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Environmental monitoring for sustainable land management in New Zealand's production landscapes

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About this report series

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Executive Summary

This report supports the development of the New Zealand Sustainability Dashboard (NZSD), a sustainability assessment and reporting tool for the country's primary industry sectors.[1] The environmental framework proposed for monitoring sustainable management of New Zealand production landscapes can be readily integrated with other NZSD frameworks focusing on the social well-being, good governance, and economic resilience dimensions of sustainability. The NZSD environmental framework has an overarching goal to protect, and where necessary restore, 'agro-environmental integrity', which we define as:

> *The state which sustains the full potential of land and its natural capital, ecosystem processes and services to efficiently and indefinitely produce healthy, high quality food and fibre while enhancing natural heritage values and meeting global environmental change obligations.*

It recognises the need for an integrated management approach implemented across multiple spatial scales and governance jurisdictions to maintain livelihoods, social well-being and restore ecological integrity in New Zealand. Four target outcomes of agro-ecosystem integrity, 11 objectives and 22 indicators are proposed for NZSD to guide farmers, their communities, industry bodies, local and national policymakers, and the New Zealand public towards agro-ecological integrity (see schema on next page). The indicators are practical, locally grounded and universally acceptable, in particular being closely matched to systems currently being designed and tested by the United Nations' Food and Agricultural Organisation (Sustainability Assessment of Food and Agriculture systems) and by the Department of Conservation and regional councils (a coordinated biodiversity monitoring and reporting system). The four target outcomes of the NZSD environmental monitoring programme are:

1. Natural capital of production landscapes is maintained: Natural capital underpins biological production and sustainability of intensive farming in New Zealand. Examples of components of natural capital that will be monitored by NZSD include soil quality, availability of pollinators or nitrogen fixers, intact vegetation to keep the land intact and soils moist. The dashboard will monitor 'ecosystem services', the flows of materials (like food and fibre itself), energy, regulation benefits (like biological pest controls that allow farmers to use fewer pesticides) and information. Natural capital stocks combine with manufactured and human capital services to provide human welfare. The NZSD is designed to help farmers, industry facilitators, policymakers and regulators to combine forces to maintain flows of services by securing or building all these capital stocks. Three specific objectives are addressed that help maintain natural capital in New Zealand production landscapes: (a) maintaining ecosystem processes (focusing on soil, water, landcover, ecosystem disruption and pollination); (b) reducing agricultural pest threats (considering new and established agricultural diseases, weeds and pests); and (c) limiting environmental pollutants (assessing risk and persistence of toxins).

2. Resilience of New Zealand agriculture is secured for future productive use: Farmers, industry, rural communities and the agricultural economy of New Zealand must learn how to deal with uncertainty and to adapt if they are to withstand new threats, shocks and drivers that challenge New Zealand agriculture as we know it now. Three key objectives are addressed to support building resilience of New Zealand agriculture for the future:

AGRO-ENVIROMENTAL INTEGRITY

Overarching goal for NZ production lands

OUTCOMES *Critical components for achieving goals*	OBJECTIVES *Key factors contributing to targeted national outcomes*	INDICATORS *Parameters that can be assessed in relation to an objective*
E1 NATURAL CAPITAL MAINTAINED	Maintaining ecosystem processes	SOIL STATUS WATER QUALITY & YIELD LAND COVER ECOSYSTEM DISRUPTION POLLINATION
	Reducing agricultural pest threats	NEW AGRICULTURAL DISEASE, WEED & PEST SPECIES AGRICULTURAL DISEASE, WEED & PEST DOMINANCE
	Limiting environmental pollutants	ENVIRONMENTAL RISK OF TOXINS ECOSYSTEM LEVELS OF PERSISTENT TOXINS
E2 RESILIENCE SECURED FOR FUTURE USE	Minimising material & energy subsidies	NON-RENEWABLE MATERIALS ENERGY USE
	Buffering against socio-economic pressures and shocks	AGRO-ENVIRONMENTAL FINANCIAL RESOURCES AGRO-ENVIRONMENTAL GOVERNANCE
	Maintaining agro-biodiversity	GENETIC STOCK BENEFICIAL SPECIES STATUS LANDSCAPE FUNCTIONAL HETEROGENEITY
E3 CONTRIBUTED TO NATIONAL 'NATURAL HERITAGE' GOALS	Improving ecosystem representation & composition	ECOSYSTEM REPRESENTATION & PROTECTION ECOSYSTEM COMPOSITION OCCUPANCY OF ENVIRONMENTAL RANGE
	Preventing extinctions & declines	STATUS OF THREATENED SPECIES
	Reducing conservation pest threats	NEW CONSERVATION WEED & PEST SPECIES CONSERVATION WEED & PEST DOMINANCE
E4 GLOBAL ENVIRONMENTAL CHANGE OBLIGATIONS MET	Reducing emissions	GREENHOUSE GAS EMISSIONS
	Increasing carbon sequestration	CARBON STORAGE & FLUXES

(a) minimising material and energy subsidies (considering renewable versus non-renewable resource use); (b) buffering against socio-economic pressures and shocks (focusing on agro-environmental financial investments and governance strategies); and (c) maintaining agro-biodiversity (assessing genetic stocks, beneficial species and landscape functional heterogeneity).

3. Production landscapes contribute to national 'natural heritage' goals: A high proportion of New Zealand's species are endemic (found nowhere else in the world) – making these species both valuable and highly vulnerable. New Zealand production landscapes occur in lowland, fertile and warm areas, which can support high abundance and diversity of indigenous biota. Natural ecosystems in these landscapes, however, are highly fragmented and potentially vulnerable. There is limited information available to demonstrate whether biodiversity representation and persistence is improving or not. Three key objectives are addressed to support national 'natural heritage' goals: (1) improving ecosystem representation and composition; (2) preventing extinctions and declines; and (3) reducing conservation pest threats.

4. New Zealand meets global environmental change obligations: The United Nations Framework Convention on Climate Change established an international policy context for the reduction of greenhouse gas emissions and increases in carbon sinks to address the global challenge of anthropogenic interference with the climate system. Agriculture releases significant amounts of greenhouse gas emissions to the atmosphere; it will also likely be adversely affected by global warming. Two key objectives are addressed to meet New Zealand's global obligations: (a) reducing greenhouse gas emissions and (b) increasing carbon sequestration.

The environmental monitoring programme proposed here will now be road-tested by deploying NZSD prototypes in collaboration with *Sustainable Wine New Zealand*; *ZESPRI* and packhouses that grow, process and market kiwifruit; and a variety of natural resource and farming enterprises operating within Ngāi Tahu's *Ahi Kā Kai* programme.

The main next steps for development and refinement of NZSD's agro-environmental integrity monitoring are:

1. Integration with social, governance and economic frameworks within NZSD to form a common goal and harmonised data-gathering process to build a prioritised, minimum set of interlinked and composite indicators. As soon as practicable, a working party should be convened to integrate the NZSD monitoring frameworks with those currently being developed by New Zealand's Department of Conservation and regional councils.

2. Work with producers, industry facilitators and policymakers to agree on specific measures and scoring systems for each indicator. Start by co-opting some of the more fragmentary indicators already being monitored by each sector and then gradually migrating and broadening the scope of monitoring into a long-term and more comprehensive package. Linking to existing standards, thresholds and protocols will help. Smaller steps and smoother transition will be less disruptive than major redesign.

3. Main priorities (based on importance and cost) are: soil status, land cover, energy use, beneficial species, landscape functional heterogeneity, and ecosystem representation and protection.

4. We expect agricultural and conservation weed and pest issues to be high priority in some catchments but not others, so we recommend that collaboration trials with regional councils and DOC target those catchments to maximise the benefits of the collaboration.
5. Work with all stakeholders and kaitiaki to develop Māori and cross-cultural dimensions to indicators and their measures.
6. Check and calibrate initial indicators for their scientific reliability and repeatability. Any indicators that fail the reliability checks outlined above should be rapidly modified to fix the problems or immediately eliminated from the NZSD framework.
7. Broaden scope of monitoring to fill gaps: Start substituting or adding indicators to achieve the protection of the emerging multidimensional sustainability criteria. Gap analysis to guide this broadening should prioritise (a) existing sector risk and opportunity management plans, and then higher-level gap analyses to cover (b) the Response-Pressure-State-Benefits and (c) all ecosystem services categories.
8. Ensure that NZSD doesn't overburden producers: If necessary, eliminate indicators that (a) are not judged important or relevant, (b) that change slowly, (c) where a formal power analysis has demonstrated that reliable information or baselines have been obtained already, or that sampling can be rested for a while.
9. Continually consult the producers and other stakeholders to refine the indicators.
10. Deploy formal choice modelling to guide indicator refinement. The choice modelling can directly measure producers' preferences for what to include in the beta-generation NZSDs and demonstrate to the farmers that they are in the drivers' seat.
11. Start with least sensitive information to build trust and confidence among participants.
12. Substitute performance-based indictors in the place of practice-based indicators where practicable.
13. Substitute measureable indicators in the place of qualitative indicators where practicable.
14. Research important indicators that are not yet ready for sector-wide deployment. Trials on a test panel of vineyards, wineries, orchards, farms and forests should be completed before sector-wide roll-out.

We expect and encourage continual challenge and refinement of the agro-environmental integrity indicators proposed in our framework, and especially rapid evolution of the metrics used for each indicator as the NZSDs are operationalised. Nevertheless we have proposed a general framework that we hope is sufficiently complete and flexible to confront global and national needs, while still being cast in locally grounded and relevant terms for producers and agricultural industry sectors to future-proof what they do best: the efficient production of high quality food and fibre in a way that maintains the natural capital of the land and contributes to shared national and global goals for environmental care.

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The New Zealand Sustainability Dashboards

This report supports the development of the New Zealand Sustainability Dashboard (NZSD[1]), a sustainability assessment and reporting tool for the country's primary industry sectors (Appendix 1). Over the next five years, the proposed framework will progressively be developed and adapted to create a separate NZSD to meet the specific needs of each participating production sector (kiwifruit, wine, pastoral, forestry and aquaculture) and related Ngāi Tahu Ahikā kai initiative[2] (Figure 1).

A companion report[3] focuses on the general design criteria for monitoring sustainability and the special features of the NZSDs (see steps ❶–❸ in Figure 1). This report will now apply those criteria to design an overarching environmental sustainability framework and associated indicators for the NZSDs. Accompanying reports consider other components of sustainability: Māori culture,[4] social well-being,[5] economic resilience,[6] farm management[5] and tools for communication and learning.[7] A synthesis report[5] highlights where integration of all these strands will add collective value and how overlap between indicators that are relevant to several dimensions will be managed.

Our framework is designed to nest comfortably within the *Sustainability Assessment of Food and Agriculture systems* (SAFA) protocols[8] that are about to be launched by the United Nations' Food & Agriculture Organisation (FAO). The SAFA framework is the most comprehensive, practical and flexible of the 14 international frameworks and sustainability tools that we reviewed to ensure that the NZSD is globally relevant[i]. Both SAFA and NZSD focus on individual farming enterprises as the key site of monitoring, action and learning for sustainability – creating a 'bottom up' approach. The SAFA protocols are cast in such general terms that they allow the NZSD framework and indicators to simultaneously meet both local and international sustainability criteria. The universality and adaptability of SAFA protocols also enable the NZSD to deploy monitoring methods that can be assessed by the producers themselves. This reduces costs, increases coverage and improves statistical inference because all producers participate, thereby avoiding subsampling and chance. Best of all, self-monitoring and instantaneous feedback to individual farming families through the NZSD software and its online network makes monitoring much more than a purely compliance requirement: it will drive learning and improved performance that is tuned to the local ecology, land, financial, social and human capacity to produce food and fibre in an efficient, profitable and ethical way.

While the design of this NZSD environmental monitoring framework is primarily rooted at a local orchard, vineyard or farm level, we have also designed it to meet the regional, national and global sustainability monitoring needs. In particular, we focus on aligning to a nationally coordinated system currently being developed and implemented for biodiversity monitoring and reporting by the Department of Conservation[9,10,11] and the regional councils[12,13] (Appendix 1). This close alignment of the NZSD to such local and national frameworks is valuable because it will facilitate cross-scale linkages and integrated management throughout New Zealand. This will provide an opportunity for the NZSD to better support national environmental policy, state of environment reporting and coordinated sustainable land management advocacy.

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[i] See Table 1 and associated discussion in Moller & MacLeod (2013)[3].

