the importance of improved crop germplasm (based on the access to and use of crop genetic resources collections) and improved agronomic practices as a strategy for climate change adaptation in agriculture. The important conclusion of their study is that there are a few target crops that will be particularly vulnerable to climate change in different regions. Adaptation strategies focused on these crops must be carried out in the face of other constraints such as labour shortages and rising energy costs. More specific climate change-related constraints are considered in the following sections.

2.2 Water

Of all the biotic and abiotic stresses affecting crop yield, drought has probably the greatest limiting effect (Boyer 1982). A high priority for the future is to develop genotypes that yield significantly with reduced amounts of water; this is discussed further in Section 3.3.2. This should be combined with the development of cropping systems where available water can be used with much greater efficiency.

Increased variability in rainfall will lead to a greater risk of drought during cropping seasons in many regions of the world. Rising temperature will increase rates of water loss to the atmosphere from plants and soil. Predictions also suggest large increases (hundreds of millions) in the number of people who will be exposed to increased water stress (IPCC 2008) across greater areas (OECD 2006). Although total water supply may increase in some regions, precipitation will be more variable and there will be additional risks of poor water quality and flooding, as well as salt water flooding in some regions.

2.2.1 Water and yield

Plants require water for growth and tissue expansion (Steduto *et al.* 2009). However, more than 90% of the water required by terrestrial plants is not 'used' in metabolism but is lost through transpiration (T). A distinction is often made between 'water-limited' and 'wet' environments. What is usually meant by the former is that water availability 'limits' crop productivity to below the maximum or potential production when water supply is less than the demand for water set by atmospheric conditions. Yield of most crops is restricted by water availability in most environments and ensuring appropriate water availability to plants during important developmental stages is a key challenge to increasing food crop production. There is an important difference between crops that remain alive during very severe droughts but may never yield significantly (desiccation resistance) and crops that sustain yields under water scarcity (drought resistance).

The term water use efficiency (WUE) can be used on different scales: harvest, farm, field, plant and down to the leaf. It can be applied to the water lost in producing just the economic yield, or the biological yield which can be all the above-ground biomass, or (more rarely) the total biomass. It can include or exclude the evaporation from the soil and plant surfaces directly. It can also be applied across different timescales. At the crop or field scale, it can be used for time spans of days or months, or the entire crop growing season, or per year. At the leaf or plant scale, it can be applied when considering the flow of CO_2 and water vapour into and out of leaves. The highest WUEs can often be achieved when productivities are very low. Improvements therefore need to be balanced against the need to maintain yields.

2.2.2 Water use and its impacts

Agriculture currently accounts for around 70% of annual use of global water resources (FAO 2002; WRI 2005). In hot, dry regions, much larger amounts of water are needed to produce the same grain yield than in less stressed regions (Wallace & Gregory 2002).

Most of the water used in agriculture is for irrigation. Globally, irrigated areas of land are increasing, although the rate of increase appears to be slowing (Faurèsa *et al.* 2003). Although irrigated areas account for less than 20% of the world's cropped land, they produce nearly 50% of the global food (Döll & Siebert 2002). Reduction in irrigated areas or the amount of irrigation could therefore have very serious impacts on global food supply.

Significant abstraction of water for irrigation has resulted in large reductions in river flows (Ma *et al.* 2003) leading to general environmental degradation and in extreme cases to an acceleration of desertification and more 'super' dust storms. Increased agricultural activity driving increased desertification can drive climate change at an increased rate. Water levels in many major regional aquifers and ground water levels in many regions have fallen to unprecedented levels (Wu 2007). Exploitation of land and unsustainable practices, particularly in arid regions, can result in severe degradation of soils and potential desertification, initiated by loss of vegetation and soil erosion.

Using predictions of future availability of irrigation water (eg Scholze *et al.* 2006), it will be important to identify the most vulnerable people, places and sectors (climate change hotspots) but there is currently a shortage of good quality information of this kind. At a regional scale, the major problems in water supply are in regions with low rainfall and high evaporative demand, and those with expanding populations, such as North Africa, Southern Africa and the Near East (Wallace & Gregory 2002; FAO 2003). Wealthy countries that are short of water often import food from elsewhere, meaning that 'virtual water' is traded, which may be to the detriment of the environment in the source country.

The food supply chain and other crop trades exert many pressures on global water resources, with a resultant strain on the human population and ecosystems worldwide (Chapagain & Orr 2008a). The production of food, biofuel and other commodities can drive over-abstraction and pollution of groundwater and freshwater ecosystems in many water-scarce parts of the world. Decisions on the use of water for irrigated agriculture are therefore increasingly moral and ethical choices, as well as economic ones. Understanding how much water a nation (or a business) requires—its water footprint (WF)—and how this water is consumed (different crops grown in different climatic zones with different cropping, processing and transport methods) is the first step in forming views on the appropriateness of different food choices.

The agricultural WF of the UK is 74.8 Gm^3/yr or 73% of the total WF. The internal WF of UK agriculture is 28.4 Gm^3/ yr while the external component is 46.4 Gm^3/yr. A larger share of the internal WF is related to livestock production and cereal products (wheat and barley), whereas the larger share of the external WF (EWF) is related to products originating from oil crops, cotton products, livestock products and stimulants (coffee, tea and cocoa). Most of the products responsible for the EWF are not grown in the UK, mainly because of unsuitable agro-climatic conditions (Chapagain & Orr 2008b).

Reducing the use of agricultural water is an aim that requires combined agronomic, physiological, biotechnological/genetic and engineering approaches which may be collectively described as water saving agriculture. As Kofi Annan, UN Secretary General, declared, 'we need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water—more crop per drop' (UN 2000). This issue has been summarised recently by Pennisi (2008).

2.2.3 Increasing risks of flooding

Existing weather patterns leading to river and coastal flooding have a dramatic effect on crop production. Particularly sensitive areas in this context are the deltas of southeast Asia which provide much rice for local and regional consumption. The consequences of increasingly turbulent and unpredictable weather patterns, driven by climate change, have been discussed in many studies (eg Scholze *et al.* 2006). Rising sea levels leading to exacerbated coastal flooding are predicted to have dramatic effects on many countries.

2.3 Temperature

Recent reports suggest that global temperature increases are occurring more rapidly than previously predicted (Field 2009). In early February 2009, for example, southeastern Australia experienced temperatures of up to nearly 50°C. A risk of more frequent catastrophic crop failure is correlated with an increase in the frequency of extreme events (Semenov 2009).

Temperature is an important factor in controlling changes in the development of plants. An increase in temperature caused by climate change is predicted to speed plant development (Sadok *et al.* 2007). When combined with the lengthening of the cropping season, this change may increase yield. However, when assessing the effects of temperature on crop yield, it is necessary to take account of extremes, particularly if these occur during the sensitive stages of growth. Different developmental stages vary in sensitivity to temperature extremes. For instance, very significant reductions in the yield of wheat can be caused by high temperatures during and after flowering (Wardlaw & Moncur 1995). Rice is similarly sensitive to extreme daytime temperature and humidity during flowering and also suffers yield loss if night-time temperatures are high so that assimilate accumulation is reduced (Wassmann *et al.* 2009).

Climate change will cause soil temperatures as well as air temperatures to increase. This is already a problem for temperate crops grown in tropical regions. It is predicted that UK wheat yields in 2050 will be considerably reduced due to heat stress induced by climate change (Semenov 2009).

Exposure to frosts can also have a catastrophic effect on susceptible crops. Many crops of tropical origin are prone to chilling injury and their use in high latitudes is temperature limited. Fruit crops exposed to frost at the time of flowering may suffer complete yield failure. There are molecular approaches to understanding major genes affecting this response (Knox *et al.* 2008). There is a need for crops that can be autumn sown, which will survive and grow through the winter in low temperatures.

2.3.1 Indirect impacts of elevating temperatures

Elevated temperatures have various indirect effects including an increased water requirement. Combined stresses, particularly of drought and heat stress, can have particularly severe effects (Prasad *et al.* 2008). A second indirect effect of temperature is on plant defence and disease resistance (Wang *et al.* 2009c); high temperatures may extend the range of diseases (Evans *et al.* 2008). The ability of the highly invasive tasselled reed (*Phragmites australis*) to suppress other plants is also enhanced by high temperatures and its effects may be exacerbated under conditions of increased global warming (Rudrappa *et al.* 2009).

2.4 Ozone

Tropospheric O_3 concentrations are increasing at alarming rates due to energy generation, transport, agriculture, industrial processes, biomass burning and land use changes such as deforestation (eg Jaffe & Ray 2007; Royal Society 2008b). Ozone is considered to be the most damaging of all air pollutants to plants (Ashmore 2005). Most literature reports suggest that rising tropospheric O_3 pollution (itself the third-highest contributor to global warming) will suppress the global land carbon sink by reducing photosynthesis and stomatal conductance, leading to increased atmospheric CO_2 concentration and potentially also to further increased radiative forcing (Sitch *et al.* 2007). The most important direct effects of O_3 on terrestrial plants are those on leaf functioning and on leaf and root growth. Two of the most important factors determining O_3 sensitivity of crops and indeed of all plants are the control of the flux of O_3 into the leaf and the capacity of the leaf to deal with oxidative stress through detoxification and repair (Wieser & Matyssek 2007).

Current estimates of O_3-induced yield losses have been made for wheat, rice, maize and soya bean (Van Dingenen *et al.* 2008). Ozone concentrations for the year 2000 were estimated to have resulted in global crop losses of $14–26 billion, which is significantly higher than estimated losses as a result of climate change. Among all crops, soya beans and wheat are especially sensitive. The greatest yield losses for wheat were in India (28%) and China (19%). Europe suffered the greatest relative yield loss for soya beans (20–27%). Maize, across all regions, was the least affected crop. The study predicts that by 2030, ambient O_3 pollution will reduce global wheat yields in most regions by a further 2–6% on top of the reductions reported in 2000 levels. Negative effects of O_3 have also been reported on crop quality for a range of crops (eg Agrawal 2007) and on protein contents of crop yield (Piikki *et al.* 2007). There may also be a direct effect of O_3 on reproductive processes, leading to reduced seed and fruit development and abortion of developing fruits.

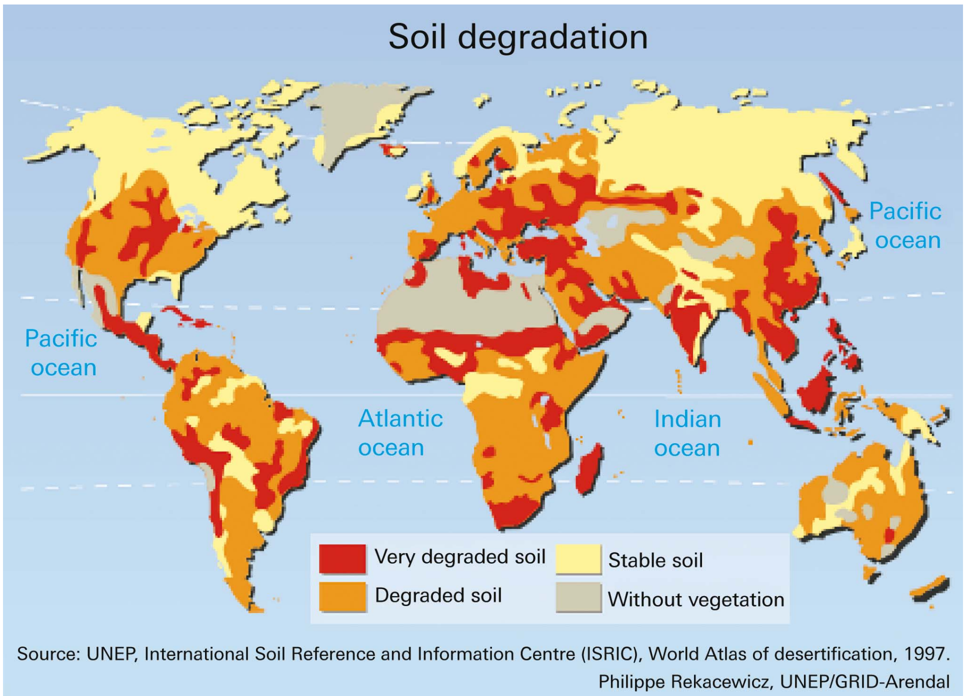
Recent reports suggest that O_3 concentrations within the range predicted for 2050 may increase transpiration and reduce drought tolerance by altering hormonal regulation of stomata and leaf growth (Mills *et al.* 2009). This may be particularly problematic for plant growth as high O_3 concentrations and hot and dry weather commonly occur together.

2.5 Soil factors

Soil is a non-renewable (at least over non-geological timescales) resource that is fundamental to sustainable crop production. Soil is subject to loss by erosion through the action of wind and water. This has serious consequences for crop productivity. Soil can also be damaged by industrial pollutants and physical compaction, and a substantial area of high quality agricultural soil is destroyed each year by rapid urbanisation in many countries. Continuing global soil degradation has been highlighted and maps have been constructed which indicate the scale, location and causes of the problem. A recent relevant initiative is GlobalSoilMap.net, a consortium that aims to make a new digital soil map of the world, predicting soil properties at fine resolution (Sanchez *et al.* 2009b). Soil degradation (see Figure 2.1) is of paramount importance and all present production and future predictions of crop yield depend upon the maintenance and improvement of soil quality. The availability of land with good quality soil for agriculture is a prerequisite for meeting production needs; as soil is lost or degraded and population increases, the area of land available to feed each human being is dangerously declining, creating a further imperative to increase yields.

Soil quality reflects the total properties of a soil and its fitness for purpose (which may differ with location and time) including fertility (crop nutrients), drainage and water-holding capacity, ease of cultivation (relating to physical structure and soil organic matter content), freedom from contaminants (biological and chemical) and biological

Figure 2.1. Global soil degradation. Source: UNEP (2009).



attributes, both beneficial and adverse. The latter relates to the population densities and identities of resident pests and diseases as well as the beneficial soil flora and fauna that sustain soil ecosystem functions (eg nitrification, aeration, nutrient cycling) and counter adverse impacts (eg denitrification or regulation of pest populations).

2.5.1 Microbiological properties of soil

The microbial diversity in a fertile soil has been compared to the biodiversity of a tropical rain forest (Beneddeti *et al.* 2005). Soil fungi and bacteria are critical for the recycling of carbon and major nutrients, particularly nitrogen, from organic inputs derived from plants and animals. Inputs of organic material in the form of crop residues and animal manures encourage the maintenance of an active microbial population, although the impact of soil use (eg for different crops) on microbial diversity is not well studied. Much soil microbial diversity is maintained in a dormant condition (spores and other resting structures) and the majority of microbial activity is associated with the zone surrounding plant roots (rhizosphere) where other impacts such as enhanced nutrient uptake (mycorrhizae) and amelioration of root diseases (biocontrol) can occur. Soil microbes also contribute to the maintenance of a friable soil structure.

2.5.2 Physical properties of soil

The physical properties of soil are determined by the underlying geology, the way it has been managed in the past and the way it is currently managed. A soil that is resistant to wind and water erosion is usually also a soil that readily allows water infiltration (ie is well drained) and has a high water-holding capacity. These characteristics are strongly correlated with adequate organic matter content resulting from animal manures and return of crop residues. Organic matter also encourages microbial activity and nutrient recycling.

A well-drained, well-aerated, friable soil that is not compacted promotes high crop productivity when water and nutrients are not limited. Good seed beds conducive to the germination, emergence and establishment of annual crops raised from seed are easier to prepare from well structured soils. In addition, the energy required for cultivation is significantly less in well structured soils. For example, it has been demonstrated that the energy savings from incorporating wheat straw into arable soils to improve soil conditioning are greater than the use of that straw as an off-take feedstock for the production of biofuels or electricity via combustion (Powlson *et al.* 2008).

In regions where soil of appropriate quality is in short supply, artificial growing media can be used. These may be solution culture, rockwool or coir in glasshouse production. Increasingly waste products may be digested to produce an inert growing substrate to which microbes and nutrients can be added. This approach can not only contribute to the production of artificial 'soils' but also result in the generation of CO_2 and energy that can be used in the production process.

2.5.3 Salinity

Of the land farmed in dry-land agriculture, about 2% is affected by secondary salinity. Of the irrigated land, 20% is salt affected (Athar & Ashraf 2009). Salinity is a soil condition characterised by a high concentration of soluble salts. Globally, more than 800 million ha of land are salt affected (6% of the world's total land area) (FAO 2006). Most of this salt-affected land has arisen from natural causes. Weathering of parental rocks releases soluble salts of various types. The other cause of accumulation is the deposition of salts carried in wind and rain. A significant amount of agricultural land has become saline as a result of irrigation or from bringing new land into cultivation, both of which cause water tables to rise and concentrate the salts in the root zone.

Plants differ greatly in their tolerance of salinity, as reflected in their different growth responses (Munns & Tester 2008). Of the major cereals, rice is the most sensitive and barley the most tolerant.

2.5.4 Toxicity

Aluminium (Al) is the third most abundant element in the Earth's crust. At low pH values (pH < 5.5), the toxic species of aluminium, Al^{3+}, is solubilised from aluminosilicate clay minerals into soil solutions and is toxic to crop plants (Kochian *et al.* 2004). Al toxicity mainly targets the root apex, resulting in inhibited root growth and function. As a result, Al toxicity leads to severe impairment in the acquisition of water and nutrients from the soil, which results in a significant reduction in crop yields on acid soils. As up to 50% of the world's potentially arable soils are acidic, with a significant proportion of these acid soils found in the tropics and sub-tropics in developing countries where food security is most at risk, Al stress represents one of the most important constraints for agricultural production worldwide (Kochian *et al.* 2004).

2.6 Crop nutrition

2.6.1 Major crop nutrients

The availability of nitrogen (nitrate or ammonium), phosphorus (phosphate) and potassium are crucial determinants of global sustainable crop yields. There is widespread nitrogen and phosphate deficiency in crop production which means that the potential yield of crop genotypes is not reached. This deficiency is particularly acute in the developing world where nutrient inputs are completely inadequate because they are unaffordable or unavailable.

Potassium is also a major crop nutrient and an appropriate balance between nitrogen and potassium is essential, since inadequate levels of available potassium reduce the capacity of the plant to exploit nitrogen. To ensure yield benefits from applied nitrogen a sufficiency of potassium is essential. Elevating available potassium will not influence yield when crops are grown at low nitrogen levels.

The discovery of a process for the synthesis of ammonia (the Haber–Bosch process) in 1908 heralded the start of 'industrial' agriculture. Global food security now depends completely on the chemical synthesis of nitrogen fertilisers and the mining of rock phosphate which is a non-renewable resource. Over 50% of the nitrogen in the global nitrogen cycle was synthesised industrially in the last 100 years (Smil 2000a, 2001). The Haber–Bosch process is energy demanding and currently uses hydrogen from natural gas. It would be highly desirable to find alternative sources of hydrogen, such as electrolysis powered by electricity generated from renewable sources. It is projected that synthetic nitrogen fixation will demand 2% of total global energy utilisation by 2050 (Glendining *et al.* 2009).

Provided there are no other constraints (such as insufficient water) there is a linear relationship between biomass accumulation and available soil nitrogen, up to an optimum. Optimum nitrogen nutrition is a key to obtaining the full genetic potential from improved or elite cultivars.

Nitrogen fertiliser application increases the economic and energy costs of agriculture, and also promotes release of nitrogen oxides that are themselves greenhouse gases. Nitrogen fertiliser use in crop production currently represents the dominant component of fossil fuel exploitation by agriculture (at least 40% for an intensively managed wheat crop where emissions are approximately 400 kg CO_2 per ha) (Glendining *et al.* 2009). Processes of denitrification also mean that nitrogen fertiliser use inevitably increases the emissions of NO_X (potent greenhouse gases) from agriculture (Harrison *et al.* 1995). The factors that influence NO_X emissions from soil are not well understood and require more research (Milne *et al.* 2005). Agricultural cropping and animal production systems are also important sources of atmospheric N_2O, a major greenhouse gas. Agricultural systems have been estimated to produce about a quarter of global N_2O emissions (Mosier *et al.* 1998). Consequently it would be highly desirable to achieve the same yield increment with less added synthetic nitrogen.

Biological nitrogen fixation (primarily by *Rhizobium* species) and recycling through green manures, composts and animal manure represent important ways in which reliance on synthetic nitrogen might be reduced and nitrogen losses to water and non-agricultural ecosystems minimised. However, the off-take of nitrogen in crops for human consumption, limited recycling of human waste to agriculture and leaching to water mean that substantial inputs of nitrogen derived from chemically synthesised ammonia or urea are essential to the maintenance of current yields.

In many soils, applied inorganic phosphate rapidly becomes inaccessible to plants due to its adsorption to soil mineral particles and occlusion in association with iron or aluminium oxides. In situations where available phosphate levels are low, mycorrhizal associations are critically important and phosphate deficiency is the primary constraint on yield.

It is possible to recycle phosphorus (super phosphate fertiliser, produced by treating animal bones with sulphuric acid was the first synthetic fertiliser), particularly from animal sources. However, loss to water and adsorption in soil mean that the supply of phosphorus in agricultural systems needs to be continuously replenished; mined rock phosphate represents the only substantial supply. The primary rock phosphate reserves in North America, North and South Africa, Russia and southeast Asia are likely to be exhausted before the end of the 21st century if trends continue (Smil 2000b; Zapata & Roy 2004).

2.6.2 Secondary, micro and functional crop nutrients

In different crops and cropping systems as well as different regions, yield and quality can be constrained by the availability in soil of nutrients that are required by crops in small concentrations. Deficiencies of sulphur (S), calcium (Ca) and magnesium (Mg) which are classed as secondary nutrients cause significant yield reductions in some crops and regions.

There are six micronutrients essential for plant growth: boron (B); copper (Cu); Iron (Fe); manganese (Mn); molybdenum (Mo) and Zinc (Zn). Micronutrient deficiency can usually be rectified when diagnosed and the significance of elevating the levels of some of these elements (eg Fe) in crops relates to their importance in human nutrition as much as crop nutrition.

There are five elements considered to be functional in plants but not essential: sodium (Na); vanadium (V); cobalt (Co); silicon (Si) and chlorine (Cl). Of these, Si has relevance in the context of crop production as a competitor for arsenic (As) uptake (Ma *et al.* 2008). Arsenic may accumulate at dangerous levels in the diets of those who depend on rice grown in soil and water containing high As concentrations and low Si.

2.7 Pests, diseases and weed competition

Pests, diseases and weeds have a significant impact on the sustainability of food crop production. Disease-induced losses essentially represent wasted inputs of energy, water, nutrients and labour. Worldwide crop losses due to weeds, pests and diseases have been estimated for eight major crops (wheat, barley, rice, maize, soy, cotton, sugar beet and potato) as 26–40%. In the absence of control measures such as resistant varieties, crop protection chemicals and crop rotations, losses would be 50–80% (Oerke & Dehne 2004).

2.7.1 Pests

Pests can cause significant losses of food production, and there are chemical and non-chemical approaches to minimising these losses (Yudelman *et al*. 1998). Table 2.1 lists the major pests of maize, rice and wheat.

Locusts, larvae of Lepidoptera, and other herbivorous chewing insects can cause very substantial crop losses as can root-attacking nematodes and sucking insects such as aphids and leaf-hoppers; the latter are also important vectors of diseases caused by viruses and phytoplasma. Corn borer and corn rootworm cause much damage; rootworm also affects nitrogen and WUE by damaging the root system. Damage to cobs by corn borers facilitates the entry of fungi such as *Fusarium* and *Aspergillus* species that contaminate the seed with poisonous mycotoxins.

Many crops, especially fruit and vegetables, are prone to rot after harvest and before or during transport to consumers. Seeds from cereal and legumes are prone to losses from bruchid beetles, grain and meal moths. Temperature and humidity control can reduce, though not eliminate, these losses.

Arthropods and nematodes can also act as disease vectors. Aphids and leaf hoppers, for example, can act as vectors of viruses and phytoplasmas. Many different genera of nematodes cause plant disease, usually by infecting and colonising roots. Feeding occurs through a hollow stylet that can penetrate plant cell walls. Most are endoparasites, invading root tissues and carrying out most of their feeding from inside the root. Two genera of endoparasitic nematodes are the source of much crop damage in wheat, potato, soya beans and many other crops. These are the cyst nematodes (*Heterodera* sp. and *Globodera* sp.) and root knot nematodes (*Meloidogyne* sp.). Nematodes are particularly difficult to control with pesticides. Soil fumigation with methyl bromide has been widely used until recently, but the use of this toxic chemical is now severely restricted although there are few alternatives.

Vertebrate pests are also a significant problem. Rodents and other large herbivores can inflict significant losses on crops during their growth and development as well as post harvest. In industrialised countries, these losses are usually adequately controlled by regulating the populations of rats, rabbits or deer using poisons, gassing or shooting. In developing countries, recourse to such methods of control is more limited and losses can be considerable in field as well as plantation crops (Sridhara 2006).

2.7.2 Diseases

Diseases have an impact on loss of crops, pre and post harvest. There is a cost associated with their control through crop-protective chemistry and resistant varieties. Significant losses are caused to crop yields from a variety of fungi and oomycetes (microscopic fungus-like organisms), bacteria and viruses across a range of crops. Some examples are summarised in Table 2.2.

2.7.3 Weed competition

Among biotic constraints on crop protection, weeds have the highest loss potential (32%), followed by pests and pathogens (18 and 15% respectively) (Oerke & Dehne 2004). Losses due to weed competition represent a

Table 2.1. Major pests of maize, rice and wheat.

Crop	Pests
Maize	Armyworms—common, fall, true (*Pseudaletia unipuncta, Spodoptera frugiperda, Pseudaletia unipunct*)
	Borers—Europeran corn, lesser cornstalk, potato stem, stalk (*Ostrinia nubilalis, Elasmopalpus lignosellus, Hydraecia micacea*, *Papaipema nebris*)
	Corn delphacid (*Peregrinus maidis*)
	Corn earworm (*Helicoverpa zea*)
	Corn flea beetle (*Chaetocnema pulicaria*)
	Corn leaf aphid (*Rhopalosiphum maidis*)
	Corn silkfly (*Euxesta stigmatis*)
	Cutworms—black, western bean (*Agrotis ipsilon, Striacosta albicosta*)
	Rootworm—corn, western corn (*Diabrotica virgifera, Diabrotica barberi*)
Rice	Rice gall midge (*Orselia oryzae*)
	Rice bug (*Leptocorisa oratorius*, *L. chinensis*, *L. Acuta*)
	Hispa (*Dicladispa armigera*)
	Rice leaffolder (*Cnaphalocrocis medinalis*, *Marasmia patnalis*, *M. Exigua*)
	Stemborer (*Chilo suppressalis, Scirpophaga incertulas*)
	Rats (various species)
	Rice weevils (*Sitophilus oryzae*)
Wheat	Aphids (various species)
	Armyworms, cutworms, stalk borers and wireworms (various species)
	Cereal leaf beetle (*Oulema melanopa*)
	Flies—hessian, sawfly (*Mayetiola destructor, Cephus cinctus*)
	Mites (various species)
	Nematodes— cereal cyst, seed gall, root knot (*Heterodera avenae, Anguina tritici, Meloidogyne* spp.)
	Slugs, snails, grasshoppers, and crickets (various species)
	Stink bugs (various species)
	Thrips (various species)
	Wheat stem maggot (*Meromyze Americana*)
	White grubs (various species)

significant waste of resources (water and nutrients) that would otherwise be available to the crop. Weeds essentially represent unwanted production of a biomass that can also impede efficient harvesting. There is an increasing problem of resistance to herbicides and the establishment of populations of some weed species which are no longer readily controlled. The outstanding success of the development of herbicide-resistant crops that enables the use of a broad-spectrum herbicide such as glyphosate has been a major advance in the reliability of weed control in maize and soya bean, although reports of weeds with glyphosate resistance are also increasing. The need for variety of herbicides with a range of modes of action to be available is an essential component of effective weed management. The effects of weed competition have been extensively discussed elsewhere (for example, see Zimdahl 2004).

Weeds can cause severe losses in wheat, with dwarf varieties particularly vulnerable. Similarly in maize, weeds are a major problem for seedlings. One of the major challenges to cereal production in Sub-Saharan Africa is the widespread occurrence of parasitic weeds. Probably the most important is *Striga*, which infests an estimated 20–40 million ha of farmland cultivated by poor farmers throughout this region. The tiny seeds are carried in run-off eroded soil and contaminate traded seed to infest an ever-increasing area. In Kenya, an estimated 75,000 ha of land is infested with *Striga* (80% of farmland in Western Kenya). Every year *Striga* damage to crops accounts for an estimated US$7 billion in yield loss (about 4 million tons) in Sub-Saharan Africa, and affects the welfare and livelihood of over 100 million people (Scholes & Press 2008).

2.8 Energy and greenhouse gas emissions

Production in many developing countries is constrained by energy inputs. Animals or human labour are often used for soil cultivation; to provide the energy required to do

Table 2.2. Examples of diseases affecting a selection of crops.

Crop	Pathogen, disease, bacteria or virus	Effect
Apples and pears	Fireblight disease *(Erwina amylovora*)	Destructive bacterial disease that kills blossoms, shoots, limbs and sometimes entire trees.
Banana	Black Sigatoka disease (*Mycosphaerella fijiensis*)	Necessitates weekly sprays with fungicides in major banana producing areas. Since the major worldwide commercial cultivar (Cavendish) is susceptible, there is concern that security of supply may be undermined.
	Panama disease (Fusarium)	As the disease progresses, younger and younger leaves collapse until the entire canopy consists of dead or dying leaves.
	Xanthomonas wilt (*Xanthomonas campestris*)	Pathogen enters the vascular system of the plant, destroying the fruit bunches and eventually killing the entire plant.
Barley	Powdery mildew (*Blumeria graminis*)	Fast evolving and severe constraint on barley production necessitating regular fungicide applications in northern Europe.
Beans	Bacterial blight (several species)	Losses occur from death of plants, partial loss of leaves, and pod-spotting quality factors.
Brassicas	Black-rot (*Xanthomonas campestris*)	Seed-borne vascular disease that can cause affected leaves to drop prematurely and distortion of leaves, dwarfing and plant death.
Cassava	Cassava mosaic virus (*Geminiviridae* family)	Plant pathogenic virus that may cause either a mosaic appearance to plant leaves, or chlorosis, a loss of chlorophyll.
Citrus fruit	Citrus canker (*Xanthomonas axonopodis*)	Infection causes lesions on the leaves, stems and fruit of citrus trees, including lime, oranges and grapefruit. A fruit infected with canker is safe to eat but too unsightly to be sold.
Potato	Potato late blight (*Phytophthora infestans*)	Causes devastating losses necessitating widespread fungicide applications.
	Bacterial wilt (*Ralstonia solanacearum*)	Very destructive, especially during hot and wet seasons. Plants wilt and die suddenly.
Rice	Many fungal diseases (particularly *Magnaporthe grisea*)	Despite intensive breeding for resistance, losses are still considerable in Africa and Asia.
Soya bean	Soya bean rust (*Phakopsora pakirhizi*)	Causes a major reduction in yields in Brazil.
Tomato	Bacterial speck disease (*Pseudomonas syringae*)	Cool, moist environmental conditions contribute to the development of the disease, which has now established itself as a major production problem in northern USA.
Wheat	Ug99: a race of stem rust caused by *Puccinia graminis* (see Case study 3.5)	Overcomes previously effective disease resistance genes; currently affecting yields in Africa.

work, they need food. In developing countries, where mechanisation may be limited, the energy inputs required to grow food (from human and animal labour) represent a significant part of the constraint on production. In the UK, agriculture uses about 1.5% of UK total energy and accounts for 0.8% of total carbon emissions (Warwick HRI 2007).

In addition to CO_2, the other significant greenhouse gas associated with crop production is N_2O, as discussed in Section 2.6.1. Agriculture accounts for the majority of the N_2O emissions in the UK (DEFRA 2009a).

2.9 Maintenance of genetic resources and germplasm availability

Genetic variation in crops and their relatives is vital for agricultural development. Many modern varieties have incorporated traits, for example disease resistance, that were transferred by conventional breeding using different varieties, landraces and relatives. However, genetic uniformity and a narrowing genetic base may lead to decreased resilience in the face of environmental stress (as discussed further in Chapter 4) and the potential for continued novelty and improvements in the future depends to a great extent on the availability of diverse genetic resources.

Yet crop genetic diversity has declined steeply in recent decades. In India, for example, 30,000 rice varieties were once grown, yet now most acreage is under a few higher yielding varieties. The preservation of genetic diversity in genebanks is essential if crop genetic improvement is to continue. Preservation of resources for the major crops is expensive. One estimate for the crops of the CGIAR Institutes is that an endowment of several hundred million dollars would be required to maintain the existing genebanks in perpetuity (Koo *et al.* 2003). A recent example of institutional innovation is the Global Crop Diversity Trust's new seed bank in Svalbard.[4] It is clear that efforts to ensure germplasm conservation must remain a priority for all crops and all environments.

The constraints that limit the production of food crops globally include soil fertility, water availability, pests, diseases and weeds. The nature of these constraints varies at a regional level and they will be affected by climate change over the next 30 years. The following chapter describes a range of biological science-based technologies that should help address these various challenges.

4 See http://www.croptrust.org/main.

3 Developments in biological science with potential benefits for food crop production

Summary
Over the next 40 years, biological science-based technologies and approaches have the potential to improve food crop production in a sustainable way. Some of these technologies build on existing knowledge and technologies, while others are completely radical approaches which will require a great deal of further research. Genetic improvements to crops can occur through breeding or GM to introduce a range of desirable traits. Improvements to crop management and agricultural practice can also address the constraints identified in the previous chapter. There are potential synergies between genetic and agroecological approaches. Different approaches will be needed for different regions and circumstances. There is a need to balance investment in radical new approaches that may have major consequences on productivity with investment in approaches which deliver modest improvements on a shorter timescale.

3.1 Introduction

Major historical advances in crop production processes (such as plant breeding, fertilisers and crop protection chemicals) have resulted in substantial increases in the production of food crops. So far, the increases in production have effectively kept pace with the increase in net global population but, as described in Chapters 1 and 2, the future challenge to feed an increased global population is unlikely to be met by existing technology. In this chapter we describe recent developments in biological science that could be translated into new technologies to help meet this challenge through the genetic improvement of crops and changes in crop management.

The science underpinning food crop production—as in all areas of biology—is being revolutionised by several new technological developments, including those in imaging and various types of biochemical analysis. These methods are now very sensitive and they can be applied in a high throughput mode so that many plants—sometimes many thousands of plants—can be analysed in a single experiment. Imaging tools enable whole plants to be analysed, living subcellular structures to be viewed and the chemical constituents of cells to be characterised in detail. The most powerful and informative new methods available in research are based on the ability to determine genome sequences relatively quickly and cheaply.

Additional power is added to these technologies through the widespread use of computing technologies to handle large datasets. The biological processes relevant to productivity of food crops can now be dissected more completely and there is an unprecedented opportunity to translate this research into the genetic improvement of crops or changes in crop management.

To illustrate the potential for a revolution in crop science we first describe the new research tools. It should be stressed that, although many of these tools are concerned with genetic and genomic analysis of food crops, the output of the research is not necessarily in genetic improvement. The identification of a gene or set of genes associated with improved performance of a crop could be used just as easily to elucidate a novel crop management strategy.

The final section of this chapter describes ways in which the output of the research tools can be translated into technology for improved food crop production. Throughout the chapter we have indicated (where possible) whether such applications are expected in the short (up to 5 years), medium (5–15 years) or long (greater than 15 years) term. However, it is difficult to predict the exact pace of development and breadth of use of new technologies as these will depend on factors such as social issues, economic markets and research infrastructure that are discussed in Chapter 4.

3.2 Tools for research and technology

The research tools described in this section are either for genetic (Section 3.2.1) or phenotypic analysis (Section 3.2.2) of plants. The genetic analysis targets their DNA whereas the phenotypic investigations involve their biochemical, physiological or morphological characteristics. Most of the research tools described here provide information that is then used to develop new varieties or crop management practices. However, there are some instances, for example with genetic modification (GM), when the research tools can also be used in applied technology.

3.2.1 Genetic analysis

3.2.1.1 Genome sequencing

Complete genome sequences of crop plants and microbes are particularly important because they provide detail about all of an organism's genes and the proteins that the organism can synthesise. When linked with new methodologies for assigning function to genes and high throughput technologies for analysis of RNA, proteins and small molecule metabolites (Section 3.2.2.2), the analysis of genome sequences is referred to as genomics and it provides a powerful framework for the dissection of complex biological processes in detail.

Genes or combinations of genes affecting crop production can be easily identified using genomics. In genetic improvement strategies these genes can be targeted in breeding programmes or they can be transferred into crops by GM as described in more detail below. However, it should be stressed that the information from genomic studies is also important for the science that underpins changes in crop management. The information about genes, proteins and metabolites in crop plants allows strategies for crop management to be developed that maximise agronomic performance of crops in a sustainable way.

New methodologies for determining DNA sequences are orders of magnitude more efficient than the methods used for the first generation of genome sequences from model organisms and man. There are several versions of these new methods and it is likely that others will emerge in the near future. Sequencing a genome is currently being transformed from a multimillion pound project into one costing less than one million pounds for a completely new genome and a few thousand pounds for an individual of a species for which a full genome is already available. Generating the DNA sequence data is now straightforward and cheap: the computational analysis and annotation of the sequence is the most expensive and time-consuming part of a genome project.

Genome sequencing methods were first applied to the model plant species *Arabidopsis* and we now have complete genome sequence data of *Arabidopsis thaliana*, rice, maize, sorghum, soya bean, poplar, grapevine and papaya. With the introduction of the new sequencing technology it is likely that ongoing genome projects for wheat, potato, tomato, sunflower, apple, pear, peach, strawberry and other crops can be accelerated.[5] Other crop genome sequences could be completed in relatively short times and it will be possible to generate data from several varieties of previously sequenced crops.

3.2.1.2 Marker technology

Plant breeding is a well established method for improving the performance of crop plants by making defined crosses between genetically distinct parents, screening progeny for desired trait combinations and selecting preferred individuals with better combinations of characteristics that can then be bulked and developed into lines and varieties. The procedures for screening progeny for desired traits are often the most challenging stages in conventional plant breeding because many plant lines have to be tested for phenotypes that may be difficult to assay. Disease resistance, for example, can normally be identified only after extensive testing of multiple plants in each line for susceptibility. Similarly, yield enhancements cannot be identified by collecting the products from a single plant; the products from several plants need to be combined and measured accurately in replicated tests. The advances described below allow these screening procedures to be streamlined.

5 See http://www.Phytozome.net.

Breeders and geneticists can often show that defined traits are conferred by specific genes, or are associated with quantitative trait loci (QTL)—stretches of DNA strongly associated with the gene for a particular trait. These traits are often difficult to measure, requiring laborious and incompletely reliable assessment methods. It therefore makes breeding easier if instead of measuring the trait, a molecular DNA genetic marker linked to the QTL can be monitored in progeny. This method is cheaper and more reliable. In addition, undesirable traits are often genetically linked to desired traits. This is known as linkage drag. DNA markers help identify rare plants in a breeding program in which the desired trait is retained but deleterious traits are left behind. This is referred to as marker-assisted selection (MAS). DNA marker technology has evolved through several stages. In its most advanced form, it is based on a genome sequence and generates dense genetic maps in which the markers are very close to, or may actually represent, the gene of interest. More complex applications of MAS involve selection for traits affected by multiple genetic loci.

An example of the application of MAS is in the development of submergence-tolerant rice. In rice, the major genetic determinants of flooding tolerance have been identified and, using this information, MAS has been employed to develop flooding tolerant varieties (Hattori *et al.* 2009; Singh *et al.* 2009; Voesenek & Bailey-Serres 2009). Many other examples of MAS suggest that this approach will be increasingly important in breeding as genome sequence data become available for more crop plants.

3.2.1.3 Genetic modification

Traditional and marker-assisted plant breeding involve the introduction of novel traits into crops by crossing as described above. The crosses might involve different genotypes of the crop or they might involve the crop and a related species (interspecific crosses). Progeny of the crosses are selected for traits of interest using DNA markers. Traditional plant breeding is slow, taking 10 years or more for a breeding cycle. Furthermore, breeding of some crops which are not propagated by seed, such as potato and banana, is extremely difficult. In molecular GM, novel genes are introduced, either individually or in small groups, into a crop plant. The genes inserted may either be from the same species (this is known as cisgenics) or from another species (transgenics). These methods circumvent the crossing cycle associated with conventional genetic improvement and in cisgenic approaches they allow transfer of genes within a species but without the complication of linkage drag.