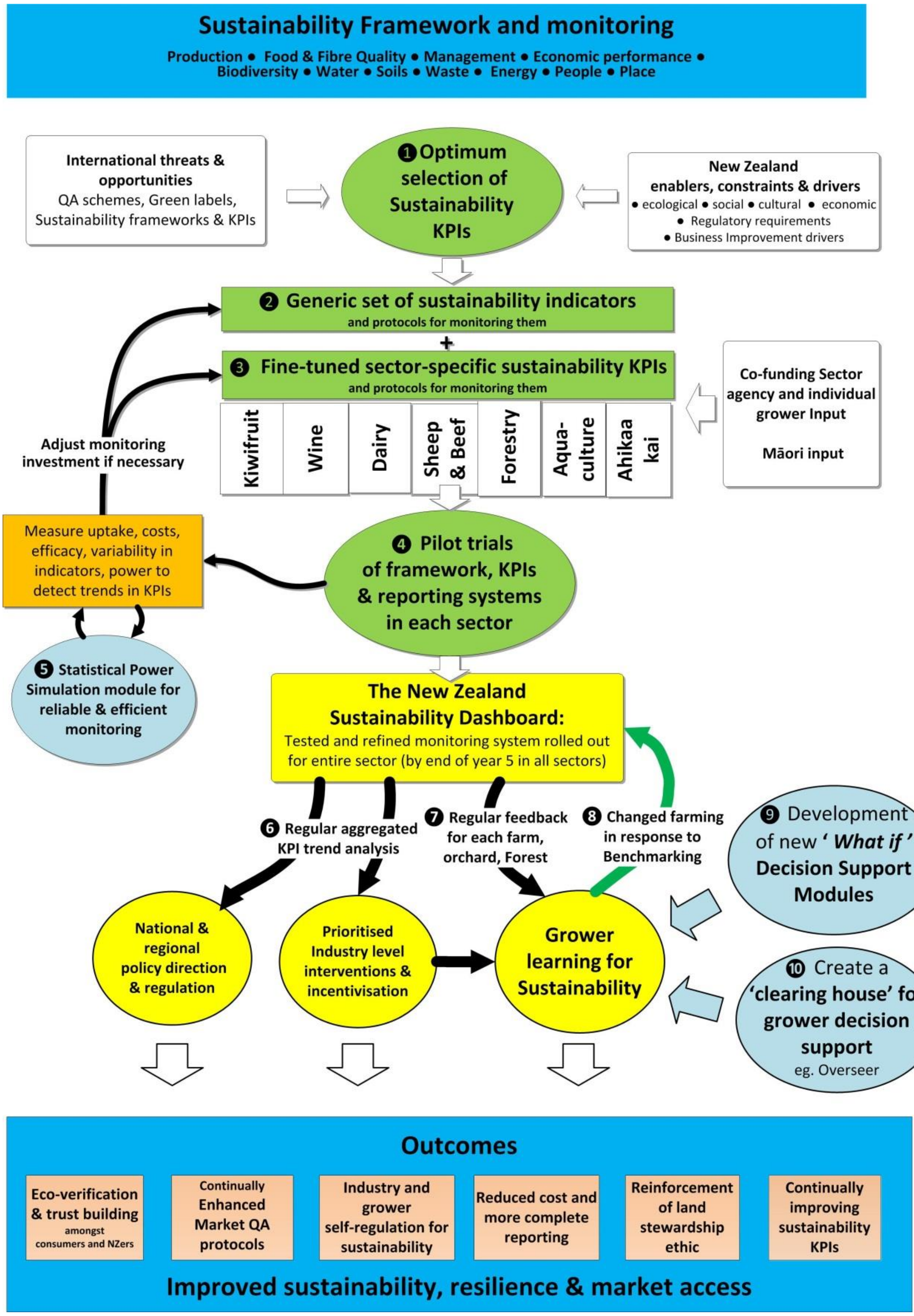

Figure 1: The New Zealand Sustainability Dashboard project map.[1]

The fundamental first step in developing an effective environmental monitoring design is to clearly define the goals and vision of the framework.[14,15] Such goals are currently lacking for New Zealand production landscapes, hence we begin this report by briefly reviewing the special features of their ecology and agriculture in order to define a concept of 'agro-environmental integrity' that makes sense for New Zealand. We then describe four target outcomes that are essential components of agro-environmental integrity:

1. Natural capital of production landscapes is maintained
2. Resilience of New Zealand agriculture is secured for future productive use
3. Production landscapes have contributed to national 'natural heritage' goals
4. New Zealand has met global environmental change obligations

We then propose 11 objectives and 22 indicators under these target outcomes as the basis of the NZSD's environmental sustainability monitoring. Our report ends by considering the next steps for operationalising and refining the framework.

Agro-environmental integrity – a national goal for New Zealand production lands

Meeting the needs of New Zealand's agro-ecosystems

Definitions for agro-environmental integrity and the design of a monitoring framework to attain it must be locally grounded if they are to be used and inspire local environmental care. This means that the target outcomes and indicators must closely match local ecological, social and economic risks and benefits.[ii]

Special features of New Zealand ecology (Box 1) underscore particular needs to:

- safeguard threatened species
- maintain biosecurity
- enrich relatively new soils derived recently from forests
- prevent erosion
- restore indigenous habitat (especially woody vegetation and wetlands)
- manage keystone introduced species that provide ecosystem services
- build motivation and capability to improve environmental care especially in low-lying fertile landscapes.

Special features of New Zealand's society and economy (Box 2) dictate that those ecological challenges and opportunities will need to be achieved:

- within a highly intensive form of agriculture that is already very efficient
- by relying on imports of large quantities of 'ecological subsidies' (fertilisers, supplementary feeds, cheap energy sources)
- little overt subsidisation or payment for ecosystem services from public funds
- little regulation of what happens (or doesn't happen) on private land

[ii] See Moller & MacLeod (2013)[3] for a discussion of the value of mapping these links to Responses, Pressures, State and Benefits (RPSB) models.

- inclusion of Māori dimensions of sustainable land management governance, goals and knowledge.

Box 1: Key ecological features of New Zealand's agro-ecosystems

Taxonomic uniqueness and vulnerability adds international responsibility

- New Zealand taxa are often poorly known on a global scale because they are mainly in southern and tropical areas.
- New Zealand taxa have high levels of endemism in two senses: a very high proportion of indigenous species are not found in other countries; and much of the evolutionary uniqueness occurs at 'high taxonomic levels' (genera, family or superfamily levels). No other populations of such taxa exist elsewhere in the world, so New Zealand has a particular global responsibility for preventing indigenous species extinctions.
- There is inordinately high abundance of birds, some insect groups and snails in New Zealand ecosystems.
- Like many island ecosystems, many of New Zealand species are k-strategists (i.e. they have low reproductive rate, slow growth, delayed maturation, and are long lived) and thus particularly vulnerable to disturbance.
- Many New Zealand plants are vulnerable to fire and browsing and have not evolved defence mechanisms to cope with introduced predators and browsers.

Invasion ecology features makes biosecurity paramount

- Ecological separation and isolation of the New Zealand landmass before the eruption of predatory land mammals and snakes means that indigenous species lack defences against introduced predators and browsers (including domesticated agricultural stock). This makes them particularly vulnerable to introduced species.
- Lack of biotic resistance to invasion (predation, competition, parasitism), coupled with widespread habitat disturbance for agriculture, has made New Zealand production landscapes particularly invadable by exotic species. A much wider range of species could penetrate New Zealand's ecological communities and many have become pests and much more abundant here than where they came from because they are released from competition, predation and parasitism.
- Species extinctions in the face of habitat loss and modification and the onslaught of introduced predators and competitors have further emptied out New Zealand ecological communities, so they remain relatively 'open' to invasion by further animals and plants.
- New Zealand's ecological communities, especially those within production landscapes where ecological disturbance is ongoing, are therefore extraordinarily vulnerable to biosecurity incursions and these are harder to control when they happen.
- A large part of New Zealand agriculture's competitive advantage is based on efficiency; this in turn is based on a comparative absence of pests that constrain production or force use of expensive and environmentally risky pest control overseas
- Biological control can be particularly valuable by careful insertion of natural enemies of pests transferred from original sources.

Habitat loss and fragmentation is extreme

- Forest cover in the majority of New Zealand landscapes has been reduced below the level of an expected 'extinction threshold' (c. 30% native habitat cover) in 55 political districts, and long-term trajectories predict that ongoing deforestation threatens to force another five districts below the critical threshold within the next 45 years.[16]
- Within New Zealand farms,[17] the area of native habitats has decreased at least six-fold in just four decades: land classified as 'unimproved' in 1960 covered 53% (i.e. 9 million ha) of total agricultural area, compared with only 8% (i.e. 1.3 million ha) categorised as 'mature or regenerating native scrub or bush' in 2002.
- Retention and restoration of habitats in agro-ecosystems is a top priority. Additional biodiversity benefits could potentially be derived by applying predator control to such areas, but these are yet to be demonstrated.[18],[19]

Box 2: Key ecological features of New Zealand's agro-ecosystems (continued)

New Zealand geology and climate

- New Zealand climates are highly oceanic with long relatively cool growing seasons and mild but predictable winters.
- New Zealand rocks are generally low in phosphorus and soils derived from them are of moderate to low fertility.

New Zealand soils

- Soils now under agriculture supported forests until relatively recently, so they mostly have moderate levels of stored carbon and much higher natural capacity for agriculture than desertified and salinated soils (e.g. as found in Australia). Initial problems of low soil pH after conversion are quickly and inexpensively solved by applying lime.
- Volcanic ash soils of the North Island retain high carbon levels and are relatively forgiving of current farm soil management, but alluvial soils from throughout New Zealand are prone to losing carbon if not managed well.
- Recent trend to applying urea risks emulsifying stored carbon in soils.

Key ecosystem services are now provided by introduced species

- Soil genesis, structure, aeration, nutrient retention and uptake by crops depend heavily on introduced earthworms.[20,21] A diverse guild of native earthworms have been displaced by agriculture and many may now be globally extinct.[22]
- Introduced honey bees and bumblebees are main pollinators of crops in New Zealand agro-ecosystems. Potential roles in displacing indigenous species and promoting weed abundance are much debated.[23,24]

The warmer lowland sites hold greatest interest for conservation and farming

- Agriculture is targeted in the warmer and naturally more fertile landscapes of New Zealand where farming is most productive[25] because of warmer and more prolonged growing seasons, and fertile alluvial soils.[26,27] These were also converted first for agriculture because they could be easily accessed by sea, river and rail transport.[28]
- High rates of local endemism among invertebrates occur in lowland habitat patches.[29,30,31] Around 35% of New Zealand is formally protected, but nearly all of this is in montane to alpine regions.

Box 3: Key social, political and economic features of New Zealand's agro-ecosystems

High reliance on agricultural exports for national prosperity

- Over 50% of New Zealand's export earnings are derived from primary production.[32]
- The Ministry of Business, Innovation and Employment has set a goal of approximately doubling the export volumes of primary produce by 2025 (5.5–7% p.a. increase)[33].

Highly intensive agriculture

- A strong and steady trend for intensification[17,34] since 1960, as indicated by (a) increasing stocking rates and yields, (b) increased use of farm fertiliser, pesticide and food stock inputs, and (c) conversion to more intensive forms of agriculture.
- Intensification potentially threatens the environment, biodiversity and even the sustainability of agricultural production; although there are site-specific examples of adverse impacts.[35] The exact nature of this threat and the extent of its impact are poorly understood[36] as long-term fine-scale environmental indicators are lacking.

Increasing reliance on ecological nutrient, food and water subsidies

- Along with increasing use of irrigation systems at local scales, the value and amount of pesticide, fertilisers and feed products imported into New Zealand have escalated over the last 50 years to support increasing yields in the cropping and livestock industry.[17,34,37,36,38]
- Development of a New Zealand urea production facility has triggered increasing reliance on nitrogen application and displacement of traditional nitrogen fixation by clover in pasture management.
- Questions have been raised about the sustainability of such practices,[34,36,39] in particular whether these supplies of external inputs can be maintained into the future. Are these management practices degrading or buffering natural resources in New Zealand agro-ecosystems?
- There have been prolonged and steady increases in the use of irrigation to drive more intensive agriculture and especially to convert low intensity pastoral farmland into dairy production.
- Agriculture dries out ecological landscapes.[40]

Neoliberal deregulation and lack of subsidisation

- Deregulation and removal of financial subsidies for the farming sector in the mid-1980s (following a number of economic crises, e.g. wool and oil price crashes) are frequently cited as the key drivers of change in the agricultural industry in recent decades.[17] Reduced direct intervention by the government in the economy aimed to encourage markets to allocate economic resources more efficiently.
- The Resource Management Act (RMA) empowers regional councils to intervene in farming to some degree but these legislative warrants have been infrequently applied and regulation is generally avoided. There has been recent increasing attention to regulating water quality management and allocation of water in critical catchments.

Rural community resilience in New Zealand

- Hollowing out of local services driven by increased mobility and urbanisation.
- Severe lack of employment opportunities for young people in rural areas

Māori dimensions of sustainable land and resource management

- High level goals of the RMA, Conservation Act, Environment Act, Fisheries Act require meaningful consultation with Māori and in some cases to give effect to the principles of the Treaty of Waitangi and/or kaitiakitanga (Māori environmental stewardship). An emerging set of case studies emphasise that Māori seek to manage land and environment in different ways and for different reasons.
- There is emerging interest in indigenous agro-ecological approaches to farming in a distinctly Māori way.
- The NZSD's agro-environmental integrity monitoring framework will incorporate cultural indicators where possible. Dashboards will be hosted and developed by Ngāi Tahu's Ahi Kā kai programme, by Māori kiwifruit producer enterprises, and by Māori communities for sustainable forestry in the North Island.[1]

Some international threats are less pronounced[9]

- Virtually none of New Zealand's native terrestrial and freshwater biota is managed for economic gain (except for eel and whitebait fisheries), some fire-induced tussock grasslands and some forests).
- International practice often suggests measures suited to densely-settled rural areas and indigenous subsistence farming and is closer to a micromanagement of an economic landscape.
- As New Zealand taxa are poorly known on a global scale, dominant international conservation practices are often centred on organisms with quite different responses to stressors.
- International indicators measuring air pollution and aerial deposition of contaminants (ozone, nitrogen, sulphur etc.) are of limited concern in New Zealand.

Ecological integrity within natural ecosystems

Traditionally the most important emphasis of New Zealand's environmental movement has been on preserving natural ecosystems and preventing extinction of threatened species. Managers, policy analysts and researchers have therefore framed goals for environmental management in terms of protecting or restoring 'ecological integrity'. In 2005, a working party of New Zealand researchers and conservation managers considered that ecological integrity requires that the *full potential of indigenous biotic and abiotic features and natural processes are functioning in sustainable communities, habitats, and landscapes.*[9] The term encompasses all levels and components of biodiversity, and can be assessed at multiple scales, up to and including the whole of New Zealand. At larger scales, ecological integrity will be achieved *when all the indigenous organisms (native plants, animals, fungi, etc.) typical of a region are present, together with the key processes that sustain functional relationships between all these components, across all of the ecosystems represented in New Zealand.*[9] Components of this definition of ecological integrity, and proposed indicators to measure current ecological integrity (Appendix 1), include:

- Species occupancy (to avoid extinctions) – Are the species present that you would expect?
- Indigenous dominance (to maintain natural ecological processes) – Are the key ecological processes maintained by native biota?
- Ecosystem representation (to maintain 'a full range of ecosystems') – Are the full range of ecosystems in New Zealand protected somewhere?

This concept of ecological integrity was adopted to decouple from other terms (ecological condition; biodiversity condition; ecosystem health; ecosystem status; biological integrity; biodiversity integrity) that have been proposed as encapsulating conservation goals. Those earlier terms fail to adequately convey the multiple dimensions or the potential outcome of a national biodiversity conservation strategy promoted by the working party. The terms 'health' or 'condition' were rejected because they

> *…rely on analogies with human health [which] are inappropriate for a biological system'* and because *'idealised states will be challenging to define and sustain. … Similarly, an indigenous ecosystem with a high number of exotic plants and animals in it is 'sick' or in 'poor 'condition' only in the sense that we prefer exotics not to be there; as an ecosystem it may have high levels of diversity and functionality. Finally, it is not necessarily appropriate to define an ecosystem as 'ill' or in 'poor condition' when a range of biodiversity and ecosystem processes might remain, and many ecosystem services are still provided.* [iii]

Ecological, rather than biological integrity was selected for because it

> *…targets the highest level of biodiversity organisation (i.e. the ecosystem), explicitly includes abiotic components, and recognises the appropriate level for much of DOC's management activities as conservation concepts broaden beyond the protection of single species.* [iii]

[iii] (Lee et al. 2005, p 100)[9]

Integration to achieve environmental integrity within production landscapes

It is important to realise that ecological integrity[9] is defined as a goal mainly for 'natural' or 'semi-natural' environments on public conservation land.[iv] Its accent on 'natural' processes and ecosystems, and on indigenous species dominance and representation, reflects a predominating preservationist paradigm. As such it is not directly and wholly transferable to guide an environmental monitoring programme on New Zealand's production landscapes where introduced species (grass and fodder crops, fruit, grapes, cattle and sheep etc.) underpin primary production of food and fibre. Nevertheless, if production landscapes are going to contribute to conserving and restoring New Zealand's heritage at local, regional, national and global levels, many of the elements of ecological integrity promoted[9] must be integrated with simultaneous and sustainable delivery of 'provisioning services'.[v]

The need for integrating environmental care with efficient and productive agriculture has been well recognised in New Zealand for decades in both international and national policy instruments. For example, key targets of the Convention on Biodiversity include:

- 'improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity' and
- 'areas under agriculture … are to be managed sustainably, ensuring conservation of biodiversity'.

Similarly, the New Zealand Biodiversity Strategy (2000)[41] states a need for New Zealand to '*sustain the more modified ecosystems in production and urban environment*'.

The FAO's upcoming SAFA protocols collect most of the environmental components of sustainable food and fibre production under an 'Environmental Integrity' dimension (Box 4). There is no formal definition of the 'integrity' of ecosystems in their context, but it directs attention mainly to biophysical elements of agro-ecosystems and the continuance of ecological flows between them.[vi] The water and biodiversity themes are the main intersections with New Zealand's ecological integrity concept, but most of SAFA's monitoring is directed towards the provisioning, regulating and supporting components of ecosystem services, and thereby primarily underwriting human needs and values. Natural ecosystems and protection of threatened species are included in most food and fibre production standards (Box 5). However there is relatively little attention to restoration or protection of highly modified fragments or restoration within production landscapes and none of the agricultural standards prevent habitat conversion for agriculture.

[iv] Lee et al. (2005, p. 99)[9] emphasised that biodiversity on private land was increasingly important, but that their framework 'at certain levels has been designed specifically to meet DOC's requirements as derived from the Statement of Intent'.

[v] See *Box 3 Ecosystem Services* of Moller & MacLeod[3] (2013)

[vi] We speculate that the word 'integrity' has been incorporated by SAFA partly because of its resonance with the values and ethical imperatives for farmers, foresters and fishers to behave kindly to the environment. The wider context of the whole SAFA programme aims to define and monitor their actions, so the primary focus is on linkages between coupled social, economic and ecological dimensions.

Box 4: Environmental Integrity in FAO's Sustainability Assessment of Food and Agricultural Systems

To protect the integrity of Earth's ecosystems, the use of natural resources and the environmental impacts of activities must be managed such that negative environmental impacts are minimised and positive impacts fostered. The following themes of environmental sustainability are addressed.

Dimension E: ENVIRONMENTAL INTEGRITY	
E1 Atmosphere	Greenhouse Gases; Air Quality
E2 Water	Water Withdrawal; Water Quality
E3 Land	Soil Quality; Land Degradation
E4 Biodiversity	Ecosystem Diversity; Species Diversity; Genetic Diversity
E5 Materials and Energy	Material Use; Energy Use; Waste Reduction and Disposal
E6 Animal Welfare	Health and Freedom from Stress

The state of the world's ecosystems, assessed in 2005 under the Millennium Ecosystem Assessment,[42] concluded:

- Human actions are fundamentally and to a significant extent irreversibly changing the diversity of life on Earth and the integrity of the environment.
- Critical ecosystem services on which development depends, including air and water purification, soil conservation, disease control, and reduced vulnerability to natural disasters such as floods, droughts and landslides, are compromised.
- The poor are overwhelmingly located in rural areas and natural resources are their most important asset.
- Human activity including land conversion for agriculture leading to habitat loss, fragmentation and degradation, overexploitation of species due to hunting, fishing and trade are considered the main drivers of the pressures on environmental integrity.

Box 5: Biodiversity conservation for monitoring food and fibre production standards

No single performance- or practice-based indicator is used to measure biodiversity or management to support it.[43,44] Some target pressures, others responses and some the status of the plants, animals and habitats themselves. For example, a recent review[45] of biodiversity requirements of 36 standards and certification schemes used internationally, including 12 agricultural ones, identified the following biodiversity components:

- All standards mentioned protection of habitats and 94% gave some consideration to habitat loss or restoration. None of the 12 agricultural standards explicitly seek to prevent habitat loss.
- Few standards refer specifically to modified habitats and even fewer promote the enhancement or restoration of habitats.
- Most (87%) recognised protected areas and a few prescribed how to operate in or near them.
- 'Priority Conservation Areas' (zoning as having high conservation value but not formally protected) occur in less than half the standards.
- Protection measures for species occur in 94% of standards, and threatened species in 86%. There are references to sustainable use of species and management of invasive species in most standards, but not in any of the agricultural ones.
- Few standards refer to biodiversity offsetting.

The Group on Earth Observations (GEO) proposed a platform (Biodiversity Observation Network – BON) to compile existing information streams from monitoring and observation programmes into a system. Its aim is to produce a more comprehensive view of the status of biodiversity and socio-ecological systems[46] and to improve availability and interoperability of information relating to the global environment[47] and thus facilitate research, assessments and decision-making. To support this initiative, a framework of essential biodiversity variables (EBVs) has been proposed for study, reporting and management of biodiversity change.[48] Classes of EBVs include:

- Genetic composition (e.g. allelic diversity)
- Species populations (e.g. changes in abundance and distribution)
- Species traits (e.g. changes in phenology showing trends in vulnerability)
- Community composition (e.g. taxonomic diversity)
- Ecosystem structure (e.g. remote sensing of height, cover, biomass of habitat types)
- Ecosystem function (e.g. nutrient retention, nutrient output/input ratios)

The EBV framework emphasises the importance of repeated measures for the same taxa at the same locations or regions mainly at short-term intervals (1–5 years) although a few may be medium term (10–50 years). It aims to provide an end product that might look outwardly simple, but which combines elaborate observation and modelling systems. They emphasise scalability, temporal sensitivity, feasibility, relevance and a balance of generalisability and local specificity. These are all key design criteria for the NZSD.[3]

There is a growing awareness in New Zealand that even highly modified ecological landscapes also have an intrinsic, ecological, and social value,[29,49,50,51] partly because indigenous biota will flourish in greater variety and abundance in the warmer and more fertile lowlands than in upland national parks, and partly because they have become part of our history, lives and loves – part of place and identity that make us New Zealanders.[52]

Integrating environmental care '*ki uta, ki tai*' ('from the mountains to the sea')[53] into production landscapes recognises that all the ecosystems between are ecologically connected in ways that defy land ownership or human governance boundaries. Ecological flows between reserves and production areas can either help or hinder national efforts to reverse declines of indigenous biota.[54] Ecological restoration can be faster and less expensive in production landscapes.

An additional focus on agro-biodiversity, including common and introduced plants and animals

Much of the thrust of the Convention on Biological Diversity (CBD) stemmed from 'Agenda 21', a policy statement upheld by the 1992 Rio Conference. Chapter 14 of Agenda 21 concerns Agricultural Biodiversity, which it defines thus:[vii]

> …***agricultural biological diversity*** *means the variability among living organisms associated with cultivating crops and rearing animals and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems. The unique feature of agricultural biological diversity is the emphasis on its utility to human beings.*

Introduced plants and animals provide most of the food and fibre produced by New Zealand's agriculture, and key services to keep the ecosystem functioning. For example, introduced honey bees are the main pollinator of our crops. Introduced earthworms promote soil aeration and structure, organic matter, nutrient retention and transfer to grass and crops and crucial plant breakdown to service the detrital chains of ecosystems. Agro-ecosystem integrity must therefore include care for a whole suite of additional animals and plants than those normally considered in ecological integrity. The NZSD will therefore include monitoring and guide management of introduced biodiversity for its own sake, and does not have a goal to reduce 'exotic dominance' in the landscape as a whole.

As agricultural biodiversity may consist of species that are either introduced or indigenous, the ecological resilience of New Zealand's agro-ecosystems may be contingent on the retention of both native and introduced biota on production lands.[36] Today's seemingly redundant species may be tomorrow's agricultural biodiversity. Native species may affect the abundance of agricultural biodiversity, and vice versa, through a myriad of 'indirect ecological interactions' within the food web.[55] It will be important to understand and manage ecological flows not only between reserves, but also between reserves and the surrounding matrix of production land, especially along the margins of production landscapes and national parks.

The overall importance of considering the introduced and common species alongside the indigenous ones and systems feedbacks (including social and economic links) was clearly signalled in New Zealand's Biodiversity Strategy:

> *This Strategy is about managing threats to New Zealand's total biodiversity — both introduced and indigenous. A significant portion of our export wealth — critical to our ability to protect our indigenous biodiversity — is generated by the sale of our introduced biodiversity. And our biosecurity threats are often common to both. Introduced biodiversity is neither all 'good' nor all 'bad'; threats or benefits of individual introduced species most often depend on the situation in which they arise. The interactions between the introduced and indigenous elements of our biodiversity are complex and dynamic and need to be understood and addressed if we are to achieve our biodiversity goals.*[viii]

[vii] UNEP/CBD/COP/3/14, p. 2.

[viii] MfE & DOC 2000,[41] p. 8.

Despite these national and international calls for including consideration of introduced species and environmental care on private land, there has been very little coordinated and publicly funded research, monitoring, targeted management or policy development to secure introduced biodiversity and all biodiversity on private land in New Zealand (Box 6 illustrates the case for bird conservation, but it applies equally to invertebrates and lizards).

Box 6: The forgotten 60%: opportunities for bird conservation in New Zealand's production landscapes? [36,54]

Birds as environmental indicators

- Birds are useful indicators of ecosystem health because they are (i) conspicuous; (ii)taxonomically well known; (iii) iconic features of New Zealand's endemic biota; (iv) often at the end of food chains (this makes them sensitive indicators of environmental health); and (v) could be a valuable "Market Flagship" species to encourage consumers to buy New Zealand produce.[56,57]
- Production lands cover 58% of New Zealand, yet birds are little studied and not regularly monitored in these environments.
- Negative impacts of agriculture on birds are well known in Europe and North America and central to political and economic interventions for agro-ecosystem sustainability there.[58,59,60,61]
- A review[54] of 95 papers and reports about birds in New Zealand's production lands found only 3 that focused on overall species distribution and abundance; 64 that concerned ecology and management of pests and introduced species; and 28 that concerned the ecology and management of native species.
- Some indigenous species travel over 100s of kilometres and therefore can exploit resources over 1000s of square kilometres covering multiple ownership and management jurisdictions. Some species co-dependent on production and unmodified ecosystems in a region.

Key questions to guide bird conservation in New Zealand's production lands

- Is the widely held perception that native species are rare in the agricultural landscape correct? There is mounting evidence that introduced species are simply more conspicuous or abundant than native species.[62,63,64,65]
- What regulates bird populations in production landscapes?
- Do production lands provide important food and breeding areas for native species that frequent native habitats and landscapes at other times of the year?
- At what spatial scale is it best to integrate bird management within New Zealand?
- Does investment in restoration of habitats (cover and quality) take priority over predator control for bird conservation in production landscapes; or do we need both habitat and predator control to succeed?[19]
- How much woody vegetation and other ecological refuges are needed to secure viable populations of native and introduced species in production lands?[40,66] What is the cost and benefits in terms of production or economic return from increasing proportions of ecological refuges?
- Which woody species and where should they be placed within farms to maximise conservation of birds?
- What are the key focal bird species for maintaining ecosystem services in production landscapes?

Key recommendations for NZSD

- Shift to a more landscape-based sustainable use approach (rather than a single-species approach) to help indigenous and introduced species
- Future research should focus on effects of:
    - habitat modification
    - increased farm inputs
    - increased stocking rates and yield
    - altered predator–prey regimes on birds
    - perceptions of farmers and wider New Zealand society towards birds and their conservation
    - better estimates of actual extent and costs of bird damage
    - barriers and enablers to trigger more active conservation of birds in production landscapes
    - ecological connectivity between production and less modified landscapes
- Collaboration and coordination of a national bird monitoring scheme should be instigated to integrate monitoring over natural, semi-natural and modified landscapes of New Zealand.

Land-sparing and land-sharing for integrating biodiversity conservation and agriculture

Two major strategies are promulgated to combat agricultural impacts on biodiversity: 'land-sparing' and 'land-sharing'.[67,68,69,70] Land-sparing is based on the presumption that by intensively developing some areas, other areas can be spared from any development and biota sustained within those reserved areas.[37,71,72] It is fundamentally a 'land allocation' model (a subset of 'biodiversity offset' strategies). Some areas are set aside primarily for conservation goals, while others are farmed intensively with a primary goal to maximise production and feed people, even if an unintended consequence will be that biodiversity on the production land dwindles or disappears. Provided that there is a social and economic feedback loop in place, it could result in a net gain for biodiversity over large spatial scales. New Zealand has already developed most of the fertile lowlands and hence, at a national and even a landscape scale, remaining land available for agricultural development is predominantly marginal land and is already well represented in the public conservation lands.[52,ix]

Conversely, land-sharing suggests that sympathetic land management (also called wildlife-friendly farming) can result in high biodiversity in ecosystems that are also tuned to efficient and intensive production. The land-sharing approach is advocated widely in Europe and in many tropical countries and applied through various environmental certification schemes such as LEAF[x] and agro-environmental schemes in general. Land-sharing is obviously the main strategy left for New Zealand at a broad scale now that most of the indigenous forest ecosystems have been removed to make way for farming.[27,36,73,74] Land-sharing approaches must predominate in the 'conservation' phase of adaptive cycles[xi,75] where there is little room left to set aside land at large landscape levels for biodiversity protection. It is also a matter of practical reality that New Zealand's Resource Management Act constrains removal of large tracts of indigenous vegetation, so the predominating philosophy for New Zealand farmers and conservation advocates must now be land-sharing and restoration of unfarmed habitats within production landscapes.