GM-based methods are used widely as a routine tool in research and they have greatly facilitated major advances in plant biology over the last 25 years. They are particularly important in the ongoing task of assigning function to each of the 10,000 to 20,000 genes which have been identified in each species and in elucidating the cellular mechanisms in plant biology. The application of GM techniques in crop plants, however, has been controversial. In the USA, Argentina, Brazil, India and Canada, GM crops are grown widely (125 million ha in 2008), whereas in Europe and Africa (except South Africa) they are largely absent (ISAAA 2008).

The first generation of GM technologies, including those that are the basis of commercial applications, involve the insertion of novel genes into the recipient genome and selection for best performance (see Case study 3.1). Since plant genomes are predominantly non-coding DNA the insertion site does not normally disrupt essential genes. However, a novel approach to GM involves the use of engineered zinc finger proteins that can be targeted at specific sequence motifs in the genome to disrupt specific genes or to introduce mutational changes at defined sites adjacent to the zinc finger target site (Shukla *et al.* 2009; Townsend *et al.* 2009). This is an exciting new development because the modifications are introduced so precisely. Published examples of this technology involve maize and the outputs could be developed as products in the 5–10 year period. In principle the method could be transferred into other crop species within 5 years. New genotypes and lines could be developed within 10 years.

GM should not be viewed as a single technology—potential benefits and complications vary depending on the nature of the gene being transferred and the plant into which it is transferred. In this chapter we consider the potential benefits of GM in crop plant improvement alongside innovations in conventional breeding and crop management. Chapter 4 addresses the potential complications of GM alongside those of other innovations in crop technology.

Case study 3.1. Genetic modification of maize for insect resistance

Bt toxin and the corn borer

The caterpillars of the European corn borer moth can cause significant yield losses to maize by damaging the ears and stalk of the plants. *Bacillus thuringiensis* (*Bt*) is a bacterium which produces hundreds of 'crystal' proteins toxic to a range of insect pests, including corn borer caterpillars. *Bt* bacterial preparations rich in crystal protein have been used as an insecticide for some crops since the 1930s.

Development of transgenic maize

A transgenic (GM) maize resistant to the corn borer was created by inserting a single gene for a *Bt* crystal protein into the maize genome. This causes the maize plants to produce the protein, which is ingested by pests when they eat the plant. Transgenic *Bt* crops express a very high level of toxin, making this a highly effective approach. Because damage caused by insect feeding allows entry of mycotoxin-producing fungi, a secondary benefit is that *Bt* maize also has lower levels of fungal mycotoxins in the grain than non-*Bt* maize, thus enhancing its safety as food or feed (Munkvold & Hellmich 2000; Wu 2007). To date, this type of *Bt* maize is the only GM crop approved for commercial cultivation in Europe (first approved in 1998) (Brookes 2008; GMO Compass 2008). In the US, many GM maize lines on the market also make a different *Bt* protein targeted against corn rootworm.

Constant exposure of insect pests to the *Bt* toxin creates an evolutionary pressure for the development of resistance. However, the use of non-*Bt* crop refuges allows sufficient numbers of the *Bt*-susceptible pests to survive to lessen this evolutionary pressure.

Recent developments

Most *Bt* maize grown commercially now has more than one *Bt* gene, giving resistance to a variety of pests. The latest version for release in 2010 has six *Bt* genes (Dow AgroSciences 2009). This maize variety also allows a reduction in the size of the non-*Bt* refuge needed to avoid resistance in target pests.

Bt cotton varieties are grown widely throughout the world and additionally *Bt* genes are being introduced into many other crops, including vegetables, as a means of providing resistance to insect pests.

Non-target organisms

As the toxin is contained within the plant rather than sprayed on the field, it only acts directly against insects that feed on the plant. Some laboratory tests seemed to indicate that the pollen of *Bt* maize presents a threat to monarch butterflies. However, further studies showed that *Bt* maize pollen did not in fact pose a threat as the density of pollen on the milkweed leaves on which monarch caterpillars feed is much lower than that which would cause harm. This is because there is only a short time during which the caterpillars might be exposed to *Bt* pollen and only a portion of caterpillars feed on milkweed in close proximity to *Bt* maize fields (Sears *et al.* 2001; Wolfenbarger *et al.* 2008). Control of insect pests with insecticides poses a greater risk of damage to non-target organisms than control with transgenic *Bt* protein.

There have been some reports of other insects becoming pests in *Bt* cotton areas in China, and it is possible that this could also happen for *Bt* maize (Wang *et al.* 2008). However, the increase in insecticide use for the control of secondary insects in cotton is far smaller than the reduction in total insecticide use due to *Bt* cotton adoption (Wang *et al.* 2009d).

3.2.2 Phenotype analysis

Marker-assisted plant breeding places the emphasis on DNA screening rather than on detailed analysis of the plant phenotype. However, the breeding cycle is further enhanced whenever plant phenotypes can be analysed with higher resolution and greater precision than previously. In this section we describe various developments in phenotype analysis that can be combined with MAS to enhance the identification of crop plants with agronomically useful genes or combinations of genes.

3.2.2.1 Phenotyping platforms

It is now possible to screen many different plant genotypes quickly and simultaneously for the traits expressed (phenotype) using 'phenotyping platforms' (Finkel 2009) . These systems involve the use of precisely defined environmental conditions and sophisticated imaging and other recording methods to monitor the growth and development of crop plants (Xie *et al.* 2006; Rajendran *et al.* 2009). When combined with high-resolution genetic maps or with mutant collections in which a high proportion of genes in a genome are disrupted, these platforms are a very effective way of revealing sets of genes that influence agronomically significant phenotypes. Trait data can often be obtained automatically. For instance, root platforms now allow dynamic characterisation of root system architecture and sites of root water uptake in hundreds of plants using non-invasive systems built on computer tomography (de Dorlodot *et al.* 2007). Other systems make it possible to introduce drought stress and measure biomass, transpiration, leaf growth and architecture, root growth and architecture and soil water uptake in many plants in a single experiment.

These phenotyping platforms are sophisticated, resource-intensive facilities and they are not appropriate for local breeding institutions. However, they are an essential component of the research infrastructure in leading national and international research centres where they are required for full exploitation of high-resolution genetic maps and genome sequence data.

3.2.2.2 High throughput analysis of small molecules

Plants make an enormous diversity of small molecules, which include mediators of communication between plants, between microbes and between plants and microbes. High throughput analysis (a technique which allows the fast analysis of a large number of molecules in parallel) based on mass spectrometry now allows these small molecule populations to be better described (Schauer & Fernie 2006). In some instances functions can be assigned to these small molecules by combining mass spectrometry output with expression profiling and phenotype analysis. These high throughput approaches have revolutionised our ability to analyze the natural chemicals in plants and other organisms: it is no longer necessary to devise separate assay methods for each type of chemical because in a single sample it is now possible to identify thousands of compounds.

Application of these methods now allows a chemical profile of individual plants in the progeny of breeding crosses or following particular crop management strategies. Individual compounds or sets of compounds can then be used as indicators of useful traits in the way that DNA markers are used as described in Section 3.2.1.1. In large-scale breeding programmes and trials of new crop management practice it may be easier and more efficient to assay the compounds rather than the traits when there are many plant lines or crop treatments under investigation. In effect this would be a 'metabolic marker' approach that could be used together with, or instead of, DNA markers.

Recent work illustrates the potential of this approach: a set of metabolites was identified that is associated with plant acclimation to cold (Guy *et al.* 2008). This work was carried out in the model species *Arabidopsis* but similar analyses could be repeated in crops and applied to a variety of traits. These assays would provide metabolic markers, for example, of crucial stress-sensitive stages of development of our major crops, eg grain abortion and early seed growth under drought or other crucial traits. The development of these methods is not as well advanced as DNA MAS but they are likely to be an important complementary approach over the next five years.

In the longer term new technologies for chemical characterisation also link to the development of novel crop protection chemicals. Many of the existing crop protection chemicals are based on natural compounds found in plants. Some herbicides are plant hormone derivatives and compounds to protect from disease may be based on chemicals in plants involved in signalling during disease resistance. With the availability of high throughput methods to characterise the chemical composition of crop plants there is a long-term opportunity to identify novel compounds that can be applied to crop plants sustainably.

3.2.2.3 Isotopic analysis for drought resistance or high water use efficiency

In 1982 Farquhar and co-workers developed a method for assessing water use efficiency of crops using the ratio of the abundance of the natural isotopes of carbon, ^{13}C and ^{12}C (Farquhar *et al.* 1994). During diffusion and biochemical fixation of CO_2, the ratio $^{13}C/^{12}C$ is different from the normal abundance in the atmosphere. The ratio depends on the balance between diffusion into the leaf and demand, so a measure of the ratio gives a measure of water use efficiency. The approach has now been used to investigate water use efficiency in many crops. In C3 plants, the technique has led directly to the selection of improved crop varieties, most notably Q15 in wheat (Condon *et al.* 2004). However, it is not suitable for screening C4 plants such as maize.

3.2.2.4 Modelling

Progress in breeding for high and stable yields in crop plants under many kinds of environmental stress would be greatly speeded up if it were possible to predict the consequences for the phenotype of a plant of changing the genotype. There are many reports of traits selected for their impact on drought responses of plants. However, for many reasons, prediction of the impact of these on yields is not straightforward. It is now well established that any trait can confer a positive, negative or neutral effect depending on the environment under which the plant is growing. Even in the most successful field analyses, a given allele of a gene usually results in a positive effect in only half of the environments in which it is tested. Developing a capacity to allow prediction from genotype to phenotype is complicated by interactions between genetic controls (of functioning, growth and development) and the environment. Plant modelling can help us navigate a path through this complexity. Combining field studies and genetic analyses using modelling allows prediction of different effects of an allele at different sites (Hammer *et al.* 2006). The analysis provides some estimate of the frequency with which this allele will have positive effects over years at a given site. This scenario-testing allows informed decisions to be made on variety development for different climatic regions and will help capture the interactions between genotype and environmental factors. Within this framework, physiological simulation will show how different traits interact. Genetic simulation allows some control of sources of error and helps determine what level of 'knowledge' is required to enable faster advances than existing breeding methods.

There is great potential for further research into the modelling of water use in different plant genotypes and the use of remote sensing and biosensors to optimise the use of irrigation water. Computer modelling is likely to have applications in both the long and the short term. In the short term, for example, it can be a useful research avenue because it allows irrigation regimes to be optimised depending on the genotype of plant and other environmental parameters including soil type and sunlight. In the longer term, modelling and supercomputing could be used as part of genetic improvement strategies, using both GM and conventional breeding, to design the optimal plant for a high CO_2 world (Zhu *et al.* 2007).

3.3 Applications of research

In the following sections we describe how research tools could be used to develop new technologies in food crop production in order to address the constraints identified in Chapter 2. We have considered abiotic stress, biotic stress, soils, mineral nutrition of crops and nutritional quality of crop products as separate topics. However, in many instances, a new technology will address multiple topics. These topics include reference to both genetic and crop management strategies. First, we consider possible genetic improvements to enhance yield potential.

3.3.1 Genetic yield potential

F1 hybrid crops (first generation offspring of different parents) often exhibit greater vigour than either parent. This phenomenon—hybrid vigour or heterosis—is not well understood but its existence points to additional unrealised yield potential in plant genomes up to 50% greater than that of inbred crops (Duvick 1997; Lippman & Zamir 2007) (see Case study 3.2). F2 or later generation hybrids may also exhibit transgressive segregation—traits that are beyond the range of the parents. In the F2 or later progeny of a cross between tomato relatives, for example, the fruit may be redder and larger than those of either parent (Tanksley & McCouch 1997). Harnessing these effects is not straightforward because they could involve multiple genetic loci and contributions of the two genomes that are either unequal or synergistic. F1 hybrid seed can be produced when self-fertilisation is prevented but in many species, such as wheat, production of F1 hybrid seed is currently difficult and expensive.

To exploit heterosis with existing technology it is necessary to hybridise related plant genotypes for each round of seed production. The complicated procedures for production of F1 hybrid seed are not appropriate for many developing countries where the infrastructure does not exist for maintenance of the required seed supplies. If the F1 hybrid seed could be propagated asexually then the repeated cycles of seed production could be avoided and the benefits of heterosis could be realised more widely. In such a situation it would be easier to maintain supplies of seeds: it would be possible even for farmers to maintain seeds. Asexual propagation of hybrid seed would also facilitate exploitation of transgressive segregation.

One approach to the propagation of hybrid seeds involves exploitation of a process—apomixis—in which plants produce seed in the absence of sexual reproduction. Some species are naturally apomictic and it is likely that other species including crops can be made apomictic by mutation or GM. Examples in which apomixis would be advantageous include wheat, in which self-fertilisation and sexual production cannot be easily prevented. It would also be useful in crops like cassava and potato in which seed from self-fertilisation does not breed true. Apomixis is an area of active research but it may take more than 10 years to translate this research into a successful breeding programme.

Modification of photosynthetic efficiency could also result in massive yield increases. One approach to this involves attempts to introduce a C4 photosynthetic pathway into plants (Hibberd *et al.* 2008) as an alternative to the standard C3 pathway. C4 photosynthesis is found in drought-tolerant grasses such as maize and sorghum, but not in wheat and rice. It seems that the C3 to C4 transition has evolved independently several times in different plant species and that the key enzymes are present in both C4 and C3 plants (Wang *et al.* 2009b). It may be possible to engineer this transition by GM targeted at key regulatory proteins affecting the expression of enzymes in the C4 pathway. Comparative genomic information from rice, maize and sorghum (Paterson *et al.* 2009) will help in this objective. Alternatively, a recent report describes how the transfer of five bacterial genes introduced a metabolic shunt into the photosynthetic pathway of a C3 plant that mimicked some of the effects of C4 metabolism including

Case study 3.2. The development of hybrid maize

Hybrid vigour

While testing his theory on the origin of species, Darwin compared inbred and cross-pollinated (hybrid) maize and found that the hybrids were taller than the inbred plants and were more tolerant of cooler growing conditions. This 'hybrid vigour' (heterosis) was further studied by William Beal at Michigan State College, who observed increased grain yields in hybrids of different varieties.

Single and double crosses

In the early 1900s, experiments were conducted in which plants were self-pollinated for several generations to produce pure-breeding lines, which were then crossed to produce hybrids. The resulting high-yielding hybrids could be produced every year. These hybrid seeds could easily be produced by removing the tassels from one block of inbred maize plants to allow pollination by an adjacent block of a second inbred line. This is more easily done on a large scale with maize than other cereal crops as maize is wind pollinated and the male and female flowers are on separate organs.

However, as seed yields of the inbred parents were low with this method, the cost of hybrid seed was too high for farmers. When an additional, 'double cross' was performed (by crossing two of the single cross hybrids to produce the seed sold to farmers), yields were better than open pollinated varieties although not as good as the best single crosses. Seed production from 'double crosses' between high-yielding single cross hybrid parents became routine in the 1930s. Because of the doubling of yields, adoption of hybrid maize increased from 0 to 50% of Iowa's corn acreage in just six years following its release in 1932.

Commercial development

Farmers could either grow hybrid maize by purchasing the single cross parent seed and performing the cross on their farm, or by purchasing ready to plant hybrid seed from farmer cooperatives or commercial seed companies. The latter emerged as the preferred choice.

Although hybrid maize was first developed in the 1930s, the basis of hybrid vigour is still unknown. Further improvements in yield have largely resulted from improvements in the yield of the inbred lines. By the 1960s, the inbred lines were high yielding enough to use as seed parent and produce single cross hybrids for sale (which had a higher yield and were cheaper to produce than the best double crosses). Yields are now 4–5 times greater than those achieved with self-pollinated varieties in the 1920s. The aim of commercial seed companies is to increase yields again from about 150 to 300 bushels per acre by 2030.

Source: Duvick (2001).

increased biomass production and light energy harvesting (Kebeish *et al.* 2007).

Transfer of C4 metabolism into rice could achieve a yield increase of up to 50% (Hibberd *et al.* 2008), but the real gain could be a substantial increase in water use efficiency, a character normally associated with C4 plants. Engineering a *bona fide* C4 metabolism into a C3 plant may take at least 10 years but the metabolic shunt method could be achieved sooner.

3.3.2 Abiotic stress

Abiotic stress describes the impact of non-living factors such as drought, salinity, heat and toxic heavy metals. Genetic improvement and modified management of crops both have a role to play in dealing with abiotic stress.

3.3.2.1 Crop management strategies to mitigate the effects of abiotic stress

There are diverse crop management strategies to mitigate the effects of abiotic stress. Some of these strategies have been derived empirically. The use of seed mixtures has been trialled to increase the robustness of yield against environmental stresses (see Case study 3.3). For example, genotypes of beans selected for high capacity to acquire phosphorus often have shallow roots (Lynch 2007). This can cause problems for crops in water-scarce environments, where deep roots can be advantageous for water scavenging. Mixtures of genotypes can be planted to buffer the crop yield against combinations of stresses. In such mixtures, it is possible that shallow rooted genotypes may also benefit from the extraction of water by deep rooters in the community (Caldwell & Richards 1989). Development of these techniques requires an understanding of the different crop ideotypes that are helpful to combat different environmental stresses.

Turner (2004) has shown how wheat yields in Western Australia have increased by around 3-fold in 70 years, as rainfall has decreased. This has been achieved largely by changing the planting date of the crop to cover the ground while there is water available in the soil. This greatly reduces unproductive water loss via soil evaporation.

Other options which would not require major scientific advances for their initial implementation, where

Case study 3.3. Seed mixtures to increase robustness of yield under complex environmental stress

The architecture of plant root systems is important for the acquisition of resources and specific root structures are best adapted to particular abiotic stresses (Lynch 2007). Root structure can therefore be limiting to growth and yield in variable environments, as the plant will only be adapted to one particular set of conditions.

Root size, root placement and root length are determined by interactions between the plant's genotype and the environment in which it grows. Crop management techniques can be used to optimise these characteristics. In addition, production of root hairs and cortical air spaces can enhance root function. There is substantial genetic variation in all these variables and there is often a trade-off between different root morphologies (Ho *et al.* 2004). For example, water acquisition might be optimised at the expense of phosphorus acquisition. This can be a problem for plant improvement because plants are always impacted by complex stresses rather than by single environmental variables. For instance, soil drying will reduce both water and nutrient availability to roots.

Genotypes that result in a deep tap root are best adapted to drought-prone environments, particularly when the drought occurs late in the season when reproductive structures are developing. Genotypes that result in roots close to the surface of the soil scavenge effectively for immobile nutrients and are generally better adapted to low-phosphorus environments. Plant improvements to develop dimorphic root systems, with maintenance of adequate root biomass in both shallow and deep soil layers, appear to be helpful in environments where both water and phosphorus are co-limiting.

Where plant improvement is not possible and distribution of rainfall is erratic, sowing a mixture of seeds of varieties with shallow and deep root types might produce more stable crop yields. When soil water is in plentiful supply, plants having shallow roots would improve nutrient efficiency and probably also improve yield in low-phosphorus soils. When water supply is limiting, plants having deeper root systems would provide some tolerance to drought during growing seasons when a shallow rooted crop might otherwise not yield. The most appropriate mixture of root types for a particular geographic or climatic region might depend on soil fertility and the likelihood of drought (Beaver & Osorno 2009).

Additional source: Ho *et al.* (2005).

appropriate, include conservation agriculture, intercropping and agroforestry methods in which plants are protected from stress by other adjacent species. Intercropping is the practice of growing two or more crops in the same place at the same time. Particularly in the tropics, intercropping cereals with vegetables, and maintaining leguminous tree cover to provide shade, wood and mulch, could improve overall ecosystem performance (Gliessman 1998; Leakey *et al.* 2005; Scherr & McNeely 2008). Intercropping has potential in both industrialised and non-industrialised agriculture as a strategy to mitigate abiotic stress. It may also aid control of weeds, pests and diseases. These approaches are often based on traditional practice and with more research into interactions between plants they could be more widely adopted.

Regulated deficit irrigation regimes, in which plants are mildly stressed to activate stress tolerance mechanisms, increase water use efficiency of the plant (Davies *et al.* 2002). They can be combined with methods such as protected cropping and mulching the soil. There is an energy cost to this but in combination with deficit irrigation very high water use efficiencies can be achieved. Deficit irrigation can also be used as an effective tool for growth regulation, reducing vegetative growth in favour of reproductive development in fruit crops and thereby enhancing 'crop yield per drop of water' and crop quality (Loveys *et al.* 2002). In monocarpic cereals (which die after seeding), where a substantial proportion of grain yield can be derived from resources remobilised from the stem, grain yield can be substantially increased by deficit irrigation treatments after flowering. If plant death is delayed, for example by too much nitrogen in the soil, grain yields can be restricted by substantial accumulation of stem carbohydrates. These can be mobilised to the grains by mild soil drying.

In some instances there is good crop yield under drought provided that the transpiration rate is maintained or increased. However, there is always a risk of crop failure with this strategy if the drought conditions are extreme. Decreasing cumulative water loss (eg by reducing stomatal conductance, leaf growth or the length of the cropping cycle) to increase water use efficiency (biomass accumulation per unit of transpired water) is a more conservative strategy which generally results in yield restriction. Increasing water uptake from soils (while ensuring that water is available at critical developmental periods) can be a useful strategy, which is why phenotyping of root characteristics is receiving so much research attention.

Many crops around the world are now grown with protection against environmental extremes. This is commonly plastic film fashioned into a simple tunnel structure. This structure will often result in an increase in crop quality and can also greatly increase the water use efficiency. Recently, films with altered spectral properties have been used to modify plant morphology, fruit quality (Ordidge *et al.* 2009) and to improve pest and disease control. An advanced example of protected cropping to enhance resource use efficiency is the use of the seawater greenhouse (Seawater Greenhouse 2009). Here, solar energy is used to power seawater evaporators and then pump the resulting cool air through the greenhouse, which lets in photosynthetically useful light while reducing the infra-red heat load. This can reduce the air temperature by up to 15°C compared to the outside air temperature. At the other end of the greenhouse from the evaporators, the water vapour is condensed. Some of this fresh water is used to water the crops, while the rest can be used for cleaning the solar mirrors. The nutrients to grow the plants could come from local seaweed or even be extracted from the seawater itself.

It is likely that there could be great benefit from additional research into the science that underpins these various crop management strategies. Very few of the examples given above have benefited from the research tools referred to in 3.2.

3.3.2.2 Genetic improvement of tolerance or resistance to abiotic stress

Commercial and conventionally bred wheat genotypes with high water use efficiency and a yield increased by 10–15% are now available in Australia but this yield advantage is seen only in dry-land, low-yielding environments (Condon *et al.* 2002). In other examples drought tolerance was developed but was not found useful in the field. The drought tolerance was defined by survival under very severe stresses, but it did not provide any yield advantage under the stress conditions usually experienced in productive field situations. However, drought tolerance is a complex concept strongly dependent on the phenotyping methods used. It will be important to ensure that these methods identify the genotypes with yield advantage under the mild stress conditions usually experienced in commercial agriculture.

Several GM lines have been developed with drought and other stress tolerances, but they remain to be tested in the field. These include crops with over-expression of bacterial RNA chaperones (Castiglione *et al.* 2008), and NF-Y class transcriptional regulators (Nelson *et al.* 2007) in which drought tolerance is reported. RNA silencing to down-regulate poly ADP ribose polymerase (Vanderauwera *et al.* 2007), and over-expression of a cyanobacterial flavodoxin (Tognetti *et al.* 2006) may also increase tolerance to a whole range of stresses in plants. These approaches have been successful in controlled conditions and are undergoing regulatory approval. In addition, several targeted genetic approaches to salt tolerance involving GM have shown promise: these include modified expression of genes involved in the transport of Na+ (HKT) and those in the salt-overly sensitive (SOS) signal transduction pathway.

Genetic approaches may also be taken to overcoming aluminium toxicity. These may involve introduction of aluminium resistance genes encoding transporters of organic acids (OAs) such as citrate or malate (Delhaize *et al.* 2009; Liu *et al.* 2009; Ryan *et al.* 2009). In the rhizosphere, the released OAs form non-toxic complexes with Al^{3+} ions.

3.3.3 Biotic stresses including weeds, pests and diseases

Biotic stresses cause major losses to crops during cultivation periods and also during post-harvest storage. For that reason there has been intensive research into genetic and crop management strategies to mitigate these losses. In many respects this research into plant defence has been highly effective and there are many examples of current and emerging crop protection strategies, as described below. However, complete success is impossible because weeds, pests and pathogens can evolve so that they can overcome defence systems in plants or agricultural ecosystems.

3.3.3.1 Crop management strategies to mitigate the effects of biotic stress

Integrated pest management

Integrated pest management strategies may address multiple challenges and do not necessarily require genetic changes to the crop. In many instances they exploit natural defence systems and avoid the application of synthetic crop protection chemicals. For instance, the push-pull approach to *Striga* (witchweed) and stem borer infestation of maize involves intercropping with Desmodium and Napier grass (see Case study 3.4). Other integrated crop/pest management successes may be explainable through conceptually similar mechanisms or may involve pesticides/herbicides produced by the crop itself. More complete understanding of volatile and allelochemical secretions from plants would help the development of these approaches.

Other crop management strategies

Other crop management strategies may also help control pests and diseases. These approaches include use of biological control agents such as sterile insects that displace fertile members of the pest population, and cultivation methods including rotations and physical barriers to pests and diseases such as traps and screens. Pest and disease forecasting based on environment-driven models enable more effective and efficient timing of control measures. Thresholds can be established based on monitoring crops to determine whether intervention is necessary—monitoring systems can be very sophisticated based on semiochemicals or potentially automated assessment of air-borne spores or volatiles.

Crop protection chemicals

Chemicals are used widely to protect against weeds, pests and diseases. These compounds are the mainstay of global crop protection and they are likely to remain so for the foreseeable future. However, they increase the likelihood of

Case study 3.4. Integrated pest management: push-pull systems (vuta sukuma)[6] in East Africa

Maize pests in East Africa

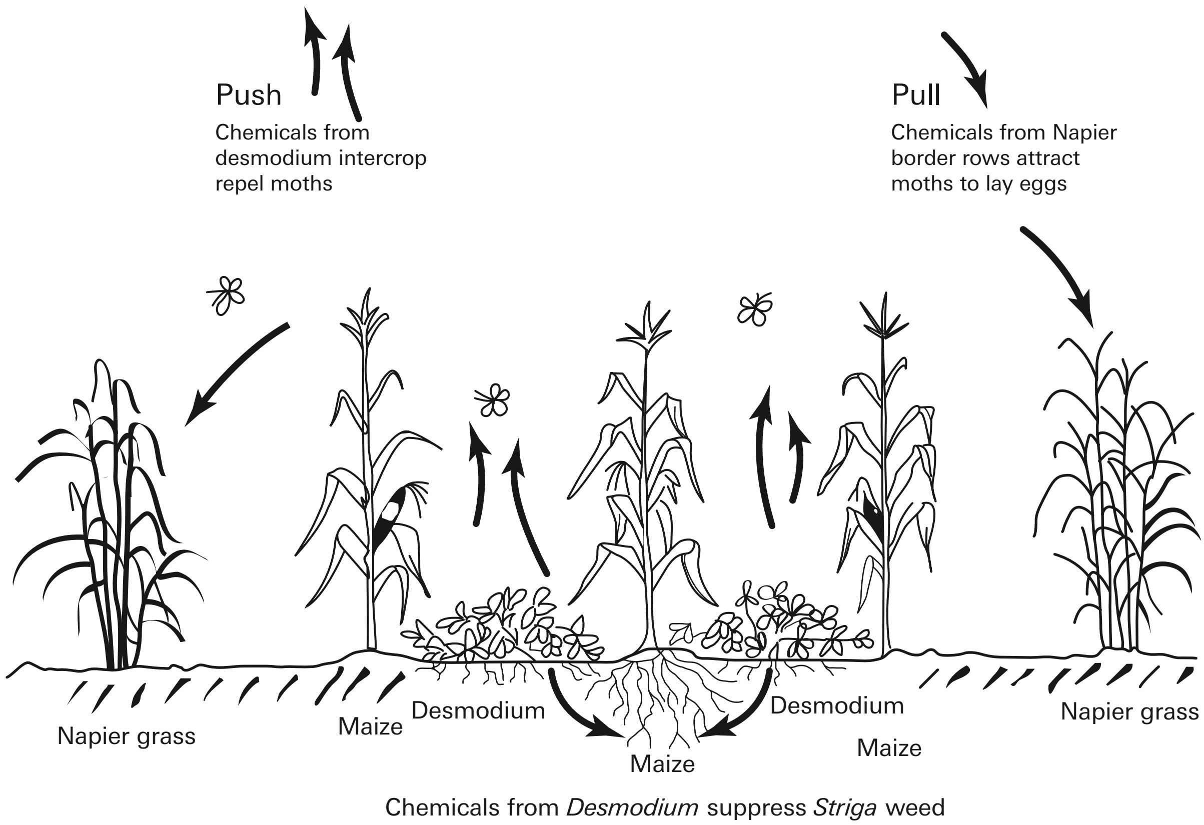
Maize is an important crop in East Africa for food security and cash income for farmers. The maize stalk borer (*Busseola fusca*) and spotted stem borer (*Chilo partellus*) are major pests. The larvae of these moths can cause yield losses of 30–40% (Amudavi *et al.* 2007; Hassanali *et al.* 2008). A further constraint is the parasitic weed *Striga hermonthica* (witchweed) which causes a loss of 30–50% to Africa's agricultural economy on 40% of its arable land (Amudavi *et al.* 2007).

Push-pull system

A 'push-pull' system for integrated pest management in maize crops has been developed by the International Centre for Insect Physiology and Ecology (Kenya) and Rothamsted research (Cook *et al.* 2007; Hassanali *et al.* 2008). This system combines knowledge of agro-biodiversity and the chemical ecology of these stem borers with *Striga* management, and is summarised in the diagram below. Different components of the system are designed to *push* away pests and to *pull* in their natural enemies.

The maize field is first surrounded by a border of the forage grass *Pennisetum purpureum* (Napier grass). Napier grass is more attractive to the moths than maize for laying their eggs (the 'pull' (*vuta*) aspect). The Napier grass produces a gum-like substance which kills the pest when the stem borer larvae enter the stem. Napier grass thus helps to eliminate the stem borer in addition to attracting it away from the maize.

In addition, rows of maize are intercropped with rows of the forage legume silverleaf (*Desmodium uncinatum*). *Desmodium* releases semiochemicals which repel the stem borer moths away from the maize (the 'push' (*sukuma*) aspect). An alternative repellent intercrop is molasses grass (*Melinis miniutiflora*) which also produces semiochemicals that attract natural enemies of the stem borer moth (Whitfield 2001). *Desmodium* has the additional benefit of fixing atmospheric nitrogen, thereby contributing to crop nutrition. Remarkably, *Desmodium* has also been found to be toxic to *Striga*, so has an additional crop protection benefit. Finally, the ground cover provided by *Desmodium* helps with soil and water conservation.



Source: *The Gatsby Charitable Foundation, The Quiet Revolution: Push-Pull Technology and the African Farmer*

Results and uptake

Push-pull has increased yields of farmers in areas of Kenya where stem borer and *Striga* are prevalent by more than 100% (Amudavi *et al.* 2007). It has been adopted by more than 10,000 farmers in Kenya, Uganda and Tanzania

6 This system is sometimes referred to by an alternative Swahili spelling: *vutu sukumu*.

(Amudavi *et al.* 2007). Promotion of the push-pull strategy has taken place through the public extension system, NGOs, the private sector, mass media (including radio shows and printed media), and farmer field schools. Push-pull systems are of relatively low cost as they do not require as many purchased inputs compared to the application of pesticides. They illustrate the hybrid nature of the science—both work on elements of the cropping system and their agroecological interactions.

What next?

One of the limits to the uptake of push-pull has been the availability of *Desmodium* seed. This will need to be addressed if uptake is to be increased. Work is being undertaken to further understand and increase the performance of all push-pull components (for instance, through research into pests and diseases of the companion crops). Development of push-pull strategies for crops other than maize is another goal.

Additional sources: Amudavi *et al.* (2008); Khan *et al.* (2008a, b & c).

resistant organisms, so careful management is required to prolong their useful life. Population genetics can contribute to good practice. In addition there is a potential hazard because most current crop protection chemicals are fungicides or insecticides. They are toxic for the pest or pathogen and there is always a risk, as with DDT (dichloro-diphenyl-trichloroethane), that non-target organisms will also be affected.

Chemical science for the development of new crop protection chemicals is largely outside the scope of this report. However, there is potential for a novel class of crop protection chemicals that are fundamentally different from those most widely used at present. The novel compounds would resemble chemicals present in plants that activate or prime natural resistance mechanisms and, because they do not target pests and pathogens directly, they could have environmental advantages over currently used compounds (van Hulten *et al.* 2006; Beckers & Conrath 2007). β-Aminobutyric acid, for example, is a naturally occurring compound that primes defence mechanisms to be activated more rapidly and to a higher level by pathogens. Naturally occurring salicylic acid and derivatives induce disease resistance mechanisms in plants in the absence of pathogens so that the treated plant is resistant. Similarly jasmonic acid treatment of seedlings has also been reported to 'prime' disease and pest resistance.

In one application a plant-derived primer of defence is applied to seeds (World Intellectual Property Organisation, Patent Application WO 2008/00710). The plants developing from these seeds are reported to have a persistent defence against insect pests with the outlook that long-lived protection can be achieved without the need to apply chemicals in the field. This property would have significant benefits to farmers and the environment and subject to development tests there is the prospect that these primer compounds could be introduced within a 5–10 year period.

The use of high throughput analysis of small molecules (Section 3.2.2.2) in plants will lead to the identification of other novel chemicals involved in disease resistance pathways in crops and may allow the development of additional crop protection chemicals targeted at the plant rather than the pest over a 10 year period or greater.

Herbicides

Herbicides are a special case among crop protection chemicals because the weedy target and the protected crop are both plants; the challenge is to kill the weed but not kill the crop. Some herbicides damage cereals and other grasses less than broad leaved (dicotyledonous) plants. However, GM and conventional breeding approaches enable the creation of crops that resist broad spectrum herbicides such as glyphosate (which targets the shikimic acid pathway), Basta/bialophos (which targets glutamine synthase), the sulphonylureas and imidazolinones (which target acetohydroxyacid synthase) and 2,4-D (an auxin mimic) (Duke 2004). The benefits of these herbicide-resistant crops are potentially limited by the evolution of weeds that resist the herbicide. It is clear, for example, that extensive use of glyphosate in North America has led to glyphosate-resistant weeds (Duke 2004), and consequently the use of glyphosate will need to be combined with other herbicides for effective weed control. However, it should be noted that herbicide tolerance in weeds will evolve irrespective of whether the herbicide is applied to herbicide-resistant crops or as part of a conventional weed control strategy (Beckie 2006).

In sorghum crops, the treatment of seeds of herbicide-tolerant hybrids has been found to be effective at tackling infestations of the weed *Striga* (Tuinstra *et al.* 2009). Similarly, CIMMYT, in collaboration with the Weizmann Institute of Science (Israel), with funding from the Rockefeller Foundation, has developed a unique product for *Striga* control in maize. It combines low-dose herbicide seed coating applied to herbicide-resistant maize seed that can leave a field virtually clear of emerging *Striga* blooms throughout the season (Kanampiu *et al.* 2003; De Groote *et al.* 2008). This imidazolinone-resistant maize was produced by artificial selection rather than GM methods. Conventional breeding approaches also show promise (IITA 2008).

Control of weeds in conventional cropping systems is achieved by tillage combined with herbicide application. However, the use of herbicide-resistant plants provides good weed control with little or no tillage and so a secondary benefit from the use of these crops has been the spread of reduced tillage systems in which soil erosion is reduced (Duke 2004; Beckie *et al.* 2006). The use of herbicide-resistant crops—either GM or conventionally bred—is an approach available now for major crops and it could be introduced for others in the near future.

3.3.3.2 Genetic protection against weeds, pests and diseases

Disease resistance in plants: R genes

A classic approach to control of diseases in plants is based on disease resistance (R) genes that are typically present in some but not all cultivars of a crop species and its wild relatives. Transfer of these genes by crosses between resistant and susceptible cultivars has been successful but is a lengthy process and may be associated with a yield penalty due to linkage of the desired gene to genes that confer deleterious traits. This breeding approach can now be greatly accelerated through the use of MAS (see Section 3.2.1.2). As an alternative, the cloned R gene can be transferred between cultivars or species using GM (see reference to cisgenic approaches in Section 3.2.1.3).

Two topical examples of disease resistance problems involve late blight in potato and stem rust in wheat. Potato yields are threatened by the emergence of new strains of late blight (Song *et al.* 2003; Fry 2008) but fortunately there has been considerable effort to identify and clone new genetic sources of resistance from wild potato relatives (Song *et al.* 2003). Extension of this approach will allow a rich diversity of cloned late blight R genes to be deployed in various GM combinations to maximise durability of resistance.

Similarly, in wheat there is a pressing need to develop resistance against a new highly virulent strain of stem rust (Ug99) that is spreading from east Africa (Case study 3.5). There are a few cultivars, but many wild wheat relatives carry R genes providing resistance to Ug99 and, once isolated, these R genes could be transferred easily into a range of wheat cultivars using GM.

There are many other examples of diseases in crops that could be controlled by R genes transferred by MAS (Section 3.2.1.2). There is the possibility that research projects initiated in 2009 could be translated into useful field resistance within 10 years. Both GM and MAS approaches would be greatly accelerated by more extensive crop genome sequences. However, irrespective of whether the approach is conventional or GM, there is a need to manage the use of resistant varieties so that resistant breaking pests and pathogens are not selected for the field.

Control of pests and disease using defence pathway genes

Other genetic approaches to the control of invertebrate pests also involve the transfer of plant genes between plants. However, unlike R genes which are involved in the recognition of pathogens, the transferred genes encode proteins responsible for the production of defence compounds (such as alkaloids, cyanogenic glycosides and glucosinolates). Sorghum, for example, makes a cyanogenic glycoside called dhurrin. The entire pathway for dhurrin biosynthesis from tyrosine, via two cytochromes P450 and a glucosyl transferase, has been transferred from sorghum to *Arabidopsis*, where it confers enhanced resistance to the flea beetle *Phyllotreta nemorum* (Tattersall *et al.* 2001; Kristensen *et al.* 2005).

Case study 3.5. Breeding for resistance: UG99

Stem rust in wheat crops

Stem rust is a fungal disease which produces blister-like pustules on cereal crops including wheat, and can cause substantial (50–70%) losses. A new race of stem rust, UG99, was identified in Uganda in 1998. UG99 spread in 2006 to Yemen and Sudan, has now reached Iran, and is predicted to spread towards North Africa, the Middle East and West South Asia where large areas of susceptible wheat varieties are grown under conditions favourable to the fungus. There are fears of a global epidemic. Some wheat strains were initially resistant to UG99, but new variants of UG99 have since arisen that cause stem rust on these previously resistant varieties.

Types of rust resistance

There are two types of resistance: race-specific resistance and adult plant resistance (APR). Race-specific resistance results from a single resistance gene that recognises a specific gene in the stem rust fungus. A mutation that enables the stem rust fungus to overcome this resistance gene will result in renewed susceptibility to the disease. APR depends on several different genes and therefore a mutation in the rust enabling it to overcome APR is less likely. However, this type of resistance is usually more prominent in mature plants than in young seedlings. Two APR genes have recently been isolated (Fu *et al.* 2009; Krattinger *et al.* 2009). It has been proposed that APR varieties of wheat could be planted in primary risk areas for UG99, with combinations of race-resistant varieties planted in secondary risk regions (Singh *et al.* 2008).

Current status

Since 2005, led by CIMMYT, wheat varieties and land races from 22 countries and international centres were screened in Kenya and Ethiopia to look for additional sources of UG99 resistance. Forty-six different stem resistance genes have been catalogued, but the majority of these confer race-specific resistance. Some high yielding wheat varieties with durable resistance have been developed, and the next step is to ensure that these varieties are readily available in susceptible regions. The migration of UG99 is being carefully monitored (CIMMYT 2009).

It would be necessary to confirm that the newly produced compounds did not affect the palatability or safety of the food products from the engineered crops. However, as the dhurrin pathway in this example is transferred from a crop plant (sorghum), there is no reason in principle why the approach would be incompatible with safe food and it could be used to transfer insect resistance in, for example, potato leaves. The example also establishes the principle that complete metabolic pathways can be transferred between plants using gene technology without having complex secondary effects (Kristensen *et al.* 2005).