At smaller within-farm scales, trade-off of land-sparing and land-sharing is still very important and are competing considerations. Allocation of some of the land within each individual farm, orchard, vineyard or production forest for biodiversity conservation should always be encouraged. Promotion of wildlife-friendly farming within each farm enterprise locks in active environmental management at small spatial scales within ecological landscapes and thereby provides resilience for meta-populations that are connected between many farms and wider ecological landscapes. The more farmers that contribute local care, the more biodiversity will be secured at catchment, regional, national and

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[ix] Rowarth (2008) argues that intensification of New Zealand agriculture will bring net conservation gains by reducing the amount of natural habitat that is converted to agriculture. We remain sceptical that direct feedback links hyper intensification in some areas and consequent land-sparing in others in some countries, so the result is intensification without protection of offset areas. Usually habitat reservation and farm development will be promulgated by very different actors and landowners that will not be influenced or compensated by the other. Landscape intensification by agricultural development to maximise short term profit will therefore assert little or no feedback to reduce the conversion of other natural habitats in most countires, and certainly not in New Zealand where a neo-liberal private ownership rights model drives land allocation.

[x] 'Linking Environment and Farming'

[xi] See Darnhofer et al. (2010)[77] for a description of the cycles where a rapid 'exploitation' phase in land development, resource development or even market penetration of a new agricultural product turns to a 'conservation', then 'collapse' and eventually 're-organisation'.

ultimately global scales. We take the pragmatic view that the farm owners and managers are the keystones for biodiversity protection and enhancement in New Zealand's agricultural social-ecological system because they ultimately control investment decisions and farming practice on their land. There is very little regulation and no substantive help for New Zealand farmers to encourage habitat retention, fencing, predator control or habitat restoration on private land.[52]

The need for better integration of production and conservation outcomes was highlighted by New Zealand's Biodiversity Strategy, which noted key challenges to be:

> *… finding ways to maintain the indigenous biodiversity values of natural habitats and ecosystems outside public protected areas, and to sympathetically manage indigenous biodiversity in production landscapes and seascapes. Both these tasks involve restoring connections between presently isolated fragments of natural ecosystems.*[xii]

The NZSD design and emphasis sits squarely on the premise that both land-sharing and land-sparing will be needed within farm boundaries if intensive agriculture is to be ecologically sustainable in New Zealand. Indicators should target land cover and connectivity metrics within farms to track progress and consequences for all sustainability indicators (including production, profit, animal welfare and biodiversity) but not neglect to measure biodiversity, especially but not exclusively agro-biodiversity, within the production spaces of the farms as well.

Meurk and Swaffield (2000)[76] provide a useful discussion on the spatial requirements that suit indigenous biodiversity within New Zealand's productive landscapes. Of particular importance is the presence of large woodland patches, structurally dominated by either indigenous or introduced species. Although these suggestions follow best professional practice and a logical theoretical projection for reconfiguring woody vegetation in New Zealand farmland, their suggested target for change (25% for overall woody vegetation cover) is a broad-scale guess rather than informed predictions of trade-off models. A what-if decision-making tool (❾ in Figure 1) will be developed to predict optimal trade-offs between environmental, economic, production and social outcomes for each farm if woody vegetation is increased or decreased. Woody vegetation intercepts light and nutrients that could otherwise produce crops and food, but also could provide several other potential benefits (Figure 2). The NZSD attempts to capture financial benefits of price premiums and access to niche markets by demonstrating and verifying the success of both land-sharing and land-sparing on New Zealand farms and turn those benefits back to the farmers to incentivise and meet some of the costs of their investments. If agro-environmental schemes are introduced to New Zealand, the NZSD could also potentially help quantify the benefits and losses in monetary terms to help set market rates for 'Paid Ecosystem Services' of the type being implemented in many parts of the world[77,78,79,80,81,82,83,84] and recently including in Australia (Box 7).

[xii] *MfE & DOC 2000[41] p 9*

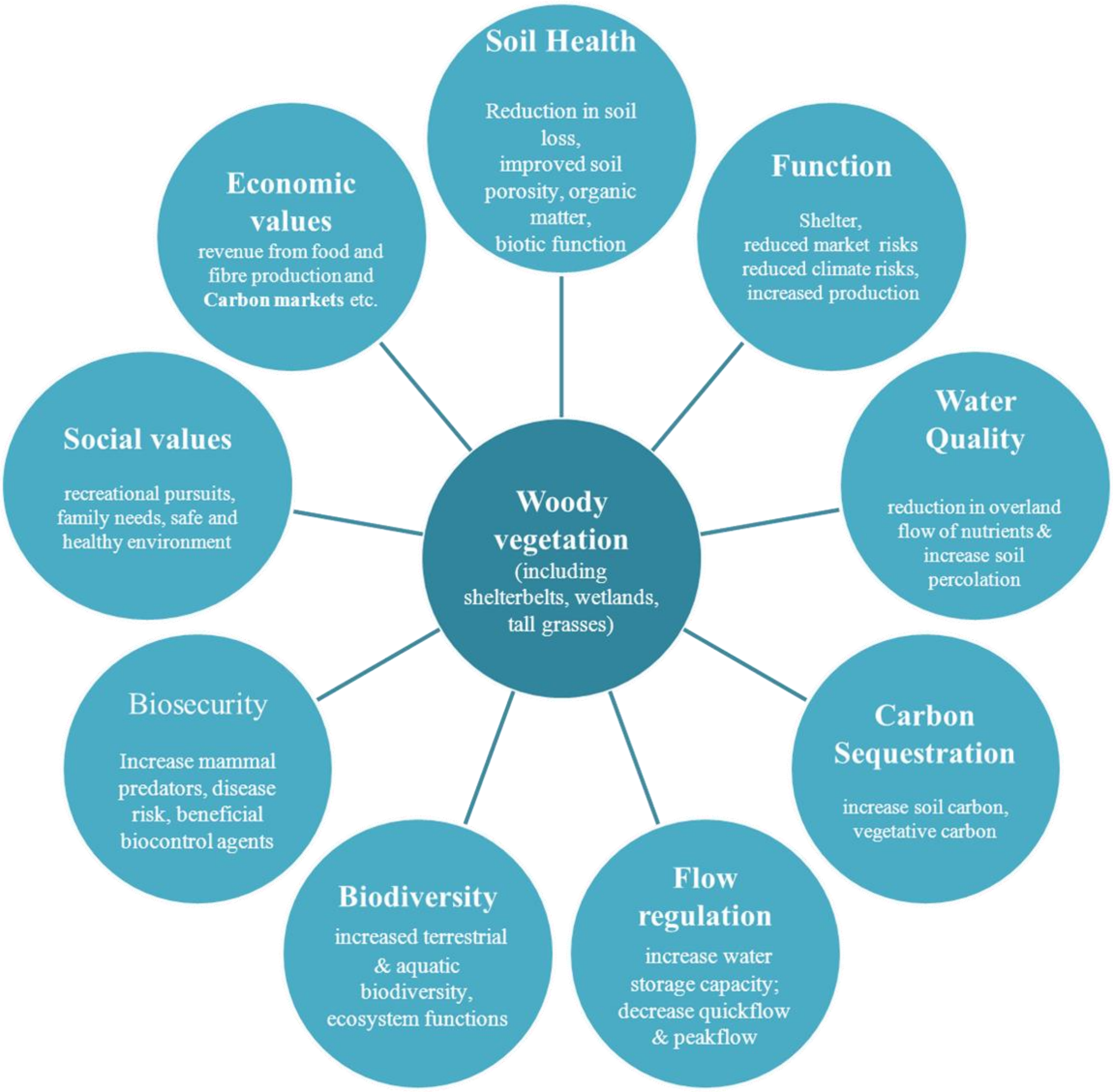


Figure 2: Retention or restoration of woody vegetation on farms can make several contributions to multifunctional agricultural landscapes, but also might reduce production and profit.

Box 7: Australia's Environmental Stewardship Program: a pathway for New Zealand?

The importance of incorporating biodiversity conservation into sustainable agricultural practices has been recognised in Australia and internationally.[85] Approximately 77% of Australia's land area is managed by farmers, Indigenous communities and other private landholders. In this context, policies promoting biodiversity have increasingly concentrated on the sustainable use of environmental resources on private land.[86,87]

The Environmental Stewardship Program (ESP) was established in 2007, and incorporated into the Ruud Government's Caring for our Country initiative in 2008. The ESP aims to protect and enhance the condition of targeted sites of National Environmental Significance, listed under the *Environmental Protection and Biodiversity Conservation Act* (1999). The ESP operates using a market-based approach whereby the Australian Government provides payments to private landowners as an incentive to achieve explicit environmental outcomes. At each funding round, reverse auctions are held to allocate contracts. Landholders are invited to nominate a price for achieving targeted environmental outcomes. Successful bidders are awarded long-term contracts for up to 15 years' duration, while annual payments are performance-based to ensure compliance. Environmental metrics are calculated to quantify landowners' environmental performance.[85,86,88]

The initial ESP project targeted the critically endangered Box Gum Grassy Woodland (BGGW) ecological community. Land use intensification for agriculture has severely reduced the extent of these woodlands so that less than 5% of their original coverage remains, often in small and degraded fragments. As at October 2010, the project had secured the protection of 26,474 ha of woodlands at a cost of AUD $70.5 million (approximately have of DOC's biodiversity budget). The average annual cost was $202 (AUD) per hectare, per year.[89]

In general, market-based approaches like the ESP (used as part of a broad mix of complementary policy options) have several advantages over traditional regulatory responses that have been unable to cope with complex environmental problems such as biodiversity decline. Market-based instruments allow a greater degree of flexibility in implementing environmental programmes; provide incentives to encourage innovation and promote ongoing environmental improvement; and ensure that environmental outcomes are achieved cost-efficiently – an important priority given the constraints on conservation budgets.[86,90,91,88]

In the ESP case study, a market-based approach is the best option to influence environmental outcomes on private land on such a large scale – over the first four years, five projects covered 45,000 ha through contracts with over 260 landowners. The commitment to long-term annual funding is an innovative feature of the ESP that addresses a barrier to success in many environmental programs.

Overall landholder experiences of the Program were positive. However, areas that could be improved were also identified. In particular there was a lack of understanding of the market-based instruments used including the operation of the reverse auction and the use and calculation of environmental metrics.[88] The design of environmental metrics is a significant challenge for market-based programmes in general.[85,92] Environmental metrics need to be transparently calculated and well understood by participants while integrating the value of a range of ecosystems services that reflects the preferences of stakeholders and the wider community (on whose behalf, the Government purchases environmental stewardship services). A further, related challenge is to create a broader market including a wider pool of buyers including multiple levels of government, private investors and philanthropic organisations.[88]

An independent review of the ESP, conducted by Marsden Jacob Associates (2010)[91] concludes that it was robustly designed, well implemented, and effectively delivered biodiversity conservation results in a short time frame and across a large scale. The reverse-auction approach was confirmed as the most appropriate market-type mechanism for allocating funding and delivering cost-efficiency. Ultimately, it was recommended that the Australian Government extend the ESP. The Gillard Government accepted this recommendation, announcing it would invest $84.2 million (AUD) over four years in a new round of the ESP.[93]

Agricultural intensification: a mounting threat to agro-ecosystem integrity?

Recent reviews have highlighted an accelerating rate of agricultural intensification in New Zealand that may threaten both the environment and the sustainability of food production.[17,34] Understanding the extent and nature of environmental impacts associated with intensification is one of the most pressing issues facing New Zealand public, agricultural sectors, government agencies and conservation scientists. Although farming in New Zealand is based on introduced species, it still relies on the services provided by natural capital, which it can also impact, to sustain production:

> *Agricultural activities can generate a range of environmental benefits. These include aesthetic value, recreation, water accumulation, and supply, nutrient recycling and fixation, soil formation, wildlife protection and flood control, and carbon sequestration by trees and soil. However, major changes in farming practices in the past forty years have brought new pressures to bear on natural resources.*[xiii]

Some commentators uncritically confuse extensification with intensification when they are criticising farmers for not retaining sufficient woody vegetation within their farm boundary to maintain viable populations of both native and introduced plants and animals on their land.[35] Removing woody vegetation to make way for more pasture is actually a form of extensification of farming <u>within the landowners' boundary</u>, whereas it can be considered as a form of intensification if the entire farm boundary is defined as the land unit.[36] More careful definition of terms will aid a search for an optimal balance between strategies that trade off intensification of the land already planted in pasture or crops and disintensification.

Integrated environmental monitoring and reporting in New Zealand

New Zealand has only published two national state of the environment reports[94,95] and until very recently[96] was the only OECD (Organisation for Economic Co-operation and Development) country not legally required to undertake such reporting. In addition, national and regional biodiversity indicators are scarce, with the Ministry for the Environment (MfE) recently being criticised for releasing simple report cards on 'a patchy, ad hoc and occasional basis', as these were considered 'a major step backwards' for the health of New Zealand's environment.[97] Nationally, the need for robust and factual environmental reporting has been identified as critical to the management of our natural capital. While the New Zealand Biodiversity Strategy[41] outlines a high-level goal of halting the decline of biodiversity, the ability to measure our progress against this goal is limited by the paucity of data to measure biodiversity status and trend.[98] Also, in a recent review of the most 'enduring questions' for New Zealand's production lands, the following were identified as the second-most important and the 'highest priority for enhancement':[99]

[xiii] PCE[34] quoting OECD

- How sustainable are our farm management practices – including animal health and welfare – and are farmers and other users factoring in the full social cost of natural resources consumed?
- What is the agricultural sector doing to reduce greenhouse gas emissions and/or compensate through environmental enhancements and maintaining biodiversity?