Artificial resistance mechanisms

One of the most successful GM approaches to disease resistance, particularly to plant viruses, involves a concept known as parasite-derived resistance. A gene from a pathogen or parasite is introduced either intact or as a fragment into the genome of a host organism in the expectation that its RNA or protein product would interfere with the parasite such that the transformed plant would be resistant (Fuchs & Gonsalves 2007). Parasite-derived resistance can operate through RNA- or protein-based mechanisms and probably the best established examples involve resistance against viruses. Parasite-derived resistance in GM papaya against papaya ring spot virus is used very successfully in Hawaii and could be employed in many other examples.

RNA-based, parasite-derived resistance against nematodes and herbivorous insects is starting to be tested (Huang *et al.* 2006; McCarter 2009). The initial results indicate that in the longer term (10 years or more) this approach could underpin useful technologies for crop protection against pests and pathogens other than viruses.

Another approach allows control of invertebrate pests with plants that are engineered to make insecticidal proteins. One of the most successful applications of GM technology involves crops engineered to make the insecticidal protein from *Bt* (Gould 1998; O'Callaghan *et al.* 2005). These plants show elevated resistance to insects such as corn borer, corn rootworm and cotton boll weevil and, due to careful management with refugia as discussed in Section 3.3.3.2 (*The need to manage disease resistance*) (Gould 1998), there are only a few indications of insects evolving to overcome the resistance in the field. The *Bt* approach has been or could be used to protect maize, cotton, potato, brassicas and other plants against various pests and it may even be effective against nematodes (Wei *et al.* 2003). The use of GM *Bt* crops has resulted in substantial reductions in the application of insecticides that are toxic to non-target insects and farmers (Qaim 2009). The next generation of *Bt* maize lines are designed to express six different *Bt* genes giving resistance to a range of pests.

Bt crops were planted on 46 million ha in 2008 (ISAAA 2008). Warning signs that target insects may evolve the ability to overcome the resistance in glasshouse and field conditions (Tabashnik 2008; Tabashnik *et al.* 2009) and the sustainability of this approach may require that it is used as part of integrated pest management (Section 3.3.3.1—*Integrated pest management*) rather than in blanket monocultures.

Genetic control of post-harvest losses

Major losses of crops occur after harvest, during storage or transit. Such losses are currently estimated at 20% (Pimentel 2002). In some instances post-harvest losses can be reduced by improved storage, drying and processing. Solutions may be related to engineering and material science (Bindraban & Rabbinge 2004). However, storage potential of food crop products to extend the period of availability and minimise losses in store is an important trait which may be enhanced through biological mechanisms. There is scope in some instances for pre- and post-harvest crop losses to be mitigated by genetic improvement. In some respects this topic is an extension of pest and disease resistance because the damage to the harvested crop is often caused by insects or fungi. The solutions, therefore, overlap with approaches to prevent pest and pathogen attack and include the use of pesticides or pest-resistant varieties of crop.

However, there are additional approaches that are specific to post-harvest storage. A famous example involves ripening-resistant tomatoes in which softening of cell walls during ripening is suppressed (Brummell & Harpster 2001). These fruit can be harvested when ripe and do not spoil rapidly during storage. A higher proportion of these fruit can be harvested using mechanical devices than with conventional varieties and the post-harvest losses are reduced. This outcome can be achieved by both breeding and GM approaches and one of the first generation of GM crops included tomato in which ripening-related polygacturonase was suppressed. It is likely that similar improvements could be obtained with a variety of soft and perishable fruits although additional research may be needed to identify the relevant target enzymes (Matas *et al.* 2009).

Longer term genetic strategies

Plants protect themselves against disease via multiple defence mechanisms. Most plant species are completely resistant to the pathogens that are specialised to infect other plants ('non-host resistance'—NHR). For example, rice is resistant to cereal rusts, and tobacco is resistant to potato late blight. Understanding the molecular basis for NHR could enable more durable resistance to be engineered into crops. It might be possible, for example, to transfer NHR genes between species using GM and there has been good recent progress towards identification of the relevant genes (Lipka *et al.* 2005; Jones & Dangl 2006).

A second genetic approach to NHR is based on genomic studies of plant pathogens. From this work various pathogen-derived molecules ('effectors') that suppress host defences have been identified (Ellis *et al.* 2009). Better understanding of effectors may enable modification of their host targets to reduce susceptibility, and may also help prioritise R genes that recognise the most indispensable effectors; such R genes will be more difficult for the pathogen to overcome. It might be possible, for example, to identify genes conferring quantitatively expressed or partial resistance genes in the host that could be involved in interactions with these effectors. Such partial resistance genes may be more durable in the field than the R genes (Section 3.3.3.2 – *Disease resistance in plants: R genes*) deployed in conventional resistance strategies (Leach *et al.* 2001). Stacking of such genes via MAS could accelerate the production of cultivars carrying multiple partial resistance genes and, once the genes have been defined, assist introgression via cisgenic GM methods. However, with approaches based on either host factors or the effectors of the pathogen, there is still considerable additional work to be done and it is likely that it will take 10–20 years before these scientific studies could be translated into technologies that are useful in the field.

The need to manage disease resistance

Even when genetic pest and disease resistance is available it should be managed carefully to prevent selection of resistance-breaking strains of the pest or pathogen. Various strategies are available, including the use of refugia, in which a reservoir of susceptible plants allows the pest to survive without selection for resistance-breaking strains. This approach has been successful with insect-resistant plants (Gould 1998) but depends upon the requirement for sexual reproduction in the pest species and it would not be applicable to pathogens and pests that multiply asexually. A second crop management strategy involves the use of mixed seed in which the different genotypes carry variant resistance genes. Such strategies would be expected, based on theoretical considerations discussed by Jones and Dangl (2006), to confer more durable disease resistance than single gene resistance in unmixed seed and this prediction is supported by observation (Finckh *et al.* 2000).

The use of seed mixtures could be introduced in the short term with certain major crops but unfortunately the utility of this concept has not been widely investigated and the mechanisms associated with resistance in mixtures is not well understood. Disease resistance strategies including GM and conventionally bred crops would therefore benefit in the medium and long term from further investigation of resistance in mixed populations of field-grown crops.

3.3.4 Mineral nutrition of crops

Nutrient uptake efficiency can be a major limiting factor in crop yield. An understanding of soils and soil microflora is particularly important for the development of enhanced nutrient uptake efficiency. In addition, it will be possible to breed or engineer cultivars with an enhanced capacity to take up nutrients through modifications of the root system. The examples given below refer primarily to phosphorus (P) uptake but similar considerations apply to nitrogen (N), potassium (K) and micronutrients.

3.3.4.1 Crop management for improved uptake of mineral nutrients

McCully (1995) and others have called for the study of ‘real root systems’, including the microorganisms in the zone surrounding the plant roots which can have both beneficial and damaging effects on plant growth and development. Some of these associations, for instance mycorrhizae (symbiotic associations between a fungus and plant roots), have been much studied while other less-studied plant–microbe interactions may allow some scope for enhanced crop performance, particularly under environmental stress (Belimov *et al.* 2009).

Mycorrhizae are particularly important because most plant species acquire P via mycorrhizal symbioses: of the various types of mycorrhizal symbiosis, the arbuscular mycorrhiza (AM), formed with fungi in the phylum Glomeromycota, is most relevant to agriculture. Some have concluded that future agriculture will certainly involve an explicit role for AM fungi, either by cultural practices that favour the persistence of the mycelium in soil (eg reduced cultivation) or by direct modification of the fungal community (Leigh *et al.* 2009).

In addition, genetic variation in rhizosphere modification through the efflux of protons, organic acids and enzymes is important for the mobilisation of nutrients such as phosphorus and transition metals, and the avoidance of aluminium toxicity.

There is a need for predicting the performance of particular plant–fungus combinations in a range of environmental conditions and methods of manipulating (by appropriate cultural practices) the fungal community so as to promote the most effective fungi. Fundamentally, this means improving biological understanding of AM fungi. In the absence of P inputs to agricultural soils, ignoring the contribution of mycorrhizal fungi would be unwise.

3.3.4.2 Genetic improvement for improved mineral nutrition of crops

Since the main problem in P acquisition is the slow rate of diffusion through soil, one solution is to have a more widely dispersed root system. (Similar considerations apply to root scavenging for water.) Cultivars that have shallow angles of branching of the main lateral roots concentrate more root growth in relatively P-rich surface layers. There has been good progress towards understanding the genetic basis of variation in root system architecture (Lynch 2007). There is also good understanding of the functional relationships and trade-offs associated with the costs of the developed root system and the benefits of P acquisition. Variation in the length and density of root hairs is important for the acquisition of immobile nutrients such as phosphorus and potassium. Genetic variation in root cortical aerenchyma formation and secondary development ('root etiolation') are important in reducing the metabolic costs of root growth and soil exploration (Lynch 2007).

Lynch has argued that genetic variation in these traits is associated with substantial yield gains in low-fertility soils and that crop genotypes with greater yield in infertile soils will substantially improve the productivity and sustainability of low-input agroecosystems (Lynch 2007). In high-input agroecosystems, these traits will reduce the environmental impacts of intensive fertilisation.

Engineering of nitrogen fixation into non-legume crops has been a long-standing target of biotechnologists. Three approaches have been envisioned. The first involves modification of crop plants so that they support symbiosis with a nitrogen-fixing bacterium or blue-green alga. The second approach involves transfer of bacterial nitrogenase genes into the chloroplasts of crop plants. These approaches are both still long term, there is little research activity in this area and it is unlikely that they could be harnessed to develop a nitrogen fixing crop within the next 15 years. A third approach is to move the plant genes required for production of a symbiotic nitrogen-fixing nodule from leguminous plants to others that cannot currently support such a symbiosis. As the plant genes required for nodule development become better understood, this prospect now appears less fanciful, but is still at least 10 years away (Markmann & Parniske 2009).

3.3.5 Soils

Intensive cultivation of soils damages soil structure and leads to overuse of groundwater resources. Soils become cracked, and seedbed preparation increasingly requires frequent ploughing. This damage both increases costs and reduces yield. Zero-till systems of production have been developed to address these problems. This requires a new generation of cheap and affordable machinery. Zero-till sites have reported increased yield, as well as evidence of reduced greenhouse gas emissions, fewer weeds, more beneficial insects and improved water use efficiency (Hobbs *et al.* 2008; see also Case study 3.6).

Double digging is a method of deep soil preparation which can be used to improve soil fertility and structure. The idea of double dug beds is being widely promoted by local NGOs in Kenya. Double dug beds are combined with composts and animal manures to improve the soil. A considerable initial investment in labour is required, but the better water-holding capacity and higher organic matter mean that they are able to sustain vegetable growth long into the dry season. Once the investment is made, little more has to be done for the next two to three years. Many vegetable and fruit crops can be cultivated, including kales, onions, tomatoes, cabbage, passion fruit, pigeon peas, spinach, peppers, green beans and soya. The use of double dug beds in Kenya has improved food security. In particular, the health of children has improved through increased vegetable consumption and longer periods of available food (Pretty *et al.* 2003).

Biochar (charcoal) addition to soils is an ancient practice which has recently begun to assume wider significance. As a by-product of the pyrolysis of plant-derived biomass (for energy generation without releasing carbon), incorporation of biochar represents a means of sequestering carbon (due to its long half-life in soil) and there is increasing evidence that it can also reduce nutrient leaching and impact on the slow release of nutrients to enhance crop yields (Marris 2006).

Case study 3.6. Conservation agriculture in Burkina Faso, West Africa

The predominant ecosystem type in southwest Burkina Faso is moist savannah with tropical grassland and widely spaced trees. This region is sometimes referred to as a potential breadbasket for Africa due to its high crop and livestock productivity potential. However, productivity is currently low across much of the region due to poor soil nutrient fertility, variable rainfall and inadequate biomass availability. Farmers usually grow a range of subsistence crops—mainly maize, pearl millet, sorghum, groundnut and cowpea.

Over 20 million ha of savannah land (with similar agroecology to Burkina Faso) have been sustainably intensified and diversified in Brazil using conservation agriculture principles. From 2002 to 2007, an FAO conservation agriculture pilot study was carried out in five communities in Burkina Faso, with the following aims:

- to expand crop choices to increase production of livestock feed;
- to improve soil-crop-water management for sustainable production intensification; and
- to diversify and expand the range of food, feed and tree crops and their integration with livestock into the existing cotton- and maize-based systems.

What is conservation agriculture?

Conservation agriculture is resource-saving agricultural crop production that aims to deliver high and sustained production levels while conserving the environment. Interventions such as mechanical soil tillage are minimised (or eliminated), and external inputs such as agrochemicals are applied in a manner which minimises any disruption to biological processes. The key features of conservation agriculture are:

- Minimum mechanical soil disturbance.

Crops are planted directly into the soil. In conventional agriculture, soil tillage leads in the long term to reduction in soil organic matter which in turn leads to soil erosion.

- Permanent organic soil cover.

This provides nutrients for crops and maintains soil structure. Cover can be provided either by crop residues or a cover crop such as *Mucuna*, which prevents the loss of topsoil, suppresses weeds and fixes nitrogen.

- Diversified crop rotations (in annual crops) or crop associations (in perennial crops).

Adoption in Burkina Faso

The FAO and Institut National pour de l'Environnement et de Recherches Agricoles (INERA) funded a 5-year farmer participatory project to test and select technologies aimed at overcoming the limitations of the current cotton and maize based crop-livestock production systems. This took place at five pilot locations in southwest Burkina Faso, and involved the following components:

- minimum till;
- crop rotation;
- crop cover management;
- farmer field schools for integrated production and pest management.

Land was prepared using animal-drawn trampling knife rollers, which minimised disturbance to the soil, and flattened vegetation and residues. Direct seeding then took place by hand using Brazilian-made jab planters and animal-drawn seed disc drills. This minimised soil disturbance during seeding and achieved efficient plant spacing. The range of crops in the cropping system was extended. New cereal–legume associations were introduced. Improved cereals were used and legumes provided additional benefits: soya beans for vegetable oil and *mucuna* for ground cover. *Brachiaria* and species of local grasses were also grown for the production of silage for livestock, to increase soil organic matter and to provide surface protection. Cassava was introduced as a new crop for both food and feed. Living fences of fodder trees such as *Acacia* and *Ziziphus* were also planted around the sites to protect crops and residues from livestock during the dry season. As well as providing a 'living fence', using trees in this way can also provide erosion control, biofuels and fruit.

Results

The technologies introduced through the pilot project have resulted in substantial increases in agricultural production, thereby increasing food security and farmer income. The increased livestock feed availability during the dry season has helped smallholders enhance their income from livestock products, while also improving soil moisture supply and soil health. Conservation agriculture technologies for crop diversification and crop intensification are now ready for scaling up and further adaptation.

Source: FAO (2009a, b); Kassam *et al.* (2009).

3.3.5.1 Perennial crops

The conversion of annual crops into perennial plants could help sustain the health of cultivated soils. Perennials make up most of the world's natural terrestrial biomass. In contrast, grain and oilseed crops that are the foundation of the human diet are normally grown as annual crops. To date there are no perennial species that produce adequate grain harvests. However, there are breeding programs aimed at developing perennial grain crops in wheat, sorghum, sunflower, intermediate wheatgrass and other species (Cox *et al.* 2006). Perennial crops would store more carbon, maintain better soil and water quality and would be consistent with minimum till practice. These crops would also manage nutrients more conservatively than conventional annual crops, and they would have greater biomass and resource management capacity. Given adequate support these efforts could lead to the development of perennial crops within 10 years (Cox *et al.* 2006).

Other approaches to perenniality involving GM and based on an ability to regulate the transition from vegetative to floral meristems in plants could be developed in the 10–15 year period and would be based on recent progress towards understanding the genes that influence perenniality (Wang *et al.* 2009a). The widespread use of herbicide-resistant crops allows good weed control without tillage and so promotes the health of cultivated soils (Cook 2006).

3.3.6 Nutritional quality

It is generally accepted that diversity is the preferred approach to a balanced diet. However, when a diverse diet or supplements are not available, both genetic and non-genetic approaches can be used to enhance the nutritional content of a stable crop and avoid 'hidden hunger' due to shortage of micronutrients. The preferred strategy to eliminate hidden hunger will always involve strategies to increase the diversity of diet with increased access to fruit and vegetables. However, in regions where the lack of infrastructure or other factors prevents diversification of the diet, the introduction of biofortified varieties may provide a good short-term solution. The advantage of a biofortification approach is that it capitalises on a regular intake of a staple food that will be consumed over a long period even in the absence of international development agencies. The requirement for a one-off investment to develop the appropriate seeds is also a consideration (Nestel *et al.* 2006). The importance of nutritional content and the dietary contribution of food crops to achieve nutritional security, especially vitamin A, zinc and iron, is widely recognised (Copenhagen Consensus 2008). However, the importance of palatability to the consumer must not be ignored. Nutritional quality can also be enhanced by the removal of toxic components through crop management and by genetic enhancement.

3.3.6.1 Crop management to enhance nutritional quality

There are several methods by which the nutritional content of the harvested crop can be improved through targeted management and particularly by the use of fertilisers containing trace elements. These include production systems to improve grain quality and nutritional value. There has been an increased focus on agronomic biofortification within the international fertiliser industry (White & Broadley 2005; Bruulsema *et al.* 2008). Whole crop management systems exist to improve quality, health and nutrition, for instance in cassava (Nassar 2006). However, the full potential of these approaches requires further research into the processes through which the nutrient content of crops can be influenced by fertiliser applications.

Mild drought stresses have been shown to result in enhanced flavour and aroma in some food crops (Santos *et al.* 2007) in addition to enhanced concentration of health related metabolites (such as ascorbic acid and other antioxidants).

3.3.6.2 Genetic improvement of crops to enhance nutritional quality in regions with diet deficiency

Golden rice is a transgenic line that could help to combat vitamin A deficiency (Dawe *et al.* 2002). The first generation of Golden rice varieties contained only low levels of β-carotene and there was some scepticism as to whether their introduction would mitigate vitamin A deficiency and benefit poor, rice-dependent households. However, there are now lines with much higher levels of β-carotene (Paine *et al.* 2005) and good evidence from clinical trials that it is an effective source of vitamin A (Tang *et al.* 2009).

A trial of orange-fleshed sweet potato in Mozambique also illustrates how vitamin A deficiency can be mitigated by supplies of biofortified staple crops (see Case study 3.7). Genetic improvement of cassava can enhance nutritional quality (protein, carotenoids and minerals) using wild relatives.[7] The HarvestPlus programme (see also Case study 3.7) is working to improve the nutritional quality of maize and rice. Recently, rice plants have been engineered with elevated iron levels in the rice kernels (Wirth *et al.* 2009).

Case study 3.7. Biofortification of orange-fleshed sweet potatoes for combating vitamin A deficiency

Vitamin A deficiency

Vitamin A is needed for good eyesight, and extreme deficiency leads to blindness. It is estimated that worldwide, 250,000 preschool children go blind due to vitamin A deficiency every year (Bouis 2008). One method of combating micronutrient deficiency is through the use of supplements or fortified foods. However, this is not an option for the rural poor, who may live too far from the nearest market and cannot afford to buy these products. An alternative method of enhancing Vitamin A in the diet is through biofortification. This involves breeding staple crops which have high levels of micronutrients.

How is it done?

The micronutrient content of staple foods can be increased through conventional breeding where adequate germplasm variation is available. The HarvestPlus programme is working towards producing sweet potato lines with high levels of the vitamin A precursor β-carotene. The target level of β-carotene depends on the levels available to the consumer following cooking and digestion, and whether the sweet potato will be the sole source of vitamin A in the diet. Studies have shown that feeding β-carotene-rich sweet potato to school children increases their vitamin A stores in the liver (van Jaarsveld *et al.* 2005). Orange-fleshed sweet potato lines with high levels of the vitamin A precursor β-carotene have been identified.

Micronutrient-dense traits are generally stable across all environments, which makes it easier to share germplasm internationally. Furthermore, micronutrient traits can be combined with traits for high yield.

7 'Decades of cassava research bear fruit.' Available online at: http://www.idrc.ca/en/ev-5615-201-1-DO_TOPIC.html.

Cost

Costs of developing biofortified sweet potatoes are largely associated with the initial research and development of biofortified varieties, after which costs are low. An international system is already in place to develop modern varieties of staple foods (including sweet potato) and so the key cost component lies in enhancing the micronutrient.

Uptake

Sweet potato is used because this is already a locally consumed food. These modified sweet potatoes have a slightly different colour and flavour from conventionally grown varieties. However, women farmers in Africa have been willing to try growing them and feeding them to their children. Once seeds have been made available to farmers, the seed from that harvest can be saved to re-plant in subsequent years, which makes it a cheap and sustainable system for the farmers. Therefore, after the initial cost of developing the biofortified seed the costs are low.

What next?

Further research is needed to determine how uptake of the biofortified crop might be increased.

Additional sources: Nestal *et al.* (2006); Tanumihardjo (2008).

3.3.6.3 Genetic improvement of crops to enhance nutritional quality in regions with varied diets

There are proposed genetic improvements of plants with claims of enhanced nutritional content for use in industrialised countries. These include GM soya bean and oilseed rape with near-zero trans-fat potential and high concentrations of long-chain omega-3 and omega-6 fatty acids (Kinney 2006). Fruit and vegetables have also been developed with high levels of cancer protecting compounds, such as flavonoids in the purple tomato (Butelli *et al.* 2008).

3.3.6.4 The use of lost and orphan crops for improved nutrition

Many 'lost crops' with high nutritional value exist and have potential for domestication (National Academies 2008). It should not be difficult to select nut and fruit species with desirable attributes for different needs. Removing or inactivating pathways producing compounds that are toxic to humans could enable plants that are productive in poor, drought-prone areas to be grown as valuable crops. Improvement of minor (orphan) crops is necessary to ensure dietary diversity and the provision of particular plant-derived raw materials. It may also be possible to engineer the removal of toxic metabolites from plants that could crop well in hostile environments. However, it could be argued that in light of the urgency of potential food shortages, the domestication of orphan crops should not be a priority.

3.3.6.5 Toxins and toxic elements

Fungi producing mycotoxins that are damaging to human health infest sites of insect damage in cereal grains. Reduced levels of mycotoxins can be achieved, therefore, through the use of *Bt* maize produced by GM (Section 3.3.3.2—*Artificial resistance mechanisms*) (Bakan *et al.* 2002). The Sterile Insect Technique (SIT) is a proven species-specific technology that uses sterile insects to interfere with the breeding dynamics of selected insect pests (Dyck *et al.* 2005). This may be useful for maintaining low levels of mycotoxins and for control of other aspects of post-harvest quality. Like the *Bt* crops, it could be considered as a science-based approach available for use in the short term.

Other sources of food toxicity in some areas of Asia derive from the contamination of crops grown in soils polluted by arsenic, cadmium and mercury. This is a major problem that could be resolved through breeding and GM technologies targeted to the genes involved in toxic element accumulation. However, these genes have yet to be identified and this approach would have to be considered as long term, over a period of 10 years or more. Phytoremediation might also be useful in these situations, involving GM or other plants that have the ability to sequester toxic compounds from the soil (Salt *et al.* 1998; Zhao & McGrath 2009).

Toxins may also be produced in the plant. In cassava, for example, cyanogenic glycosides render many varieties toxic, necessitating extensive food processing prior to safe consumption. GM or marker-assisted breeding approaches could reduce levels of such toxins (Siritunga & Sayre 2003), though a less toxic (to humans) cassava might also be more susceptible to pests.

3.3.6.6 Animal food quality

There is scope for improving the quality of crops for animal foods as with human foods. However, there are also some specialised examples in which genetics can be used to improve the usefulness of crops as animal foods. Phytic acid in grain for animal feed immobilises phosphate and is poorly metabolised by monogastric animals. It passes through the gut of these animals, resulting in phosphate-rich manure that contributes to waterway eutrophication. Low phytic acid grain (Shukla *et al.* 2009) used for poultry food may reduce phosphate pollution from chicken or pig farms and thereby contribute to sustainable food production. Such grains have been developed by random (Shi *et al.* 2005) or targeted mutation (Shukla *et al.* 2009; see Section 3.2.1.1) and by GM (Bilyeu *et al.* 2008).

Oily fish such as salmon and herring provide omega-3 fatty acids for the human diet. These molecules are synthesised by phytoplankton that are eaten and then move up the marine food chain. In fish farming these compounds are provided through fishmeal. For each unit of product, several units of fishmeal have to be provided so that the sustainability of fish farming is vulnerable to shortages of wild fish supply. However, it is now possible to engineer oilseeds such as soya bean to produce SDA, an omega-3 fatty acid precursor (Monsanto 2009). This material could enter the fish feed or indeed chicken feed chain, resulting in fish or chicken in the human diet enhanced with omega-3 fatty acids. It is likely that this innovation could be applied in the near future.

3.4 Conclusion

A range of technologies and practices have been described in this chapter which could be used to increase food crop production and improve nutritional quality in light of the various challenges described in Chapter 2. Some of these are starting to be used widely. Others have likely future benefits over the next two decades. Opportunities exist for the application of existing technologies, the development of new crops and practices and the longer term investigation of radical new approaches which might result in dramatic changes in productivity. It should be stressed that no one approach should be ruled out in favour of another. Different approaches will be appropriate in different circumstances. Furthermore, the largest improvements stand to be gained where both the 'seeds and breeds' and management aspects of a system are optimised. This in turn requires the necessary social and human capital. When considering how these approaches might translate into use in the field, it is essential to consider possible impacts, side effects and wider consequences. These are discussed in the next chapter.

4 Consequences and complications of innovation in food crops

Summary

Changes to agricultural technologies and practices have both positive and negative consequences for the environment, human health, societies and economies. Potential adverse impacts on the environment include those on biodiversity and the provision of ecosystem services. The sustainable intensification of agriculture requires a new understanding of these impacts so that interventions can be targeted to minimise adverse effects on the environment. Potential health and environmental impacts of new crop traits need to be well understood and managed. Little proactive attention is given to the economic context of changes to agriculture. Increasing production without consideration of economic and social conditions can amplify rather than reduce income inequities. For technologies to be successful and sustainable, they need to fit with local economic contexts. Farmers' own expertise needs to feed into processes of research and innovation. Systems for extending and translating knowledge into changed practices need to be improved.

When problems are complex, new technologies rarely provide straightforward solutions. Technological innovations can introduce unintended complications, necessitating trade-offs between costs and benefits. This chapter highlights some of the potential consequences associated with new technologies and practices for food crop production. We consider the environment, human health, social issues, markets and research infrastructure as separate factors, although we acknowledge their interrelatedness. Our conclusion is that innovation towards the sustainable intensification of agriculture must take into account these complexities, demanding improved scientific understanding and good governance.

4.1 The natural environment and externalities

The primary objective of agricultural systems is to produce food, fibre, fuel or other products for human or livestock consumption. But meeting the objectives of food production may have intended or unintended side effects (Robinson & Sutherland 2002; Green *et al.* 2005; Millennium Ecosystem Assessment 2005; Birdlife International 2008a).[8] Agriculture can negatively affect the environment through the overuse of natural resources as inputs or through exporting pollutants from pesticides and fertiliser use. Such effects are called negative externalities because they are costs that are not factored into market prices (Baumol & Oates 1988; Dobbs & Pretty 2004). Sensitive agricultural practices can contribute to the accumulation of natural capital by improving soil quality, biodiversity, and water services.

Externalities in the agricultural sector have at least four features:

1. their costs and benefits are often neglected;
2. they often occur with a time lag;
3. they can damage the welfare of groups whose interests are not well represented in political or decision-making processes; and
4. the identity of the source of the externality is not always known.

The central challenge for new technologies and practices in food crop production is to find ways of increasing production while minimising any negative impacts and at the same time increasing the stocks of natural capital (see Table 4.1).

4.1.1 Ecosystem services

Changes to crop production practices have resulted in the degradation of the physical environment, topsoil loss, water table effects, desertification and even local climate change (Tilman *et al.* 2002) (see Case study 4.1). This impact can be caused by increased intensity of agriculture or conversion of habitat for farming. External impacts include the consequences of fertiliser and pesticide use on nutrients and toxins in groundwater and surface waters.

It is now accepted that ecosystems such as forests and wetlands provide a range of services including air quality regulation, water regulation, erosion regulation, water purification and waste treatment, disease regulation and climate regulation at a range of scales from local to global (EASAC 2009) (see Box 4.1). Agriculture relies upon, but also has impacts upon, these ecosystem services. As agricultural systems shape the assets on which they rely for inputs, a vital feedback loop occurs from outcomes to inputs. Sustainable agricultural systems should have a positive effect on natural, social and human capital, while unsustainable ones feed back to deplete these assets.

8 See also the papers in the special issue of Philosophical Transactions of the Royal Society of London B **363**, 1491, 447–466.

Table 4.1. Potential side effects of differing agricultural technologies and practices.

Technology or practice	Examples of potential negative side effects	Examples of potential positive side effects
Agroforestry—for increasing yields and rehabilitating degraded lands, especially leguminous trees	Nitrogen leaching of leguminous trees Pest harbouring in new habitats	Increased carbon sequestration in soils and timber Mixed habitats for beneficial organisms Reduced salinity and water logging
Beetle banks and flowering strips	Loss of productive agricultural land	Reduced insecticide use and losses to watercourses
Engineering with nano-emulsions, mechanisation and robotics	Escape of nano-particles [a]	Reduced losses of important nutrients, water and pest control agents to environment
Herbicide-tolerant crop	Reduced in-field biodiversity Herbicide resistant weeds based either on the crop or flow of a gene into crop relatives	Reduced use of harmful herbicide Increased soil carbon if zero-tillage system also used
Insecticide	Loss of higher trophic level organisms (eg predators, bees) Adverse effects on human health Pollution of ground and surface water	Indirect effect of reducing land required for agriculture
Insect-resistant crop	Insects may be selected for their ability to overcome the resistance	Reduced use of insecticides
IPM—use of both manufactured products and ecological management	Likely to be lower than for traditional use of pesticides [b]	Reduced losses of beneficial insects and arthropods Reduced water pollution Addition of fish to wetland rice-based systems
Manures and composts	Losses of nutrients to surface and ground water Losses of N_2O to atmosphere	Reduced fertiliser use (if a substitute) Increased soil quality and texture
Mineral fertiliser	Nitrogen and phosphorus losses to ground and surface water Losses of N_2O to atmosphere Eutrophication of surface water	Indirect effect of reducing land required for agriculture
Multiple or mixed cropping with legumes, use of green manures	Possible increase in nitrogen leaching	Mixed habitats reduce pest incidence Increase in carbon sequestration in soil (if added as green manure)
Pheromones for pest reproduction disruption and inundative biological control	Likely to be minimal if highly host-specific although there may be insect dispersal to remote areas	Reduced pesticide use (if replaced) Increased incidence of parasitoids and predators
Precision agriculture for pesticides and fertilisers	Likely to be lower side effects than for conventional applications	Reduced losses to ground and surface water
Push-pull system for IPM and weed control	Likely to be low	Reduced use of pesticides Damage to viability of *Striga* Increased resilience of system

Soil and water conservation, contour farming, mulches and cover crops	Losses of nitrogen to groundwater	Reduction in soil erosion Increased infiltration and recharge of aquifers Increased carbon sequestration if plant material added to soil
Water conservation and harvesting	Retention of water in watersheds through reductions in surface run-off	Reduction in soil erosion
Recessional rainfed agriculture		Increased infiltration and recharge of aquifers
Zero-tillage or conservation tillage	Losses of N_2O to atmosphere from fertilisers Leaching of herbicides to groundwater	Increased carbon sequestration in organic matter in the soil Reduced soil erosion Reduced water run-off Cleaner waterways

(a) Analysis of nano-particles in the environment is available in Royal Society (2004).

(b) There are potential *indirect* environmental side effects if conventional, high-yield agriculture is replaced by systems that use IPM and produce lower yields, requiring, on average, an expansion of agricultural land.

Case study 4.1. Water use in the Shiyang River Basin

The negative impacts of over-use of water in agriculture combined with the influence of a changing climate are well illustrated in the Shiyang River Basin, an inland river basin in Gansu Province in northwest China. Shiyang has a large human population with very significant exploitation of its water resources. In consequence, water shortage constrains its social and economic development and results in some of the worst ecological and environmental deterioration in China. With an increasing population (by 159% in 50 years), the amount of cultivated land in the basin has expanded greatly (by 51%). Large-scale irrigation has been introduced in the middle reach of the basin. The introduction of leakage-free canals and more extensive exploitation of underground water have further expanded the irrigated area. Water usage due to human activities has exceeded the carrying capacity of the water resources in the basin, leading to a dramatic shift of water allocation between the upper and lower reaches and a rapid reduction in the water table in lower reaches (the Minqin oasis). Much of what was once a lake and which had become productive agricultural land is now a desert. The oasis is shrinking in area, natural vegetation relying on underground water is disappearing, and desertification is accelerating (see Kang *et al.* 2008).

In this region, the dropping water table makes it very difficult to sustain productive agriculture, resulting in the abandonment of villages and population emigration. Agricultural practices are changing with more protected cropping introduced to increase water use efficiency. In the oasis, a research station established jointly by China Agricultural University and Wuwei City (Gansu Province) is helping the region's farmers introduce 'water saving agriculture techniques'. These biological and engineering solutions allow the production of 'more crop per drop' of water available. The hope is that these practices will sustain food production, restore the water table with positive ecological consequences, and allow small quantities of water to be used to establish drought-resistant plants at the southern limit of the desert to prevent further desertification. If this programme is not successful then the consequences for the local population will be serious. The loss of vegetation from the area, which is surrounded by massive deserts, would also contribute to global warming.

4.1.2 Biodiversity in agricultural systems

Taking the UK as a well documented case, there is evidence for widespread changes in biodiversity in agricultural landscapes. Farmland weeds declined by about 90% over the last century (Robinson & Sutherland 2002) and there have been dramatic losses in recent decades of much of the flower-rich farmland habitat, such as hay meadows (Wilson 1992). Many farmland specialist species have declined in recent decades including around half of the relevant plants, a third of insects and four-fifths of bird species (Robinson & Sutherland 2002). The intensification of agriculture in the UK has been identified as contributing to declines in threatened farmland bird species (BirdLife International 2008b). The greatest declines in Europe over the last 25 years of farmland ecosystem birds have been in the more intensively farmed areas of north-western Europe and least in eastern Europe, where the largest bird populations remain (Donald *et al.* 2001). In North America many bird species characteristic of farmland or grassland habitats have declined over recent decades (Peterjohn & Sauer 1999).

In Europe, significant impacts of agriculture on biodiversity in agroecosystems have arisen from the development of

Box 4.1 Ecosystem services

Climate regulation (global). Ecosystems play a key role in absorbing and managing levels of GHGs in the atmosphere.

Climate regulation (regional). Changes in land cover have affected regional and local climates, both positively and negatively, with a preponderance of negative impacts such as reduced local rainfall near tropical deforestation.

Air quality regulation. The ability of the atmosphere to cleanse itself of pollutants has declined slightly since pre-industrial times but probably not by more than 10%.

Water regulation. The effect of ecosystem change on the timing and magnitude of runoff, flooding and aquifer recharge depends on the ecosystem involved.

Erosion regulation. Land use and crop/soil management practices have exacerbated soil degradation and erosion.

Water purification and waste treatment. Globally, water quality is declining, although in most industrial countries pathogen and organic pollution of surface waters has decreased over the last 20 years.

Disease regulation. Ecosystem modifications associated with development have often increased the local incidence of infectious diseases, although major changes in habitats can both increase or decrease the risk of particular infectious diseases.

Pest regulation. In many agricultural areas, pest control provided by natural enemies has been replaced by the use of pesticides. Such pesticide use has itself degraded the capacity of agroecosystems to provide pest control.

Pollination. There is established but incomplete evidence of a global decline in the quantity of pollinators. Declines in abundance of pollinators have rarely resulted in complete failure to produce seed or fruit, but have more frequently resulted in fewer seeds or in fruit of reduced viability or quantity.

Natural hazard regulation. People are increasingly occupying regions and localities that are exposed to extreme events, thereby exacerbating human vulnerability to natural hazards.

Source: Millennium Ecosystem Assessment (2005)

more effective herbicides and pesticides, increased drainage, larger fields, greater mechanisation, the rapid shifts to winter cereals (and the consequent loss of over-winter stubbles), the move away from hay making to silage (Potts & Vickerman 1974; Chamberlain *et al.* 2000) and the increase in the area of land farmed (see Section 4.5).

The impact of agriculture on biodiversity can be associated with reduced efficiency of crop production. This point is illustrated by research in the 1980s in southeast Asia in which it was found that pest attacks on rice increased when pesticides were used. Insecticides were eliminating the natural enemies of insect pests such as spiders and beetles (Kogan 1998), so the pests were able to multiply very rapidly.

However, the careful use of science-based technology in agriculture need not lead inevitably to the deterioration of biodiversity. In the southeast Asian example referred to above, the introduction of integrated pest management (IPM) resulted in remarkable achievements in human and social development and was associated with more effective agriculture. Farmer field schools are now being deployed in many parts of the world to introduce IPM: by 2005, more than 4 million farmers had been trained in 175,000 field schools in 78 countries. Indonesia has the largest number of trained farmers with 1.1 million, while there are significant numbers in other countries such as Vietnam (930,000), Bangladesh (650,000), Philippines (500,000), India (255,000), Egypt (210,000), China (130,000), Thailand (75,000), Nepal (57,000), Kenya (46,000) and Sri Lanka (45,000) (Eveleens *et al.* 1996; Braun *et al.* 2005).

Similarly, in Europe it has been established that the ecological and environmental importance of farmland can often be enhanced at little cost. There has been considerable research into the habitat requirements of a range of declining bird species and the means of restoring their populations (Newton 2004). The practicalities of such solutions have been assessed by the Royal Society for the Protection of Birds at their trial farm, which has markedly increased the densities of a range of farmland species while increasing profits. A similar farm-scale scheme run by the Game Conservancy Trust has demonstrated the potential to use agriculture to provide food and habitats for farmland birds (Stoate *et al.* 2004).

Agri-environment schemes are a favoured solution for maintaining or enhancing wildlife in farms. Their impact has been variable (Kleijn & Sutherland 2003), but with greatest success when carefully targeted (Ausden & Hirons 2002; Evans & Green 2007). In one example, a well researched and focused agri-environment scheme was introduced in southwest England with the objective of restoring the cirl bunting (Peach *et al.* 2001); the population increased 5-fold between 1989 and 2003 (Wooton *et al.* 2004).

However, although the effects of agriculture on biodiversity can be minimised with careful management, as described above, these effects cannot be eliminated totally if agricultural production is increased. It is inevitable that any move to intensify agriculture or to increase the area of cultivated land will present challenges for biodiversity and ecosystem services.

4.1.3 Gene flow

It has been known for many years that genes can flow from a crop into related crops or weedy relatives by pollen transfer (Dunwell 2008). Conner *et al.* (2003) refer to Charles Darwin's experience with cabbage seed stocks that were contaminated by pollen from purple kale grown more than half a mile away to produce what he called 'purple bastards'. They also review other examples of gene flow between crops and weeds. Historically, the effect of such gene flow has not been perceived as an agricultural or environmental problem, but routine measures are taken to minimise genetic contamination of seed supplies and testing is carried out to maintain purity. The recent introduction of GM crops has highlighted this issue, although there is no evidence that transgenes and endogenous genes differ in their ability to move into or out of a crop. Since absolute genetic containment of crops is impossible (Dunwell & Ford 2005), the current regulation of GM crops addresses both the likelihood and potential consequences of such gene transfer. The frequency of gene-flow is substantially dependent on the breeding system of the crop (inbreeding or outbreeding) and the relative magnitude of the source of pollen relative to the density of recipient plants.

Genes for disease resistance and other traits have been bred into many crops for nearly a century by crossing between crop varieties or by crossing between a crop and related species. Spread of the conventionally bred genes into sexually compatible relatives will have occurred but there is no indication of harm even when crops are grown in centres of natural biodiversity for the crop. There is no good evidence that these crops have resulted in environmental or other damage.

GM techniques may be used to transfer genes that could otherwise have been transferred from plant to plant by conventional breeding. This *cisgenic*, as opposed to *transgenic*, approach (see Section 3.2.1.3) has the potential advantage that it accelerates the cycle of crop improvement and allows the introduction of new useful traits without other less useful traits ('linkage drag'—see Section 3.2.1.2) (Jacobsen & Schouten 2007; Porteus 2009). However, there are no such products on the market at present, and it should be noted that they would be covered by current environmental assessment procedures required for GM crops. Existing European and UK legislation and procedures for risk assessment are currently effective as a means for assessing the impact of pollen flow and other potential risks of GM crops. GM crops have been grown in several European countries and there are no reports of environmental damage to date (Brookes 2008).