The same review considered these issues poorly informed because they were: (1) a relatively new area of focus, where what is meant and what should be measured is still uncertain; and (2) a very complex topic with many interdependencies to consider.[99]

To safeguard New Zealand's environmental resources, and address increasing pressures associated with land-use intensification, OECD's recommendations for improved environmental management include: (1) strengthen and harmonise monitoring of major pressures on biodiversity and ecosystems, both within and outside protected areas; (2) further develop partnership approaches to conserving biodiversity on private land, prioritising conservation of ecosystems that are under-represented in public conservation lands; and (3) expand availability of quantitative indicators and time-series data related to environmental quality, assuring public relevance and public access. Hence, the development of a robust and trusted nationally harmonised system for calculating and delivering regular and timely measures of biodiversity change at different scales, addresses a significant need (Box 5); our framework will support New Zealand to meet its reporting obligations on biodiversity both nationally (e.g. state of environment[94,95]) and internationally (e.g. OECD; CBD; IPBES[100,xiv]).

There are multiple stakeholders involved in monitoring and managing the environmental domain, each fulfilling different roles and addressing different needs (e.g. Table 1). For example, within New Zealand's local government sector alone, there are 78 authorities responsible for the protection and management of the country's biodiversity on private land, under their administration of the Resource Management Act 1991 and the Local Government Act 2002.[101] In addition, to addressing four National Priorities for protecting rare and threatened native biodiversity on private land,[102] regional councils are required to monitor terrestrial indigenous biodiversity to meet their key statutory, planning and operational requirements.[12] In particular, they:

- Need to quantify the state of terrestrial indigenous biodiversity across a region and monitor spatio-temporal trends
- Need to monitor and assess the impacts of key threats and drivers
- Need to assess and facilitate improvements in biodiversity management and policy
- Need compatibility with existing frameworks for state of the environment reporting to enable regional councils, Department of Conservation (DOC), and the Ministry for the Environment (MfE) to contribute information on a common basis for regional and/or national reporting purposes.

[xiv] More than 90 countries joined the Intergovernmantal Platform for Biodiversity and Ecosystems Services (IPBES) in 2012. It operates rather like the influential Intergovernmental Panel on Climate Change (IPCC) and is promotiong more coordinated monitoring, research and interventions to support biodiversity and ecosystems sevices throughout the world. The NZSDs could contribute valuable information for their initial global assessments and a model for bottom-up involvement of practitioners like farmers, fishers and foresters.

Table 1: Key government agencies and their monitoring roles (● = major, ○ = minor)

Stakeholder	Key responsibilities	Identify data needs	Collect data	Process & report data	Use & report [xv]
Ministry of Foreign Affairs and Trade	Responsible for protecting and promoting New Zealand's interests overseas; includes providing the government with advice on foreign and trade policy and on international climate change negotiations.	●			●
Statistics New Zealand	To give New Zealand the statistical information it needs to grow and prosper. To tell the story of New Zealand through statistics that are relevant, accessible, and trustworthy.	●	○	●	●
Ministry for the Environment	Establishing and implementing legislation and policy regarding biodiversity. National environmental standards, policy statements, environmental management and reporting.	●	○	○	●
Ministry for Primary Industries	Maximising export opportunities for the primary industries; improving sector productivity; increasing sustainable resource use; and protecting New Zealand from biological risk.[103]	●			●
Environment Protection Agency	Administers applications for major infrastructure projects of national significance.[104] Regulates new organisms (plants, animals, GM organisms) and hazardous substances and chemicals. Administers the Emissions Trading Scheme and New Zealand Emission Unit Register.	●	○	○	●
Ministry of Business, Innovation and Employment	Scientific policy advice	●			○
Department of Conservation	Primarily responsible for managing public conservation land, it also has a responsibility to preserve biodiversity (in particular halt extinctions) over the entire New Zealand landmass	●	●	●	●
Regional, District and City councils	Resource Management Act	●	●	●	●
Parliamentary Commissioner for the Environment	To maintain or improve the quality of the environment by providing robust independent advice that influences decisions. To hold the Government to account for its environmental policies and actions.[105]	●			●

[xv] To assess and facilitate improvements in biodiversity management and policy.

Until recently, there was no coordinated system for monitoring and reporting on the protection, restoration or sustainable management of biodiversity. DOC and regional councils are currently working together to develop a coordinated system for monitoring and reporting on biodiversity.[9,10,12] Their systems build on the foundations laid by the national Land Use and Carbon Analysis System (LUCAS) run by MfE (Table 2). Our environmental framework will build links to these initiatives to facilitate integration and development of a monitoring and reporting system that is both cost-effective and resilient in the long term. We have chosen 'natural heritage' indicators in the Sustainability Dashboard that will closely align to those being used or considered in national biodiversity monitoring frameworks administered by the Department of Conservation[9,10,11] and the regional councils[12,13] (Appendix 1). Our goal is to enable famers and agricultural sector professionals to contribute to state of environment reporting in particular, thereby assisting a key challenge of the New Zealand Biodiversity Strategy to '*enhance communities' opportunities and capacity to be involved in biodiversity management*'.[xvi] Matching the NZSD, DOC and regional council frameworks will allow collaborators to pool data to achieve maximum statistical power and coverage. Co-funding by industry, ratepayers and government could benefit everyone by sharing costs. Even more importantly, integration of monitoring themes and data provides for much improved systems-level information and understanding.[46]

[xvi] MfE & DOC 2000,[41] p. 10.

Table 2: Monitoring initiatives reviewed to inform the NZSD's environmental monitoring design, their origin and scope, drivers (■) and spatial scales (●) for implementation. Bold text highlights three schemes of particular interest.

Code	Initiative	Origin	Scope	Key drivers			Spatial scales				
				Policy	Market assurance	Business improvement	Farm	Industry	Regional	National	International
NZSD	New Zealand Sustainability Dashboards[1]	Local	Sustainability	■	■	■	●	●	●	●	●
LEP	Land and Environment Plans[106]	Local	Sustainability	■			●	●	●	●	
ARGOS	Agricultural Research Group on Sustainability[18]	Local	Sustainability		■	■	●	●			
BMRS	**Biodiversity Monitoring & Reporting System**[9]	Local	Environment	■					●	●	●
TBMF	**Terrestrial Biodiversity Monitoring Framework**[12]	Local	Environment	■					●	●	
LUCAS	Land Use and Carbon Assessment System[107]	Local	Environment	■						●	●
SAFA	**Sustainability Assessment of Food & Agriculture Systems**[8]	International	Sustainability	■	■	■	●	●	●	●	●
OECD	Organisation for Economic Co-operation & Development[108]	International	Sustainability	■						●	●
MP	Montreal Process Criteria and Indicators[109]	International	Sustainability	■	■	■		●		●	●
COSA	Committee on Sustainability Assessment[110]	International	Sustainability	■	■	■	●	●	●	●	●
SAN	Sustainability Agriculture Network[111]	International	Sustainability	■	■	■					
UNIL	Unilever[112]	International	Sustainability		■	■	●	●			
FA	Food Alliance[113]	International	Sustainability		■		●	●			
LEAF	Linking Environment and Farming[114]	International	Sustainability		■	■		●		●	●
RISE	Response-Inducing Sustainability Evaluation[115]	International	Sustainability			■	●	●			
GRI	Global Reporting Initiative[116]	International	Sustainability			■		●			
EPI	Environmental Performance Index Framework[117]	International	Environment	■						●	●
BIOBIO	Biodiversity Indicators for European Farming Systems[118]	International	Environment	■			●	●	●	●	
BWI	WWF Biodiversity & Wine Initiative[119]	International	Environment		■	■	●	●			
CG	Conservation Grade[120]	International	Biodiversity		■					●	●

A definition of Agro-environmental Integrity

We propose that the following definition of agro-environmental integrity be adopted as the overarching goal of the environmental monitoring within the New Zealand Sustainability Dashboards:

> ***Agro-environmental integrity*** *is defined as that state which sustains the full potential of land and its natural capital, ecosystem processes and services to efficiently and indefinitely produce high quality food and fibre while enhancing natural heritage values and meeting global environmental change obligations.*

It recognises the need for an integrated management approach implemented across multiple spatial scales and governance jurisdictions to maintain livelihoods, social well-being and restore ecological integrity in New Zealand. The NZSD agro-environmental monitoring framework will therefore be structured around achieving four outcomes (Figure 3):

- *Natural capital of production landscapes is maintained*
- *Resilience of New Zealand agriculture is secured for future productive use*
- *Production landscapes contribute to national 'natural heritage' goals*
- *New Zealand meets global environmental change obligations*

These outcomes will result from achieving 11 nested objectives. Twenty-two indicators will be used to monitor progress towards those objectives, some of which may be supported by multiple measures.

The following four sections of the report outline the rationale and indicators for four key outcomes of agro-ecosystem integrity. We customised international best practice guidelines (Table 3) to select indicators to meet the specific features and opportunities of the NZSDs' bottom-up and participatory approach and the special emphases of New Zealand's ecology.

To help prioritise selection and identify where further development is required, indicators within each outcome have been broadly classified according to their importance, readiness for immediate deployment, costs and measurability (Table 4). Where a potential indicator has been ranked a 'low' importance in the following framework, this should be interpreted in a relative sense only. <u>All</u> the issues we have included here are important for agro-environmental integrity in an absolute sense but some measures should be adopted earlier and attract more investment than others.

We also provide an assessment of the likely 'recurrence' required for repeated measurements. Measurements of fast-moving variables need to be repeated frequently for trend detection and early warning of threats and opportunities. In many cases we suggest an adaptive monitoring process where more detailed and frequent monitoring kicks in only when and where risk or opportunity is signalled.[xvii] This relieves the monitoring burden on all agricultural enterprises and will help concentrate the attention of

[xvii] See Moller & MacLeod (2013)[3] for suggestions for monitoring rotors and scaling up monitoring where and when it is most needed.

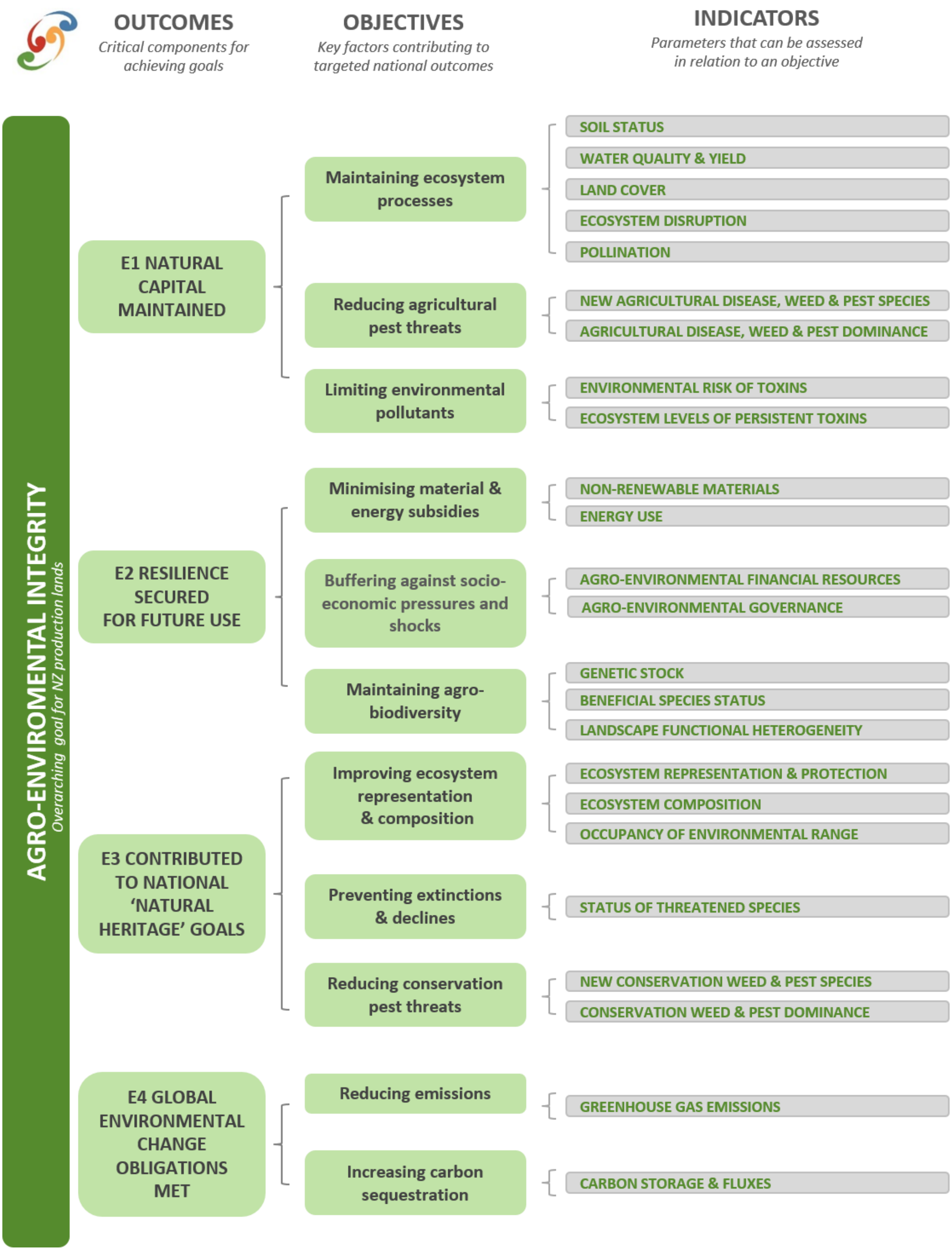


Figure 3: A proposed monitoring framework for securing agro-environmental integrity in New Zealand's production landscapes.