Most existing GM crops (ie glyphosate herbicide resistance and *Bt* insect resistance) utilise non-plant genes. Various hypothetical scenarios could be envisaged in which these and any other transgenes would have environmental impacts and it is an integral part of existing regulation that all theoretical risks are assessed before the release of any GM plant into the environment is permitted. Specific examples in which environmental impact issues may arise include the following (Dunwell & Ford 2005):

1. Herbicide resistance. The flow of herbicide resistance genes from transgenic or non-transgenic plants to weeds may complicate weed control (Section 3.3.3.1).
2. Insect resistance. The possible effects of the insecticidal protein on non-target organisms are considered in environmental risk assessments (Marvier *et al.* 2007; Duan *et al.* 2008; Wolfenbarger *et al.* 2008). Transfer of resistance genes may provide a selective advantage to a wild relative and therefore alter its competitive ability (Section 3.3.3.2).
3. Stress tolerance. The transfer of a gene conferring tolerance to abiotic stress may theoretically alter the competitive ability of a wild relative (Section 3.3.2).
4. Viral genes. Concern has been expressed that virus resistance genes may recombine with viruses or that viral gene products may be used by and give new properties to viruses. However, virus-resistant transgenes have been used in the field to protect papaya plants against viruses in the USA (Hawaii) and there are no indications of damage. The consequence, on the contrary, has been the restoration of papaya cultivation to areas in which it was being eliminated by papaya ringspot virus (Fuchs & Gonsalves 2007) (Section 3.3.3.2).
5. Genes affecting pollen production. There are several examples in which it has been suggested that transgenes would be useful if they blocked pollen production. Such genes could be used to prevent gene flow. They could also be used to generate male sterile parents for use in hybrid seed production or as part of a strategy by which biotechnology companies could prevent use of the plants without having a proprietary chemical to release the block on pollen (Lemaux 2009). However, there are no commercial programmes to use this type of technology at present.

4.2 Human health

Food has an obvious link with health. Health is promoted by sufficient food of good quality and variety, and damaged by either too much or too little with an unbalanced nutrient content. Any intervention in food crops and their production has the potential to affect human health through nutritional content or potentially harmful components.

There is concern that certain novel crops may introduce health hazards if the product is eaten. A previous Royal Society report (2002) and the Government's GM Science Review (2003/2004) assessed the possibilities of health impacts from GM crops and found no evidence of harm. Since then no significant new evidence has appeared. There is therefore no reason to suspect that the process of genetic modification of crops should *per se* present new allergic or toxic reactions.

Crop plants have begun to be modified to produce biopharmaceuticals (Spök *et al.* 2008). Plant-produced insulin, for example, has recently entered clinical trials.[9] Inevitably there has been contamination of food crops by the biopharmaceutical and we consider it likely that future contaminations will occur. As biopharmaceuticals begin to be engineered into plants it seems most sensible that, to avoid possible risks, the target plants should not be food crops.

4.3 Social and economic systems

The introduction of new agricultural technologies can have complex social and economic consequences both for people in the immediate farming area and more distant groups through markets for land, labour and physical inputs and outputs. Beneficial technologies and techniques can take time to filter through to farmers and to expand into widespread practice. If new technologies are introduced without consideration of infrastructure, institutions, markets, cultures and practices, success can be short-lived or there can be serious unintended consequences. New technologies typically offer greater or lesser benefits depending on scale, and often benefit larger-scale farmers more than smallholders.

In parts of the developing world, when harvests are good, prices then fall as local markets become oversupplied. Investment in increased productivity therefore needs to go hand in hand with investment in better market channels and transport infrastructure. Farmers need to be able to recoup increased production costs, which is difficult if prices are falling, as well as to invest in their own farms. Increasing production without consideration of underlying economic conditions can amplify rather than reduce income inequities. The approaches of organisations such as the Gates' Foundation and the Alliance for a Green Revolution in Africa now recognise that productivity increases alone will not solve the problems of hunger and farmer livelihoods. Investment is also required in physical and institutional channels for getting inputs to farmers and crops to market.

New technologies change the productivity of different factors (particularly land and labour) and hence the value of different resources. For example, some new techniques may reduce the amount of labour required, restricting opportunities for employment in agriculture. New crop varieties may increase the yields on irrigated land, pushing up rental prices and increasing competition for water. It is often difficult to predict in advance the multiple consequences that flow from a change in the productivity of land and labour, since subsequent changes in price produce further shifts in behaviour, investment and re-allocation of land and labour. New technologies may cause a loss of income to agricultural labourers no longer needed in the fields, but this may be compensated for by the generation of jobs in crop harvesting and processing.

In all agricultural systems, there are producers of various sizes and incomes, with different levels of knowledge. New technologies are often taken up first by those farmers with access to sufficient money and information to be able to take a risk by trying something new. These early adopters may then benefit from productivity gains or lower costs, putting pressure on their poorer competitors, who risk being forced out of farming and becoming landless. Technologies can therefore widen the gap between rich and poor farmers.

Farmers' knowledge is a vital asset that needs to be brought into the process of designing more productive farming systems. Farmers have their own understanding of soils, climate and the use of different agricultural practices in their geographic location (Reij *et al.* 1996; Scoones 2001; Scoones & Thomson 2009). These need to be part of the search for solutions for improved crop productivity and more resilient agroecological systems. Decades of work has gone into the development of farmer participatory methods, for crop breeding, insect/pest control, soil conservation and fertility management (Pretty 1995). Working through farmer organisations is often the best way to gain this effective collaboration between formal science and local understandings (Pretty 2003). Maximising yield may not be the primary motivation for many farmers. Given the uncertainties of climate and markets, they may choose instead to reduce uncertainties, boosting their resilience by diversifying their output. Farmers must also serve the complex needs of consumers, who will be interested in how crops keep, how they taste and how they cook.

Seed markets, formal and informal, are vitally important. In developing countries, some farmers prefer purchased seed despite its cost because it is disease free and higher quality than saved seed.[10] The use of purchased seed also allows the farmer to benefit from the hybrid vigour of F1 seed in some species (Section 3.3.1). Some farmers will experiment with new seed but also retain their own varieties, which contain a broad spectrum of desirable characteristics. But many farmers, particularly subsistence farmers, never buy seeds, relying instead on informal systems of saving, swapping and bartering. New technologies used to develop traits that may be useful for these farmers therefore need to

9 Press Release: 'SemBioSys Genetics Inc. announces clinical results with plant-produced Insulin, SBS-1000 shown to be bioequivalent to Humulin(R) R (recombinant human insulin)', 19 March 2009; see also Aviezer et al. 2009.

10 Oral evidence from Professor Michael Lipton.

be linked to appropriate trading systems and not compromise the use of farmer-saved seed.

In Africa, innovation needs to appreciate the high density of small rural farms operating at or near subsistence level. Technologies that offer benefits only to larger farms, or force the creation of larger farms and the subsequent displacement of smallholders, may exacerbate current problems rather than alleviate poverty (Adesina 2009). If research is to focus on addressing the needs of the small-scale producers, their needs and constraints must be considered in the design of new systems.

4.3.1 Intellectual property

Many examples of new crop technology—especially GM crops—are protected by patents. The use of patents has mixed consequences (Murray & Stern 2007). In some instances—with high value crops in industrialised countries—this strategy has stimulated the commercial development of products and their application. However, intellectual property restrictions have major impacts on the access to new technologies, especially for the poor (Glover & Yamin 2003; Lea 2008). The potential for patent protection has engendered mistrust of the technology because it may restrict the options of farmers or force those with no other options into restrictive and expensive commercial relationships. For these types of application it makes sense to review alternative strategies to patenting. These alternatives include open-source strategies akin to those in the computer software industry,[11] plant variety rights (PVR) and public ownership of patents. As with other sectors, there is a clear need for the public sector, private companies and farmers to increase their capacity to design and build credible and cost-effective IPR systems that meet the needs of each country. The International Treaty on Plant Genetic Resources for Food and Agriculture recognises the connections between intellectual property regimes, biodiversity and poverty alleviation. Breeders' rights and patents need to be balanced against the diversity and availability of germplasm for agriculture and research.

We have highlighted in the previous chapter the importance of agronomy, and improvements to crop management, including mixtures and agroecological methods that reduce inputs into crop systems. These improvements to crop management are often not linked to a specific product that can be marketed or intellectual property that can be secured and may be of little interest to private R&D. Where this type of research will have environmental benefits or advantages for poor people, it will need to be supported by the public sector or other non-commercial agencies.

11 See, for example, the BIOS project at CAMBIA in Australia, available online at: http://www.bios.net.

4.4 Extension and technology transfer

Extension and technology transfer systems have always been important to agricultural development. These encapsulate a range of education, advice and consultancy activities designed to spread new research and techniques into agriculture. Many extension services around the world have been cut back and privatised over the last two decades. They are often severely underfunded despite the critical links they provide between research scientists and farmers and the vital role that they play in ensuring a return on investment in research by translating new knowledge into innovative practices. They also help to form social capital, often a necessary factor in the adoption and adaptation of new technologies. In many farming systems, extension systems tend to focus on male farmers and ignore the very significant role played by women in assuring the family's food production (World Bank 2008). Cultural factors may prevent women from being able to access advice from usually male extension staff. Hence, where women are the principal food producers, the design of research and extension systems needs to take this into account (Doss & Morris 2001).

England and Wales no longer have a public agricultural extension service. This limits the ability of UK farmers to make the most of science, or scientists to learn from agricultural experience, and reduces channels of communication between farmers about improved practices. It also limits the ability to assess technologies in their contexts. One result has been a sharp decline of confidence amongst UK farmers in government (Hall & Pretty 2008). This reduction in social capital limits the possibility of the emergence of novel and sustainable food production systems. UK farmers need ways to act collectively to maintain collective ecosystem services.

Knowledge transfer models often assume a linear model of innovation—a one-way flow from scientific discovery, through technological application, to implementation and productivity benefit. Such a model works for new seed varieties and other inputs supplied by the private sector, but tends not to address the complexity of extending changes in practice and agronomy, which require voluntary and sustained behaviour change. In many countries, attempts at knowledge exchange have attempted to make up for reductions in publicly funded applied research, demonstration and extension. New possibilities offered by ICT and mobile phones may allow information about markets, weather, new products and processes to be transmitted more effectively, and might be a way forward in many countries. Innovation in agriculture happens within basic research, within farming practice and everywhere in between. It is enabled through the links between different parts of the system.

Any approach to agricultural improvement has to recognise the distinctive contributions of public, private and charity sectors. Policy makers need to be aware of the advantages, interests and limitations of each and balance them accordingly. Large global organisations, such as the Gates, Rockefeller and Ford Foundations, the CGIAR research institutes, or multinational food and agricultural companies, all play a valuable role in generating and delivering new technologies widely. Research-based companies will inevitably focus on those areas where they will be able to capture a return on their research investments. Their targets are therefore likely to be improved products (seeds and other agricultural inputs) which can be sold. Where public sector research results in improved crops, public–private partnerships may be involved in getting improved seed to farmers.[12] But where the focus is on improved practices, investment is likely to be led by the public or charity sectors.

Market mechanisms alone are unlikely to deliver improved crops and practices that address the problems of poor people, and the solutions offered only by the private sector may bring increased productivity at too high a social and environmental cost. Public sector funding should therefore emphasise those crops or countries where the private sector does not have sufficient financial incentive to make investments for long-term return, nor address the needs of poorer farmers.

4.5 Innovating towards sustainable intensification

There will be, at least in the short term, few easy answers to the question of how to increase yields sustainably. There are likely to be trade-offs between economic gain from increased production and external impacts. The impacts of agriculture on the natural environment, societies and economies need to be understood and managed. Agricultural change is often presented as a choice between unsustainable intensification of agriculture and extensive systems with fewer negative impacts. Our conclusion is that we must aim for sustainable intensification—the production of more food on a sustainable basis with minimal use of additional land. Here, we define intensive agriculture as being knowledge-, technology-, natural capital- and land-intensive. The intensity of use of non-renewable inputs must in the long term decrease. This is particularly true for nitrogenous fertilisers that will in future need to be manufactured using renewable sources of energy and hydrogen. Finding ways of reducing the processes of denitrification will also impact positively on GHG emissions and the sustainability of agricultural systems (regardless of the source of nitrogen inputs).

Historical increases in food production have been linked to the amount of land used. There has been a 6-fold increase in the land area devoted to agriculture over the last 300 years from under 6% in 1700 to about 32% today (Klein 2001). Over half of the agriculturally usable land has been converted into land for growing crops or raising stock (Green *et al.* 2005) with commodity crops such as soya bean and oil palm accounting for large increases in recent decades, with consequences for tropical forests (Donald 2004). This rate of increase clearly cannot continue as indicated by Waggoner's calculation (1995) that the area of cropland would have to be almost doubled by 2050 in order to maintain per capita food production. However, not all current farmland would be needed if global yields per hectare achieved the level achieved in Europe and North America (Balmford *et al.* 2005; Green *et al.* 2005). Cross-country comparisons have shown lower deforestation rates in countries with higher agricultural yields (Barbier & Burgess 1997) while the expansion of the agricultural area was lower in those countries with greater increases in yield (Southgate 1994).

Cultivating any additional land is likely to require considerable investment and incur social and environmental costs which will outweigh the advantages of the extra food produced, while constraints of soil quality and climate will mean that lower than average yields will be produced as a result of this extra cultivation (FAO & OECD 2009). Ploughing additional land will also increase GHG emissions (Ovando & Caparrós 2009).

The general approach in the EU has been for widespread low-intensity agri-environment schemes, which have had limited success. The alternative and preferable approach involves greater targeting with more intensive agri-environment schemes, often involving habitat restoration, in areas of particular importance to society. The focus should be on the restoration of habitats that are most important for flood protection, carbon sequestration, critical biodiversity or enhancing the health and quality of life of local people (Sutherland 2004), linked inevitably with greater intensification in other areas. Understanding how to manage landscapes to provide these multiple benefits is a major challenge that, among other factors, will require careful and sensitive application of the technologies described in Chapter 3.

The negative impacts of past agricultural change reinforce the need proactively to assess the broader impacts of new technologies and practices, and to monitor these over time (ACRE 2007). They also provide a strong rationale for future technologies and practices that will contribute to the sustainable intensification of agricultural systems. Science is a vital part of any approach to improving agriculture. Ensuring it makes a positive difference requires analysis and management of possible negative side effects—intended and unintended—and an awareness of how scientific innovation sits in a wider context. Managing the role of science therefore requires a multi-faceted approach to policymaking, recognising the range of choices faced. The next chapter contains some recommendations to help policymakers realise the potential of science to make a positive difference to people's lives across the world.

12 See, for example, the partnership between CIMMYT, the Kenya Agricultural Research Institute, BASF (a private producer of agrochemicals), the Forum for Organic Resource Management and Agricultural Technologies, seed companies and NGOs attempts to make the Striga-killing maize-herbicide technology (de Groote et al. 2008) available to smallholders in Kenya.

5 Conclusions and recommendations

5.1 Meeting the challenge of global food security

From now until 2050, changes in population, climate and consumption patterns will put added pressure on a world food system already unable to feed its population. Food demand will increase substantially. We endorse the conclusions in several previous studies (Section 1.7) that this demand can only be satisfied if there is also a substantial increase—by between 50 and 100%—over today's levels of production of all major food crops. This increase demands urgent action, with clear short-, medium- and long-term goals.

This growth in production must be achieved for the most part without the cultivation of additional land (Section 1.3). There is insufficient water to support an increase in the cultivated area (Section 2.2) and the environmental consequences of increasing cultivated areas are undesirable (Section 1.3). Additional production will have to take place without further damage to essential ecosystem services or excessive use of non-renewable resources. We need a large-scale 'sustainable intensification' of global agriculture in which yield is assessed not just per hectare, but also per unit of non-renewable inputs and impacts upon ecosystem services. Given the expense and environmental impact of energy production, we will need agricultural systems that achieve the necessary levels of production with substantially lower reliance on fossil fuels (Section 1.5).

Sustainable intensification of global agriculture requires systems that are resilient in the face of changing climates across diverse economic, social and political conditions. It is likely that there will be trade-offs between intensification and biodiversity (Section 4.1) but the long-term goal should be to increase global food production without damage to societies or the environment.

Some organisations have concluded that the problem is one of distribution rather than production—the world currently appears to produce enough food, but the people who need it do not have access to it. Others argue that production must indeed increase, but current knowledge is sufficient—the challenge is to extend best practice into those areas that have not yet benefited from yield increases. There is also a range of views that emphasise measures to slow population growth, to reduce waste in the food chain, to discourage meat eating, and to develop the infrastructure of countries with food shortages.

The assumption of the UK government has often been that domestic food supplies can be secured through a combination of national production and global trade with diverse other sources (DEFRA 2006). We are clear in this report that the issue of food security is global. Demand for food by rich countries will divert supplies away from poorer nations and international markets alone will not equitably and sustainably address global food insecurity.

We endorse the importance of distribution, making more of existing knowledge and measures to reduce demand for certain foods. We also recognise that increases in production alone will not solve problems of poverty or hunger. The complexity of the food security challenge means that our report needs to be read in the context of others looking at different aspects of food security (Section 1.7). However, the task of increasing food availability through production on a constant area of land with reduced inputs is such an enormous challenge that no useful approach or technology can be ignored. Countries must maintain and build their capacity to innovate. Science and, in particular, the biology of crop plants and their management, is a necessary part of addressing this challenge.

Underlying our conclusions and recommendations is a sense of urgency. Even in a conventional plant breeding programme, the production of a new variety can take more than 10 years. Other innovations in crop science and related topics (such as those described in Chapter 3) have a longer cycle. Given that there could be a crisis in global food production much sooner than the 40-year horizon of this study, it is crucial therefore that the relevant research, the capacity for this research and the systems for its translation are reinforced as soon as possible.

There is a clear need for policy action and publicly funded science. The UK has a responsibility and the capacity to take a leading role in creating scientific solutions to mitigate potential food shortages. At the Rome Food Summit in June 2008, the UK led calls to create a Global Partnership for Agriculture and Food, with a commitment to double investment in agricultural research. A global initiative for the sustainable intensification of food crop production, in which biological sciences play a prominent role, is vital. We welcome government efforts, led by DEFRA, to set a clear strategy for UK food security with sustainability criteria at its heart. The next iterations of this strategy should recognise the need to look globally, in partnership with DFID (UK Department for International Development). The UK should seek to lead global food security research efforts.

Primary recommendation

1. Research Councils UK (RCUK) should develop a cross-council 'grand challenge' on global food crop security as a priority. This needs to secure at least £2 billion over 10 years to make a substantial difference. We believe this will require between £50 and £100 million per year of new government money in addition to existing research spending. This long-term UK programme should bring together all research councils, the Technology Strategy Board and key central government research funders (DFID and DEFRA) and be aligned

with comparable international activities in this area. It should be informed by dialogue with farmers, other stakeholders and members of the public. The following recommendations justify allocation of these funds to excellent and relevant research, research training and technology transfer.

5.2 Scientific targets

Past debates about agricultural technology have tended to involve different parties arguing for either advanced biotechnology including GM, improved conventional agricultural practice or low-input methods. We do not consider that these approaches are mutually exclusive: improvements to all systems require high-quality science. Global food insecurity is the product of a set of interrelated local problems of food production and consumption. The diversity of these problems needs to be reflected in the diversity of scientific approaches used to tackle them. Rather than focusing on particular scientific tools and techniques, the approaches should be evaluated in terms of their outcomes.

Recent progress in science means that yield increases can be achieved by both crop genetics (using conventional breeding and molecular GM) and crop management practices (using agronomic and agroecological methods) (Chapter 3). Advances in these two areas are interdependent. The opportunity for progress in both areas would be greatly facilitated if genome sequence data were available for multiple varieties of many different crops. We also acknowledge that developments in areas outside the remit of this study (such as chemistry, engineering and social science) will bring considerable and complementary benefits.

We stress the need for scientific developments in agronomy and agroecological practices in particular, to ensure that an ecosystem-based approach is taken in which the full consequences of changes to production systems are understood and the full range of opportunities for yield enhancement exploited. These approaches offer opportunities for relatively rapid improvements in crop management and yield increases, particularly in developing countries. New crop and soil management strategies can be introduced widely and applied to many different cultivars without the need for lengthy breeding cycles for each variety of crop (see Sections 3.3.2.1 and 3.3.3.1). An example is the push-pull approach to controlling parasitic weeds and insect pests (Section 3.3.3.1.1 and Case study 3.4). Other successful crop management approaches include integrated pest and nutrient management, soil and water conservation, conservation tillage, water harvesting, and integration of agroforestry into crop systems. However, many of the developments in crop management until now (Chapter 3) do not exploit advanced technology and developments in research. Our view is that there is great untapped potential to develop novel crop management strategies based on the type of research developments described in Chapter 3. Future research programmes should be structured to optimise the use of plants, microbes, genomes and chemicals in agricultural systems so that this untapped potential is realised.

Our enthusiasm for agronomy and agroecological approaches does not imply that genetic improvement is less important than in the past. Both genetic improvement and better crop management are vital and both should be resourced in parallel. Amongst the targets for genetic improvement of crops are some major challenges with potentially enormous benefits in food crop production that could be achieved within 20 years. There are also areas in which science could benefit food crop production in the shorter term.

The major long-term targets include modification of the metabolism of crops in order to increase the efficiency of solar energy conversion and storage or so that crops can fix nitrogen. It may also be possible to remodel the architecture of plants with radical effects on photosynthetic efficiency or by roots that more efficiently acquire mineral nutrients (Section 3.3.4.2). It may even be possible to convert annual production systems to those based on perennial types (Section 3.3.5.1). The reproductive biology of plants could also be modified with major effects on the availability and production of seed of high-yielding varieties (Section 3.3.1). These major challenges will most likely require a combination of GM and conventional breeding.

The shorter term targets of genetic improvement include production, quality and post-harvest traits. Traits affecting the ability of crops to yield well in conditions of water or temperature stress or to resist pests and diseases are particularly important for sustainable intensification. However, there is a multitude of other improved traits with significant benefit either to the producer of food or the consumer that are achievable within a 10 year period. These shorter term targets could also be achieved with a combination of GM and conventional breeding, using knowledge acquired in recent years based on work with model plants rather than crops. In the medium term it is likely that the research focus will be directly on crops and that the cycle of crop improvement can be accelerated.

Both improved crop genetics and altered crop management strategies will benefit hugely from recent advances in research methods and tools, such as genomic sequencing (Section 3.2.1.1) and high throughput analysis of small molecules (Section 3.2.2.2). These technologies make it possible to identify genes and patterns of gene expression that are associated with particular traits or with good performance of crop plants. It is then possible to target strategies for the improvement of crops or crop management strategies more precisely than at present.

The emphasis of much of the work on plants conducted over the last two decades has been on model species—Arabidopsis, tobacco and other plants that are easy to use for experimentation. Molecular genetics research has been highly successful because it focused, at least initially, on model species. However, high throughput methods can now be applied to crops as well as model species. Research applied directly to crops will generate benefits that appear more rapidly and that are more easily translatable than at present. Crop genome sequence information is a necessary foundation for the use of high throughput analysis methods and computational approaches. The cost of genome sequencing is reducing rapidly and it is therefore an achievable target to have the genome sequences from several varieties of all significant crops including those used in developing countries.

Crop improvement based on conventional breeding will continue to be important. Conventional breeding strategies are often enhanced by the recruitment of additional genetic diversity from wild crop relatives. Many cycles of crossing and backcrossing (pre-breeding) are required to detect and map useful traits from wild relatives prior to normal breeding. Pre-breeding is long term and it is a lower priority for private breeders because the payoff is slow, although it can be accelerated through the use of genome sequence data and marker assisted selection (Section 3.2). This enrichment of genetic diversity in the breeding pool is crucial to prospects for continued yield increases. Pre-breeding programmes with the major crops need to be established as soon as possible and maintained. These pre-breeding activities are most appropriately carried out in the public sector so that the resources generated are widely available, to ensure long-term commitment to germplasm enrichment, and to train the next generation of plant breeders.

Specific research recommendations

2. UK research funders should support public sector crop breeding and genomics programmes to understand, preserve and enhance the germplasm of priority crops and train the next generation of plant breeders. International programmes in collaboration with Consultative Group on International Agricultural Research (CGIAR) centres and others in Africa and India should include millet, sorghum and rice. The top UK priority should be wheat, followed by barley, oil seed rape, potato, vegetable brassicas and other horticultural crops. Public sector support for breeding needs to emphasise longer term strategic approaches than can be expected from the private sector and develop traits from public sector research.

3. RCUK should increase support for ecosystem-based approaches, agronomy and the related sciences that underpin improved crop and soil management.

4. RCUK, and BBSRC in particular, should support long-term high-risk approaches to high-return targets in genetic improvement of crops. These targets include GM crops with improved photosynthetic efficiency or nitrogen fixation. High risk approaches might also produce GM or conventionally bred crops with reduced environmental impact because they need lower fertiliser input or could be grown as perennials. Research into conventional breeding and GM approaches to increased yield and resistance to stress and disease should also continue to be funded.

5.3 The capacity to innovate

Development of new technologies for agriculture requires a cross-disciplinary approach in which mathematics, physics, chemistry, ecology and the crop sciences (including genetics, pathology, entomology and soil science) are integrated. The outcome of research in these subjects can be used to develop predictive understanding and robust options that, when linked with social and economic science, can be used for the required sustainable intensification of agriculture.

Unfortunately many universities have closed down or reduced their teaching and research in agriculture and crop science. There is a shortage of expertise in important topics, often in subjects that are closer to the farmer, where UK scientists and agronomists have traditionally played a leading role. Several key subjects are particularly vulnerable, including plant breeding, various aspects of pathology including mycology and virology, whole plant and crop physiology, agricultural entomology, nematology and soil science. There is a danger that valuable skills will be lost as researchers and teachers retire. In the few universities where relevant subjects are taught there is no evidence that students are attracted in large numbers to the few courses in these science areas, indicating that the existing courses may not be appropriately structured or presented. We welcome the BBSRC's interest in addressing skill gaps in this area. We recommend that universities should review their strategies for attracting students to the disciplines that are relevant to developments in food crop science and that they aim to retain expertise and the potential for cross-disciplinary approaches in science related to agriculture and its application. In particular, there is scope for enhancement of the plant science component in the A level Biology syllabus.

This shift away from the traditional subjects in agriculture has been accompanied by a move towards molecular biology (Tatchell 2005). Genomics and genetics, especially in model plant species, have been well supported in recent years in the UK and the rest of Europe. We welcome this support that has resulted in rapid progress towards understanding long-standing problems such as disease resistance mechanisms, developmental control, epigenetics, hormone action and plant physiology. The revival of other subjects should not be at the expense of the effort in molecular biology and genomics because, as discussed in Section 5.2, they are fundamental to necessary developments in all aspects of genetic improvement and new approaches in the management of crops.

Industry and public sector research institutes are also important in maintaining the capacity to innovate. Industry has considerable expertise, particularly in seeds, breeding and molecular GM. Research institutes have the opportunity to preserve neglected key subjects independently of the enthusiasm of students for the subject and they have the infrastructure that allows long-term challenges to be tackled. They can also focus on aspects of food crops that might benefit the environment or poor countries but would be insufficiently profitable for private sector investment.

Building on efforts by DFID and the Agriculture and Horticulture Development Board (AHDB), training and development of UK crop scientists should be broadened to include, where possible, aspects of translation and extension. Universities, research funders and institutes should look to internationalise their training through placements in developing countries. We also welcome, as a model for future strategic research, the Sustainable Agriculture Research for International Development (SARID) initiative supported by BBSRC and DFID.

Research capacity recommendations

5. Universities should work with funding bodies to reverse the decline in subjects relevant to a sustainable intensification of food crop production, such as agronomy, plant physiology, pathology and general botany, soil science, environmental microbiology, weed science and entomology. We recommend that attempts by universities and funding bodies to address this skills gap look globally. Studentships and postdoctoral research positions should provide targeted subsidies to scientists in developing countries to visit the UK and work with UK researchers.
6. In order to sustain research capacity and maximise the potential for research to be utilised, crop science research funded by BBSRC, DFID and others, together or separately, should have regular calls for proposals rather than one-off grant rounds. Grants awarded in phases will allow researchers to pursue successful ideas in the field or in new countries.
7. DFID should work with the CGIAR institutes to develop new mechanisms for international research collaborations with emerging scientific bases such as in China, Brazil, India and South Africa. Through its support for CGIAR, DFID should work with research funders and UK scientists to strengthen collaborations with international researchers. The UK should work with other partner countries to prioritise global agricultural research within the forthcoming European Commission Eighth Framework Programme.

5.4 Making science make a difference

5.4.1 Translation and extension

Unless policy heeds the specific needs of the poorest people, they are less likely to benefit from technologies to improve crop production and more likely to suffer from poor management and regulation of such new technologies. Global equity—the need to narrow the gap between rich and poor—is an essential goal in policies aimed at improving food production. Scientific research needs to understand and focus on the specific needs of farmers in the poorest countries, many of whom are women (Section 4.4). Policies for science and innovation, including extension services and intellectual property regimes, need to be aligned to ensure that the benefits of research are shared.

Relevant expertise exists within the public, private and charities sectors. There is an opportunity for research in all sectors to help achieve sustainable intensification of global agriculture. Strong public sector engagement is essential to ensure long-term programmes are implemented that the private sector would neglect because of insufficient short-term profitability. Market mechanisms alone are unlikely to deliver improved crops and practices that address the problems of poor people. Carrying out basic research in the public sector should also reduce the likelihood of intellectual property constraints preventing the widespread use of the technology in developing countries or for environmental benefit. However, the engagement of the private sector is essential for effective translation of the developments in publically funded science into agricultural applications, especially in industrialised countries.

To ensure that food crop science research is appropriately targeted there needs to be good communication between researchers, farmers and industry in both industrialised and developing countries. In that spirit we welcome the 'food strategy task force' created by the UK government to coordinate policy. It oversees a research strand, under the Government Chief Scientific Adviser, and a 'vision' strand, run by DEFRA. We welcome moves towards such a joined-up approach, but the unavoidably global vision for food security must also have the involvement and commitment of other government departments including DFID, BIS and DECC, at its core.

Agricultural extension services should be a key component of any strategy to ensure that science developments are appropriately developed and targeted. These services provide a mechanism for informing farmers about new technological developments, as well as providing a route for feedback from farmers to the research base. They could also help inform the research community so that technological innovation is appropriately targeted. Extension services also help farmers work together for the benefits of food output and the environment. We support the Technology Strategy Board's plans to create a new innovation platform on the sustainable agri-food chain, with a

UK focus. We have identified a major need to review the support for and provision of extension services in the UK and more widely, particularly in developing countries (Section 4.4).

> Translation and extension recommendations
>
> 8. Research that links UK science with developing countries, funded by DFID, BBSRC and others, should work with farmers and extension services in target countries to make sure that benefits are captured and made accessible to poor farmers.
> 9. As part of the RCUK grand challenge there should be support for joint initiatives between the public sector and industry in which the explicit aim is the translation and application of previously executed basic research.
> 10. The UK department for Business, Innovation and Skills should review relevant intellectual property systems to ensure that patenting or varietal protection of new seed varieties does not work against poverty alleviation, farmer-led innovation or publicly funded research efforts.

5.4.2 Governance

We have highlighted various social and environmental consequences of conventionally intensive agriculture (Chapter 4). These past experiences are a lesson for the future sustainable intensification of agriculture and should inform the governance of new approaches to food crop production.

The IAASTD (2008a) concluded that the assessment of new technologies for agriculture lags behind their development: 'uncertainty about possible benefits and damage is unavoidable'. Existing regulations and guidelines in agriculture seek to protect against damage to the environment, but they should also involve an assessment of *benefits* alongside an appreciation of the risks and uncertainties. The Comparative Sustainability Assessment conducted by the Advisory Committee on Releases to the Environment (ACRE 2007) provides a useful guide in this area. Assessment of benefits, risks and uncertainties should be seen broadly, and include the wider impacts of new technologies and practices on economies and societies. Stakeholders and members of the public need to be engaged in dialogue about new research and technology options. This dialogue should start with the problem that needs to be addressed, ie food security, rather than presupposing any particular solutions.

We hesitate to recommend additional regulation of new crops or to support more widespread regulation of science-based technologies in agriculture. However, we agree with the Royal Commission for Environmental Pollution (RCEP) that governance of new technologies should be informed, transparent, prospective and adaptive (RCEP 2008). We believe that regulation needs to be built on some key principles. Regulation should:

- be science-based, acknowledging areas of uncertainty alongside the assessments of risk and benefit of different approaches;
- be proactive, drawing on a wide range of expertise (scientific and social scientific) to horizon scan for potential developments in technology and practice and their intended and unintended consequences;
- be built on a shared vision of the future of agricultural sustainability, informed by dialogue with farmers, NGOs, the public and scientists;
- aim to steer research of public benefit towards addressing human needs;
- be proportionate; large-scale agricultural applications should require greater regulation than research;
- reflect public values, informed by a joined-up process of continual intelligence gathering; and
- acknowledge wider social and economic uncertainties.

We consider that continuous horizon scanning to identify future issues, combined with reviews when appropriate, models and experiments, should improve our capacity to make decisions when the evidence is available. This would reduce the risk of repeating some of the problems of biofuels, where the policy decisions were made with little information on the social and environmental consequences (Danielsen *et al.* 2009). We believe that DEFRA and DFID need to have access to independent scientific, social scientific and other stakeholder expertise (including representatives from NGOs) to evaluate new technological possibilities for global agriculture and offer advice for strategic research and extension.

> Governance recommendations
>
> 11. UK government should work with EU partner countries over the next five to ten years to develop a system of regulation for new agricultural processes and products, based on shared principles.
> 12. DFID and DEFRA should build on the work of the Food Research Partnership to establish an independent food security advisory function. This would work openly with stakeholders to help the government put future technological options into a broad social and economic context and appraise their benefits and uncertainties alongside alternatives. It would feed into and stimulate similar international efforts at CGIAR and UN level.

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7 Annexes

7.1 Project terms of reference

There are significant and growing concerns about the long-term security and sufficiency of global food-crop production due to the potential impact of many factors including climate change, population growth and changing consumption patterns, increasing urbanisation and prosperity, and competing demands for land. This study will assess the extent to which the biological and related sciences can contribute to enhancing global food-crop production over the next 30 years within the context of changing global and regional demand during this period. The study will be aimed primarily at policy makers, including those in UK Government, EU and further afield (for example, developing countries where appropriate). This work should also be of interest to other stakeholders, for example non-governmental organisations with interests in agriculture and food-crop production and it is anticipated that it will help inform the media about the contribution of science to food-crop production.

The study aims to:

- Identify and assess challenges to food-crop production in the developed and developing world.
- Evaluate targets and mechanisms for potential improvement of food-crop production including through increasing yields, enhancing nutritional value, minimising waste, increasing resource-use efficiency and reducing reliance on non-renewable inputs.
- Identify and assess biological approaches towards enhancing food-crop production. These may include biotechnological approaches to the optimisation of the genetic make-up of crops and other biological and agroecological methods such as biocontrol.
- Consider possible positive and negative impacts of crop production technologies and practices on, for example, the environment, human health and economies.
- Identify and assess any barriers to the effective introduction and use of biological approaches for enhancing food-crop production. Such limitations may include regulatory hurdles, the adequacy of the skills base and research infrastructure, knowledge and technology transfer and intellectual property rights.

Within this project, use of the term ‘food-crop’ covers annual and perennial crops grown for both human and animal consumption. Horticultural crop production methods and technologies are included in the scope of this project. The study will not directly consider non-food crops (such as biofuels) or dairy, livestock and fish production.

7.2 Call for evidence

7.2.1 Written evidence

The following organisations and individuals provided written submissions in response to the call for evidence. Organisations or individuals who have asked for their evidence not to be published have been omitted. Copies of the submissions can be obtained from the Royal Society website (http://royalsociety.org/reapingthebenefits).

Professor Bill Adams, University of Cambridge, UK.

Agricultural Biotechnology Council (abc), UK.

Dr Pedro Arraes, Embrapa, Brazil.

Professor Howard Atkinson, University of Leeds, UK.

Professor Jeff Bale, University of Birmingham, UK.

Sir John Beringer CBE.

Dr John Bingham CBE FRS.

British Society of Animal Science, UK.

British Society of Plant Breeders Ltd, UK.

Dr Stuart Bunting, University of Essex, UK.

Ayub Chege.

Professor Edward Cocking FRS, University of Nottingham, UK.

Cornell International Institute for Food, Agriculture and Development, USA.

Crop and Soil Systems Research Group, Scottish Agricultural College, UK.

CropLife International, Belgium.

DEFRA, UK.

Department of Plant Sciences, University of Oxford, UK.

Departments of Animal and Plant Sciences and Molecular Biology and Biotechnology, University of Sheffield, UK.

DG Research, EU.

Dr Amadou Makhtar Diop, Rodale Institute, USA.

Professor Thomas Dobbs, South Dakota State University, USA.

Donald Danforth Plant Science Center, USA.

Professor Tim Dyson, London School of Economics, UK.

European Plant Science Organisation, Belgium.

ESRC Innogen Centre, UK.

European Technology Platform 'Plants for the Future', Belgium.

Faculty of Life Science, University of Reading, UK.

Professor Alastair Fitter FRS, University of York, UK.

Dr Richard Flavell CBE FRS, Ceres Inc, USA.

Food Ethics Council, UK.

Dr Susan Gallagher, Scottish Government, UK.

Genewatch UK.

Sir Ben Gill, Hawkhills Consultancy Ltd, UK.

Global Crop Diversity Trust, Italy.

Global Environmental Change and Food Systems, UK.

GM Freeze, UK.

Dr Duncan Greenwood CBE FRS, Warwick HRI, UK.

Professor Perry Gustafson, Agricultural Research Service, USDA, USA.

Dr Dimah Habash, Rothamsted Research, UK.

HGCA, UK.

Institute of Biological and Environmental Sciences, University of Aberdeen, UK.

Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University, UK.

John Innes Centre, UK.

KWS UK Ltd, UK.

Professor Roger Leakey.

Professor Chris Leaver FRS.

Dr Jill Lenne.

Professor Keith Lindsey, Durham University, UK.

Jeff McNeely, International Union for Conservation of Nature, Switzerland.

Professor Graham Moore, John Innes Centre, UK.

Professor Donal Murphy-Bokern, Murphy-Bokern Konzepte, Germany.

Professor Nagib Nassar, Universidade de Brasilia, Brazil.

National Farmers' Union, UK.

National Institute of Agricultural Botany, UK.

Natural England, UK.

Nickerson UK Ltd, UK.

David Njubi, National Council for Science and Technology, Kenya.

Nuffield Council on Bioethics, UK.

Dr Rodomiro Ortiz, CIMMYT, Mexico.

Oxitec Ltd, UK.

Professor Guy Poppy, University of Southampton, UK.

Professor John Postgate.

Practical Action, UK.

Professor Arpad Pusztai.

Professor Rudy Rabbinge, Wageningen University, The Netherlands.

Dr Elibio Rech, Embrapa, Brazil.

Dr Ian Robertson, University of Zimbabwe.

Niels Roling and Jannice Jiggins, Wageningen University, The Netherlands.

Royal Society of Chemistry and Institute of Chemical Engineering, UK.

Science Council of Japan.

Scottish Crop Research Institute, UK.

Professor Toni Slabas, Durham University, UK.

The Soil Association, UK.

Sir Edwin Southern FRS.

Dr David Steane.

Syngenta, UK.

Professor Anthony Trewavas FRS, University of Edinburgh, UK.

Tropical Agriculture Association, UK.

University of Leeds, UK.

University of Nottingham, UK.

Professor Richard Visser, Wageningen University, The Netherlands.

Professor Bryan Walker.

Dr Steve Wilcockson, Newcastle University, UK.

Dr David Wood.

Yara (Prosyn) Ltd, UK.

Zurich-Basel Plant Science Center, Switzerland.

7.2.2 Oral evidence

We are grateful to the following for presenting oral evidence at a meeting of the working group:

Dr Bruce Lankford and Dr Shawn McGuire, School of Development Studies, University of East Anglia, UK.

Professor Michael Lipton, Poverty Research Unit, University of Sussex, UK.

In October 2008, the Royal Society and others held a two-day, multilateral workshop on food-crop production at the National Institute for Plant Genome Research, Delhi, India. Several working group members attended this meeting, and the discussion which took place at the workshop contributed to the evidence for the study. A report on this workshop can be found on the Royal Society's website at: http://royalsociety.org/document.asp?tip=0&id=8434.

The following individuals attended a workshop for non-governmental organisations, held at the Royal Society on 8 May 2009:

Lea Borkenhagen, Oxfam, UK.

Sue Davies, Which?, UK.

Mark Driscoll, WWF, UK.

Patrick Mulvany, Practical Action, UK.

Tom Oliver, Campaign to Protect Rural England, UK.

8 Glossary

Abiotic stresses	Constraints derived from non-living factors—heat, water etc.
ACRE	Advisory Committee on Releases to the Environment.
Aerenchyma	An airy tissue found in the roots of plants.
Agroecology	The science of sustainable agriculture, studying interactions between plants, animals, humans and the environment within agricultural systems.
Agroforestry	The combination of agricultural and forestry technologies.
Agronomy	The science of soil management and crop production.
AHDB	Agriculture and Horticulture Development Board.
Allele	One of several DNA sequences that can be found at the same physical gene locus.
Allelopathy	The phenomenon whereby one organism produces biochemicals that influence the growth and development of other organisms.
Aluminosilicate	Minerals composed of aluminium, silicon and oxygen.
Apomixis	Asexual seed production.
Aquifer	Underground layer of permeable material from which groundwater can be extracted.
Arabidopsis	A small flowering plant that is widely used as a model organism in plant biology.
Arthropod	An invertebrate animal with jointed legs and a segmented body with a horny or chitinous casing (exoskeleton), which is shed periodically and replaced as the animal grows.
BBSRC	UK Biotechnology and Biological Sciences Research Council.
Biocontrol	Biological control of pests and diseases.
Biodiversity	The variability among all living organisms from all sources (from the Convention on Biological Diversity).
Biofortification	Breeding crops to increase their nutritional value.
Biomass	The mass of living biological organisms in a given area or ecosystem at a given time.
Biopharmaceuticals	Drugs produced using biotechnology.
Biosensor	An analytical device combining a biological component with a physicochemical component.
Biotic stresses	Constraints derived from living factors—pests, diseases, etc.
Brassicas	Plants in the mustard family.
Carbon sequestration	The deliberate removal or storage of carbon in a place (a sink) where it will remain.
CGIAR	Consultative Group on International Agricultural Research.
CIMMYT	International Maize and Wheat Improvement Centre.
Cisgenic modification	A type of genetic modification where the genes inserted are from the same species as the modified plant.
Coir	A course fibre extracted from the outer shell of a coconut.
Cultivar	A plant cultivated for distinct characteristics.
DEFRA	UK Department for Environment, Food and Rural Affairs.
Denitrification	A microbial process which transforms nitrate compounds into nitrogen gas.

Desertification	The degradation of land in dry areas.
DFID	UK Department for International Development.
Ecosystem	A system of living organisms interacting with each other and with their physical environment.
Endoparasites	A parasite which feeds from inside the host.
Entomology	The study of insects.
Epigenetics	The study of how genes produce their effect on the phenotype.
Eutrophication	The concentration of chemical nutrients in an ecosystem.
Extension services	Services which connect farmers with new innovations.
F1 hybrid	First generation offspring of different parents.
FAO	Food and Agricultural Organisation (of the United Nations).
Friable	Easily crumbled.
GEF	Global Environment Facility.
Genetic improvement	The changing of a genome through breeding or genetic modification to introduce desirable traits.
Genetic modification	The direct introduction of novel genes into an organism's DNA.
Genomics	The analysis of genome sequences.
Genotype	The combination of genes which determines a particular characteristic.
Germplasm	The collection of genetic resources for a particular organism.
GHG	Greenhouse gases.
Glyphosate	A broad spectrum herbicide.
GM	Genetically modified.
Green revolution	The crop varietal development which took place in the 1950s–1960s.
Heterosis	Hybrid vigour.
High-throughput analysis	A technique which allows the fast analysis of large numbers of molecules in parallel.
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development.
Intensification	An increase in the productivity of existing land and water resources.
Intercropping	The practice of cultivating two or more crops in the same place at the same time.
IPCC	International Panel on Climate Change.
IPR	Intellectual property rights.
IRRI	International Rice Research Institute.
ISAAA	International Service for the Acquisition of Agri-biotech Applications.
Lepidoptera	Order of insects including moths and butterflies.
Linkage drag	The genetic linking of desired traits to undesired traits.
MAS	Marker-assisted selection. The use of DNA markers to select plants for a breeding programme.
Mass spectrometry	An analytical technique used to determine the chemical structure of molecules.
Metabolites	The intermediates and products of metabolism.
Micronutrients	Nutrients essential to plant health, required in small quantities.

Millenium Ecosystem Assessment	A United Nations programme which assessed the consequences of ecosystem change for human well-being and the scientific basis for action needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being.
Molecular genetics	The study of structure and function of genes at a molecular level.
Monocarpic	A term used to describe plants which die after seeding.
Monoculture	The practice of growing a single crop over a large area.
Multifunctionality	The interconnectedness of agriculture with societies, economies and the environment.
Mycology	The study of fungi.
Mycorrhiza	Symbiotic relationship between a fungus and the roots of a plant.
Nematology	The study of nematodes (roundworms).
NGO	Non-governmental organisation.
Nitrogen fixation	The biological process by which nitrogen in the atmosphere is converted into ammonia.
NRC	National Research Council.
Nutrient cycling	The movement of nutrients through an ecosystem.
OECD	Organisation for Economic Co-operation and Development.
Orphan crops	Minor crops.
Parasitism	A relationship between two different species where one (the parasite) benefits at the expense of the other (the host).
Perennial	A plant that lives for more than 2 years.
Phenotype	The observable properties of an organism.
Photosynthesis	A process which converts carbon dioxide into organic compounds using energy from sunlight.
Phytoplankton	Photosynthetic plankton.
Phytoplasma	Bacteria which are obligate parasites of plant tissue and insect vectors.
Phytoremediation	The treatment of environmental problems through the use of plants.
Prebreeding	Cycles of crossing and backcrossing used to select desired traits in plants.
Predation	The hunting of one organism by another.
PVR	Plant variety rights.
Quantitative trait loci (QTL)	Stretches of DNA strongly associated with the gene for a particular trait.
RCEP	Royal Commission for Environmental Pollution.
Refugia	Areas which provide shelter from environmental change.
Resilience	The ability of a system to recover from, or adjust to, change.
Rhizobia	Soil bacteria which fix nitrogen after becoming established in the roots of legumes.
Rhizosphere	The soil region immediately surrounding plant roots.
SARID	Sustainable Agriculture Research for International Development programme run by DFID.
Semiochemical	A chemical substance that carries a message.
Spores	Reproductive structures which can be dispersed and survive for a long time in unfavourable conditions.

Stem Rust	A fungal disease of cereal crops.
Stomatal conductance	The rate at which water evaporates from the stomata of a plant.
Striga	A parasitic weed.
Stylet	A hardened mouthpart of some invertebrates.
Sustainable system	A system which incorporates the principles of persistence (the capacity to continue to deliver desired outputs over long periods of time thus conferring predictability); resilience (the capacity to absorb, utilise or even benefit from perturbations, and so persist without qualitative changes in structure); autarchy (the capacity to deliver desired outputs from inputs and resources acquired from within key system boundaries); and benevolence (the capacity to produce desired outputs while sustaining the functioning of ecosystem services and not causing depletion of natural capital).
Symbiotic	Describes a close interaction between different species.
Transgenic modification	A type of genetic modification where the genes inserted are from a different species to the modified plant.
Transgressive segregation	The formation of extreme phenotypes in hybrid populations compared to parental lines.
Transpiration	The evaporation of water from plants.
UNDP	United Nations Development Programme.
UNEP	United Nations Environment Programme.
UNESCO	United Nations Educational Scientific and Cultural Organisation.
Virology	The study of viruses.
Water Footprint	How much water an activity requires in a year (Gm^3/yr).
WDR	World Development Report.
WHO	World Health Organisation.
WUE	Water use efficiency.

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Food Security: The Challenge of Feeding 9 Billion People

H. Charles J. Godfray *et al.*

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REVIEW

Food Security: The Challenge of Feeding 9 Billion People

H. Charles J. Godfray,[1]* John R. Beddington,[2] Ian R. Crute,[3] Lawrence Haddad,[4] David Lawrence,[5] James F. Muir,[6] Jules Pretty,[7] Sherman Robinson,[8] Sandy M. Thomas,[9] Camilla Toulmin[10]

Continuing population and consumption growth will mean that the global demand for food will increase for at least another 40 years. Growing competition for land, water, and energy, in addition to the overexploitation of fisheries, will affect our ability to produce food, as will the urgent requirement to reduce the impact of the food system on the environment. The effects of climate change are a further threat. But the world can produce more food and can ensure that it is used more efficiently and equitably. A multifaceted and linked global strategy is needed to ensure sustainable and equitable food security, different components of which are explored here.

The past half-century has seen marked growth in food production, allowing for a dramatic decrease in the proportion of the world's people that are hungry, despite a doubling of the total population (Fig. 1) (*1*, *2*). Nevertheless, more than one in seven people today still do not have access to sufficient protein and energy from their diet, and even more suffer from some form of micronutrient malnourishment (*3*). The world is now facing a new set of intersecting challenges (*4*). The global population will continue to grow, yet it is likely to plateau at some 9 billion people by roughly the middle of this century. A major correlate of this deceleration in population growth is increased wealth, and with higher purchasing power comes higher consumption and a greater demand for processed food, meat, dairy, and fish, all of which add pressure to the food supply system. At the same time, food producers are experiencing greater competition for land, water, and energy, and the need to curb the many negative effects of food production on the environment is becoming increasingly clear (*5*, *6*). Overarching all of these issues is the threat of the effects of substantial climate change and concerns about how mitigation and adaptation measures may affect the food system (*7*, *8*).

A threefold challenge now faces the world (*9*): Match the rapidly changing demand for food from a larger and more affluent population to its supply; do so in ways that are environmentally and socially sustainable; and ensure that the world's poorest people are no longer hungry. This challenge requires changes in the way food is produced, stored, processed, distributed, and accessed that are as radical as those that occurred during the 18th- and 19th-century Industrial and Agricultural Revolutions and the 20th-century Green Revolution. Increases in production will have an important part to play, but they will be constrained as never before by the finite resources provided by Earth's lands, oceans, and atmosphere (*10*).

Patterns in global food prices are indicators of trends in the availability of food, at least for those who can afford it and have access to world markets. Over the past century, gross food prices have generally fallen, leveling off in the past three decades but punctuated by price spikes such as that caused by the 1970s oil crisis. In mid-2008, there was an unexpected rapid rise in food prices, the cause of which is still being debated, that subsided when the world economy went into recession (*11*). However, many (but not all) commentators have predicted that this spike heralds a period of rising and more volatile food prices driven primarily by increased demand from rapidly developing countries, as well as by competition for resources from first-generation biofuels production (*12*). Increased food prices will stimulate greater investment in food production, but the critical importance of food to human well-being and also to social and political stability makes it likely that governments and other organizations will want to encourage food production beyond that driven by simple market mechanisms (*13*). The long-term nature of returns on investment for many aspects of food production and the importance of policies that promote sustainability and equity also argue against purely relying on market solutions.

So how can more food be produced sustainably? In the past, the primary solution to food shortages has been to bring more land into agriculture and to exploit new fish stocks. Yet over the past 5 decades, while grain production has more than doubled, the amount of land devoted to arable agriculture globally has increased by only ~9% (*14*). Some new land could be brought into cultivation, but the competition for land from other human activities makes this an increasingly unlikely and costly solution, particularly if protecting biodiversity and the public goods provided by natural ecosystems (for example, carbon storage in rainforest) are given higher priority (*15*). In recent decades, agricultural land that was formerly productive has been lost to urbanization and other human uses, as well as to desertification, salinization, soil erosion, and other consequences of unsustainable land

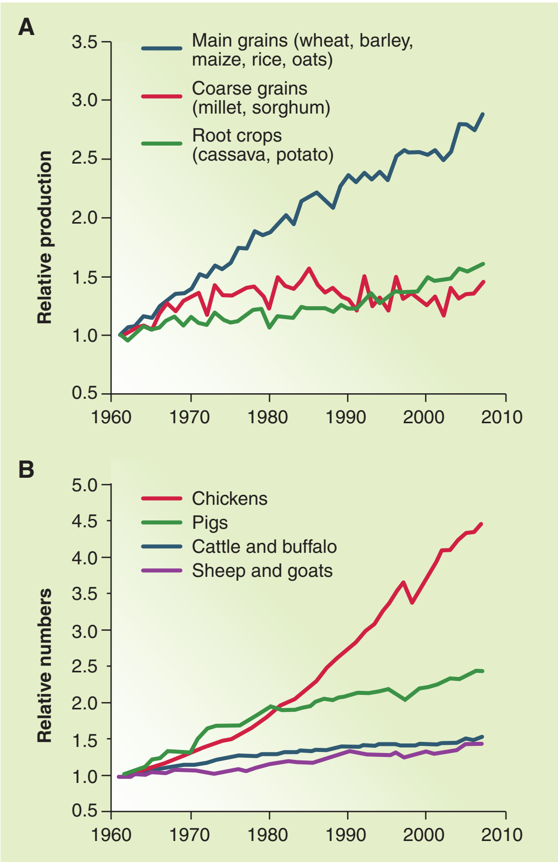

Fig. 1. Changes in the relative global production of crops and animals since 1961 (when relative production scaled to 1 in 1961). (**A**) Major crop plants and (**B**) major types of livestock. [Source: (*2*)]

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management (*16*). Further losses, which may be exacerbated by climate change, are likely (*7*). Recent policy decisions to produce first-generation biofuels on good quality agricultural land have added to the competitive pressures (*17*). Thus, the most likely scenario is that more food will need to be produced from the same amount of (or even less) land. Moreover, there are no major new fishing grounds: Virtually all capture fisheries are fully exploited, and most are overexploited.

Recent studies suggest that the world will need 70 to 100% more food by 2050 (*1*, *18*). In this article, major strategies for contributing to the challenge of feeding 9 billion people, including the most disadvantaged, are explored. Particular emphasis is given to sustainability, as well as to the combined role of the natural and social sciences in analyzing and addressing the challenge.

Box 1. Sustainable intensification.

Producing more food from the same area of land while reducing the environmental impacts requires what has been called "sustainable intensification" (*18*). In exactly the same way that yields can be increased with the use of existing technologies, many options currently exist to reduce negative externalities (*47*). Net reductions in some greenhouse gas emissions can potentially be achieved by changing agronomic practices, the adoption of integrated pest management methods, the integrated management of waste in livestock production, and the use of agroforestry. However, the effects of different agronomic practices on the full range of greenhouse gases can be very complex and may depend on the temporal and spatial scale of measurement. More research is required to allow a better assessment of competing policy options. Strategies such as zero or reduced tillage (the reduction in inversion ploughing), contour farming, mulches, and cover crops improve water and soil conservation, but they may not increase stocks of soil carbon or reduce emissions of nitrous oxide. Precision agriculture refers to a series of technologies that allow the application of water, nutrients, and pesticides only to the places and at the times they are required, thereby optimizing the use of inputs (*48*). Finally, agricultural land and water bodies used for aquaculture and fisheries can be managed in ways specifically designed to reduce negative impacts on biodiversity.

Closing the Yield Gap

There is wide geographic variation in crop and livestock productivity, even across regions that experience similar climates. The difference between realized productivity and the best that can be achieved using current genetic material and available technologies and management is termed the "yield gap." The best yields that can be obtained locally depend on the capacity of farmers to access and use, among other things, seeds, water, nutrients, pest management, soils, biodiversity, and knowledge. It has been estimated that in those parts of Southeast Asia where irrigation is available, average maximum climate-adjusted rice yields are 8.5 metric tons per hectare, yet the average actually achieved yields are 60% of this figure (*19*). Similar yield gaps are found in rain-fed wheat in central Asia and rain-fed cereals in Argentina and Brazil. Another way to illustrate the yield gap is to compare changes in per capita food production over the past 50 years. In Asia, this amount has increased approximately twofold (in China, by a factor of nearly 3.5), and in Latin America, it has increased 1.6-fold; in Africa, per capita production fell back from the mid-1970s and has only just reached the same level as in 1961 (*2*, *20*). Substantially more food, as well as the income to purchase food, could be produced with current crops and livestock if methods were found to close the yield gaps.

Low yields occur because of technical constraints that prevent local food producers from increasing productivity or for economic reasons arising from market conditions. For example, farmers may not have access to the technical knowledge and skills required to increase production, the finances required to invest in higher production (e.g., irrigation, fertilizer, machinery, crop-protection products, and soil-conservation measures), or the crop and livestock varieties that maximize yields. After harvest or slaughter, they may not be able to store the produce or have access to the infrastructure to transport the produce to consumer markets. Farmers may also choose not to invest in improving agricultural productivity because the returns do not compare well with other uses of capital and labor.

Exactly how best to facilitate increased food production is highly site-specific. In the most extreme cases of failed states and nonfunctioning markets, the solution lies completely outside the food system. Where a functioning state exists, there is a balance to be struck between investing in overall economic growth as a spur to agriculture and focusing on investing in agriculture as a spur to economic growth, though the two are obviously linked in regions, such as sub-Saharan Africa, where agriculture typically makes up 20 to 40% gross domestic product. In some situations, such as low-income food-importing countries, investing purely in generating widespread income growth to allow food purchases from regions and countries with better production capabilities may be the best choice. When investment is targeted at food production, a further issue is the balance between putting resources into regional and national infrastructure, such as roads and ports, and investing in local social and economic capital (*21*, *22*).

A yield gap may also exist because the high costs of inputs or the low returns from increased production make it economically suboptimal to raise production to the maximum technically attainable. Poor transport and market infrastructure raise the prices of inputs, such as fertilizers and water, and increase the costs of moving the food produced into national or world markets. Where the risks of investment are high and the means to offset them are absent, not investing can be the most rational decision, part of the "poverty trap." Food production in developing countries can be severely affected by market interventions in the developed world, such as subsidies or price supports. These need to be carefully designed and implemented so that their effects on global commodity prices do not act as disincentives to production in other countries (*23*).

The globalization of the food system offers some local food producers access to larger markets, as well as to capital for investment. At the aggregate level, it also appears to increase the global efficiency of food production by allowing regional specialization in the production of the locally most appropriate foods. Because the expansion of food production and the growth of population both occur at different rates in different geographic regions, global trade is necessary to balance supply and demand across regions. However, the environmental costs of food production might increase with globalization, for example, because of increased greenhouse gas emissions associated with increased production and food transport (*24*). An unfettered market can also penalize particular communities and sectors, especially the poorest who have the least influence on how global markets are structured and regulated. Expanded trade can provide insurance against regional shocks on production such as conflict, epidemics, droughts, or floods—shocks that are likely to increase in frequency as climate change occurs. Conversely, a highly connected food system may lead to the more widespread propagation of economic perturbations, as in the recent banking crisis, thus affecting more people. There is an urgent need for a better understanding of the effects of globalization on the full food system and its externalities.

The yield gap is not static. Maintaining, let alone increasing, productivity depends on continued innovation to control weeds, diseases, insects, and other pests as they evolve resistance to different control measures, or as new species emerge or are dispersed to new regions.

Innovation involves both traditional and advanced crop and livestock breeding, as well as the continuing development of better chemical, agronomic, and agro-ecological control measures. The maximum attainable yield in different regions will also shift as the effects of climate change are felt. Increasing atmospheric CO_2 levels can directly stimulate crop growth, though within the context of real agricultural production systems, the magnitude of this effect is not clear (*7*). More important will be the ability to grow crops in places that are currently unsuitable, particularly the northern temperate regions (though expansion of agriculture at the expense of boreal forest would lead to major greenhouse gas emissions), and the loss of currently productive regions because of excessively high temperatures and drought. Models that couple the physics of climate change with the biology of crop growth will be important to help policy-makers anticipate these changes, as well as to evaluate the role of "agricultural biodiversity" in helping mitigate their effects (*25*).

Closing the yield gap would dramatically increase the supply of food, but with uncertain impacts on the environment and potential feedbacks that could undermine future food production. Food production has important negative "externalities," namely effects on the environment or economy that are not reflected in the cost of food. These include the release of greenhouse gases [especially methane and nitrous oxide, which are more damaging than CO_2 and for which agriculture is a major source (*26*)], environmental pollution due to nutrient run-off, water shortages due to overextraction, soil degradation and the loss of biodiversity through land conversion or inappropriate management, and ecosystem disruption due to the intensive harvesting of fish and other aquatic foods (*6*).

To address these negative effects, it is now widely recognized that food production systems and the food chain in general must become fully sustainable (*18*). The principle of sustainability implies the use of resources at rates that do not exceed the capacity of Earth to replace them. By definition, dependency on nonrenewable inputs is unsustainable, even if in the short term it is necessary as part of a trajectory toward sustainability.

There are many difficulties in making sustainability operational. Over what spatial scale should food production be sustainable? Clearly an overarching goal is global sustainability, but should this goal also apply at lower levels, such as regions (or oceans), nations, or farms? Could high levels of consumption or negative externalities in some regions be mitigated by improvements in other areas, or could some unsustainable activities in the food system be offset by actions in the nonfood sector (through carbon-trading, for example)? Though simple definitions of sustainability are independent of time scale, in practice, how fast should we seek to move from the status quo to a sustainable food system? The challenges of climate change and competition for water, fossil fuels, and other resources suggest that a rapid transition is essential. Nevertheless, it is also legitimate to explore the possibility that superior technologies may become available and that future generations may be wealthier and, hence, better able to absorb the costs of the transition. Finally, we do not yet have good enough metrics of sustainability, a major problem when evaluating alternative strategies and negotiating trade-offs. This is the case for relatively circumscribed activities, such as crop production on individual farms, and even harder when the complete food chain is included or for complex products that may contain ingredients sourced from all around the globe. There is also a danger that an overemphasis on what can be measured relatively simply (carbon, for example) may lead to dimensions of sustainability that are harder to quantify (such as biodiversity) being ignored. These are areas at the interface of science, engineering, and economics that urgently need more attention (see Box 1). The introduction of measures to promote sustainability does not necessarily reduce yields or profits. One study of 286 agricultural sustainability projects in developing countries, involving 12.6 million chiefly smallholder farmers on 37 million hectares, found an average yield increase of 79% across a very wide variety of systems and crop types (*27*). One-quarter of the projects reported a doubling of yield. Research on the ability of these and related programs to be scaled up to country and regional levels should be a priority (Fig. 2).

Strategies designed to close the yield gap in the poorest countries face some particular challenges (*28*). Much production is dominated by small-holder agriculture with women often taking a dominant role in the workforce. Where viable, investment in the social and economic mechanisms to enable improved small-holder yields, especially where targeted at women, can be important means of increasing the income of both farm and rural nonfarm households. The lack of secure land rights can be a particular problem for many poor communities, may act as a disincentive for small holders to invest in managing the land more productively, and may make it harder to raise investment capital (*29*). In a time of rising prices for food and land, it can also render these communities vulnerable to displacement by more powerful interest groups. Where the political will and organizational infrastructure exist, title definition and protection could be greatly assisted by the application of modern information and communication technologies. Even so, there will be many people who cannot afford to purchase sufficient calories and nutrients for a healthy life and who will require social protection programs to increase their ability to obtain food. However, if properly designed, these programs can help stimulate local agriculture by providing small holders with increased certainty about the demand for their products.

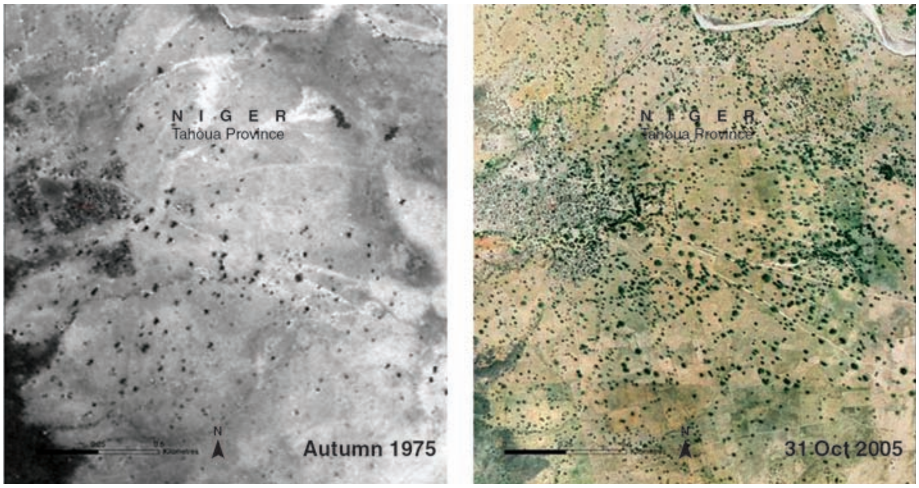

Fig. 2. An example of a major successful sustainable agriculture project. Niger was strongly affected by a series of drought years in the 1970s and 1980s and by environmental degradation. From the early 1980s, donors invested substantially in soil and water conservation. The total area treated is on the order of 300,000 ha, most of which went into the rehabilitation of degraded land. The project in the Illela district of Niger promoted simple water-harvesting techniques. Contour stone bunds, half moons, stone bunding, and improved traditional planting pits (zaï) were used to rehabilitate barren, crusted land. More than 300,000 ha have been rehabilitated, and crop yields have increased and become more stable from year to year. Tree cover has increased, as shown in the photographs. Development of the land market and continued incremental expansion of the treated area without further project assistance indicate that the outcomes are sustainable (*51*, *52*).

There is also a role for large-scale farming operations in poor-country agriculture, though the value and contexts in which this is feasible are much debated (*30*). This debate has been fanned by a substantial increase in the number of sovereign wealth funds, companies, and individuals leasing, purchasing, or attempting to purchase large tracts of agricultural land in developing countries. This external investment in developing-country agriculture may bring major benefits, especially where investors bring considerable improvements to crop production and processing, but only if the rights and welfare of the tenants and existing resource users are properly addressed (*31*).

Many of the very poorest people live in areas so remote that they are effectively disconnected from national and world food markets. But for others, especially the urban poor, higher food prices have a direct negative effect on their ability to purchase a healthy diet. Many rural farmers and other food producers live near the margin of being net food consumers and producers and will be affected in complex ways by rising food prices, with some benefitting and some being harmed (*21*). Thus, whereas reducing distorting agricultural support mechanisms in developed countries and liberalizing world trade should stimulate overall food production in developing countries, not everyone will gain (*23*, *32*). Better models that can more accurately predict these complex interactions are urgently needed.

Increasing Production Limits

The most productive crops, such as sugar cane, growing in optimum conditions, can convert solar energy into biomass with an efficiency of ~2%, resulting in high yields of biomass (up to 150 metric tons per hectare) (*33*). There is much debate over exactly what the theoretical limits are for the major crops under different conditions, and similarly, for the maximum yield that can be obtained for livestock rearing (*18*). However, there is clearly considerable scope for increasing production limits.

The Green Revolution succeeded by using conventional breeding to develop F_1 hybrid varieties of maize and semi-dwarf, disease-resistant varieties of wheat and rice. These varieties could be provided with more irrigation and fertilizer (*20*) without the risk of major crop losses due to lodging (falling over) or severe rust epidemics. Increased yield is still a major goal, but the importance of greater water- and nutrient-use efficiency, as well as tolerance of abiotic stress, is also likely to increase. Modern genetic techniques and a better understanding of crop physiology allow for a more directed approach to selection across multiple traits. The speed and costs at which genomes today can be sequenced or resequenced now means that these techniques can be more easily applied to develop varieties of crop species that will yield well in challenging environments.

Table 1. Examples of current and potential future applications of GM technology for crop genetic improvement. [Source: (*18*, *49*)]

Time scale	Target crop trait	Target crops
Current	Tolerance to broad-spectrum herbicide	Maize, soybean, oilseed brassica
	Resistance to chewing insect pests	Maize, cotton, oilseed brassica
Short-term (5–10 years)	Nutritional bio-fortification	Staple cereal crops, sweet potato
	Resistance to fungus and virus pathogens	Potato, wheat, rice, banana, fruits, vegetables
	Resistance to sucking insect pests	Rice, fruits, vegetables
	Improved processing and storage	Wheat, potato, fruits, vegetables
	Drought tolerance	Staple cereal and tuber crops
Medium-term (10–20 years)	Salinity tolerance	Staple cereal and tuber crops
	Increased nitrogen-use efficiency	
	High-temperature tolerance	
Long-term (>20 years)	apomixis	Staple cereal and tuber crops
	Nitrogen fixation	
	Denitrification inhibitor production	
	Conversion to perennial habit	
	Increased photosynthetic efficiency	

These include crops such as sorghum, millet, cassava, and banana, species that are staple foods for many of the world's poorest communities (*34*).

Currently, the major commercialized genetically modified (GM) crops involve relatively simple manipulations, such as the insertion of a gene for herbicide resistance or another for a pest-insect toxin. The next decade will see the development of combinations of desirable traits and the introduction of new traits such as drought tolerance. By mid-century, much more radical options involving highly polygenic traits may be feasible (Table 1). Production of cloned animals with engineered innate immunity to diseases that reduce production efficiency has the potential to reduce substantial losses arising from mortality and subclinical infections. Biotechnology could also produce plants for animal feed with modified composition that increase the efficiency of meat production and lower methane emissions.

Domestication inevitably means that only a subset of the genes available in the wild-species progenitor gene pool is represented among crop varieties and livestock breeds. Unexploited genetic material from land races, rare breeds, and wild relatives will be important in allowing breeders to respond to new challenges. International collections and gene banks provide valuable repositories for such genetic variation, but it is nevertheless necessary to ensure that locally adapted crop and livestock germplasm is not lost in the process of their displacement by modern, improved varieties and breeds. The trend over recent decades is of a general decline in investment in technological innovation in food production (with some notable exceptions, such as in China and Brazil) and a switch from public to private sources (*1*). Fair returns on investment are essential for the proper functioning of the private sector, but the extension of the protection of intellectual property rights to biotechnology has led to a growing public perception in some countries that biotech research purely benefits commercial interests and offers no long-term public good. Just as seriously, it also led to a virtual monopoly of GM traits in some parts of the world, by a restricted number of companies, which limits innovation and investment in the technology. Finding ways to incentivize wide access and sustainability, while encouraging a competitive and innovative private sector to make best use of developing technology, is a major governance challenge.

The issue of trust and public acceptance of biotechnology has been highlighted by the debate over the acceptance of GM technologies. Because genetic modification involves germline modification of an organism and its introduction to the environment and food chain, a number of particular environmental and food safety issues need to be assessed. Despite the introduction of rigorous science-based risk assessment, this discussion has become highly politicized and polarized in some countries, particularly those in Europe. Our view is that genetic modification is a potentially valuable technology whose advantages and disadvantages need to be considered rigorously on an evidential, inclusive, case-by-case basis: Genetic modification should neither be privileged nor automatically dismissed. We also accept the need for this technology to gain greater public acceptance and trust before it can be considered as one among a set of technologies that may contribute to improved global food security.

There are particular issues involving new technologies, both GM and non-GM, that are targeted at helping the least-developed countries (*35*, *36*). The technologies must be directed at the needs of those communities, which are often different from those of more developed country farmers. To increase the likelihood that new technology works for, and is adopted by, the poorest nations, they need to be involved in the framing, prioritization, risk assessment, and regulation of innovations. This will often require the creation of innovative institutional and governance mechanisms that account for socio-cultural context (for example, the importance of women in developing-country food production). New technologies offer major promise, but there are risks of lost trust if their potential benefits are exaggerated in public debate. Efforts to increase sustainable production limits that benefit the poorest nations will need to be based around new alliances of businesses, civil society organizations, and governments.

Reducing Waste

Roughly 30 to 40% of food in both the developed and developing worlds is lost to waste, though the causes behind this are very different (Fig. 3) (*16*, *37*–*39*). In the developing world, losses are mainly attributable to the absence of food-chain infrastructure and the lack of knowledge or investment in storage technologies on the farm, although data are scarce. For example, in India, it is estimated that 35 to 40% of fresh produce is lost because neither wholesale nor retail outlets have cold storage (*16*). Even with rice grain, which can be stored more readily, as much as one-third of the harvest in Southeast Asia can be lost after harvest to pests and spoilage (*40*). But the picture is more complex than a simple lack of storage facilities: Although storage after harvest when there is a glut of food would seem to make economic sense, the farmer often has to sell immediately to raise cash.

In contrast, in the developed world, pre-retail losses are much lower, but those arising at the retail, food service, and home stages of the food chain have grown dramatically in recent years, for a variety of reasons (*41*). At present, food is relatively cheap, at least for these consumers, which reduces the incentives to avoid waste. Consumers have become accustomed to purchasing foods of the highest cosmetic standards; hence, retailers discard many edible, yet only slightly blemished products. Commercial pressures can encourage waste: The food service industry frequently uses "super-sized" portions as a competitive lever, whereas "buy one get one free" offers have the same function for retailers. Litigation and lack of education on food safety have lead to a reliance on "use by" dates, whose safety margins often mean that food fit for consumption is thrown away. In some developed countries, unwanted food goes to a landfill instead of being used as animal feed or compost because of legislation to control prion diseases.

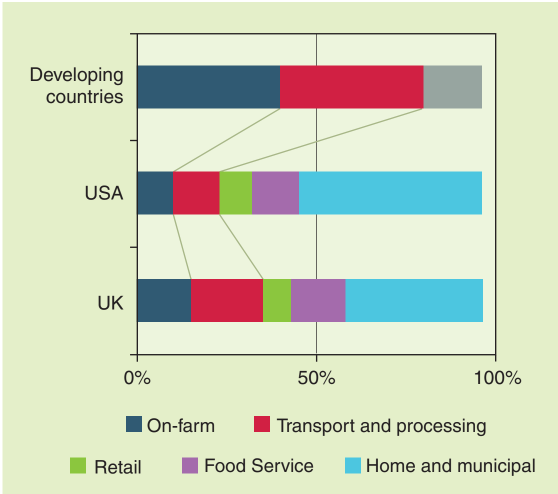

Fig. 3. Makeup of total food waste in developed and developing countries. Retail, food service, and home and municipal categories are lumped together for developing countries. [Source: (*16*, *37*–*39*)]

Different strategies are required to tackle the two types of waste. In developing countries, public investment in transport infrastructure would reduce the opportunities for spoilage, whereas better-functioning markets and the availability of capital would increase the efficiency of the food chain, for example, by allowing the introduction of cold storage (though this has implications for greenhouse gas emissions) (*38*). Existing technologies and best practices need to be spread by education and extension services, and market and finance mechanisms are required to protect farmers from having to sell at peak supply, leading to gluts and wastage. There is also a need for continuing research in postharvest storage technologies. Improved technology for small-scale food storage in poorer contexts is a prime candidate for the introduction of state incentives for private innovation, with the involvement of small-scale traders, millers, and producers.

If food prices were to rise again, it is likely that there would be a decrease in the volume of waste produced by consumers in developed countries. Waste may also be reduced by alerting consumers to the scale of the issue, as well as to domestic strategies for reducing food loss. Advocacy, education, and possibly legislation may also reduce waste in the food service and retail sectors. Legislation such as that on sell-by dates and swill that has inadvertently increased food waste should be reexamined within a more inclusive competing-risks framework. Reducing developed-country food waste is particularly challenging, as it is so closely linked to individual behavior and cultural attitudes toward food.

Changing Diets

The conversion efficiency of plant into animal matter is ~10%; thus, there is a prima facie case that more people could be supported from the same amount of land if they were vegetarians. About one-third of global cereal production is fed to animals (*42*). But currently, one of the major challenges to the food system is the rapidly increasing demand for meat and dairy products that has led, over the past 50 years, to a ~1.5-fold increase in the global numbers of cattle, sheep, and goats, with equivalent increases of ~2.5- and ~4.5-fold for pigs and chickens, respectively (*2*) (Fig. 1). This is largely attributable to the increased wealth of consumers everywhere and most recently in countries such as China and India.

However, the argument that all meat consumption is bad is overly simplistic. First, there is substantial variation in the production efficiency and environmental impact of the major classes of meat consumed by people (Table 2). Second, although a substantial fraction of livestock is fed on grain and other plant protein that could feed humans, there remains a very substantial proportion that is grass-fed. Much of the grassland that is used to feed these animals could not be converted to arable land or could only be converted with majorly adverse environmental outcomes. In addition, pigs and poultry are often fed on human food "waste." Third, through better rearing or improved breeds, it may be possible to increase the efficiency with which meat is produced. Finally, in developing countries, meat represents the most concentrated source of some vitamins and minerals, which is important for individuals such as young children. Livestock also are used for ploughing and transport, provide a local supply of manure, can be a vital source of income, and are of huge cultural importance for many poorer communities.

Reducing the consumption of meat and increasing the proportion that is derived from the most efficient sources offer an opportunity to feed more people and also present other advantages (*37*). Well-balanced diets rich in grains and other vegetable products are considered to be more healthful than those containing a high proportion of meat (especially red meat) and dairy products. As developing countries consume more meat in combination with high-sugar and -fat foods, they may find themselves having to deal with obesity before they have overcome undernutrition, leading to an increase in spending on health that could

Table 2. Comparison of the impact of grazing and intensive (confined/industrialized) grain-fed livestock systems on water use, grain requirement, and methane production. Service water is that required for cleaning and washing livestock housing and other facilities. Dashes indicate combinations for which no data are available (either because it cannot be measured or because the combination does not exist). This table does not include other impacts of differing livestock management systems such as (i) nutrient run-off and pollution to surface and groundwater, (ii) protozoan and bacterial contamination of water and food, (iii) antibiotic residues in water and food, (iv) heavy metal from feed in soils and water, (v) odor nuisance from wastes, (vi) inputs used for feed production and lost to the environment, (vii) livestock-related land-use change. [Source: (*7*, *50*)]

Water	Measure of water use	Grazing	Intensive
		Liters day^{-1} per animal at 15°C	
Cattle	Drinking water: all	22	103
	Service water: beef	5	11
	Service water: dairy	5	22
Pigs (lactating adult)	Drinking water	17	17
	Service water	25	125
Sheep (lactating adult)	Drinking water	9	9
	Service water	5	5
Chicken (broiler and layer)	Drinking water	1.3–1.8	1.3–1.8
	Service water	0.09–0.15	0.09–0.15
Feed required to produce 1 kg of meat		*kg of cereal per animal*	
Cattle		–	8
Pigs		–	4
Chicken (broiler)		–	1
Methane emissions from cattle		*kg of CH_4 per animal $year^{-1}$*	
Cattle: dairy (U.S., Europe)		–	117–128
Cattle: beef, dairy (U.S., Europe)		53–60	–
Cattle: dairy (Africa, India)		–	45–58
Cattle: grazing (Africa, India)		27–31	–

otherwise be used to alleviate poverty. Livestock production is also a major source of methane, a very powerful greenhouse gas, though this can be partially offset by the use of animal manure to replace synthetic nitrogen fertilizer (*43*). Of the five strategies we discuss here, assessing the value of decreasing the fraction of meat in our diets is the most difficult and needs to be better understood.

Expanding Aquaculture

Aquatic products (mainly fish, aquatic molluscs, and crustaceans) have a critical role in the food system, providing nearly 3 billion people with at least 15% of their animal protein intake (*44*).

In many regions, aquaculture has been sufficiently profitable to permit strong growth; replicating this growth in areas such as Africa where it has not occurred could bring major benefits. Technical advances in hatchery systems, feeds and feed-delivery systems, and disease management could all increase output. Future gains may also come from better stock selection, larger-scale production technologies, aquaculture in open seas and larger inland water bodies, and the culture of a wider range of species. The long production cycle of many species (typically 6 to 24 months) requires a financing system that is capable of providing working capital as well as offsetting risk. Wider production options (such as temperature and salinity tolerance and disease resistance) and cheaper feed substrates (for instance, plant material with enhanced nutritional features) might also be accessed with the use of GM technologies.