Table 3: Quality design criteria of environmental indicators proposed for the New Zealand Sustainability Dashboards focusing on optimal features for (a) individual indicators and (b) the entire set of indicators.[xviii]

Indicators	Criterion	Description
(a) Individual indicators	Policy relevant & meaningful	Indicators should send a clear message and provide information at an appropriate level for policy and management decision-making by assessing changes in the status of the environment (or of pressures, responses, use or capacity), if possible with reference to baselines and agreed targets. Monitoring needs to align tightly with risk management.
	Environmentally relevant	Indicators should address key properties of environment or related uses such as states, pressures, responses, use or capability.
	Neutral rather than ideologically based	Most indicators should be neutral and objective measures except where serving local values have been declared as the prime target (e.g. cultural health indicators)
	For preference quantified	Indicators should be fully quantified whenever practicable. For some issues qualitative indicators are the only reliable guide and quantification must not be forced.
	Clearly defined and repeatable	Indicators must be based on clearly defined, verifiable and scientifically acceptable data collected using standard methods of known accuracy and precision, or based on traditional knowledge that has been appropriately validated.
	Broad acceptance	The strength of an indicator depends on its broad acceptance. Involvement of policymakers, major stakeholders and experts in the development of an indicator is crucial.
	For preference performance-based	Where available and practical, it is better to measure actual performance and outcomes rather than practices that are expected to promote sustainability and resilience. Outcomes and outputs are most telling, although indicators that scale output per unit input are useful measures of efficiency.
	Affordable monitoring	Accurate, affordable measurement of indicators as part of a sustainable monitoring system, using determinable baselines and targets for the assessment of improvements and regressions, is essential. If scoring is affordable, participation and regularity of monitoring is increased.
	Affordable modelling	Information on cause-and-effect relationships should be available and quantifiable, in order to link pressures, status and response indicators. These relational models enable scenario analyses and form the basis of ecosystem approach.
	Sensitive & specific	Indicators should be sensitive in order to show trends, and where possible permit the distinction between human-induced and naturally occurring changes. They should thus be able to detect changes in systems within the time frames and on the scales that are relevant to the decisions, but should also be robust so that measuring errors do not affect their interpretation. It is important to detect changes before it is too late to correct the problems detected.
	Link indicators to targets or thresholds	Where possible all indicators should be linked to realisable, action-oriented, measurable and time-delimited targets or critical thresholds of risk, performance or best professional practice.

xviii Source: Moller & MacLeod 2013[3].

Table 3 continued.

Indicators	Criterion	Description
(b) Sets of indicators	Representative	The set of indicators provides a representative picture of the pressures, biodiversity status, responses, uses and capacity (coverage).
	Declare values and goals	Explicit declaration of goals and underlying values behind the indicators makes them interpretable in context and builds consensus in management responses
	Low number of indicators	The lower the total number of indicators, the more communicable they are to policymakers and the public, and the lower the cost of communicating them.
	Capacity to upscale	Indicators should be designed so as to facilitate aggregation at a range of spatial and temporal scales for different purposes. Aggregation of indicators at the level of ecosystem types or the national or international level requires the use of coherent indicator sets and consistent baselines. This also applies for pressure, response, use and capacity indicators.
	Mix of simple and aggregated indicators	Some aggregated scores support more holistic appraisals and improve the breadth of coverage. Reductionist and more focused indicators guide fine-grained management adjustments. Always record and archive component scores if aggregated indices so they can be used separately to link to components of farm management, weighed differently or calibrated against new indicators later.
	Wide scope & integration	The framework and indicator sets must cover and cross-link multiple dimensions of sustainability and values encompassing environment, economics, social and governance dimensions
	Trade off generalisability and specificity	Cross-comparison between sectors, regions, countries and diverse socio-ecological systems is facilitated by generalisable indicator structures and protocols cast at higher levels. More locally grounded indicators should be nested under these to guide management by analysing trends but cannot be used for wider benchmarking. A balance between universality and specificity is required. Comparability and generalisability can be incorporated by specifying the general rationale of designing an overarching indicator, even if the details of what is measured or how is not specified or equivalent in all situations.
	Data records & management	Database management requires annotation, checking of data, archiving and security management to allow others to replicate current methods.
	Linked to standards and certification requirements	Some of the indicators, targets and thresholds should be linked to standards required for market accreditation.
	Explanatory and context information monitored	Management guidance is more focused, effective and reliable if additional information is gathered to identify why the indicators change (or don't change despite interventions to drive them towards more sustainable orientations).
	Benefits are measured	Incentivise sustainability monitoring and management by quantifying indicators linked to benefits.
	Forward focus	Monitoring is part of risk management and being prepared for future turbulence (shocks and drivers). Some indicators should be chosen to monitor potential new threats and opportunities just over the horizon.

Table 4: Factors used to classify indicators

Feature	Explanation
Objective	Specific goal being addressed within a particular national outcome
Indicator	Indicator (or subtheme) title
Definition	Aspirational description of each indicator (or sub-theme)
Rationale	Background information on the relevance of the indicator.
Reviewed schemes	Percentage of 19 reviewed monitoring initiatives that monitored similar indicators (Table 5, Table 7, Table 8, Table 9).
Importance	A broad classification of importance of an indicator from an agro-ecosystem processes perspective
Readiness of indicator	A broad classification of readiness of indicator from a monitoring perspective
Cost of indicator	A broad classification of cost from a monitoring perspective
Measurability	A rough guideline on ability to accurately estimate the status or trends of the indicator
Recurrence of monitoring	A rough indication of the frequency of monitoring likely to be required
Performance measures	Examples of measures that could be used to monitor whether environmental performance is being maintained or if is being degraded or enhanced.
Practice measures	Examples of measures that could be used to monitor management actions being implemented to address the specific environmental component.
Priority	Approximate ranks of indicator deployment priority, with importance assumed to have more sway than cost. Priority is ranked (first to last), as follows:

		Cost		
		Low	Moderate	High
Importance	High	High	High	Moderate
	Moderate	Moderate	Low	Low
	Low	Low	Very low	Very low

Where the importance or cost ranking depends on local context, we have inserted stipples (and brackets around the priority ranking), and where we expect particularly wide variance in importance because of local ecology or sector characteristics, we have not shaded the rows at all.

producers when more infrequent and coarse-level monitoring suggests they are approaching a critical threshold.

Indicators can be broadly divided into three types: performance, practice and context indicators. The first are often called ‘Key Performance Indicators (KPIs)’; the second are referred to as ‘best practice’; and the third are components of ‘benchmarking’ or ‘standards’ that help define targets and drive improved performance and practice.[xix] Several context indicators will be gathered to help interpret the monitoring results, but they will be considered in the next stages of operationalising the NZSDs. In the meantime we make some general suggestions of potential examples of performance- and practice-based ‘measures’ for each proposed indicator to illustrate a range of forms that they might take. More specific measures must be developed later in collaboration with each agricultural sector that hosts its own NZSD if they are to be fully locally grounded, practical and measurable by the viticulturists, farmers, orchardists, foresters, kaitiaki themselves.

Outcome 1: Natural capital for production is sustained

Natural capital is considered pertinent to the sustainability of intensive farming in New Zealand,[34] with capital-based indicators recently being explored as a potential means for measuring agricultural sustainability.[121] Natural capital stock takes different identifiable forms (e.g. trees, minerals, ecosystems or atmosphere) or intangible forms (e.g. stored in species or ecosystems), providing renewable and non-renewable stock of natural resources that support life and enable all social and economic activities to take place at a point in time.[34,122] Each form of capital stock generates, either autonomously or in conjunction with services from other capital stocks, a flow of services that may be used to transform materials, or the spatial configuration of materials, to enhance the welfare of humans. Ecosystem services consist of flows of materials, energy and information from natural capital stocks, which combine with manufactured and human capital services to produce human welfare.[46,123] The human use of this flow of services may or may not leave the original capital stock intact.

A number of global initiatives have recently been established to support monitoring and management of natural capital and ecosystem services at different spatial scales (Box 8). Key challenges include:

- Recognising that agro-ecosystems are both providers and consumers of ecosystem services.[124] Soil structure and fertility, for example, provide essential ecosystem services to agro-ecosystems.[125] While agricultural land can help regulate soil quality, it can also be the source of adverse impacts, e.g. nutrient runoff and sedimentation of waterways.[124]
- Meeting all the needs of decision-makers at national and sub-national scales because the management of any particular ecosystem must be tailored to the particular characteristics of that ecosystem and to the demands placed on it.[42]
- Balancing attention and investments between biodiversity versus ecosystem services concepts.

[xix] See Moller & MacLeod (2013[3]) for a discussion of their relative strengths and uses. The NZSD will try to use performance-based indicators whenever possible, but practice-based indicators are less expensive, can be scored quickly by farmers and can extend the coverage of the issues monitored by being naturally integrative and grounded in farming practice.

- Understanding the trade-offs between biodiversity conservation and ecosystem service supply[126], as well as synergies and trade-offs between provisioning services and regulating and cultural services and drivers of changes in these.[46]
- Achieving sustainable intensification.[36,127,128]

Outcome 1 focuses on sustaining natural capital for production, while also recognising its importance for maintaining livelihoods and ecological components associated with New Zealand's agro-ecosystem. It sets out to address three key objectives: (1) maintaining ecosystem processes, (2) reducing agricultural pest threats and (3) limiting environmental pollutants within New Zealand's agro-ecosystems. Indicators aligned to each of these objectives are set out in **Table** 5, which also summarises their wider use in international and national monitoring schemes.

Box 8: Global initiatives for monitoring natural capital and ecosystem services

Millennium Ecosystem Assessment, a one-time historic analysis, provides a useful tool for assessment, planning and management of ecosystem services.[42] It considers state and trends in ecosystems, drivers of ecosystem change, ecosystem services and associated human well-being. It also provides (1) foresight for consequences of decisions affecting ecosystems and options for responses to achieve sustainability goals; (2) enhanced capacity for individuals and institutions to undertake assessments and act on findings; and (3) a guide for future research.

System of Environmental and Economic Accounts, developed by the United Nations' Statistical Commission, goes beyond measuring just the annual output of a country (gross domestic product, GDP), to assessing its combined produced, social, human and natural capital.[129] A number of countries (including New Zealand) are compiling accounts for natural capital (including water, energy, minerals, land and environmental protection expenditure) to manage better or to evaluate the trade-offs needed for making better development decisions (cites Australia and Mexico as leading examples). Without this information, natural assets are being overexploited and deteriorated. More accurate information is required to inform policy and ensure better economic decisions about development priorities and investments.[130]

- **Asset accounts**: Stocks and changes in stocks of natural resources such as land, forest, water, fish, soils, minerals and energy in physical and monetary terms
- **Physical flow accounts**: For the use of energy, water, other materials, air and water emissions by economic sectors
- **Monetary accounts**: Environment taxes and subsidies, environment protection expenditure, and resource management expenditure

Global system for monitoring ecosystem services change, currently under development, aims to provide information that describes the spatial and temporal patterns in the production, delivery and value of many ecosystem services at local to global scales[46]. This multiscale approach makes information compatible with the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), but also places emphasis on the national scale, developing standards for communication and protocols for collecting observations.

Table 5: Review of practice (■) and performance (●) indicators relevant to the 'natural capital maintained' outcome used by local and international monitoring initiatives (full names provided in Table 2).

Objective	Indicator	Local					International													
		LEP	ARGOS	BMRS	TBMF	LUCAS	SAFA	OECD	MP	COSA	SAN	UNIL	FA	LEAF	RISE	GRI	EPI	BIOBIO	BWI	CG
1. Maintaining ecological processes	1.1 Soil status	■ ●	■ ●	●			■ ●	■ ●	■ ●	■ ●	■ ●	■ ●	■	■ ●	■ ●			■	■	
	1.2 Water quality & yield	■ ●	■ ●	●			■ ●	■ ●	■ ●	■	■ ●	■ ●	■	■	■	■ ●	■ ●		■ ●	
	1.3 Land cover	●	■ ●	●	●	●		●	■ ●		●			●		●		●		●
	1.4 Ecosystem disruption			●							■ ●								■ ●	
	1.5 Pollination		■ ●																	■
2. Reducing agricultural pest species	2.1 New agricultural disease, weed & pest species						●				■ ●		■	■ ●		■ ●				
	2.2 Agricultural disease, weed & pest dominance	■	■ ●					■ ●	●	■	■ ●	■	■	■ ●	■	■ ●	●	■	■ ●	
3. Limiting environmental pollutants	3.1 Environmental risk of toxins						■	■		■	■	■		■	■		■	■		■
	3.2 Ecosystem levels of persistent toxins		■	●			■				■		■	■ ●		■ ●	■	■	■	

Objective 1: Maintaining ecosystem processes

Ecosystem processes are changes in the stocks and/or flows of materials (natural capital) in an ecosystem, resulting from interactions among organisms and with their physical-chemical environment.[131] Ecosystem processes are vulnerable to change and have their own characteristic rates and thresholds. As the physical, chemical and biological features and components of ecosystems change, so will the processes and, consequently, the ecosystem services. The complexity of these interactions is poorly understood, making it difficult to predict how they will change in response to changes in stressors such as agricultural intensification and climate change.

Five indicators are recommended for determining whether ecosystem processes in New Zealand's agro-ecosystems are being maintained. These indicators align closely with issues recommended for consideration within Land and Environment Plan guidelines.[106]

Soil provides the 'central engine room' for New Zealand agriculture and is a driver of land use decisions (Box 9).[34,99] Recently Statistics New Zealand[99,130] highlighted a lack of information on the quality of soil for different production purposes, the impact of soil erosion and associated farm-management practices in New Zealand.

Fresh water is among New Zealand's most valuable assets and is a vital part of the country's economy;[130] the impact and dependence of agricultural production on this resource is also one of New Zealand's most important environmental concerns (Box 9). A lack of information on the use and sustainability of water resources, not only in agriculture, horticulture and forestry industries but all industries in New Zealand was recently highlighted as a concern.[99]

Understanding New Zealand's land cover and use patterns in agricultural landscapes is important for determining the drivers of change and whether production, natural and cultural components are being maintained (Box 9). Limiting and reducing habitat conversion and degradation is also often a focus in agro-environmental standards and certification schemes – primarily motivated by conservation objectives, but also to address carbon and water pollution issues.[45]

Extreme disturbance events (e.g. disease, drought) can adversely impact production either directly (e.g. resulting in crop loss) or indirectly (e.g. increasing reliance on supplementary animal feed); ecosystems play an important role in modulating the effects of such events.[42]

Maintenance of pollination processes is crucial for crop production in some sectors, hence global declines in pollinator species are a major concern for agro-ecosystems.[124,132]

Box 9: 'Enduring questions' posed in New Zealand's Environment Domain Plan[130]

Land

What are our land cover and land use profiles, how are they changing, what is driving these changes, and what is the consequential impact on New Zealand's soils, and natural and cultural landscapes, including urban environments and conservation lands?