Aquaculture may cause harm to the environment because of the release into water bodies of organic effluents or disease treatment chemicals, indirectly through its dependence on industrial fisheries to supply feeds, and by acting as a source of diseases or genetic contamination for wild species. Efforts to reduce these negative externalities and increase the efficiency of resource use [such as the fish in–to–fish out ratio (*45*)] have been spurred by the rise of sustainability certification programs, though these mainly affect only higher-value sectors. Gains in sustainability could come from concentrating on lower–trophic level species and in integrating aquatic and terrestrial food production, for example, by using waste from the land as food and nutrients. It will also be important to take a more strategic approach to site location and capacity within catchment or coastal zone management units (*46*).

Conclusions

There is no simple solution to sustainably feeding 9 billion people, especially as many become increasingly better off and converge on rich-country consumption patterns. A broad range of options, including those we have discussed here, needs to be pursued simultaneously. We are hopeful about scientific and technological innovation in the food system, but not as an excuse to delay difficult decisions today.

Any optimism must be tempered by the enormous challenges of making food production sustainable while controlling greenhouse gas emission and conserving dwindling water supplies, as well as meeting the Millennium Development Goal of ending hunger. Moreover, we must avoid the temptation to further sacrifice Earth's already hugely depleted biodiversity for easy gains in food production, not only because biodiversity provides many of the public goods on which mankind relies but also because we do not have the right to deprive future generations of its economic and cultural benefits. Together, these challenges amount to a perfect storm.

Navigating the storm will require a revolution in the social and natural sciences concerned with food production, as well as a breaking down of barriers between fields. The goal is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, environmental, and social justice outcomes.

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53. The authors are members of the U.K. Government Office for Science's Foresight Project on Global Food and Farming Futures. J.R.B. is also affiliated with Imperial College London. D.L. is a Board Member of Plastid AS (Norway) and owns shares in AstraZeneca Public Limited Company and Syngenta AG. We are grateful to J. Krebs and J. Ingrahm (Oxford), N. Nisbett and D. Flynn (Foresight), and colleagues in Defra and DfID for their helpful comments on earlier drafts of this manuscript. If not for his sad death in July 2009, professor Mike Gale (John Innes Institute, Norwich, UK) would also have been an author of this paper.

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REVIEW

Breeding Technologies to Increase Crop Production in a Changing World

Mark Tester* and Peter Langridge

To feed the several billion people living on this planet, the production of high-quality food must increase with reduced inputs, but this accomplishment will be particularly challenging in the face of global environmental change. Plant breeders need to focus on traits with the greatest potential to increase yield. Hence, new technologies must be developed to accelerate breeding through improving genotyping and phenotyping methods and by increasing the available genetic diversity in breeding germplasm. The most gain will come from delivering these technologies in developing countries, but the technologies will have to be economically accessible and readily disseminated. Crop improvement through breeding brings immense value relative to investment and offers an effective approach to improving food security.

Although more food is needed for the rapidly growing human population, food quality also needs to be improved, particularly for increased nutrient content. In addition, agricultural inputs must be reduced, especially those of nitrogenous fertilizers, if we are to reduce environmental degradation caused by emissions of CO_2 and nitrogenous compounds from agricultural processes. Furthermore, there are now concerns about our ability to increase or even sustain crop yield and quality in the face of dynamic environmental and biotic threats that will be particularly challenging in the face of rapid global environmental change. The current diversion of substantial quantities of food into the production of biofuels puts further pressure on world food supplies (*1*).

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Breeding and agronomic improvements have, on average, achieved a linear increase in food production globally, at an average rate of 32 million metric tons per year (*2*) (Fig. 1). However, to meet the recent Declaration of the World Summit on Food Security (*3*) target of 70% more food by 2050, an average annual increase in production of 44 million metric tons per year is required (Fig. 1), representing a 38% increase over historical increases in production, to be sustained for 40 years. This scale of sustained increase in global food production is unprecedented and requires substantial changes in methods for agronomic processes and crop improvement. Achieving this increase in food production in a stable environment would be challenging, but is undoubtedly much more so given the additional pressures created by global environmental changes.

Global Environmental Change Alters Breeding Targets

Certain aspects of global environmental change are beneficial to agriculture. Rising CO_2 acts as a fertilizer for C3 crops and is estimated to account for approximately 0.3% of the observed 1% rise in global wheat production (*4*), although this benefit is likely to diminish, because rising temperatures will increase photorespiration and nighttime respiration. A benefit of rising temperatures is the alleviation of low-temperature inhibition of growth, which is a widespread limitation at higher latitudes and altitudes. Offsetting these benefits, however, are obvious deleterious changes, such as an increased frequency of damaging high-temperature events, new pest and disease pressures, and altered patterns of drought. Negative effects of other pollutants, notably ozone, will also reduce benefits to plant growth from rising CO_2 and temperature.

Particularly challenging for society will be changes in weather patterns that will require alterations in farming practices and infrastructure; for example, water storage and transport networks. Because one-third of the world's food is produced on irrigated land (*5*, *6*), the likely impacts on global food production are many. Along with agronomic- and management-based approaches to improving food production, improvements in a crop's ability to maintain yields with lower water supply and quality will be critical. Put simply, we need to increase the tolerance of crops to drought and salinity.

In the context of global environmental change, the efficiency of nitrogen use has also emerged as a key target. Human activity has already more than doubled the amount of atmospheric N_2 fixed

Sustainable intensification in agriculture

Navigating a course through competing food system priorities

A report on a workshop

Tara Garnett[1] & H. Charles J. Godfray[2,3]

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With expert contributions from Mike Appleby, Andrew Balmford, John Barrett, Ian Bateman, Tim Benton, Phil Bloomer, Barbara Burlingame, Denise Coitinho, Kath Dalmeny, Marian Dawkins, Liam Dolan, David Fraser, Andy Haines, Brian Harris, Mario Herrero, Irene Hoffmann, John Ingram, Richard Perkins, Anna Saunders, Pete Smith, Phil Thornton, Camilla Toulmin, Sonja Vermeulen, Jeff Waage, Andreas Wilkes, and Kathy Willis

The workshop was part funded by the UK Government's Foresight Programme as part of its follow up activities to the *Future of Food and Farming* Project

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Foreword

This report is based on discussions held at a two day workshop held in January 2012, co-organised by the Food Climate Research Network and the Oxford Martin Programme on the Future of Food. The workshop was facilitated by Kath Dalmeny of Sustain and funded by the Foresight Programme and the Oxford Martin Programme on the Future of Food.

The purpose of the workshop was to bring together key thinkers from the academic and policy community, and from diverse disciplines, to consider the meanings, issues and challenges around sustainable intensification in general, and particularly in relation to three areas of concern: environmental sustainability; animal welfare and human wellbeing (specifically nutrition). A list of workshop participants is provided on the next page.

This report draws upon these discussions and upon further analysis and exploration subsequent to the workshop. It was written by Tara Garnett and Charles Godfray with valuable input from all the workshop participants, most of whom provided comments on a draft version. However, it is emphasised that this report is by no means a consensus document. It should not be seen as representing the unanimous views of everyone present or endorsed by the organisations to which they belong. The role of this document, rather, is to map out some of the conceptual territory that was explored, to stimulate discussion, and to identify areas where further work is needed.

The report is aimed at policy makers, both in the UK and elsewhere, working in areas relevant to food security. While clearly 'food security' is about far more than agricultural policy alone, our intention here is to take a small part of the food security puzzle – agricultural policy – and to consider how it intersects with environmental, animal welfare and health policies. Our argument is that agricultural policy, if it is to help rather than hinder the ultimate goal of food security, needs to operate in an integrated manner with these other policy areas.

Ultimately, this report argues the case for a more 'systems' oriented approach to decision making. While it does not go so far as to define a research agenda or make policy recommendations – this would require more work than has been possible in the time available – it urges the need for a substantial programme of future activity in order to:

(a) deepen and extend understanding of systems interactions;

(b) consider and define what specific goals societies wish agricultural production to achieve;

(c) develop metrics that will enable societies to measure progress in achieving them; and

(d) implement successful policies.

The workshop participants provided invaluable input to the report, both during the workshop and subsequently by commenting on a draft version. They are listed as follows:

Tara Garnett	Food Climate Research Network (organiser)
Charles Godfray	Oxford Martin Programme on the Future of Food (organiser)
Kath Dalmeny	Sustain (facilitator)
Hannah Rowlands	Oxford Martin Programme on the Future of Food (note taker)
Mike Appleby	World Society for the Protection of Animals
Andrew Balmford	University of Cambridge
John Barrett	Department for International Development
Ian Bateman	University of East Anglia
Tim Benton	University of Leeds
Phil Bloomer	Oxfam
Barbara Burlingame	Food and Agriculture Organisation
Denise Coitinho	World Health Organisation / Standing Committee on Nutrition
Marian Dawkins	University of Oxford
Liam Dolan	University of Oxford
David Fraser	University of British Columbia
Andy Haines	London School of Hygiene and Tropical Medicine
Brian Harris	Biotechnology and Biological Sciences Research Council
Mario Herrero	International Livestock Research Institute
Irene Hoffmann	Food and Agriculture Organisation
John Ingram	NERC and University of Oxford
Richard Perkins	WWF
Anna Saunders	Department for Environment, Food and Rural Affairs
Pete Smith	University of Aberdeen
Phil Thornton	International Livestock Research Institute / Climate Change Agriculture and Food Security Programme
Camilla Toulmin	International Institute for Environment and Development
Sonja Vermeulen	Climate Change, Agriculture and Food Security Programme
Jeff Waage	London International Development Centre
Andreas Wilkes	World Agroforestry Centre
Kathy Willis	University of Oxford

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1. The context for the discussion

Food production and consumption today take place in a world of abrupt contrasts and rapid change. The global population is growing, globalising and urbanising; people on average are becoming richer and their lifestyles and expectations are changing – and these changes all influence not just how much but what kind of food they will want and can afford to eat, as well as how this food is produced and distributed, and who benefits in the process.

At the same time, while the stability and security of the food system is underpinned by its environmental resource base, the evidence overwhelmingly suggests that these resources are being depleted and damaged in ways that threaten food production in the long term and also have broader implications for human wellbeing. Much of this damage is caused by the food system itself - food is both agent and victim of environmental harms.

There is therefore increasing concern about the prospects for food security over the next forty years. It is feared that as populations grow, recent progress to reduce hunger will not be sustained and more people will go hungry. Attempts to increase food production to meet demand will generate more environmental damage, and this in turn will undermine our future capacity to produce food.

Policy makers across the world now recognise that the way in which food is produced and distributed needs to change. The question is: what does it need to change into? What does a food system that feeds people adequately while minimising environmental harms (or even improving environmental outcomes) and adapting to those that have already been generated actually look like?

Different people have different answers. The differences are shaped by their views on a broad spectrum of issues: about the relationship between different types of economic development and human wellbeing, their relationship with the natural world and their beliefs about technology; on how far the future can be and should be ordered differently from how it is at present; about whether people can and should be persuaded to behave differently from how they do today; and ultimately by how they define ‘a good life’.

These broad value-sets manifest themselves in more specific, concrete suggestions for the future of food in coming years. Some stakeholders suggest extensions and modifications of the status quo, others argue for more radical changes. Some focus specifically on food production while others address the food system as a whole.

This document looks at one particular suggested approach to food production: that we seek to ‘sustainably intensify’ production. The phrase has recently become controversial because both its critics and some of its advocates presuppose that it refers to particular systems of production. The purpose of this paper is to argue that it does not. On the contrary, since the goal of sustainable intensification is to achieve a union between sustainability on the one hand, and productivity on the other, it is unlikely to resemble anything we have today - although it will certainly adopt elements from the broad range of production systems that currently exist. Hence our purpose here is to explore what sustainable intensification might mean if both of the two words that make up the phrase - ‘sustainable’ and ‘intensification’ - are assigned equal weight.

This document begins by outlining the origin of, and controversy surrounding, sustainable intensification (2) before asking whether, in view of this controversy, it is worth retaining the idea as a useful guiding principle – and concluding that it is (3). It then (4) goes on to consider some of the main issues that need to be considered and addressed when thinking about sustainable intensification. It draws out a set of concepts (5) that emerge from a consideration of these issues and that require further exploration and clarification before offering a few conclusions (6).

2. Origin of, and controversy surrounding, sustainable intensification

Sustainable intensification is a term now much used in discussions around the future of agriculture and food security. It has only become common in the last few years, following the publication of the UK Royal Society's highly influential report, Reaping the Benefits, that explored the future of crop production, and a number of later major scientific and policy reports[1,2,3,4]. However the term actually dates back to the 1990s and was coined in the context of African agriculture, where yields are often very low, and environmental degradation a major concern[5,6,7]. This pro-poor, smallholder oriented origin of the phrase is worth noting in the context of the current controversy around sustainable intensification.

Sustainable intensification has been defined as a form of production wherein "yields are increased without adverse environmental impact and without the cultivation of more land"[8]. In this sense, the term denotes an aspiration of what needs to be achieved, rather than a description of existing production systems, whether this be conventional high-input farming, or smallholder agriculture, or approaches based on organic methods. While the intensification of agriculture has long been the subject of analysis[9], sustainable intensification is a more recent concern. It is still not clear what sustainable intensification might look like on the ground, how it might differ amongst production systems, in different places, and given different demand trajectories, and how the tradeoffs that inevitably arise, might be balanced. However it provides a framework for exploring what mix of approaches might work best based on the existing biophysical, social, cultural and economic context and a growing body of work is starting to emerge that explores what implementation might look like in practice[10].

It is important to emphasise this openness: as originally conceived, the definition does not articulate or privilege any particular vision of agricultural production. Unfortunately, this blank canvas approach, while in principle a strength, has recently proved to be a drawback:

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1 The Royal Society (2009). Reaping the benefits: science and the sustainable intensification of global agriculture, London.

2 Godfray H C J, Beddington J R, Crute I R, Haddad L, Lawrence L, Muir J F , Pretty J, Robinson S, Thomas S M and Toulmin C (2010). Food Security: The Challenge of Feeding 9 Billion People, *Science*, Vol 327.

3 Herrero M, Thornton P K, Notenbaert A M, Wood S, Msangi S, Freemand H A, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasrathy Rao P, Macmillan S, Gerard B, McDermott J, Seré C, Rosegrant M. (2010). Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems, *Science* 327, 822

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the canvas has become covered with contradictory assumptions and counter-assumptions (see Box 1) about what sustainable intensification 'is' or 'should be'.

If sustainable intensification is to be a useful aid to thinking about how food production should develop in coming years, the assumptions that underpin these different interpretations of, and attitudes to, sustainable intensification need to be exposed and explored, so that analysis as to the way forward is founded on a shared understanding of what is actually being discussed. Put simply, differing interpretations of sustainable intensification hinge upon three linked assumptions. The first is that sustainable intensification denotes a particular type of agriculture; the second that it is inherently bound up with arguments about the 'need' to produce more food; and lastly, that the 'intensification' side of the term should be privileged over 'sustainable.' These three criticisms are addressed in turn.

2.1. Description or aspiration?

The first criticism is that sustainable intensification represents a particular type or system of agriculture. In particular, it has been interpreted by some as coterminous with current high-input, high-output Western modes of production. As such, the concept has been endorsed by some interest groups, particularly the farming industry, and criticised by others, particularly those from within the environmental community[11,12]. Under this interpretation, sustainable intensification is not, as was originally intended, an *aspiration* (how food production should change), but a *description* of agricultural practices already in place that can be adapted to meet future challenges. Agroecology, often interpreted as a competing paradigm, has by contrast become aligned with smallholder systems of production, even though, ironically, sustainable intensification itself was originally coined in the context of smallholder African agriculture[13,14,15]. Agroecology is, like sustainable intensification, not a clearly defined concept but it tends to connote a preference for organic practices (although chemical inputs are not excluded), for multiple, rather than single food and non food outputs from the farm system, and for smallholder as opposed to large scale commercial production[16].

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11 ADAS et al (2011) Meeting the Challenge: Agriculture Industry GHG Action Plan Delivery of Phase I: 2010 - 2012 04 April 2011, ADAS, AEA (Agricultural Engineering Association), AHDB (Agriculture and Horticulture Development Board), AIC (Agriculture Industries Confederation), CLA (Country Land and Business Association), Farming Futures, FWAG (Farm Wildlife Advisory Group), LEAF (Linking Environment And Farming), NFU (National Farmers Union), NIAB/TAG (National Institute of Agricultural Botany/The Arable Group), ORC (Elm Farm Organic Research Centre), RASE (Royal Agricultural Society of England)

12 Tudge C (2011). What does sustainability mean? And what on earth is sustainable intensification? The Campaign for Real Farming, http://www.campaignforrealfarming.org/2011/07/what-does-sustainability-mean-and-what-on-earth-is-sustainable-intensification/ accessed 10 December 2011

13 Reardon T, Crawford E, Kelly V and Diagana B (1995). Promoting farm investment for sustainable intensification of African agriculture. MSU International Development Paper No 18, Michigan State University, Michigan, United States

14 Reardon T, Crawford E, Kelly V and Diagana K (1996). Promoting Farm Investment for Sustainable Intensification of African Agriculture, Final Report, USAID.

15 Pretty J (1997). The sustainable intensification of agriculture, Natural Resources Forum, Blackwell Publishing Ltd.

16 UN (2010). Report submitted by the Special Rapporteur on the right to food, Olivier de Schutter 17 December 2010, United Nations Human Rights Council Sixteenth session, United Nations General Assembly

Box 1: Sustainable intensification: description, aspiration, or oxymoron? A selection of views

Trojan horse? "Sustainable intensification to me sounds weird ...is there not a danger that it will be used as a Trojan horse for those who want us to have lots more biotech and GM and so forth? ... is there a potential conflict between how this idea might be used and the future of small-scale farming?"

Caroline Lucas, MEP, HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Production within an ecosystem services framework? "For us ...it means basically increasing production in a given area while reducing key environmental consequences and increasing what we call the flow to key environmental services. We are talking about key ecosystems and the services they provide."

Mark Driscoll, WWF, HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Hi tech? "...sustainable intensification ...will take many forms. Biotechnology ....will undoubtedly be part of the picture ... housed livestock will also be part of the picture".

Peter Kendall, NFU, Letter to the Sunday Times, 9 January 2012

Or all about smallholders? Sustainable intensification of agriculture is the only way to avoid localized chronic food and nutrition insecurity ....Unleashing the full potential of smallholders, including that of women farmers, is ..key"

United Nations General Assembly. Agricultural Technology for Development Report of the Secretary General: A/66/100, August 2011

Science *as distinct from* politics? On sustainable intensification..."Why is it necessary to rule out any technology if there is a prospect that it can deliver higher levels of productivity with improved resource use efficiency ...? There are of course people that want the world to be organised differently to the way it is at present - but that's politics and has little to do with science."

Ian Crute, AHDB, Farmers Guardian Debate, 7 October 2011

http://www.farmersguardian.com/home/latest-news/watch-again-food-security-debate/42133.article

What's the intended output? "for me sustainable intensification means that we have to produce more from the land, but more of what? More food, yes, but also the other things that land produces."

Philip Lowe HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Sustainable intensification *versus* agroecology? "The ..Foresight study … underlined the imperative of …'sustainable intensification' through industrial agriculture (see note)[17]. *In contrast*, this UN report on agro-ecology states that it is often labour demanding practices such as agro-forestry, leguminous cover crops and mixed cropping that have proven potential to reduce the use of inorganic fertilizers whilst substantially improving yields. "

Institute for European Environmental Policy

http://cap2020.ieep.eu/2011/3/23/un-report-on-agro-ecology

Sustainable intensification *and* agroecology? "Food outputs by sustainable intensification have been multiplicative – by which yields per hectare have increased by combining the use of new and improved varieties and new agronomic–agroecological management …and additive – by which diversification has resulted in the emergence of a range of new crops, livestock or fish

Pretty J, Toulmin C & Williams S (2011) Sustainable intensification in African agriculture, International Journal of Agricultural Sustainability, 9, 1, 5-24

Cruel gobbledegook? "[the] British Government …is currently using tax-payers money to fund research in 'sustainable intensification' of the livestock industry… Compassion is calling this a policy of gobbledygook…. The real truth is that "sustainable intensification" [is] a contradiction in terms."

Philip Lymbery, Compassion in World Farming

http://www.acompassionateworld.org/2011/10/gobbledygook/

Finally: sustainable intensification is "virtually meaningless"

Colin Tudge, author, Farmers Guardian Debate, 7 October 2011 http://www.farmersguardian.com/home/latest-news/watch-again-food-security-debate/42133.article

17 The authors of the Foresight Report would object to this characterisation.

2.2. Production or productivity?

The second assumption about sustainable intensification is that it is inherently bound up with arguments about the 'need' to produce a fixed amount of additional food over the next forty years to feed an additional two billion people. Different analyses come up with varying estimates of the increase in food required but typically a 60-120% increase on today's output is described[18] based on assumptions about future income growth and its relationship with increased consumption and changing dietary preferences. The academic and policy studies underlying these estimates typically look only at the production side and do not factor in what might be done to influence the demand side of the equation, in particular the demand for resource intensive foods such as animal products.

Broadly speaking, views on the mainstream 'more food' estimate fall into several camps. First, are those who endorse these figures; advocates are generally drawn from the farming, agribusiness or production research communities. They tend to be technological optimists and often believe demand side approaches to the problem are unlikely to be successful or desirable.

A second group question the assumptions underlying the growth estimates, emphasising the point that increases in food supply do not guarantee reductions in hunger; hunger is most often a consequence of a lack of economic access to food rather than a lack of supply (See Box 2 for a definition of food security)[19,20]. While some but not all agree that food production will need to increase, they are more cautious about giving estimates, and argue that the non supply-based determinants of food security require greater attention and may be sufficient in achieving sufficient food for all. They highlight a growing body of academic work that explores different dietary approaches to achieving food security, often assessing these in relation to their impacts on land use and greenhouse gas emissions[21,22,23].

In addition to shifting diets away from resource intensive foods such as meat and dairy products, they argue that action is needed to improve governance (influencing the affordability of and access to food), and reduce food losses and waste throughout the supply chain (representing unconsumed production). More broadly critics of the 'more food' arguments tend to challenge the current economic growth paradigm: sophisticated technologies are unlikely to reconcile economic development and environmental goals, and

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18 Conforti, P. (ed.). (2011). Looking Ahead in World Food and Agriculture: Perspectives to 2050, Rome: Food and Agriculture Organization; Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452; Tilman, D., Balzer, C., Hill, J. & Befort, B.L. (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260-20264.

19 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

20 A. Sen, Poverty and Famines (Oxford Univ. Press, Oxford,1981

21 Stehfest E, Bouwman L, van Vuuren D P, den Elzen MGJ, Eickhout B, Kabat P. (2009). Climate benefits of changing diet, Climatic Change, Volume 95, Numbers 1-2

22 Popp A, Lotze-Campen H and Bodirsky B (2010). Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production, Global Environmental Change 20 451–462.

23 Pelletier N, Pirog R, Rasmussen R (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States, Agricultural Systems 103 (2010) 380–389.

Box 2. Definition of Food Security

Food Security obtains when people have physical, economic and social access to sufficient and varied food for a healthy diet. This definition encompasses four key dimensions: food availability, access, utilization and stability:

Physical availability: addresses the supply side of food security and is determined by food production, stock levels, trade and other factors.

Economic and physical access to food: determining factors include household incomes and expenditure, markets and food prices.

Food utilization: this relates to the body's ability to make use of food nutrients and includes the need for sufficient energy and nutrients as well as good care and feeding practices, safe food preparation, dietary diversity, food distribution within households and individual health status.

Stability: The concept of stability reflects the presence of the other three elements over time. Sudden economic, climatic or other shocks, or cyclical events such as seasonal food insecurity affect the stability of supply.

Source: FAO (2008). An introduction to the basic concepts of food security, FAO, 2008 EC – FAO Food Security Programme

The **Food System** as used here describes the web of social and economic processes determining the production, distribution and consumption of food. It includes agriculture, food processing and distribution, as well as the factors affecting demand for and use (including waste) of different food types.

Source: Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London.

hence economic growth is ultimately incompatible with sustainability. Moreover, the use of GDP to measure development and progress is seen as of limited value. In short, the notion that more (or much more) food production is actually needed is characterised as part of a problematic mindset that privileges 'more' over 'fairer,' or 'wants' over 'needs.' The concern here is with the perceived insatiability of human demand, that there are no limits to what people consider to be 'enough.'

A third intermediate camp argues that the challenges are so great that action must be taken today on all fronts, on supply, demand, waste, efficiency - and population[24,25]. Given the uncertainties ahead, it makes little sense to plan for any particular stipulated level of production. It argues for a policy framework wherein the natural economic

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24 Beddington J (2009). Food, energy, water and the climate: a perfect storm of global events? http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf

25 IAP (2012). IAP Statement on Population and Consumption, IAP: The Global Network of Science Academies, 14 June 2012

response of actors to price signals along the whole food supply chain - including farmers, manufacturers, retailers and consumers - gives rise to production and consumption that is both economically efficient and environmentally sustainable.

How does this relate to the debate on sustainable intensification? Evidently, what we do to address issues of distribution, demand and waste as well as population growth will influence how much of an increase in food production is needed, with the appropriate balance of these actions varying by region and by socio-economic context. This in turn will affect the extent to which the food system potentially impacts upon the environment and upon other aspects of society. The greater the success in these other areas, the less requirement there will be to raise yields in order to increase food supplies. Indeed many, especially in the third camp described above, would argue that the goal of sustainable food security for all is not possible without action on these fronts[26,27].

Thus, it does not follow that sustainable intensification as a concept should be predicated on particular assumptions about how much more food is needed. Our argument here is that the 'need' for sustainable intensification is independent of the 'need' to produce more food. The prime goal of sustainable intensification is to raise *productivity* (as distinct from increasing *volume of production*) while reducing environmental impacts. This means increasing yields per unit of inputs (including nutrients, water, energy, capital and land) as well as per unit of 'undesirable' outputs (such as greenhouse gas emissions or water pollution).

The required 'intensity' of productivity to meet an increase in overall demand for food will depend upon progress on improving governance, reducing waste, altering dietary patterns and addressing population growth. Sustainable intensification should thus be seen as a complement to, not a substitute for actions on these fronts (Figure 1).

In principle, in a world that was highly successful in all these other areas, no increase in food production might be required. In this case sustainable intensification could enable current levels of food to be produced on a smaller area of land, enabling land to be released and allocated to other purposes, including rewilding or afforestation or the provision of other ecosystem services.

In practice, however, some increases in production to meet demand will almost certainly be required, particularly in certain regions such as sub-Saharan Africa where agriculture is a critical and underperforming driver of rural economies. Rather than setting an arbitrary global goal for the level of intensification required (which itself presupposes certain production targets) the task at the local level is to consider how yields can be increased in ways that enhance sustainability. In other words, the 'optimum' level of productivity increase is likely to be highly context specific.

Inevitably, situations will arise where there are tradeoffs between increasing yields and impact on the environment, or with the social and ethical consequences of food production. In some casesthese tradeoffs may be avoidable through changes to governance systems but in many cases they will not be, and society will need to make difficult decisions, ideally

26 Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452

27 Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London

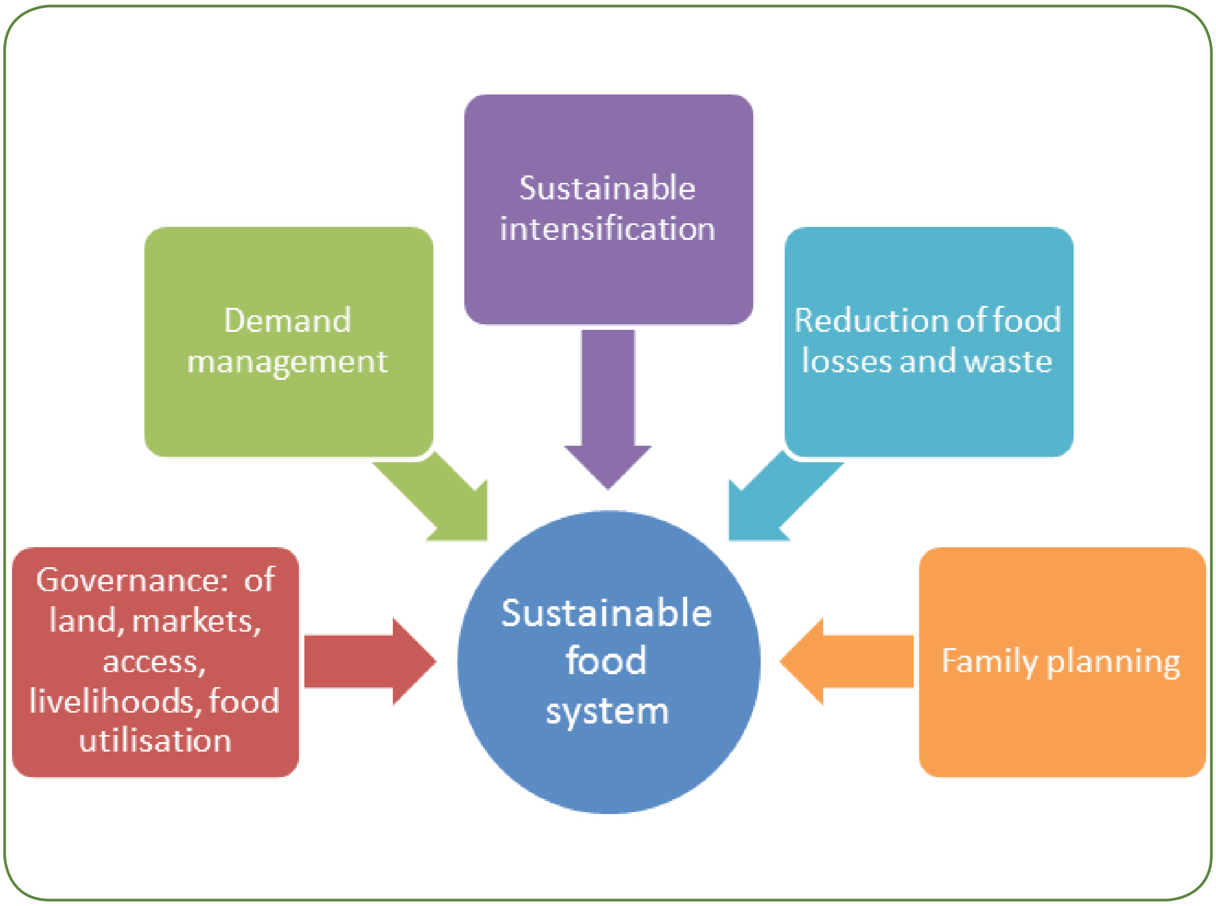

Figure 1: Sustainable intensification in relation to food demand, waste, governance and population

based on an informed scientific and socio-economic evidence base, and taking into account long-term resilience as well as short-term costs and benefits. However society resolves the tradeoffs, the challenges of combining sustainability with intensification arise. It is therefore inaccurate to link sustainable intensification with a defined requirement for a specific increase in food production. The link between the two must be broken.

2.3. The meanings of 'sustainable' and 'intensification' and their relative importance

A third set of disagreements revolves around the relationship between the 'sustainable' and the 'intensification' side of the phrase, as well as a lack of clarity on what each of these words actually means. Where major increases of yields have occurred in the past through intensification, for example after the Industrial Revolution or during the Green Revolution, they have been accompanied by environmental harm and reductions in sustainability. Critics understandably fear that the drive to increase yields will take precedence over ensuring sustainability. 'Intensification' is often associated in people's minds with systems that rely heavily on high levels of inputs such as fertilisers, water and pesticides many of which come from, or are produced using, non-renewable resources. This is in stark contrast to the Royal Society's definition of 'intensive' in the context of sustainable intensification, as a system of production which is "knowledge-, technology-, natural capital- and land-intensive”[28] and its emphasis that the “intensity of use of non-renewable inputs must in the long term decrease.” It is perhaps more helpful to understand ‘intensification’ as referring to ‘environmental factor productivity’ or ‘eco-efficiency’ – that is the efficiency with which inputs are used relative to desired outputs; and the desired outputs achieved from the system in relation to the undesirable outputs (such as water pollution or greenhouse gases). However even with this clarification, there is an additional question that needs to be considered: what do we want to increase productivity of? For example, the agroecology movement places emphasis on the importance of local, indigenous foods; discussion of sustainable intensification has as yet failed to engage with this issue – a failing that this paper identifies, arguing that there is need for more focus in this area.

The word ‘sustainable’ is, if possible, even more contentious. For some it denotes purely environmental goals (themselves multiple) whereas for others it additionally encompasses – as in the original Brundtland report definition[29] – social, economic and ethical dimensions. The original definition of sustainable intensification referred only to high-level environmental objectives. It was silent on many of the things that a large number of constituencies feel are essential to discussions on sustainability, such as the nutritional quality of what is being produced and the wellbeing of both the people who farm and the animals who are farmed. This is another gap that this paper seeks to assist in filling, mindful of the often complex interactions among environmental, social, ethical and economic goals.

Whereas most discussions of sustainable intensification have concentrated on agronomy and the environment, the discourse on agroecology normally explicitly includes social and ethical objectives within its definitional compass; it includes goals such as changes in diet, fairness and redistributive justice and a smallholder agrarian vision of agriculture. Agroecology, in short, is often held to be a movement rather than a set of farming techniques, even though not all its advocates are happy with this. While this bundling of multiple issues into the phrase gives it emotional and possibly organisational strength, it complicates assessments of the value of individual agroecological practices. Moreover, movements tend to define themselves against an “other”, a negative counter-vision against which their strengths can be compared. Sustainable intensification appears, unfortunately, to be serving this purpose for many proponents of agroecology.

Interestingly, while sustainable intensification’s critics may view the goals of intensity and sustainability as being incompatible, many nevertheless argue that agroecological methods can indeed achieve this union – the implication of course being that higher yields are indeed desirable, at least in certain contexts[30]. Once again this suggests that the problem with sustainable intensification in people’s minds may be less with the goal of more food, with less negative impact, but rather with assumptions about the agricultural model it is assumed to be advocating.

28 that is, it makes intensive use of land, rather than using a lot of land

29 Our Common Future, Report of the World Commission on Environment and Development, World Commission on Environment and Development, 1987

30 UN (2010). Report submitted by the Special Rapporteur on the right to food, Olivier de Schutter 17 December 2010, United Nations Human Rights Council Sixteenth session, United Nations General Assembly

It is argued in the paragraphs that follow that sustainable intensification is not wedded to any one agricultural approach. It is based upon the principle that in a complex world with a growing population, the more effective use of inputs and the reduction of undesirable outputs in order to achieve greater yields – intensification – is fundamentally required in order to achieve sustainability.

3. Is sustainable intensification a useful concept?

There are many other terms currently in use to capture the goal that sits at the heart of sustainable intensification – of using land, water and other inputs in better ways to provide the food we need as well as to achieve other goals – including agro-ecology and climate smart agriculture, to name but a few (see Box 2). These phrases often tend to carry more favourable associations in people's minds than those attributed to sustainable intensification. This point cannot be ignored. Whatever the 'true' semantic origin of sustainable intensification, the reality is that what any given word or phrase stands for depends upon the meanings which have accrued over time and, consequently, how these meanings resonate with decision makers and the public. The question then arises – if the phrase is so contentious, why not abandon it and use one of the others – or coin an entirely new one instead?

That is certainly an option for policy makers and merits careful consideration. However, our view is that new phrases do not magically deliver easy solutions. With all its imperfections the phrase sustainable intensification is already becoming embedded in policy and contributing to new thinking about ways of producing food[31]. It is also the case that the other concepts currently in use, such as agro-ecology an climate-smart agriculture, are themselves the focus of considerable debate and uncertainty and both their proponents and their critics have differing views on what they actually 'mean.' Also there is inevitably a risk that any new phrase will similarly be co-opted by interest groups who use it in ways that were not originally intended.

Moreover, when specific interventions are examined, removed from their rhetorical context within particular food production philosophies, there is very substantial overlap between sustainable intensification and the terms and concepts described in Box 3. Somehow, as a global society we will need to work out how to put in place a different type of agriculture – one that is capable of feeding humans but which does not damage the biodiversity and ecosystem services upon which it ultimately depends, nor the fabric of what we consider to be ethically and socially acceptable. While the different terms that have been coined may differ in what they believe may or may not be inputted to the system, and in what they feel the outputs should be, all will have to engage with the reality that there are hard tradeoffs between different desirable outcomes and uncomfortable choices for all stakeholders whatever their prior beliefs. Changing any one phrase will not alter the nature or the difficulty of the challenge. There is a need for stakeholders to come together, focus on the 'knotty' issues and identify points of commonality, instead of focusing excessively on terminological differences.

31 FAO (2011). Save and grow: A policymaker's guide to the sustainable intensification of smallholder crop production, Food and Agriculture Organisation, Rome

Box 3: Concepts related to sustainable intensification

Ecological intensification: This phrase was coined by Cassman[32] in a 1999 paper on cereal production that anticipates many of the analyses of the last few years: "At issue, then, is whether further intensification of cereal production systems can be achieved that satisfy the anticipated increase in food demand while meeting acceptable standards of environmental quality. This goal can be described as an ecological intensification of agriculture." This concept is essentially synonymous with an environmentally oriented interpretation of sustainable intensification.

Agroecology: This has been defined as "the application of ecological concepts and principles to the design and management of sustainable agricultural ecosystems… This approach is based on enhancing the habitat both above ground and in the soil to produce strong and healthy plants by promoting beneficial organisms while adversely affecting crop pests (weeds, insects, diseases, and nematodes)[33]. However it can also been seen as a "scientific discipline, as a movement, and as a practice" – sometimes all three – and the way it is used varies by context[34].

Permaculture: A movement that incorporates many ideas from agroecology but very specifically advocates certain design principles derived from observations of natural ecosystems in order to create sustainable settlements and agriculture. The concept has been much influenced by the writings of Bill Mollison[35] who at one time claimed proprietary rights on the concept.

Organic agriculture: This has been defined as "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved"[36]. Organic agriculture is regulated by bodies such as the Soil Association in the United Kingdom; these specify which practices, methods of pest control, soil amendments and so forth are permissible if products are to achieve organic certification. It is a specific type of food production, defined by process rather than product, that emphasises the sustainability of the local agro-environment and reductions in the use of synthetic inputs.

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32 Cassman, K.G. (1999). Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture PNAS, 96, 5952-5959

33 S. R. Gliessman, Agroecology (Ann Arbor: Ann Arbor Press, 1998); M. A. Altieri,Agroecology: The Science of Sustainable Agriculture (Boulder: Westview Press, 1995); M. A. Altieri and C. I. Nicholls, Biodiversity and Pest Management in Agroecosystems (New York: Haworth Press, 2005

34 Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., David, C. (2009). Agroecology as a science, a movement or a practice. A review. Agronomy for Sustainable Development

35 Mollison, Bill (1988). Permaculture: A Designers' Manual. Tagari Publications.

36 International Federation of Organic Agricultural Movements (http://www.ifoam.org/growing_organic/definitions/doa/index.html)

Ecofunctional intensification: A term promoted by the organic movement, its goal is a more efficient use of natural resources and processes, improved nutrient recycling, and innovative agro-ecological (q.v.) methods for enhancing the diversity and the health of soils, crops and livestock. Eco-functional intensification is seen as characterized by cooperation and synergy between different components of agro-ecosystems and food systems, with the aim of enhancing the productivity and stability of the agro-ecosystems, and the health of all components.

Climate smart agriculture: This term was coined by the FAO who define it as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals"[37].

Eco-efficiency: A term that first appeared as a proposal from the World Business Council for Sustainable Development (WBCSD) that was endorsed by the 1992 Earth Summit in Rio de Janeiro as an approach by which the private sector could achieve sustainability. Eco-efficiency, as defined by WBSCD, means producing "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity."[38] More recently, the International Centre for Tropical Agriculture has adopted eco-efficiency as its mission statement and is working with partners to identify more precisely what eco-efficiency in agriculture means for policy and practice[39].

Technological optimism: Though we have not found a single phrase that encapsulates it, there is a strong strand in contemporary agricultural thinking that sees technological innovation as making a major, even the majority, contribution to producing more food with less environmental impact. Proponents point to the potential and promise of precision agriculture, hydroponics, desalination, high-tech urban agriculture, artificial meat and many other technologies. The Keystone Center[40] in the United States, for example, seeks to incorporate existing innovations within a largely conventional agriculture setting but other commentators are far more ambitious. Within this broad school people differ in the importance of the role accorded to the private sector in delivering these goals, and in whether they see genetic manipulation as part of the solution or rendered unnecessary by other technological advances. and where decision makers have to act now and make hard decisions in the face of trade offs and conflicting stakeholder interests.

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37 FAO (2010). "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation, Food and Agriculture Organisation, Rome.