Supplementary enduring questions

- What is New Zealand's land use, and how is this changing spatially and temporally?
- What is New Zealand's land cover and how is this changing spatially and temporally?
- What is driving the changes in New Zealand's land use and land cover?
- What is the current and potential future impact of land use and land cover change in New Zealand?
- What is the quality and quantity of New Zealand's soil and how is this changing spatially and temporally?
- What is the impact of land use and land cover profiles on Māori and Māori-owned land and how is this changing?
- What and where are New Zealand's protected areas, how are they changing, and what is the environmental protection effort done?

Fresh water

How are the quality, abundance, and use of New Zealand's fresh water changing, and what is the impact on ecosystems and humans?

Supplementary enduring questions

- What is the quality of New Zealand's fresh water, what are the spatial and temporal trends, and how are these affected by climate change, human activity and other pressures?
- What is the quantity (stocks) of New Zealand's fresh water, what are the spatial and temporal trends, and how are these affected by climate change, human activity, and other pressures?
- What is the use (flows) and allocation of our fresh water, what are the spatial and temporal trends, and how are these affected by climate change, human activity, and other pressures?
- What impact does the change to quality, quantity, and use of fresh water have on ecosystems and humans?
- What is the health of fresh water and freshwater mahinga kai (customary food fathering areas and practices) from a Māori perspective, and how and why is this changing?
- What, where, and how is environmental protection effort being done to maintain and improve fresh water?

Indicator 1.1: Soil status

Definition	Soil characteristics are sustained and enhanced to provide the best conditions for plant growth and soil health, while chemical and biological contamination is prevented. No land is lost to agricultural production. Desertification and degraded land is rehabilitated
Rationale	Soil quality includes soil properties and processes (e.g. nutrient cycling, waste decomposition and assimilation) that determine the ability of soil to function effectively as an ecosystem component.[133] Soil quality may be broadly defined to include capacities for water retention, carbon sequestration, plant productivity, waste remediation, and other functions.
Reviewed schemes	74% of schemes, typically a combination of performance and practice measures
Importance	High
Readiness of indicator	High
Cost of indicator	Low
Measurability	High
Recurrence of monitoring	Intermittent
Performance measures	Status and trends in soil degradation, biology, chemistry and structure metrics, aiming to inform management of soil fertility, aeration and water retention capacity
Practice measures	Implementation of best management practices (including soil nutrient budgets and mitigation of farm erosion risk), or other relevant legislation, to protect soil resources
Priority	High

Indicator 1.2: Water quality & yield

Definition	The release of water pollutants is prevented and freshwater quality is restored. Withdrawal of ground and surface water and/or use does not impair the functioning of natural water cycles and ecosystems and human, plant and animal communities
Rationale	Fresh clean water is required for stock watering, irrigation of crops and pasture as well as other farm operations. It is also an important consideration for providing a safe drinking supply, sustaining natural ecosystems and associated native biodiversity, as well as highly valued recreational activities and cultural reasons.[9] Intensive agriculture can place severe stress on flowing freshwater and groundwater resources as well as reducing water quality.
Reviewed schemes	79% of schemes, typically a combination of performance and practices measures implemented
Importance	Moderate–high
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	High, specialised
Recurrence of monitoring	Intermittent
Performance measures	Status and trends in physical (including habitat), chemical or biological properties of water bodies, in production areas
Practice measures	Implementation of best management practices, or other relevant legislation, to protect water-related resources, including risk assessments for nitrogen leaching and phosphorus runoff
Priority	Low, but context dependent

Indicator 1.3: Land cover

Definition	Productive and conservation capacity of land is sustained and enhanced. Change in area, habitat loss and transformation are minimised.
Rationale	Land cover is considered a fundamental data layer in most monitoring schemes. It provides a basis for measuring temporal and spatial trends in land use and determining drivers of change. It also provides contextual information for interpreting changes in other agro-environmental indicators. Habitat mapping is also important for farmland biodiversity surveys,[118] as habitat loss is a main threat for biodiversity. Certification schemes often focus on a subset of habitats, but the terms used to describe them are often generic and indistinct.[45] Few schemes refer to modified habitats and even fewer to habitat restoration or enhancement.
Reviewed schemes	63% of schemes, typically focused on performance measures
Importance	High
Readiness of indicator	High
Cost of indicator	Low
Measurability	Moderate
Recurrence of monitoring	Occasional
Performance measures	Extent, change and transformation in cultivated and uncultivated habitats (exotic versus indigenous vegetation) at different spatial scales
Practice measures	Extent, change and transformation of agricultural land used for different land uses and the intensity of management practices within different land use types
Priority	High

Indicator 1.4: Ecosystem disruption

Definition	Disruption and vulnerability to loss of production, livelihoods and ecosystem components resulting from major disturbances (or shocks) to agro-ecosystems (e.g. fire, disease outbreaks or mass erosion events) is minimised.
Rationale	Ecosystems play important roles in modulating the effects of extreme events (shocks) on human systems. Ecosystems affect both the probability and severity of events, and they modulate the effects of extreme events. Major disturbances can adversely impact production either directly (e.g. crop losses) or indirectly (e.g. increased reliance on or costs of supplementary animal feed). These regulating services will become increasingly important because of global climate change.
Reviewed schemes	16% of schemes.
Importance	Moderate
Readiness of indicator	Moderate
Cost of indicator	Low
Measurability	High
Recurrence of monitoring	Continuous surveillance, escalated monitoring if threat found (driver or shock)
Performance measures	Frequency, extent and intensity of area affected by extreme abiotic or biotic disturbances beyond reference conditions (e.g. fires, disease outbreaks, mass erosion, extreme climate/weather events)
Practice measures	Implementation of education initiatives, regular surveillance and reporting procedures, rapid response strategies and best-practice management actions at farm and catchment levels to mitigate risk (e.g. surveillance activity targeting main pathways for entry for new diseases)
Priority	Moderate

Indicator 1.5: Pollination

Definition	Fruit set rates and yields in insect-pollinated crops are sustained and enhanced. Reliance on external pollination services is minimised.
Rationale	Fruit set is the proportion of a plant's flowers that develop into mature fruit or seeds; it is a key component of crop yield.[134] A decline in the diversity and abundance of wild insect pollinators in many agricultural landscapes is a global concern, as wild insects (native and introduced) may increase fruit set by contributing to pollinator abundance, number of species (richness) or equity in relative species abundance (evenness) or some combination of these factors.[34,132,134,135] In New Zealand, honey bees, mainly sourced from managed hives, are regarded as the most effective pollinators of commercial crops, with some horticultural and arable sectors considering these pollinators as critical to the development of an economically viable crop.[136]
Reviewed schemes	11% of schemes, only one locally (ARGOS)
Importance	Low–high
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	Moderate, specialised, indirect proxies available?
Recurrence of monitoring	Intermittent
Performance measures	Extent, timing and change in demand for different pollination services per unit area within different sectors (e.g. hives, artificial pollination, alternative insect pollinators, enhancing floral attractiveness)
Practice measures	Implementation of education and best-practice management strategies to enhance pollination services on farms,[137] optimise use of pollination services within and among sectors, minimise agro-chemical poisoning and biosecurity risks, and ensure future demand can be met
Priority	Context dependent

Objective 2: Reducing agricultural pest threats

Agro-ecosystems are increasingly recognised as both sources and sinks of disease, weed and animal pest species, which can have significant effects on biodiversity, agricultural biosecurity, global economies, and human health (e.g. Box 10). Changes in the emergence, prevalence and abundance of such pests are driven largely by socio-economic, environmental, and ecological factors.[138]

Box 10: Emerging disease affects pollinator species

The honey bee (*Apis mellifera*) is one of the most economically important insects, providing crop pollination services and valuable hive products. Emerging diseases are among the greatest threats to honey bees.[139] During the past 50 years, the global spread of the ecto-parasitic mite V*arroa destructor* has resulted in the death of many feral honey bee colonies.[139] In New Zealand, significant declines in managed honey bee colonies over the last decade have been linked to *Varroa destructor* infestations and associated viral infections.[140]

Zoonotic disease emergence at the wildlife–livestock–human interface, for example, is often associated with varying combinations of agricultural intensification and environmental change, such as habitat fragmentation and ecotones, reduced biodiversity, agricultural changes and increasing human density in ecosystems.[141] Expansion of livestock production, especially in proximity to wildlife habitats, has facilitated pathogen spillover from wildlife to livestock and vice versa. It has also increased the likelihood that livestock become amplifying hosts in which pathogens can evolve and become transmissible to humans. Some wildlife species have adapted to and thrived in the ecological landscape created by human settlement and agriculture and become reservoirs for disease in livestock and humans.

In New Zealand, tuberculosis in cattle and deer is an example of an ongoing endemic disease issue requiring significant investment to halt and reverse the problem.[142] This has included control of *Mycobacterium bovis* infection in both wild and domestic animal populations. Other wildlife species impact agricultural production, with native and introduced birds, for example, causing significant damage to grape crops in vineyards.[143,144] Biosecurity defence programmes have to weigh the biodiversity contribution of adventive species against their potential pest impacts. Careful study is needed to determine whether the indirect ecological effects of a pest plant or animal may offer unexpected net gains for agro-ecosystem resilience that outweigh the direct penalties of their abundance on farms.

Managing pests is difficult as land managers have to contend with multiple sources of uncertainty:[145] (1) observation uncertainty: measurements made on the managed system (e.g. how many pests are actually present?); (2) model uncertainty: understanding the underlying behaviour of the system (e.g. how will pests respond to different levels of pesticide?); and (3) process uncertainty: about the environment (e.g. how unpredictable weather changes the effectiveness of pesticide applications?).

Pest management monitoring typically focuses on inputs (e.g. rate and frequency of pesticide applications, trapping effort) rather than on performance outcomes[125] (e.g.

possum densities are reduced and maintained at low densities resulting in significant reductions in TB incidences in cattle).

Two indicators are recommended for monitoring agricultural pest threats. One focuses on detecting and managing new pest threats, thus meeting the regulatory requirements set out in the Hazardous Substance and New Organisms Act 1996. The other assesses changes in the dominance of established agricultural pests, posing a risk to agricultural production and the wider environment.

Indicator 2.1: New agricultural disease, weed and pest species

Definition	Minimise the risk and number of new incursions and/or sites of nationally recognised agricultural weed and pest species.
Rationale	The Environmental Protection Agency manages potential risks to the environment, the health and safety of people, Māori culture and traditions and the market economy from organisms that are new to New Zealand without limiting the country's future potential for innovation.[146] New organisms in New Zealand are regulated and managed by the Hazardous Substances and New Organisms (HSNO) Act 1996.[147] The Act defines a new organism as a plant, animal or micro-organism that is foreign to New Zealand. New organisms include: (1) new species that were not present in New Zealand before 29 July 1998; (2) organisms that have been given containment approval, genetically modified organisms (GMOs); and (3) organisms that have been eradicated from New Zealand.
Reviewed schemes	26% of schemes, typically a combination of performance and practices measures
Importance	Moderate–high
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	Moderate
Recurrence of monitoring	Continuous surveillance, escalated monitoring if threat found (driver or shock)
Performance measures	Incidences of the introduction of potentially invasive species are minimised. Occurrence of self-maintaining populations of new potential environmental weeds and animal pests
Practice measures	Implementation of best-practice management protocols to mitigate risks of new incursions
Priority	Moderate, but context dependent

Indicator 2.2: Agricultural disease, weed and pest dominance

Definition	Minimise the risk, distribution and abundance of agricultural weeds and nationally listed animal pests.
Rationale	For already established pests, management is conducted within a legislative and policy framework[148] (e.g. Regional Pest Management Strategies; National Pest Plant Accord; Biosecurity Act 1993; National Pest Management Plan for Bovine TB). Performance Management Framework for pest management.[149,150]
Reviewed schemes	74% of schemes, typically focused on practice measures
Importance	Low–high
Readiness of indicator	High
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Intermittent
Performance measures	Status and trends in distributions and abundance or prevalence of key weed, pest or disease species threatening agricultural production and agro-ecosystems. Area and per cent of production land affected beyond reference conditions
Practice measures	Implementation of management actions (e.g. waste management, biocontrol programmes or integrated pest management practices) to regulation of agricultural weeds, pests or diseases and mitigating risk including education, regular surveillance and reporting procedures
Priority	Context dependent

Objective 3: Limiting environmental pollutants

Rachel Carson's book entitled *The Silent Spring* drew the world's attention specifically to the indiscriminate toxicity of early generations of agricultural pesticides. Conventional agriculture is based on a high level of chemical inputs (e.g. pesticides and fertilisers), resulting in serious environmental impacts, health risks and loss of biodiversity in agro-ecosystems.[151] Environmental impacts include their aerial dissemination and the contamination of soil and water, with largely underestimated negative effects on biodiversity directly or indirectly exposed to these chemicals[152] (Box 11). Pesticide use also contributes to decreases in plant and animal biodiversity in agro-ecosystems as well as habitat loss. Thus, a reduction in the use of plant protection products is crucial for the implementation of sustainable agricultural systems, particularly for systems with high pesticide use. Orchards in temperate regions, for example, are among the most intensive users of pesticides (e.g. in France orchards only make up 1% of the utilised land area but use 21% of insecticides).