38 Schmidheiny, S. 1992. Changing Course: A Global Business Perspective on Development and the Environment MIT Press, Massachusetts Institute of Technology ISBN 0-262-69153-1

39 International Centre for Tropical Agriculture 2012. Eco-efficiency: from vision to reality. http://www.ciat.cgiar.org/publications/Pages/eco_efficiency_from_vision_to_reality.aspx

40 Field to Market: The Keystone Alliance for Sustainable Agriculture http://www.fieldtomarket.org/

Policy decisions made about food production should be based on evidence from both the natural and social sciences but also on political, ethical and value judgments. It would be naïve to suggest that the two can always be kept separate, yet greater clarity in distinguishing the grounds upon which decisions are made may help resolve some of the misunderstandings among groups who may be arguing for similar things. In the sections that follow we explore some of values underpinning stakeholders' approaches to agricultural production so that ongoing discussions can be based upon a shared grammar and vocabulary. Greater clarity will also help identify where strengthening the evidence base is important and where decision makers have to act now and make hard decisions in the face of trade offs and conflicting stakeholder interests.

Our purpose here is twofold: to recapture sustainable intensification from those who have sought to redefine it; and to contribute to making it an operational tool of value to practitioners and policy makers. We believe that as a conceptual framework, it provides a valuable approach to negotiating the food-environment challenges we face. Like the other concepts in Box 3 it has a vision of what needs to be achieved, but unlike many of them it does not prescribe in advance the particular route to achieving it. It is likely to draw upon principles set out in Box 3 above, but it does not inherently proscribe or advocate the use of particular inputs or techniques. As with agroecology, sustainable intensification emphasizes the importance of understanding natural processes in agro-ecosystems but it nevertheless holds that the application of any particular intervention based on ecological observation or insight requires evaluation and testing on an equal footing with any other type of intervention. An agricultural practice that emulates natural ecological processes may or may not be desirable: the point is that judgements as to its merits need to be tested empirically and supported by evidence. The same principles apply to consideration of technologies such as genetic modification. Sustainable intensification is not designed to garner support for one particular set of possible social and economic outcomes. Instead, it is best envisaged as a pragmatic process of enquiry and analysis for navigating the issues and concerns.

4. Debating sustainable intensification

What are the key issues of concern as regards food production and consumption today? Clearly there are many, but three of those that appear to be particularly contentious and come up repeatedly in discussions about sustainable intensification are issues relating to

1. environmental objectives
2. animal welfare
3. nutritional quality and what the desired outputs are from agriculture.

The first centres around defining the environmental objectives of sustainable agriculture. Do we sufficiently understand environmental impacts and interactions? What metrics are we using and what more do we need? How do we assess sustainability over space and time, taking into account human behaviour and governance issues? What is the knowledge and what are the values that we bring to the discussion?

Sustainable intensification raises many ethical issues and the focus of the second topic is on animal welfare. The consequences for the wellbeing of livestock are frequently cited as a major concern about sustainable intensification. How do people define animal welfare, what is its relationship both with environmental sustainability and with productivity, and what do we do with this knowledge?

The third focus is on the 'outputs' of sustainable intensification that are of immediate value to humans. What is it that we wish to 'intensify' productivity of? Food is the most obvious output but what foods in particular do we want or need? What about non-food outputs and outcomes?

All these issues interact with one another and certain themes or questions come up again and again. These are drawn out and discussed further in section 5. For now, two linked premises are taken as a starting point. The first is that there is still much that we do not understand. The second is that even where we have 'facts,' people assign different values and meanings to them. The task is therefore not only to work out what we know and what more we need to know, but also to understand how different stakeholders interpret and assign value to this knowledge.

We stress that the aim here is not to provide answers to all the questions about what sustainable intensification should or should not be, but rather to define the issues that need to be considered when making decisions, or when investing in research to strengthen the evidence base.

4.1. Environmental concerns: land use, biodiversity and ecosystem services

This section on environmental considerations is divided into three subsections: it begins by outlining a few general issues (4.1.1.) before looking at how definitions of environmental sustainability shift when considered over different temporal and spatial frameworks

(4.1.2). Third, (4.1.3) it considers the arguments in a debate that is core to discussions around agricultural sustainability: the land sparing versus land sharing issue.

4.1.1. General environmental issues

Food can be viewed as a type of "good" whose production relies on natural and socio-economic capital. Natural capital constitutes the components of the environment that provide ecosystem services upon which agriculture and other forms of food production rely[41]: for example soil fertility, regulation of water supply for crop and pasture growth, pollination, as well as direct provisioning services such as the supply of fish for capture fisheries. Socioeconomic capital provides the human, social and economic resources required to produce food, including inputs such as labour and fertilisers. Natural and socio-economic capital are to some extent substitutable: poor soil quality can be improved by artificial fertilisers, or natural pollinators augmented by apiculture. They also overlap – for example, artificial fertilisers are manufactured from natural capital, and natural capital only becomes a human good through application of socioeconomic or human capital. How the natural capital is managed, and the nature of the way the socioeconomic capital is deployed, can affect natural capital stocks and the flow of future ecosystem services of value to food production.

In addition to food, agroecosystems also produce other outputs of importance to humans. These may be straightforward economic goods such as fibre, wood or energy, whose value is captured directly by the farmer or landowner. Other positive but less direct outputs include supporting and regulating services such as water purification, flood control and carbon sequestration that are also of monetary value to society; these affect the wellbeing of society but do not necessarily impact upon the farmer or landowner in direct economic terms. There can also be other positive impacts whose economic value is far harder or even impossible to quantify – for example the provision of habitats for wild animals and plants (over and above those that do not directly benefit the landowner, such as pollinators and the natural enemies of pests and weeds) and the agricultural landscape itself, which is often cherished by society.

Similarly, agroecosystems can produce negative outputs that may directly impact the landowner, such as poor soil management leading to reduced fertility; or that affect other stakeholders in damaging ways. Some may be straightforward, at least conceptually, to value economically - for example greenhouse gas emissions through carbon accounting - but assigning a value to others, such as the loss of biodiversity, may be much harder to quantify and the values assigned may be highly contested.

Nitrogen run-off from agricultural land that pollutes water bodies, carbon sequestered in soils, and the wild animals that find a home on farmland, are all examples of the direct impacts of the way farming is practised. Thus the decisions made by farmers not only affect their own livelihoods but also, indirectly, the wealth, livelihoods and general well-being of a much broader set of people - from those living locally to (in the case of greenhouse gas emissions) everyone on earth.

In addition there are perhaps even more indirect impacts that operate through the

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41 Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

workings of the global food system, leading to often unpredictable consequences. For example, the production of more food will tend to reduce its price; in some cases this will benefit poor people and reduce smallholder pressures on land use while in others it may stimulate further agricultural land use change by agricultural producers (large and small) in an effort to compensate for falling farm-gate prices.

All serious discussions of the future of agricultural production today consider the importance of reducing the direct (i.e. on farm) negative environmental impacts of food production and most also are concerned with increasing the direct positive environmental impacts. Their current prominence in policy debates is at least partly due to the tireless work of the organic, agroecological and other environmental movements. The effect of production and productivity on global food prices has always been a core area of concern for food and commodity economists, and one that has dramatically risen up the political agenda in the last five years since the first food price spike of 2007/8. However, the indirect negative environmental consequences of decisions made about the way we produce food (particularly in relation to land use change) have received far less attention, although recently the debates about biofuels have highlighted their importance. The much greater emphasis placed on these indirect effects by those arguing for sustainable intensification explains some of the disagreements and frictions that arise when in discussion with proponents of other approaches to sustainable agriculture.

One harmful indirect consequence of failing to increase production on *existing* agricultural land is the resulting economic pressure to convert more land to agriculture. Most of the land potentially available for conversion to agriculture is currently forest (both in tropical and temperate regions), wetland or pasture. Conversion nearly always results in the substantial release of greenhouse gases – today, approximately half the greenhouse gas emissions attributable to food production are incurred indirectly through land conversion[42]. The negative climate changing consequences of land conversion are so great that a number of groups have argued that it should stop – that policy should be made on the assumption of no new land for agriculture[43]. Arguments to halt land conversion centre not only on the need to reduce greenhouse gas emissions. Existing non-agricultural land harbours a considerable portion of global biodiversity, the majority of which would be lost if conversion occurred. This land also provides other ecosystem services that would be very hard for humanity to replace. For example, the existence of large blocks of forest in the Amazon and central Africa seems likely to regulate the patterns of rainfall over much of their respective continents in ways whose disruption would be very harmful.

The imperatives of reducing hunger and achieving food security are often invoked to justify treating food production in a special way - what critics refer to as “agricultural exceptionalism”[44]. In its most naive form, arguments run along the lines that, with nearly a billion people on earth suffering from hunger, there is a “moral duty” to produce more food. This of course ignores the fact that sufficient food is available – the problem for most hungry people is that they are simply too poor to buy it or the necessary market and other distribution mechanisms are not in place – or both. The “duty” to produce food has been

42 Bellarby, J., Foereid, B, Hastings, A. and Smith, P. (2008). Cool Farming: Climate impacts of agriculture and mitigation potential. Greenpeace, Amsterdam

43 Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London

44 Daugbjerg, K & Swinbank, A. (2009). Ideas, Institutions, and Trade; The WTO and the Curious Role of EU Farm Policy in Trade Liberalization. Oxford University Press, Oxford

used to justify many interventions in the market that bolster local agricultural industries or that support farming and rural communities. This can be thought of as social sustainability and we discuss briefly below whether these broader social goals should be included within the concept of sustainable intensification.

If demand for food does increase then this will be reflected in higher food prices. The question then arises as to the role that sustainable intensification might play in meeting demand for food in ways that are affordable for poor people. Sustainable intensification can be thought of as a set of farming techniques that equips food producers to respond both efficiently and sustainably to these price signals, provided that the right governance framework is in place – for example one that assigns economic value to environmental impacts (what economists call externalities). However, reliance on market mechanisms is only likely to work in countries with relatively mature agricultural markets. In low income regions of the world poor financial and physical infrastructure, as well as an insufficient institutional capacity and skills base, may require more interventionist approaches to help increase productivity sustainably. Critically, broader governance structures regulating land use, together with effective enforcement need to be in place so that the price signals caused by higher demand lead to sustainable intensification rather than to agricultural expansion.

The environmental argument for sustainable intensification is thus founded on three principles:

- The consequences of converting more land to agriculture are so harmful to the environment that any increase in production must be achieved with as little additional land conversion as possible.

- Producing more from the same amount of land must be done in ways that reduce the direct negative environmental impacts of food production. This will require much more efficient use of water, energy and other inputs (increased production must be accompanied by increased productivity) and attention to the long-term sustainability of agro-ecosystems. Opportunities for positive environmental impacts (for example carbon sequestration on agricultural land) should be pursued where possible.

- While some growth in food demand is inevitable, the extent of the increase will depend upon how far policy on the demand side is successful in modifying diets, reducing waste and reducing the rate of population growth. However, relying on successes in these areas to achieve food security is as risky as relying on increases in production alone. Action is needed on all fronts in order to keep food supply and food prices within societal accepted bounds; and the role of sustainable intensification is to deliver productivity gains in ways that are environmentally and societally acceptable.

Thus at the heart of sustainable intensification are the twin goals of delivering yields high enough to remove the 'need' to encroach further on uncultivated land at the global aggregate level; but of doing so in ways that optimise the use of non-renewable inputs, and do not cause environmental damage to soils, water, air and ecosystem services on and around farmland. Achieving both goals will not always be possible and trade offs are inevitable. Different regions will need to balance objectives in ways that best reflect local environmental conditions and priorities - and these individual decisions will have implications for global sustainability. How to negotiate an acceptable balance between local and global sustainability objectives is the subject for discussion here.

4.1.2. How can we define environmental sustainability?

Sustainable food production implies a form of farming that can be continued indefinitely into the future. But what we actually mean when we talk about sustainable agriculture in an environmental context is often not clear (we return to other dimensions of sustainability below). Sometimes it represents a general aspiration to reduce the environmental harm that may undermine future food production. At other times it describes particular food production processes that only use renewable inputs. In thinking about what environmental sustainability means we need to consider how its definition changes when viewed through different spatial and temporal perspectives. For example:

- **Sector boundaries.** To what extent should agriculture's environmental costs and benefits be 'vired' to and from other sectors? For example, might greenhouse gas emissions in the production of synthetic fertilisers be mitigated by carbon capture and storage, or biodiversity losses on farmland be compensated for by the establishment of nature reserves on non-agricultural land elsewhere (see also below)? On the other hand, could ongoing growth in another economic sector (aviation, for example) be compensated for by paying for carbon sequestration activities in the agricultural sector? Or should agriculture be treated as a socio-economic activity distinct from others? Where cross-sector national strategies exist, perhaps for greenhouse gas emissions or biodiversity, then the scope to develop policy across different areas offers the prospect of more effective responses. In their absence, shifting the responsibility to other sectors risks being an excuse for inaction.

- **Spatial extent.** At what spatial scale should sustainability be defined? Might the reduction in farmland bird populations in some regions be considered sustainable if their populations increased elsewhere? If non-renewable agricultural inputs were proscribed in one area or country, leading to a decrease in yield, how might its sustainability be judged if it led to more demand for food produced in regions or countries with poor environmental regulations? On the other hand, the larger the spatial scale at which sustainability is assessed, the more stakeholders become involved. The risk is that the responsibility to increase sustainability becomes dissipated and any potential benefits lost.

- **Temporal issues.** Thinking about forms of farming that can continue indefinitely is of limited value given our inability to look into the distant future. In practice a comprehensible timespan for consideration is usually a matter of decades or perhaps a century. Beyond that the uncertainties about what technology may deliver, the nature of demand, and the state of the climate render policy making largely pointless. Nevertheless, what may happen in the next few decades can influence today's decisions about what is sustainable. For example, one may argue for investment in organic agriculture, even though yields are generally lower, in the expectation that research will identify ways of closing the productivity gap. On the other hand one may support the continued application of synthetic fertilisers in the anticipation of technological developments that will mitigate their negative effects. Moreover, farming decisions made today about what to produce and how will influence societal norms and expectations about choice, quality, price and so forth. This socio-technical interdependence can mean that new problems emerge from old solutions and vice versa.

- **Use of non-renewable resources.** A sustainable food production strategy should explicitly plan for the exhaustion of non-renewable resources. We know that there are only finite reserves of fossil fuels or mineral phosphate. Much of the water used to irrigate agriculture comes from reserves such as underground aquifers that are replenished so slowly that they are essentially non-renewable. Where reliance on non-renewable resources involves negative impacts such as greenhouse gas emissions then reductions in their use prior to them becoming exhausted may improve overall sustainability (though it is important to consider all indirect impacts – some biofuels, though renewable, have more negative effects for the environment than fossil fuels). In other cases where any negative impacts are relatively small or absent, using up non-renewable resources may make both economic and environmental sense (for example, less water extracted from rivers and more food produced) provided that plans are made in preparation for a future in which they will have been exhausted.

- **Baselines.** Farming environments deliver landscapes and provide habitats for biodiversity and one goal of sustainable food production, as typically conceived, is that they should continue to do so in the future. But the rural landscape today is not what it was even a few decades ago, and the biodiversity present today is different from what it was in the past - in most places it has been diminished. Sustainability can only be defined relative to a temporal baseline; and its identification is a political process, even though it will be informed by scientific knowledge. A concern of many conservationists is that as we lose biodiversity the baseline keeps shifting downwards, since society is unaware of or simply accepts what it has lost.

The complexities of the issues that make up sustainability, even when defined just in environmental terms, are so great that they can hamper progress towards its achievement. In practice policy makers need to set pragmatic goals and targets that can be in place long enough to justify investment by the private sector actors involved and are consistent with the best available environmental science. Examples of such targets already in place in many high income countries include directives on water quality in the farm landscape (for example nitrate and pesticide concentrations) and on different biodiversity measures. Targets for greenhouse gas emission reductions from food production are increasingly been considered, although none are yet binding. Determining exactly what these targets should be is an intensely political process and involves consideration of many non-environmental aspects of food production. There are numerous difficulties and dangers: different interest groups will attempt to align targets with their particular goals and policies; targets, to be effective, must be relatively simple to administer yet avoid perverse and possibly self-defeating incentives; and care needs to be taken to ensure that the different policy objectives set do not negate each other, and that they take into account the trade-offs among their different components. Critically, the indirect impacts need to be considered – what effects the targets may have on global food markets and how this may influence the environment elsewhere (for example the effect a GHG reduction target may have on embedded water use in agricultural production). There are also different approaches to implementing policy goals: are carrots (incentives) better than sticks (penalties for failure); should food producers be directed to adopt certain practices or judged purely by results; and what if any role does consumer information play in influencing purchasing decisions that in turn drive best practice?

Achieving targets requires metrics to assess progress. It is doubtful whether a single sustainability metric could be devised, even for the environmental aspects alone of sustainable intensification. In some areas the development of metrics is likely to be fairly straightforward. For example, the concentration of pollutants in water bodies can be measured with relative ease, while better methods for assessing the full greenhouse gas emission consequences of different farming measures is the subject of much current effort, even if capturing all the indirect consequences remains a major challenge. However, metrics for other aspects of sustainability are far harder to formulate. Biodiversity is, by definition, multidimensional and comprises everything from genetic through species to habitat diversity. It is literally impossible to measure all aspects of biodiversity and so identifying proxies is essential. But exactly what to measure among the myriad of possibilities is very hard to decide. In practice the choice is influenced by factors such as the scientific evidence base (what measures correlate best with other aspects of biodiversity), pragmatics (measuring some things is easier than others) and politics (organisations that campaign for birds and plants naturally place great value on these particular groups). Biodiversity metrics are also particularly influenced by the scale of measurement. For example, is it enough that sustainable populations of a particular species exist in some places - or should they be found everywhere?

To make these arguments more concrete we now focus on a particular environmental aspect of sustainable intensification - how to manage the land to produce multiple services in the presence of tradeoffs. This argument has been portrayed as one of specialisation: should land be managed simultaneously to produce, say, biodiversity and yield (the land is “shared” between services), or should land be specialised in some places to produce yield and in others to produce biodiversity (land “sparing”)? Given that there is an inherent trade off assumed in this argument, a larger yield in agricultural land implies that land can be “spared” for biodiversity.

4.1.3. Land sharing versus land sparing for biodiversity and greenhouse gas reduction

As discussed above, on farm decisions that affect yield can have profound off-farm consequences, through their impacts on the total area of land under farming. Land conversion leads to major emissions of greenhouse gases and also to the loss of biodiversity. One line of argument holds that since further land clearance for agriculture is undesirable, policies that promote greater wildlife on farm and the use of fewer synthetic inputs, while likely to be locally environmentally beneficial, may lead to lower yields and hence generate price signals that trigger land clearance in another region. Such ‘extensification’ should thus be avoided even if this means accepting greater environmental damage on existing agricultural land. Alternatively, it (must be acknowledged that greater levels of intensification will be required elsewhere if land conversion is to be avoided. On farm environmental impacts should nevertheless be minimised. At a global level one of the main arguments for sustainable intensification, that land conversion elsewhere should be avoided, can be characterised as a type of land sparing.

The idea of accepting Proponents of organic or “wildlife friendly” farming however, have voiced concerns about the land sparing approach. Some believe that compromising on biodiversity and other desired environmental outcomes on farm can be seen as a form of moral hazard that ultimately impedes progress towards sustainable agriculture. There are also concerns about the social implications of land sparing. There is evidence to suggest that the drive to raise yields in existing agricultural areas in order to reduce greenhouse gases and preserve natural habitats can occur at a cost to other benefits that may be derived from less intensive production. These include not only environmental 'goods' (such as on farm biodiversity) but also socio-economic benefits such as diverse food and non-food products, and smallholder livelihoods and cultures[45]. Finally, it is argued that without the governance structures in place to enforce land sparing, only one side of the contract will be realised (high yields but not spared land), a point we return to below.

Are these criticisms justified? Several groups have tried to investigate the merits of land sharing versus land sparing approaches from various environmental perspectives. Burney et al. for example calculate at a global level that in the absence of the Green Revolution, the amount of land that would need to have been dedicated to agriculture to meet current food requirements would be much greater than it is today, even under a scenario where diets remained the same as in pre-Green Revolution times[46]. Looking ahead, Tilman et al.[47] use a simple statistical projection to estimate the level of food demand by mid-century, assuming current patterns of correlation between dietary change and income and World Bank estimates of economic growth. They then calculate the greenhouse gases generated in meeting this need either by converting new land to agriculture and maintaining today's average yields or by using artificial fertilisers to boost yields without area expansion. They conclude that increasing yields is better for climate change than land conversion.

Different aspects of both studies can be criticised. In the case of Burney et al., they compared Green Revolution agriculture with low-yielding conventional food production. However, a better counterfactual might have been a scenario where Green Revolution levels of investment were focused on organic agriculture or related approaches. Tilman et al. similarly do not consider an agroecological alternative that might enable higher yields and a lower level of land conversion. On the other hand their estimates of the greenhouse gas emissions that would result from the application of synthetic fertilisers do not take into account the potential savings that would arise if they were applied more judiciously and effectively, for example through precision agriculture techniques. The study also fails to take account either of the potential for achieving in changes in demand or reducing waste in the food system, both of which would moderate the increase in supply needed).

We are not aware of a "macro" level estimate of the global loss of biodiversity that was avoided or caused by the Green Revolution, nor what might be the consequences for biodiversity of different strategies for meeting the future demand for food. Indeed, only recently have quantitative studies sought to explore the relative advantages of land sparing and land sharing at a landscape scale. An important recent study by Phalan et al. sought to

45 Homewood K, Lambin E F, Coast E, Kariuki A, Kikulai I, Kivelia J, Said M, Serneels S and Thompson M (2001). Long-term changes in Serengeti-Mara wildebeest and land cover: Pastoralism, population, or policies? PNAS 98, 22, 12544–12549

46 Burney J A, Davis S J and Lobell D B (2010). Greenhouse gas mitigation by agricultural Intensification, PNAS, www.pnas.org/cgi/doi/10.1073/pnas.0914216107

47 Tilman, D., Balzer, C., Hill, J. & Befort, B.L. (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260-20264.

shed light on this issue[48]. Taking originally forested tropical and sub-tropical landscapes as its focus, it looked at the distribution of birds and plants across a spectrum of land use types (from continuous forest to pure farmland) in India and Ghana. For a given agricultural yield target, they calculated whether less intensive agricultural practices on a greater area of land are more supportive of biodiversity than more intensive practices on a lesser area of land with greater preservation of forest. The study found that for realistic yield targets, land sparing 'wins,' and that this is particularly the case when the analysis is restricted to species with small geographical ranges, which are often of the greatest conservation interest. It concluded that in principle, the best strategy in these regions for conserving biodiversity is to set aside protected forest reserves, while simultaneously investing in relatively high-yield intensive agriculture to meet food demand and support rural livelihoods.

This study thus appears to provide strong scientific evidence for the biodiversity benefits of land sparing – although it does not thereby conclude that a greener version of conventional farming is sufficient and the way forward. It should be reiterated at this point that 'sustainable intensification' does not denote simply a greening of the status quo. There are important scientific and non-scientific caveats and provisos in the study (most mentioned by the authors) whose elaboration may be of help in the development of sustainable intensification policy.

Consider first the more scientific issues:

- Biodiversity is only one environmental outcome, and birds and plants only one component of biodiversity. The study did not examine or quantify the impacts of intensive agriculture on ecosystem services of benefit to the farmer (for example soil structure), to the broader community (for example water quality) or to the world (greenhouse gas emissions). The effects that nitrogen and pesticide applications might have if they leaked into the environment, especially into freshwater bodies, were not measured. All these would need to be tested against impacts arising from less intensive systems.

- The study only looked at one type of habitat (tropical forests); studies in other areas might have drawn different conclusions. For example, in regions such as the Mediterranean, the present mix of plant and animal species has been shaped by millennia of human agricultural activity and flourishes in areas of low-intensive food production. Exactly what pure "land sparing" would be in this context is not clear and past land sharing has essentially sustained the biodiversity we now value[49].

- The study considered a single spatial scale; issues of land sparing and land sharing can arise at multiple spatial scales from within a farm to across the globe.

A similar methodology can be applied to issues of extensification and intensification in the UK. It has been shown that British organic farms support greater butterfly biodiversity that conventional farms - although more species still exist on what the UK designates "sites of special scientific interest" (SSSIs). If the landscape is required to produce a specified

48 Phalan P, Onial M, Balmford A and Green R E (2011). Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. Science 333, 1289

49 Benton, T.G., Dougill, A.J., Fraser, E.D.G. & Howlett, D.J.B. (2011) The scale for managing production vs the scale for managing ecosystem service production. World Agriculture 2: 14-21

amount of food, then for most realistic assumptions butterfly biodiversity is maximised by farming conventionally, provided that the resulting spared land is converted to SSI-quality habitat[50]. The optimal solution thus depends on the way any spared land is managed[51].

Further research is clearly needed to explore these issues in a broader array of habitats. Such work should ideally incorporate a broader range of environmental outputs and ecosystem services and consider how they interact. There is a need to understand these interactions both at fine grained resolutions and at larger spatial scales, as well has how these change over time. Science in these areas is still evolving and new technological aids such as Geographic Information System (GIS) mapping can help.

But these technical discussions can yield only partial insights. Studies such as Phalan et al. provide important and relevant evidence but not clear direction to policy makers. Decisions have to be made within a much more complex multi-dimensional socio-political environment that takes into account issues such as the following:

- As noted, birds and plants are just two aspects of biodiversity and biodiversity just one amongst many environmental outputs of the way we use land. There is no non-arbitrary metric that we can use to compare the relative importance of, for instance, mitigating greenhouse gas emissions against reducing the loss of bird species. There may even be conflicts between goals of protecting one species versus another. Although the economic valuation of ecosystem services can provide a limited framework for comparing different consequences, ultimately the relative weightings given to the different outcomes reflect individual and societal values and beliefs.

- Land sparing requires that the governance of land use is sufficiently sophisticated and operates on a sufficiently large scale that the bargain is met[52,53] – that land really is spared for biodiversity in the face of possibly strong economic, social and political pressure for its exploitation. There is a profound asymmetry in land conversion: converting natural environments to land suitable for agriculture is quick, taking weeks or months and seldom more than a year. Taking agricultural land and managing it for nature or returning it to nature (rewilding) can be achievable but is much slower. Moreover, it may be impossible if the soil has been dramatically altered (for example by long periods of fertiliser application) or if species composition has been severely altered or reduced, or if species have gone extinct. There is a concern that intensification in the name of land sparing may only result in immediate loss of on-farm diversity with no long term guarantees that the “spared land” will remain in its current state. Equally, good governance is also essential to ensure that land sharing strategies yield real benefits for on farm biodiversity and other ecosystem services. Assessments of agri-environmental schemes applied under the Common Agricultural Policies (a form of

50 Hodgson, J; Kunin, W E.; Thomas, CD; Benton, TG; Gabriel, D (2010) Comparing organic farming and land sparing: optimising yield and butterfly populations at a landscape scale. Ecology Letters 13, 1358-1367.

51 Benton TG (2012) Managing agricultural landscapes for production of multiple services: the policy challenge. International Agricultural Policy 1: 7-18.

52 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

53 Perfecto, I. and J. Vandermeer. (2010) The agricultural matrix as an alternative to the land-sparing/agricultural intensification model: facing the food and biodiversity crises. Proceedings of the National Academy of Science 107:5786-5791

institutionalised land sharing) suggests that this approach does not necessarily deliver on its environmental objectives with potentially very large costs.

- A by-product of increasing yields in certain areas to allow land sparing may be that agriculture becomes more profitable, and that local financial and physical infrastructure, as well as the skills base associated with food production, are all improved. This might lead to a type of moral hazard, a greater incentive to renege on the land sparing agreement, or at least to renegotiate it. It may also lead to more subtle changes such as increased specialisation in the most profitable crops – intensification beyond that originally envisaged[54]. Critics see biodiversity loss as a ratchet with these types of feedback turning the wheel through more and more notches. On the other hand, these concerns apply equally to 'land sharing' strategies. There is nothing inherent in land sharing that acts as a restraint on human demand for certain foods or other agricultural products. In the absence of effective governance farmers practicing land sharing strategies may nevertheless seek to increase their profits by specialising (so reducing on farm biodiversity benefits) or bringing additional land into production, with damaging environmental consequences.

Promoting local intensification also has consequences for the stakeholders involved, and how the benefits are distributed will be of concern both to policy makers and others. The beneficiaries might be large national or international corporations, local small or medium-sized enterprises, or small-scale farmers. In some contexts there will be concern that intensification will favour some groups over others. In particular, where land rights are poorly defined or protected, smallholders may be excluded from their land which may undermine their livelihoods, culture and human rights, and may cause them either to encroach further onto uncultivated land (undermining land sparing and damaging livelihoods) or to migrate into the cities. Urbanisation tends on the whole to be correlated with more land- and resource-intensive dietary patterns, such as increased meat consumption[55,56], as well as increased removal of nutrients from agricultural systems into the oceans, and so enforced urbanisation may dilute the land sparing effect. In other words, 'leakage' of environmental impacts can occur not only over space, but over time as certain systems of production lock people into unsustainable patterns of consumption. This said, where policies to promote wildlife friendly farming fails to ensure financial security for poor farmers, there will be substantial social costs translating into poorer outcomes for health and education. Both the scientific and the non-scientific issues around biodiversity and greenhouse gas emissions emphasise the importance of land use governance. No matter what the scientific evidence, without a trustworthy regulatory framework in place, the complex trade-offs underlying land sparing can probably never be made to work. A similarly dysfunctional regulatory environment likely renders formal land sharing unworkable. The question then becomes whether the adoption of one strategy over the other leads to a greater number of perverse incentives, both environmental and social.

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54 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

55 Stage J, Stage J and McGranahan G (2010). Is urbanization contributing to higher food prices? Environment and Urbanization 22:199.

56 Nutrition and the Prevention of Chronic Diseases, Report of a Joint FAO/WHO Expert Consultation, WHO Technical Report Series 916, WHO, Geneva, 2003

The difficulties of developing and implementing effective systems of governance are clearly enormous. At one level this challenge is technical - it is about ascertaining what mix of policies - including regulations (for example prohibiting cultivation on certain areas of land), fiscal measures (from payments for ecosystem services to taxes on nitrogen inputs) and voluntary agreements (industry cooperation on shared goals) - might be most effective. Policy makers can, to an extent, develop strategies based on assessing the success of existing land use legislation (such as protected areas), as well as on market mechanisms such as product certification schemes and codes of conduct. However, it is difficult to see how local or national governments can make decisions for global benefit in the absence of global agreements on land use, or globally implemented measures to internalise the economic costs of environmental damage and benefits. Policy makers also face the difficult task of developing policy in the face of future unknowns – of deciding whether to base decisions on social and economic norms today or in anticipation of social, economic and governance changes or technical innovations tomorrow.

Ultimately, however, technical judgements on what constitutes sustainability will be interpreted by the values people hold and these will in turn shape the policies that are developed in response. People will prioritise objectives on the basis of their attitudes to risk and to trust, their assumptions and aspirations around broader social and economic governance of the food system and their views about what food production 'should' look like – economically, socially and aesthetically. Is smallholder production a 'good' in itself? Is diversity of agricultural outputs and outcomes better than a narrow focus on a particular crop (discussed further below)? Separating issues of science (natural and social) and issues of values is important but can be difficult, and both have a rightful place in how society develops agricultural and land use policy.

Finally, while so far the discussion has focused on difficult choices and uncertainties surrounding understanding, values and governance, the picture is not always murky. It will be possible to identify 'hotspot' areas where there are very clear win-wins between productivity gains, land sparing and reduced on farm environmental impacts. For example, in parts of Sub-Saharan Africa – the birthplace of the sustainable intensification concept[57,58] where yields are low, farmland soils are degraded and deforestation is ongoing, measures to improve soil fertility are likely to have benefits across all these areas of concern.

4.2. Animal welfare and ethics

The environmental impacts caused by the livestock sector have been well documented. Livestock have been estimated to account for 12-18% of current global greenhouse gas emissions and occupy around 70% of agricultural land – a figure that includes a third of all arable land. They are also major users of available freshwater consuming 8% of the global total. Livestock are implicated in deforestation and associated biodiversity loss and carbon dioxide release, in water contamination and in land degradation[59,60]. Food and Agriculture

57 Reardon T, Crawford E, Kelly V and Diagana B (1995). Promoting farm investment for sustainable intensification of African agriculture. MSU International Development Paper No 18, Michigan State University, Michigan, United States

58 Pretty J (1997). The sustainable intensification of agriculture, Natural Resources Forum, Blackwell Publishing Ltd.

59 Livestock's Long Shadow, FAO, Rome, 2006.

60 Environmental Balance: Summary. Bilthoven, Netherlands Environmental Assessment Agency (PBL), Bilthoven, 2009.

Organisation (FAO) estimates suggest that, assuming current trajectories, demand for, and associated production of, livestock is set to increase substantially by 2050 – by 73% for meat and 58% for dairy on today's levels[61]. Unless something is done, livestock's share of global emissions and its contribution to other impacts is set to grow. Hence sustainable intensification has been proposed as a critical way forward for the livestock sector.

Sustainable intensification has its origins in crop production, but has sparked controversy when applied to animal production because of ambiguity of what it means in this context. One meaning is simply an increasing use of indoor systems where waste emissions, food, water and temperature are more under control. There is potential here to develop systems that actually improve animal welfare. Another meaning, however, is that intensification refers to the efficiencies that would be achieved by demanding more of individual animals[62] – yet more eggs from hens already developing brittle, easily broken bones because of the demands of egg-laying, more milk from cows already showing metabolic disorders and shortened life spans and broiler chickens already at risk of lameness and cardiovascular disorders[63,64]. It is this second sense of intensification that causes concerns about animal welfare, implying as it does that individual animals will be under even greater stress than they are now. Almost by definition, there will be an inevitable decline in the animals' welfare. In discussing the relationship between sustainable intensification and animal welfare, it is therefore important to be clear which meaning of intensification is being proposed and what exactly is meant by animal welfare.

Most of the thinking on animal welfare has been undertaken in high income countries and is thus influenced by their particular sets of values and traditions, a strong focus on scientific enquiry and the pastoral romanticism that developed in parallel with industrialisation. Welfare is a complex concept that involves several different elements but in general, welfare definitions tend to include the requirement not only that animals are in good health, but also that they are somehow experiencing a 'life worth living.' So, by many accounts good animal welfare requires that: animals are healthy; unpleasant affective states such as fear, pain and frustration are avoided or minimized; and that animals can live in ways that suit their natural adaptations, including being able to carry out types of behaviour that they are strongly motivated to perform. These elements are present, for example, in the "Five Freedoms" of the United Kingdom's Farm Animal Welfare Council[65], and in the definition of animal welfare of the World Organisation for Animal Health[66]. However, disagreements about animal welfare often arise because different people emphasize these different elements to different degrees. For example, farmers who keep hens in small cages often emphasize the hygiene and control of parasites that cages allow, while critics point to the frustration that arises because the cages severely limit the birds' behaviour. Stakeholders also differ in the weight they place upon achieving animal welfare as compared with economic considerations, issues of food security or simply food

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61 FAO (2011). World Livestock 2011: Livestock in food security, Food and Agriculture Organisation, Rome

62 Pew Commission on Industrial Farm Animal Production, 2009. Putting Meat on the Table: Industrial Farm Animal Production in America, A Project of The Pew Charitable Trusts and Johns Hopkins Bloomberg School of Public Health.

63 Webster, J., 2005. Limping Towards Eden. Wiley-Blackwell, UK

64 Fraser, D., 2008. Understanding Animal Welfare: The Science in its Cultural Context. Wiley-Blackwell, UK

65 Five Freedoms, Farm Animal Welfare Council http://www.fawc.org.uk/freedoms.htm

66 OIE (2011). Article 7.1.2. Introduction to the recommendationsfor animal welfare Chapter 7.1 in Terrestrial Animal Health Code, World Organisation for Animal Health, http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_1.7.1.htm

preferences. The challenge is to develop systems that are geared to improving animals' quality of life but that also meet the need to reduce emissions and waste.

The 'good health' aspect of animal welfare is generally uncontested since there is a clear economic case to be made for keeping animals healthy: healthy animals are more productive. However the arguments for ensuring 'quality of life' go beyond the instrumental –they are essentially normative and therefore subject to more disagreement. While in high income countries, the principle that animal welfare is desirable and a good in itself (over and above its contribution to animal health) is fairly prevalent, this is much less so in low income countries where, importantly, good welfare for humans has not yet been achieved. In these contexts a better standard of human living is considered to be the priority, with greater access to affordable animal-source foods an important component of this. Animal welfare may often be dismissed as a rich world luxury, although this sometimes reflects lack of awareness of the benefits that better welfare in animals can bring to humans, as discussed later in this section.

All this is relevant to the discussion on sustainable intensification because in recent years life cycle analyses have shown that intensive systems (that is, systems based on high external inputs) tend to deliver more meat, milk or eggs per unit of greenhouse gases emitted than their more extensive counterparts. This is because intensive systems are more productive. While an individual more productive animal may generate more emissions than an individual less productive one in absolute terms, fewer animals are required to deliver a given amount of edible output, the overall effect being a reduction in emissions measured per given volume of output. Measures to improve productivity further might therefore, by reducing the number of livestock needed to deliver a specified quantity of meat, milk or eggs, lead to additional greenhouse gas savings. This finding has provoked concerns that the climate mitigation imperative will override ethical considerations and the goal of sustainable intensification will be used to justify systems of production that cause animal suffering.

The shift towards larger, more productive units has been accompanied by a rise in livestock numbers overall and a significant growth in per capita, as well as absolute consumption of animal products. It has been argued that intensification stimulates demand (through greater efficiency leading to reduced food prices) so that reductions in greenhouse-gas emissions per unit output are outweighed by an overall absolute increase in impact. In the absence of measures to address consumption of these resource intensive foods, the risk is that more efficient production will generate a 'rebound' effect; these arguments are similar to those that have been advanced in criticism of land sparing, discussed above. These arguments merit further investigation: while there is certainly an association between the growth in commercial intensive livestock production and consumption of low cost animal products further research is needed to ascertain the direction of causation: that is, whether intensification stimulates growth in consumption, or whether it represents a response to increased demand that might mitigate some of its negative consequences while exacerbating others. In practice, causation may run different ways in different circumstances.

Returning to the relationship between intensification and animal welfare, the issue can perhaps be usefully explored through two conceptual lenses. The first considers what intensification means, and looks like, in different contexts. The second looks at intensification in the context of governance.

4.2.1. What does 'intensification' imply in different contexts?

The first lens considers what 'intensification' - with either meaning - looks like and means for welfare in different contexts. Livestock systems in high and low income countries are currently very different and intensification has potentially different outcomes for welfare. When considering what 'intensification' actually means, it is important to consider the baseline against which productivity gains are measured as well as the meanings that are attributed to the word in different contexts, by different stakeholders.

In low income countries, yields in the extensive and smallholder systems that characterise a large part of livestock production are on the whole very low. Measured in terms of milk or meat output per unit of greenhouse gases emitted, these systems are inefficient (although see discussion in 5.3 below) since the energy they do obtain is spent on maintenance rather than on growth. At the same time, welfare even in its most uncontroversial sense - good health - can also be low since many livestock are not only malnourished but suffer from endemic diseases and a lack of adequate veterinary care. These diseases also affect human health (since livestock diseases can pass to humans) both directly and indirectly through economic losses.

When development agencies promote intensification in these contexts, the term tends to mean replacing subsistence production with systems that range from the very small-scale (such as the 'zero grazing' systems involving one or two cows) to medium-scale commercial production. In such cases, intensification is likely to mean a certain degree of confinement in pens, stalls, barns or fields; access to more nutritious feeds, potable water and vaccines; and specialized skills in animal health, care and nutrition.

These developments can yield significant productivity gains and can potentially be achieved through relatively simple adjustments to practices, combined with appropriate market incentives and institutional support[67]. With the right research and development, animal welfare can even be improved. Farmers are also likely to benefit both economically and in terms of their health. What is more, since the existing productivity baseline is very low, improvements in productivity can deliver substantial environmental benefits, both relative (impact per kg of output) and absolute (total impact)[68,69]. In short, human, animal and economic win-win-wins are possible.

In high income countries, intensification has different connotations. Productivity is already high since significant investments have been made in selecting productive breeds, in formulating and feeding diets that are high in energy- and protein-rich cereals and oilseeds, and in the construction of often confined housing systems that control the conditions in which livestock are reared.

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67 McDermott JJ, Staal S J, Freeman HA, Herrero M and Van de Steeg J A (2010). Sustaining intensification of smallholder livestock systems in the tropics, Livestock Science 130 (2010) 95–109

68 Thornton P K and Herrero M (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics, PNAS www.pnas.org/cgi/doi/10.1073/pnas.0912890107

69 FAO (2010). Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment, Food and Agriculture Organisation, Rome

Moreover, at the herd level, the greenhouse gas efficiency of highly productive animals can be questionable. For example, in dairy farming higher mortality rates due to ill health and infertility-related culling mean that more initially unproductive (yet still greenhouse gas emitting) replacement heifers need to be reared to compensate[70]. Hence the productivity of any individual animal needs to be viewed in relation to the overall health and fertility of the herd as a whole. Policy makers and the farming industry are increasingly recognising the need for a broader definition of productivity that considers the livestock group over time, and are starting to breed for 'robustness' rather than yields alone, at least in some high income countries.

The relationship between intensification and infectious diseases is similarly complex. Livestock kept indoors are less likely to come into contact with and so contract diseases from wild animals. For example, poultry kept indoors are less likely to be exposed to avian influenza from wild birds. On the other hand the densities at which animals are kept in intensified systems increases the risk of infectious disease spread and can encourage the use (including the prophylactic use) of greater amounts of antibiotics. The emergence of resistant bacteria strains poses concerns for human health and has led to, for example, recent guidance by the United States Food and Drug Administration that antibiotics that are medically important in human disease treatment should not routinely be used for animals[71]. The greatest risks of disease outbreaks are likely to occur in situations where smallholders (less extensive) and commercial (intensive) units coexist[72].

Overall, the relationship between health, productivity and environmental impact can be summarised as follows. Where productivity is low, measures to increase productivity by providing more nutritious food and medication and care that reduces diseases is likely to lead to a triple win: food production is increased, environmental harm per unit of production is reduced, and the animals are likely to have better quality of life.

However, at higher levels of productivity, the relationship is likely to be more clouded and cannot be predicted without empirical study. Measures to increase productivity may or may not have overall benefits when viewed over time or at the herd level (as in the case of dairy cows, above) due to the effects on fertility and longevity. Moreover, the level of intensification that is optimal for reducing environmental effects may not be optimal for animal welfare, particularly measured according to criteria related to the animal's ability to perform natural behaviours. The challenge in such cases will be to identify the various wins and losses for each of food production, animal welfare and environmental cost, and arrive at acceptable trade-offs.

It is important to recognise that what is acceptable may vary from culture to culture depending on the level of importance attached to animal welfare. There are many societies, especially among the industrialising transition economies, where for different reasons there is little tradition of concern about the conditions in which animals are kept. There are fears, particularly by animal welfare advocates, that an emphasis on sustainable

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70 Garnsworthy, P.C., 2004. The environmental impact of fertility in dairy cows: a modelling approach to predict methane and ammonia emissions. Animal Feed Science and Technology 112, 211–223.

71 FDA News Release: FDA takes steps to protect public health, April 11, 2012, http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm299802.htm

72 Slingenbergh J, Gilbert M, Balogh K de and Wint W (2004). Ecological sources of zoonotic diseases Rev. sci. tech. Off. int. Epiz., 23 (2), 467-484.

intensification, while focusing on yields and the environment, will do nothing to advance the cause of animal welfare and may even impede it. The question then is: could this risk be managed by ensuring that sustainable intensification has something explicit to say about the need to achieve good welfare? This question leads onto the issue of governance - the second lens through which one might consider the sustainable intensification-animal welfare relationship.

4.2.2. Governance

The policy context within which livestock production occurs will determine the welfare outcome. If society decides that the safeguarding of whatever it regards as good animal welfare is an ethical non-negotiable then 'intensification' will have to be constrained by the standards that it specifies. Just as we accept a ban on slavery or child labour in the UK, however economically effective it might be, so a society can choose to prioritise particular moral objectives over environmental efficiency. In other words, since intensification 'at all costs' is something that society can choose to avoid, the question then arises as to whether the definition of sustainable intensification should incorporate some kind of internal "ethical control mechanism" into its definition - for example that it should require environmentally sustainable increases in productivity without unacceptable (however defined) costs to animal welfare. This can be seen as an ethical version of BATNEEC – modified to BATNEEEC - Best Available Technology not Entailing Excessive *Ethical* Cost – as it were.

Of course, the difficulty would be finding common ground within society to define "unacceptable." Alternatively, sustainable intensification could retain a purely environmental definition but be viewed and operate within the context of laws, standards and codes of practice that determine farm practice in relation to welfare (equivalent to cross-compliance). The merits of folding multiple goals into the definition of sustainable intensification or maintaining a narrow ecological definition which is then situated within these wider concerns, are discussed further in 5, below.

Ultimately, reconciling environmental, economic and welfare goals will be much easier to achieve if greater efforts are made in one key area of governance – demand management. As noted elsewhere, demand management has in any case been highlighted as an important strategy in achieving a sustainable food system. Measures to reduce consumption of animal products in high consuming countries, to moderate the growth in demand elsewhere, and to reduce waste and losses throughout the supply chain, will reduce the level of intensity required to meet demand for these foods. This, by lowering the level of supply needed to match demand, can enable the welfare risks that can arise in very highly productive systems to be avoided.

4.3. Human-centred outcomes: nutrition

One of the goals of sustainable intensification is to increase agricultural productivity. But productivity of what? Sustainable intensification needs to focus on delivering goods and other outcomes that have societal value and exactly what they are will determine how it is implemented.

What does society – or rather the multiple and competing stakeholders who comprise society – value? While the main purpose of agriculture is to provide food, it is not the only one. Other desired outputs and outcomes include fodder (grains and crop residues), fibres, traction, soil fertilisation (manure, legumes), bio-energy, economic benefits such as livelihoods and employment, security in the form of liquid assets such as land and livestock, and status, cultural, environmental and aesthetic outcomes. Different stakeholders prioritise these differently; for example farmers and the agricultural industry may place greatest emphasis on profits; consumers are generally most interested in their individual welfare (including not only nutrition but also the provision of non-food 'goods' such as tobacco, coffee or alcohol) while governments seek to balance these many competing interests. Biofuel production is fast becoming a major desired output from the system for many stakeholders.

Even taking food as a single output, there are further questions to consider. Productivity is often measured in terms of volume or kilocalories per unit of input, but other nutritional metrics could be and have been used, such as protein, or certain vitamins or minerals[73,74,75]. Beyond nutrition, one might wish to measure individual or cultural food preferences or even reliability of yield – a metric that encapsulates the food security definition of stability over time.

Which metrics are selected, and how the 'answers' they give are interpreted, give rise to different conclusions as to which systems of production are most likely to deliver the desired intensity of outputs in a sustainable way. As noted in the discussion on land sparing/sharing, much of the criticism surrounding sustainable intensification stems from concerns that the multiple outputs and outcomes that some farming systems achieve will be ignored. Instead simple, and single metrics, such as volumes, or kilocalories are used to measure success on the food side, and by these measurements conventional monocultural systems tend to score highly. These metrics might indeed be telling us something important but there is a risk that a focus on simple measures of efficiency can lead to investment only in high yielding production systems that deliver high output per unit of greenhouse gas emissions (or other metric), but may not fully serve the full nutritional needs of the global population or provide other outputs important to sustainable livelihoods, including those that are harder to define.

Taking nutritional objectives to start with, worldwide, malnutrition affects billions of people. Nearly a billion people are under-nourished; their diets lack sufficient calories and other nutrients, leading to stunting and long term impacts on cognitive development and health. Even more people, two billion, have diets lacking in the right mix of nutrients, particularly essential micronutrients, for healthy development[76]. These include a growing number of people suffering from "over-nutrition" and energy dense, nutrient poor diets that lead to obesity and chronic disease.

As incomes increase, many people are shifting to diets dominated by meat and dairy products, oils and refined carbohydrates. As a result around 1.5 billion people worldwide

73 Smedman, A., Månsson, H., Drewnowski, A., Edman, A (2010). Nutrient density of beverages in relation to climate impact. Food & Nutrition Research, 54: 10.3402/fnr.v54i0.5170.

74 Davis J, Sonesson U, Baumgartner D U and Nemecek T (2010). Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. Food Research International 43 1874–1884

75 Scarborough P (2010). Nutrient Density to Climate Impact index is an inappropriate system for ranking beverages in order of climate impact per nutritional value. Food & Nutrition Research, 54 10.3402/fnr.v54i0.5681

76 http://www.wfp.org/hunger/faqs

are obese or overweight. Obesity is no longer only a rich world problem – most of these people are citizens of low and middle income countries, and many of them are poor[77]. These people are at risk of a range of diet-related illnesses including cardiovascular disease, strokes, diabetes and some cancers. Some of them may, at the same time, suffer from micronutrient deficiencies.

How does sustainable intensification engage with this complex problem of malnutrition, including in its over- and under-nutritional forms ? How can approaches be developed that allow for and enhance dietary quality? Is it possible to have a discussion about sustainable nutrition without addressing broader systemic issues about what people should be incentivised and disincentivised to consume – and where does sustainable intensification sit within this debate?

One approach that has been advocated to address the diet-related problems we face is to seek to contain or reverse the trend towards diets increasingly rich in refined carbohydrates, meat, vegetables oil and sugars. This could be done by regulating food supply or price to make healthy foods more accessible and affordable relative to unhealthy foods, and by incentivising production of a diverse range of grains, tubers, fruits and vegetables, including those that may be less commercial varieties indigenous to the locality of production. Proponents argue that this approach combats not only macro- and micronutrient deficiencies (by supporting local production for local consumption) but also addresses dietary imbalance and micronutrient deficiencies which contribute to the incidence of obesity-related chronic diseases. It may also be seen as supporting some environmental sustainability objectives. The FAO, for example, explicitly links nutritional diversity with crop biodiversity, and considers diversity not just in terms of the range of foods produced and consumed (maize, beans, carrots) but the diversity within type (different varieties of carrot, for example)[78].

In principle, these measures, if effectively implemented, are likely to lead to improvements in people's diets; individuals consuming a wide variety of foods are more likely to be able to obtain all the nutrients that they require, including those that are likely to be needed in the diet but whose role is not fully understood and that are therefore not the focus of current fortification programmes. Dietary diversity can thus be seen as providing nutritional resilience in so far as it provides more than the sum of its known parts. We do not, however, know what impact this approach might have on overall land requirements for agriculture and hence what its environmental impacts might be. Moreover these approaches require structural change in the food system, and even assuming that the political will is there, these change will take time.

A more immediate response to the problem of malnutrition is to enhance, through fortification, the nutritional content of the foods that people are most likely to eat. Fortification and biofortification programmes have a particular value in addressing the dietary problems of those too poor to have access to more diversified, healthy diets, and who generally subsist on small amounts of cereal staples. Beyond this, fortification may be seen as politically and culturally simpler to implement than more diverse systems of production and consumption. It also has the advantage of reaching net food purchasers in

77 http://www.who.int/mediacentre/factsheets/fs311/en/ accessed 13 February 2012

78 FAO (2010). Final document: International Scientific Symposium Biodiversity and Sustainable Diets: United against Hunger. 3-5 November 2010, Food and Agriculture Organisation, Rome

urban and rural areas who cannot afford to buy micronutrient rich food such as vegetables, fruit, pulses and animal products. The foods most likely to be fortified are those based on the production of high yielding commodity crops that may be more efficient to produce, measured in terms of greenhouse gas emissions per yield per area. Consumption of these crops is also growing world-wide and in this sense, fortification programmes such as Harvest Plus run *with* rather than counter to global dietary trends. However, while fortification can help address micronutrient deficiencies, the foods that tend to be the focus of fortification programmes (vegetable oils, salt and refined grains) are those that are implicated in the rise of overweight, obesity and associated chronic diseases. In contrast, recent efforts to increase the nutritional content of food by traditional plant breeding or genetic interventions (biofortification) are often targeted at crops grown by very poor people. This includes species such as sorghum, millet and cassava which are the few crops that can be grown in very dry, marginal conditions. These are much more likely to have positive rather than negative nutritional outcomes.

While advocates of fortification and biofortification might argue that the "best" (nutritional adequacy through diversity) is the enemy of the "good" (action now to combat malnutrition), critics might respond that these interventions do not so much 'top up' inadequate diets, as prolong food systems that are inherently inadequate and contribute to the growing problem of overweight and obesity. They would argue that the fortified diet is based on an only partial understanding of nutrition and the role of, and interactions among different micro nutrients, and so it risks being nutritionally inadequate. A focus on fortification as a substitute for more systemic change may also skew policy decisions and business investments that in turn shape agricultural developments into the future.

Once again, which approach is favoured very much depends not just on our values about what we should be producing and consuming, but on our beliefs about governance, the role of the market, and about how far decision makers should and can alter policies, regulations and pricing structures to alter current patterns of production and of consumption.

The role of meat and dairy products in the context of 'sustainable' diets – that is, the demand management aspect of the sustainable food security equation (see Figure 1, above) – is complex and nuanced. On the one hand, animal products are micronutrient rich and have a key role to play in addressing malnutrition, particularly in children[79,80,81]. On the other hand, they are a major contributor to greenhouse gas emissions and are consumed in quantities excess to requirements, both in high income countries and increasingly in transition economies.

In principle, restraining demand for meat and dairy foods by high consumers could help reduce the burden of chronic diseases, deliver greenhouse gas reductions and free

79 Neumann C G, Murphy S P, Gewa C, Grillenberger M and Bwibo N O (2007). Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. J Nutr.;137(4):1119-23.

80 Murphy S P and Allen L H (2003). Nutritional Importance of Animal Source Foods, Journal of Nutrition, 133, 11 Supplement: 2, 3932S-3935S

81 Dror D K and Allen L H (2011). The importance of milk and other animal-source foods for children in low-income countries, Food & Nutrition Bulletin, 32, 227-243(17)

up substantial areas of land[82,83,84,85]. Demand restraint will undoubtedly make it easier to align the 'sustainable' and 'intensification' sides of the production challenge, and, by reducing pressure on land use, help avoid indirect leakage effects over space and time. Arable and pasture land currently used to rear livestock could then be "spared" not only for environmental and other purposes but also to grow a more diverse range of nutrient-rich plant and tree-based foods.

The question then arises: should the definition of sustainable intensification encompass health, as well as environmental objectives? Clearly healthy diets are an important policy goal. Achieving it will require actions to influence both supply (what food is produced) and demand (what is consumed). Equally it can be argued that an environmentally sustainable food production system may well be impossible if demand for foods with particularly large environmental footprints, such as meat and dairy products, is not modified[86] – and these are the foods whose over consumption often causes health problems. However while measures to align health and environmental goals are an urgent policy priority for the food system as a whole, it is less clear whether sustainable intensification *per se* should be tasked with nutritional objectives. In the same way that sustainable intensification should not become embroiled in discussions about how much food is needed (2.2 above) , it could be argued that it should it concern itself with what kind of food is produced. Rather, it is for society, to define what its production and consumption goals are. The role of sustainable intensification is then to deliver higher productivity (however defined) in ways that are sustainable (however defined). This question of whether non-environmental goals should be included in the definition of sustainable intensification is an important subject for debate, with valid arguments on both sides, and is discussed further below.

82 Stehfest E, Bouwman L, van Vuuren D P, den Elzen MGJ, Eickhout B, Kabat P. (2009). Climate benefits of changing diet, Climatic Change, Volume 95, Numbers 1-2

83 Friel S, Dangour A, Garnett T, Lock K, Butler A, Butler CD, Chalabi Z, Roberts I, Waage J, McMichael A J, Haines A. (2009), Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture The Lancet, 374: 2016–25

84 Westhoek H, Rood R, van den Berg M, Janse J, Nijdam D, Reudink M and Stehfes E (2011), The Protein Puzzle, The Hague: PBL Netherlands Environmental Assessment Agency.

85 Scarborough P, Allender S, Clarke D, Wickramsinghe K and Rayner M (2012). Modelling the health impact of environmentally sustainable dietary scenarios in the UK European Journal of Clinical Nutrition doi: 10.1038/ejcn.2012.34

86 Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452

5. Cross cutting themes and questions

In the discussion above, certain themes and questions come up over and again. The purpose of this section is to explore these in more detail and if possible to identify research questions whose exploration could further understanding in these areas.

5.1. Our goals for the food system and the role for sustainable intensification within it

One important theme to emerge is that we, as a society, need to define what the goals are for the food system – bearing in mind that in reality multiple, often interacting food systems operate within this concept. Broadly speaking, one might define the overarching vision for a food system as one that is nutrition-driven, equitable and ethically acceptable and that sits within long-term environmental limits. However this sort of definition is too broad; there is a need to develop a more detailed, context-specific vision of what a sustainable food system might look like, within which more localised food systems operate and taking into account the multiple factors that constitute both sustainability and food security. What is also essential is that different stakeholders recognise that they bring not just their knowledge, but also their values and ethical concerns to the discussion which are influenced by their own particular contexts.

Figure 2 identifies just some of the issues that need to be taken into account when considering the food system as a whole.

Sustainable intensification sits somewhere within this framework – but where? As the analysis above has indicated, sustainable intensification, if it is to be a meaningful aspiration, needs to be mindful of the social, economic and ethical context within which food production activities take place. A key question to consider therefore, is how formally these other concerns should be connected with the definition of sustainable intensification. Should the definition limit itself to environmental criteria or should it also encompass broader social and ethical concerns such as labour standards, animal welfare, or human nutrition (Figure 3)?

There are advantages and disadvantages to both approaches. A narrow environmental definition would leave society to define goals for food production (what type of food, limited by what sort of ethical requirements) and seek to deliver these in a way that is as ecologically sustainable as possible. This definition is simpler, although still complex in view of the difficulties of assessing sustainability over space and time, and in recognition of people's different value sets. It also has the advantage of not being normative – it allows for various sustainable food systems to be envisaged, based on different social and economic models, not one.

The danger with this narrow approach is that if non-environmental goals, such as improved working conditions, animal welfare or better nutrition, are excluded, they may be sidelined or given less prominence. For example, in many parts of the world the concept

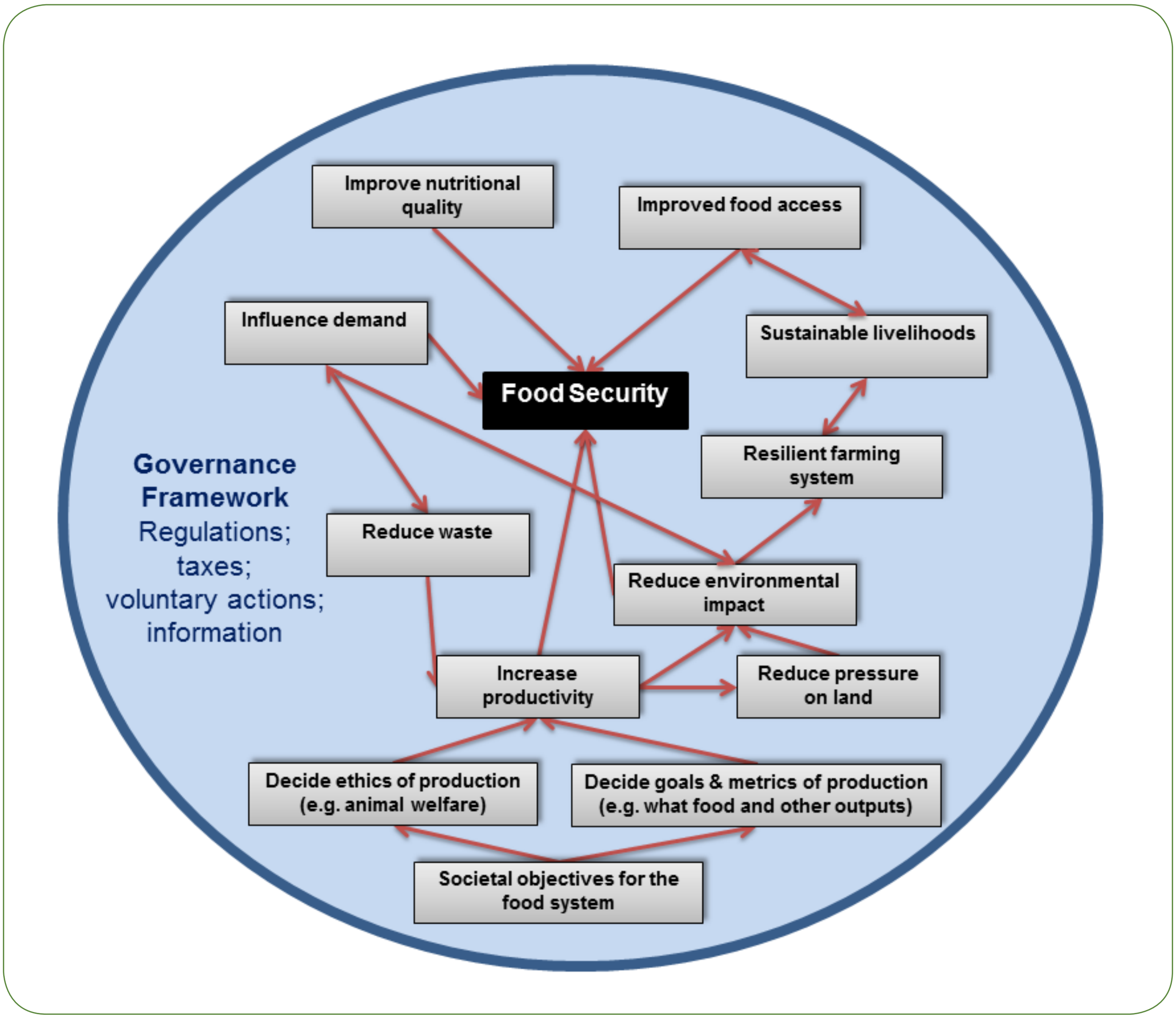

Figure 2: Elements of a sustainable food system

of animal welfare is weak or missing. Where sustainable intensification is used to justify systems of production that cause suffering to animals, the definition will continue to be treated with hostility by those from within the animal welfare community. It may therefore be desirable to define certain ethical parameters that constrain productivity objects – the BATNEEEC approach suggested above. Safeguarding welfare can also help production and environmental sustainability goals in the many contexts where win-wins are achievable. This is an issue that urgently needs to be investigated and resolved.

5.2. The need for better scientific understanding and refined metrics

Any decisions that society makes on changing the food system clearly need to be based on sound scientific knowledge. A major theme to emerge from the discussions above is that our understanding of how complex systems function over space and time needs to be improved. We also need to develop better metrics for measuring progress against targets.

In the environmental domain, further research into the interactions among water, carbon and nitrogen cycles is needed, as well as the relationship of all these factors to the different components of biodiversity. In a globally connected food system actions taken in one place

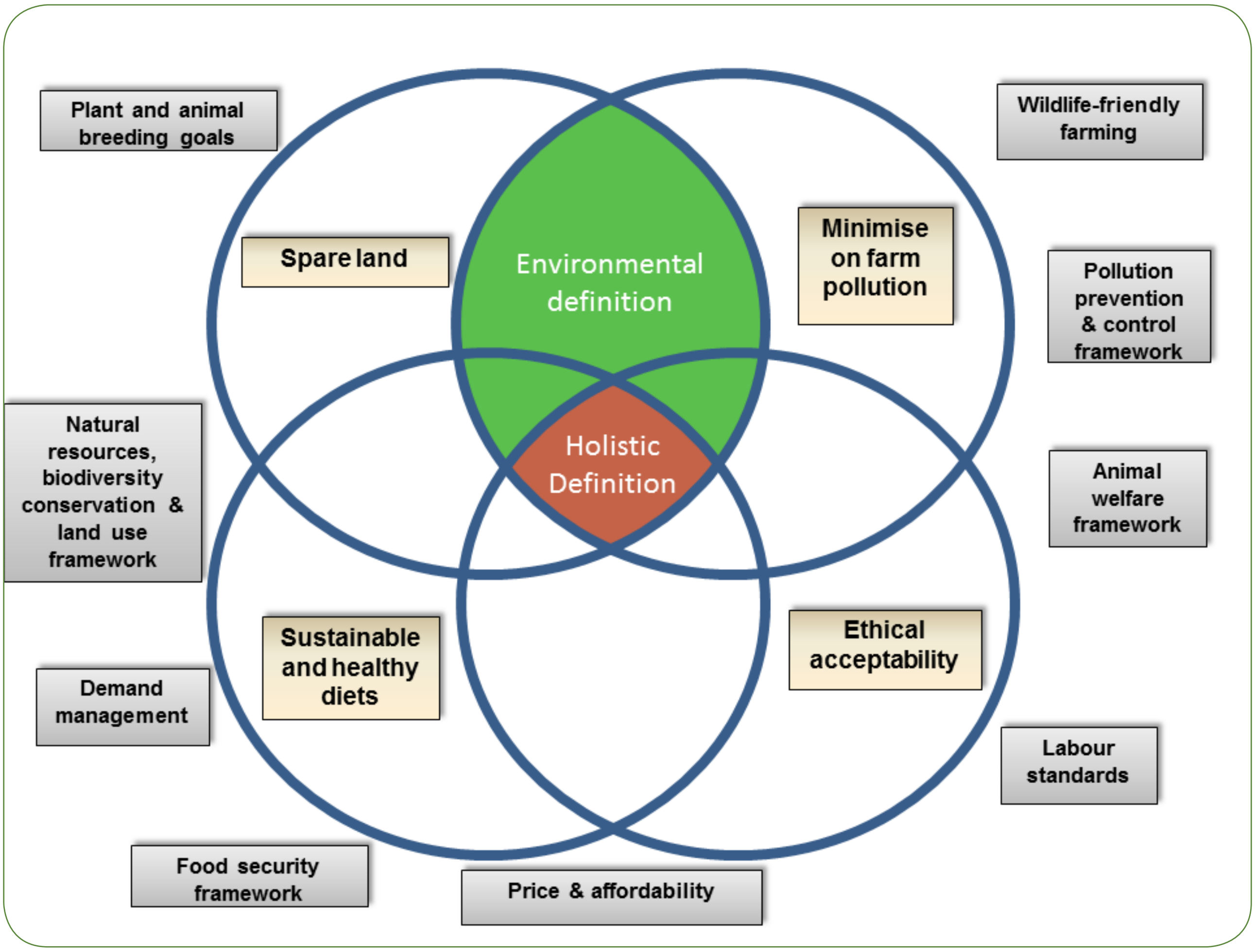

Figure 3: What is the scope of sustainable intensification?

are very likely to have indirect consequences in geographically distant areas as well as multiple effects that ramify into the future. It is therefore essential to understand system interactions both at very fine grained resolutions and at broader spatial and temporal scales. A greater understanding of these interactions needs to be accompanied by the development of better metrics for assessing environmental outcomes.

Taking livestock production as an example, intensive systems can, as noted above, achieve high outputs of meat, eggs or milk per unit of greenhouse gases emitted. Defined according to this metric they can be seen as preferable to more extensive systems although the relationship between these systems and the absolute growth in demand for livestock products (and associated absolute increase in emissions), requires further investigation (see above). They often score less well when viewed from the perspective of the use of irrigation water and fossil fuels. While intensive systems may use less land than extensive systems, they make use of different types of land and this may have implications for sustainability in the longer term. Intensively reared livestock, particularly monogastrics, are highly dependent on soy, a high quality source of protein; there have been concerns about the effects that interactions between the soy and cattle ranching industries have in driving both direct and indirect land use change in the Amazonian region and the Cerrado[87]. These interactions are complex, not fully understood, fluctuate in relation

87 Barona E, Ramankutty N, Hyman G and Coomes O T (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon, Environ. Res. Lett. 5 024002

to changing commodity prices[88] but nevertheless have been confirmed to exist.[89] Also requiring investigation are the consequences of 'efficient' meat production on consumption trajectories over time. It can be argued that technological transformations, by massively increasing the supply of these foods, potentially foster new consumption habits and norms that in turn feed future growth in demand. A different perspective, however, is that this form of production allows currently disenfranchised people to eat the types of food that are enjoyed by those with high incomes. The contribution of system innovations to the 'consumption rebound effect' needs to be explored further in view of, on the one hand, the policy imperative to address hunger and malnutrition and, on the other, to address overconsumption and environmental damage.

Extensively grazed ruminants have the advantage of utilising land unsuited to crop production, are less reliant on grain inputs that require the use of scarce arable land, and potentially also have a role to play in contributing to soil carbon sequestration. However, there are also many examples where the landscape is over-grazed, causing soil degradation and soil loss, or where land with large carbon stores (or with great carbon storage potential) is converted to extensive pasture – deforestation in the Amazonian region being a prominent case in point. Moreover, the role of well managed grazing livestock in contributing to soil carbon sequestration is context dependent; in many regions pasture has achieved carbon equilibrium and no longer continues to sequester carbon. Grazing livestock may provide an economic, aesthetic or cultural rationale for not converting the land to other uses, but they do not always actively contribute to additional carbon uptake.

As regards nutrition and the broader livelihood outputs from the farm system, it is important to move beyond crude metrics such as yield, or calories, or income. As in the case of the environment, there is a need to understand the interactions and interdependencies of different elements of the farm system, to develop better metrics for measuring the multiple nutritional and non-nutritional goods and services that obtain and to link them to key anthropometric indicators of health status such as stunting or wasting. A key research priority is to understand how nutritional, environmental and economic outcomes interact.

It is often pointed out that farmers seek to hedge against risks not only by planting a variety of crops on farm (perhaps in combination with livestock) but also by engaging in a diverse range of on- and off-farm income and livelihood promoting activities. Hence to measure the output of just one crop from the farm system would give a misleading indication of the value the farmer gains from the system in relation to its environmental impacts. There is a real need to develop metrics that capture the multiple nutritional and non-nutritional outputs that can be obtained from agriculture, and to assess these against environmental objectives. For example, in a mixed farm system can we measure the diverse outputs that are obtained from the system, including the nutrients from different sorts of food and the values of non food goods (fodder, soil fertilisation timber), and examine how these outputs inter-relate? Can we develop ways of comparing these yields with those from specialised systems where the same outputs are produced by a number of individual single-output farms? Can an integrated system deliver more than the sum of its

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88 Macedo M N, DeFries R S, Morton D C, Stickler C M, Galford G L and Shimabokuro Y E (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s, PNAS, doi:10.1073/pnas.1111374109

89 Arima E Y, Richards P, Walker R and Caldas M M (2011). Statistical confirmation of indirect land use change in the Brazilian Amazon Environ. Res. Lett. 6

parts or are more specialised systems more effective in delivering outputs? How do these systems compare in relation to environmental impacts? Once again, understanding these interactions both at different spatial and temporal scales is needed.

5.3. Resilience and its relationship with diversity and productivity

This need for a systems perspective links to another major theme: the concept of resilience.

Resilience and sustainability are related but not identical concepts. Ways of producing food that can continue indefinitely into the future are by definition sustainable (though see above for discussion of the complexities involved). Part of this "continuability" is the ability to withstand perturbation – be it environmental (weather), biological (pests and diseases) or human (recessions, civil unrest). The resilience of a system is its ability to recover from a shock. Some resilience is essential for sustainability but a highly resilient system that bounces back rapidly after a perturbation possesses both stability and sustainability. One particular system might show high resilience to one type of perturbation but low resilience to another. For example, closed-system hydroponics using renewable inputs may be highly stable and sustainable and have high resilience to drought and other weather shocks, but because of high running costs low resilience to economic shocks.

Are diverse systems more resilient than simpler systems? In the ecological sciences this is a complicated question that has been the subject of intense research over the last two decades[90]. There is evidence that some properties of ecosystems show greater resilience (often equated with stability or a reduced tendency to fluctuate) in more diverse communities. The two main reasons for this are that (i) more complicated communities are statistically more likely to contain at least some species that are relatively little affected by the perturbation and (ii) in diverse communities one species is more likely to be able to compensate for damage done to another. There may thus be an "insurance effect" of biodiversity. But while ecologists have demonstrated that diversity can be associated with resilience, the effect is subtle and has not always been found where looked for. Perhaps the most consistent finding is not at the community level but at the level of the species: within-species genetic diversity increases the resilience of that species to perturbations involving pathogen attack.

Do these ecological insights help us to design resilient agricultural systems? The disease risks of genetically homogenous crops and livestock have been recognised since the dawn of modern agriculture. In principle genetic diversity can be maintained in the field by growing different varieties of crops or keeping different breeds of livestock; or it can be maintained "on the shelf" in seed banks or germplasm. Agronomists have long explored different disease management strategies and it is clear that the best approach for optimising resilience depends both upon the ecology of the disease system and on the socio-economic context. In-field genetic diversity is likely to be the best strategy for low-income smallholder farmers. Moving from within- to between-species diversity there is plentiful evidence that monocultures are more susceptible to pests, especially because the natural enemies of the pest frequently do not prosper in such landscapes. Greater resilience to pests and diseases can normally be obtained by diversifying crops, though often (but by no means always) at the expense of yields. The optimum level of diversity is then determined by the environmental costs and benefits of different cropping and crop

90 Cardinale, B.J. et al. (2012) Biodiversity loss and its impact on humanity Nature, 486, 59-67.

defence strategies. Diversity is more likely to be favoured when the full costs of agricultural externalities are included (for example the costs of pollution) and in low-income contexts where advanced crop protection is not available or feasible. There is also an argument that in high-input conventional agriculture some of the potential benefits obtained in more diverse systems (for example those that integrate livestock and crops) are poorly appreciated and hence are not included in considerations about how production systems might be optimised. Further research here is clearly needed.

The potential advantages of mixed, diverse systems in providing the full range of human nutrients was discussed in Section 4.3. To understand what a nutritionally *resilient* diet might be we need to know the response to perturbation of, for example, the mix of crops. For example, if the perturbation is a drought then it is important that the most drought-resistant crops are able to support healthy human life until better conditions return. A problem in arid Africa is that the most drought-resistant crops are often nutritionally unbalanced. Biofortification may thus have a role in improving dietary resilience in the short term. On the other hand if the biofortified crop is relied upon as the main food source over long periods of time, the risk is that people may not obtain the full of range of nutrients required for optimal health.

There are deep parallels between the theories of ecological and economic resilience. Intensification may change the balance of economic risks that producers are exposed to and there is clearly a need for greater understanding of the relationship between environmental and economic resilience. Concentrating on single agricultural outputs increases exposure to negative price movements or to weather shocks; on the other hand it leads to economies of scale and increases the pay-off in normal years. More generally, livelihoods that depend purely on agriculture are susceptible to economic or physical conditions that affect the whole sector. As with ecology and agronomy these risks can be hedged either from outside the system by taking out insurance against future unwelcome eventualities, or from within the system by diversifying into multiple agricultural commodities (or non-agricultural sources of income). Which of these strategies leads to more resilient and hence sustainable outcomes again depends upon context - in the absence of insurance, biological diversity strategies are likely to work best in low-income situations.

5.4. Values and ethics

When considering the desired outputs from the system, the metrics we use and the notion of what constitutes resilience, scientific information will only get us so far. The values and ethical perspectives we bring to the discussion are equally important. This is not at all to say that values substitute for scientific knowledge – on the contrary. But facts needs to be contextualised, and meaning assigned to numbers. Beyond a certain point the values and ethical perspectives we bring to the discussion will influence what we want the food system to deliver, how we prioritise the different indicators of sustainability that science provides, the power and motivations we attribute to individuals, businesses and governments and the scale and time frame we adopt. All these shape what the ‘right’ course of action is judged to be.

Many of the disagreements about sustainable intensification arise because while differences in values underpin the different approaches proposed, they are implicit, and not made clear. This means that people are often talking at cross purposes. There is a real need for policy makers to take values more seriously and to explicitly incorporate analysis of the different perspectives that people bring into discussions about food security and sustainability.

5.5. Governance

Many of the uncertainties around sustainable intensification reflect uncertainties about governance in the food system, both by governments and other actors. In the absence of global controls on land use change, on GHG emissions from agriculture or indeed on any of the concerns that arise when considering sustainability and the food system, it is very hard to ascertain how theory will translate into practice. Will land sparing work or will it be undermined by the workings of economic markets? How will national level policies on agriculture influence global food prices and what will the knock on effects be on people's health and on the environment? Can knowledge about the relationship between environmental sustainability and diets be turned into a set of policies that influence people's consumption patterns? What policies will enable farmers and other stakeholders to make decisions that are sustainable not just in the short but in the long term?

The absence of global agreements on all these issues cannot be an excuse for inaction by individual governments and other key stakeholders in the food supply chain. Leadership by individual countries can benefit not only their national interests but also contribute to collective progress in developing transnational regulations. Policy makers can make a start by prioritising the easy wins, where there are clear synergies among competing goals and less risk of leakage. Obvious areas for more work include collaborative action to raise productivity in sub-Saharan Africa and in other low yielding regions; to improve animal welfare in situations and countries where there are clear synergies between animal health and productivity; and to fund scientific research that focuses on systems thinking and the development of metrics that better reflect the inter-relatedness of agriculture's multiple inputs and outcomes.

What is also clear is that governance around sustainable intensification can never be 'just' about the environment since agricultural production has impacts that go far beyond the ecosystem. How food is produced, who produces it, what and how much is consumed and by whom, are all factors that have far reaching consequences for people's health, for human development, and for the welfare of animals reared for consumption. A system of food production that is socially, economically or ethically unacceptable to a large fraction of the population will lack "continuability", or resilience, however ecologically attuned it may be.

6. Conclusion

Sustainable intensification is still a new and evolving concept. For now, it is most accurate to see it as providing an intellectual framework, or process of enquiry and analysis for navigating the issues and concerns, rather than a clearly defined set of principles and practices. Further work is needed to see what sustainably intensive systems might look like in the field, and how they vary from context to context.

However, we believe that certain key insights do emerge from the discussion above as to what sustainable intensification needs to be – and what it is not. They are summarised as follows:

- Both words in the phrase sustainable intensification need to carry equal weight. Intensification, by reducing pressure on land and other resources, underpins sustainability. Equally, food production in the context of a growing population, must ultimately be sustainable if it is to continue to feed people in the future.

- Sustainable intensification is not a movement or a grand socio-political vision. It is not a strategy for the food system as a whole but just for one component within that strategy.

- Sustainable food security requires actions on multiple fronts. On the demand side actions are needed to reduce population growth rates and to curb high levels of per-capita consumption, particularly for resource intensive foods. The food system needs to be more efficient by improving governance and reducing food losses and waste throughout the food chain, from farm to plate. On the supply side more food will need to be produced with much less impact on the environment through, we conclude, sustainable intensification. No one of these actions on its own is able to achieve sustainability and security in the food system. Sustainable Intensification should therefore be seen not as a substitute for, but as a complement to these other necessary measures.

- Sustainable intensification as a concept should be decoupled from specific production targets. Sustainable intensification is about optimising productivity and a range of environmental and possible other outcomes.

- Sustainability needs to be viewed over space and time in order to include the indirect effects and consequences of different policies that may impact on other regions and future generations. The indicators used to measure sustainability may also vary according to temporal and spatial scales.

- Societies need to negotiate what outputs and outcomes from the system they want to intensify production of and to develop metrics that enable us to measure progress against targets.

- Much can be done with existing knowledge but there is also a need for more research that takes a more systemic approach to food production. Greater understanding of how the various elements of complex systems interact is needed, both at fine grained and broader spatial and temporal scales. This understanding needs to encompass not just environmental interactions but also the relationship between the environment, human health, ethics and livelihoods. In short, there is a need to recognise better that human technical and societal innovations and the environment influence one another, and to understand these interactions further.

- More work is needed to translate this thinking into the development of metrics that are relevant to different stakeholders in different contexts, to assist them in implementing appropriate strategies.
- It is necessary to decide whether sustainable intensification is most helpfully defined only in environmental terms, or whether it should specifically incorporate a broader range of social and ethical concerns. If the former, sustainable intensification nevertheless needs to be mindful of these other concerns, and of the potential for tradeoffs and perverse outcomes.
- There are major opportunities for improving environmental and productivity outputs simultaneously in agricultural systems with current low levels of production. However, trade-offs between yields and environmental outputs are more prevalent in high external input production systems.
- More work is needed to ascertain what mix of policies is needed to transform thinking about sustainable intensification into practice. In particular it is important to identify what can be achieved at the national or even more local level, and where further work is needed to improve the international governance framework.
- While there is a need for more scientific knowledge, it must be recognised that values shape stakeholders' different attitudes to the food system and their views on what the way forward should be. More deliberate exploration of these different values will help society obtain a deeper and shared understanding of what the challenge is and of what solutions might work.