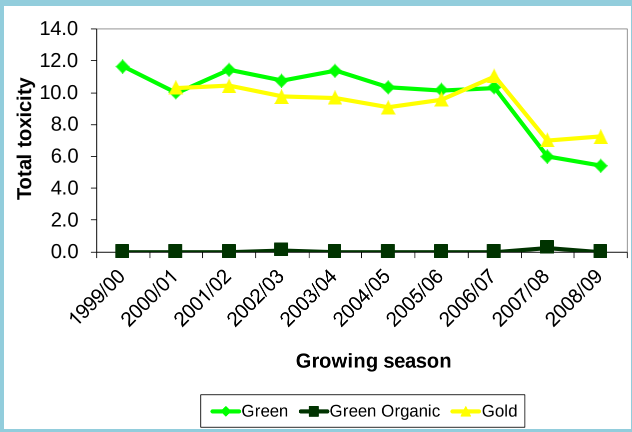
In addition to meeting the regulatory requirements set out in the Hazardous Substance and New Organisms Act 1996, New Zealand's agricultural sectors need to address increasing consumer concern about pesticide residues in food, and the impact of crop protection practices on the environment, by developing strategies to minimise pesticide use through greater adoption of integrated pest and disease management systems.[153] Such systems aim to minimise pesticide use by avoiding unnecessary applications, optimising pesticide timing and making greater use of selective and more benign pesticides. Demonstrating performance towards lower pesticide use and safer crop protection practices and related environmental benefits (e.g. improved status of key indicator species or guilds) is also important (e.g. Box 11).

Two indicators are recommended for assessing the risks posed by chemical pollutants and their persistence in the environment.

Box 11: Environmental risks of pesticides

Trends in toxicity risk

Trends in pesticide use were assessed within three management systems in New Zealand's kiwifruit sector.[154] Thirty-six orchards were surveyed by the Agricultural Research Group on Sustainability (ARGOS). These were located in 12 clusters, with each cluster having three orchards: one integrated management 'Green', one integrated management 'Gold' and one organically managed Green 'Organic'. Within each orchard, pesticide applications were classified according to the eco-toxicity risk posed to terrestrial vertebrates (using the Environmental Protection Agency databases), as well as the frequency and area of spraying events. Toxicity risk on Organic orchards was very low compared with the other management systems, where a drop in the toxicity ranking was observed in 2007/08. A change in the types of sprays used rather than a reduction in sprays applied was determined as the driver of trend for a decline in pesticide toxicity.



Native bird densities

Using bird survey data collected from the same kiwifruit orchards in New Zealand, ARGOS found composite measures of breeding season densities, both of all native species and the subset of native insectivores, were higher on organic orchards than integrated management ones.[155] However, pesticide use and habitat composition variables were better predictors of native bird densities than management system, with native bird densities negatively associated with pesticide toxicity ranking and/or positively associated with woody vegetation cover. A complete conversion to an organic system may not, therefore, be required to improve biodiversity in agro-ecosystems. Instead, the transfer of specific land management practices known to benefit biodiversity in organics has the potential to enhance biodiversity in other more intensively managed systems (e.g. integrated management). This may be a path towards attaining biodiversity benefits at a larger scale, since such changes may be more attractive than a conversion to organic.

Wonky fish

Anthropogenic pollution and disease can cause both lethal and sub-lethal effects in aquatic species but our understanding of how these stressors interact is often not known. Contaminants can reduce host resistance to disease, but whether hosts are impacted at environmentally relevant concentrations is poorly understood. A recent New Zealand study investigated the independent and combined effects of exposure to the common herbicide glyphosate (e.g. 'round-up') and the trematode parasite *Telogaster opisthorchis* on survival and the development of spinal malformations in juvenile *Galaxias anomalus*, a native freshwater fish.[156] Parasites and glyphosate were shown to act synergistically on aquatic vertebrates at environmentally relevant concentrations, and that glyphosate might increase the risk of disease in fish. These results have important implications when identifying risks to aquatic communities and suggest that threshold levels of glyphosate currently set by regulatory authorities do not adequately protect freshwater systems.

Indicator 3.1: Environmental risk of toxins

Definition	Minimise the toxin risk posed to different taxa within agro-ecosystems and surrounding areas by chemical use.
Rationale	Pesticide use contributes to biodiversity loss and soil and water contamination, but the impact and extent of these effects is largely underestimated.[151,152] A reduction risk of toxins in agro-ecosystem and surrounding environments is crucial for implementing sustainable agricultural systems, particularly for sectors where pesticide use is high.
Reviewed schemes	53% of schemes, predominantly focused on practice measures
Importance	Moderate
Readiness of indicator	Moderate
Cost of indicator	Low
Measurability	High
Recurrence of monitoring	Continuous
Performance measures	Status and trends in toxicity risk of pesticide use is assessed for different taxa
Practice measures	Implementation of education initiatives and best-practice management at farm and catchment levels to mitigate risk
Priority	Moderate

Indicator 3.2: Ecosystem levels of persistent toxins

Definition	Minimise the number of accidental release/chronic contamination events and presence toxins in selected tissues of wildlife, and agricultural produce, and humans
Rationale	Public and consumer concerns about pesticide residues in food, the environment and humans need to be addressed. Hence international certification schemes often place a strong emphasis on safe use and storage of hazardous chemicals on farms as well as transparent processes for declaring and managing accidental or chronic contamination events.
Reviewed schemes	53%, typically practice measures
Importance	Low
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	High, specialised
Recurrence of monitoring	Occasional
Performance measures	Toxins in selected tissues (introduced and native wildlife species, agricultural produce and humans) for which poisoning is suspected
Practice measures	Implementation of safe use and storage of toxic substances for plant protection, livestock treatments, cleaning, on wildlife is ensured. Frequency of events of accidental release and chronic contamination by chemicals
Priority	Very low

Outcome 2: Resilience is secured for future use

This outcome focuses on securing environmental resilience for future use of the production landscape. It sets out to address three key objectives: (1) minimising material and energy subsidies; (2) buffering against socio-economic pressures and shocks; and (3) maintaining agro-biodiversity.

Resilience is 'the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identify and feedbacks.'[157] If socio-ecological systems are to be strong enough to withstand perturbations by new threats, we must learn how to deal with uncertainty and adapt to changing conditions,[158] rather than just learning what makes ecosystems vulnerable[159] There are four crucial aspects of resilience:[157] (1) Latitude: the maximum amount a system can be changed before losing its ability to recover; (2) Resistance: the ease or difficulty of changing the system; (3) Precariousness: how close the current state of the system is to a limit or 'threshold'; and (4) Panarchy: the resilience of a system at a particular focal scale will depend on the influences from states and dynamics at other scales due to cross-scale interactions.

Adaptability is the capacity of stakeholders in a system to influence resilience and avoid crossing the system into an undesirable regime.[157,160] Transformability is the capacity to create a fundamentally new system when ecological, economic or social conditions make the existing system untenable.

Objective 4: Minimising material and energy subsidies

Intensification of agriculture both globally and locally is largely dependent on increased use of external inputs (Table 6).[17,34,36,161] As such inputs (e.g. fertiliser, fossil fuels) are often costly, significant risks to future farming and yields associated with increasing and increasingly volatile fossil fuel prices.[161] Inputs also often rely on non-renewable resources, make up a significant component of the energy footprint for food production[162] and/or increase the risk of environmental impacts both on and off the farm (e.g. nutrient runoff; biodiversity loss.[124,163] From a fundamental ecosystem perspective, however, increased inputs are not wholly a threat, as intensively managed agro-ecosystems are only sustainable in the long term if the outputs of all components produced are balanced by appropriate inputs.[36,164] A key challenge is to optimise energy inputs, while reducing greenhouse gas emissions and improving yields to meet the anticipated requirements to provide food, fuel, chemicals and materials for a growing global population.[161]

Table 6: Comparison of internal and external resources/processes for farming[xx]

Component	Internal	External
Sun	Main source of energy	Supplemented by fossil fuels
Water	Mainly rain and small irrigation schemes	Large dams, centralised distribution and deep wells
Nitrogen	Fixed from the air and recycled in soil organic matter	Primarily from inorganic fertiliser
Minerals	Released from soil reserves and recycled	Mined, processed and imported
Weed & pest control	Biological, cultural, mechanical and locally available chemicals	With pesticides and herbicides
Energy	Some generated and collected on farm	Dependence on fossil fuel
Seed	Some produced on farm	All purchased
Management decisions & information	By farmer and community, gathered locally and regularly	Some provided by input suppliers, researchers, extensionists – assumed to be similar across farms
Animals	Integrated on farm	Production at separate locations
Cropping system	Rotations and diversity	Monocropping
Varieties of plants	Thrive with lower fertility and moisture	Need high input levels to thrive
Labour	Labour requirement greater – work done by family living on farm and hired labour	Labour requirement lower – most work done by hired labour and mechanical replacement of manual labour
Capital	Initial source is family and community; and accumulation invested locally	Initial source is external indebtedness or equity; and accumulation leaves community

Critical questions about the sustainability of agricultural intensification in New Zealand that deserve attention include (Box 12):[34,36,39,163]

- Can New Zealand achieve more sustainable agriculture by making better use of internal resources and being less dependent on external inputs?
- What are the overall agro-ecosystem responses to the type of inputs, the degree and the way they are applied?
- What are the adverse impacts of extracting of imported resources at their original source (e.g. biodiversity footprint of palm oil kernels) and will their continued use present a risk for New Zealand products in the marketplace?
- Can the supply of external subsidies of nutrients, chemicals and energy from fossil fuels be maintained indefinitely for New Zealand farmers?
- Is development and uptake of renewable energy resources responding sufficiently fast and on a large enough scale to allay concerns about climate change and dwindling fossil fuel reserves?

[xx] Source: PCE (2004)[34]

- Is the rate of extraction of energy, nutrients, protein and vitamins as food and fibre increasing faster than their regeneration by solar energy, natural regenerative processes and artificial inputs by farmers?

Two indicators are recommended for monitoring energy and material resources use (**Table** 7).

Box 12: 'Enduring questions' posed in New Zealand's Environment Domain Plan[130]

Energy

What is the environmental impact of New Zealand's generation, distribution and use of energy, and to what extent are renewable options taken?

Supplementary enduring questions

- What and where are New Zealand's current energy resources and what is the potential for future exploitation and development?
- What and where is the environmental impact of energy generation, distribution, and use occurring in New Zealand?
- What and where is the environmental impact through the life cycle of renewable energy generation, and which types of renewable energy best support New Zealand's sustainable development?
- To what extent are energy conservation and energy efficiency options being taken, and where and how are these affecting the demand for energy?
- What and where are the environmental-cultural risks and impact of energy generation, distribution, and use, for Māori, and how can they minimised?
- What and where is environmental protection effort being done to address the environmental impact of energy generation, distribution, and use?

Materials and Waste

How do production and consumption patterns in New Zealand affect waste generation and minimisation?

Supplementary enduring questions

- What and where are the effects of production and consumption on New Zealand's environment?
- To what extent is New Zealand adopting technologies, production methods, and best practices that make more efficient use of natural resources, minimise waste, and reduce the impact on the environment from production and consumption?
- What and where is the total amount and composition of waste generated, recycled and disposed of in New Zealand?
- To what extent are Māori values affected by current waste management practices?
- What environmental protection effort is undertaken to reduce the impact of waste on the environment?

Table 7: Review of practice (■) and performance (●) indicators used by local and international monitoring initiatives (full names provided in Table 2) relevant to the 'resilience secured for future use' outcome.

		Local					International													
Objective	**Indicator**	**LEP**	**ARGOS**	**BMRS**	**TBMF**	**LUCAS**	**SAFA**	**OECD**	**MP**	**COSA**	**SAN**	**UNIL**	**FA**	**LEAF**	**RISE**	**GRI**	**EPI**	**BIOBIO**	**BWI**	**CG**
4. Minimising material & energy subsidies	4.1 Non-renewable resources						■			■	■	■		■	■	■		■		
			●						●			●		●						
	4.2 Energy use						■			■		■		■	■	■		■		
			●				●					●			●	●				
5. Buffering against socio-economic pressures & shocks	5.1 Agro-environmental financial support						■	■	■			■			■	■				
			●					●				●			●	●				
	5.2 Agro-environmental governance	■					■	■	■		■	■		■	■	■				■
			●								●	●			●	●				
6. Maintaining agro-biodiversity	6.1 Genetic stock							■												
							●		●									●		
	6.2 Beneficial species						■						■	■	■					■
			●					●				●		●				●		
	6.3 Landscape functional heterogeneity[xxi]	■					■			■	■	■	■	■					■	■
		●	●				●	●	●	●					●			●		

[xxi] Mainly cited as habitat diversity rather than a focus on functionality per se.

Indicator 4.1: Non-renewable materials

Definition	Non-renewable resource use and waste generation is minimised.
Rationale	Modern agriculture is heavily dependent on fossil resources directly for crop management and indirectly for fertilisers, pesticides and machinery production.[161] Nitrogen fertiliser production in particular uses large amounts of fossil fuels. Waste generation (hazardous and non-hazardous) is also a significant concern. Food waste within food supply chains, for example, means non-renewable inputs to its production are also wasted and highlights an opportunity for improved system efficiencies.[8,165]
Reviewed schemes	53% of schemes, mainly practice measures
Importance	Moderate
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	High
Recurrence of monitoring	Intermittent
Performance measures	Trends in the extent and rate of substitution of non-renewable materials (renewable versus non-renewable). Margin for potential waste generation to reach best achievable target for sector. Reuse and recycling rates are maximised
Practice measures	Volume, application rate and type of non-renewable and renewable materials used. Implementation of education and best-practice management to reduce use of non-renewable resources and waste generation
Priority	Low

Indicator 4.2: Energy use

Definition	Overall energy consumption is minimised and use of sustainable renewable energy is maximised.
Rationale	Global energy use, primarily from fossil fuel resources, is a major concern, in as far as it contributes to the degradation of air, water and soil quality as well as human and ecological health.[8] To reduce the use and impact of fossil fuels, two main strategies are promoted: (1) increased energy efficiency through technology and eliminating waste; and (2) use of more renewable/alternative fuels (e.g. solar and wind power).
Reviewed schemes	42%, mainly practice measures
Importance	High
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Continuous
Performance measures	Status and trends in energy use and efficiency for different sectors. Proportion of farms/businesses meeting energy use compliance/certification requirements
Practice measures	Amount and type of fuels used. Implementation of education and best-practice strategies for increasing energy efficiency
Priority	High

Objective 5: Buffering against socio-economic pressures and shocks

Devising ways to sustain the earth's ability to support diverse life, including a reasonable quality of life for humans, involves making tough decisions under uncertainty, complexity and substantial biophysical constraints as well as conflicting human values and interests.[166]

Agriculture is a dynamic industry that has witnessed many changes in the type, diversity and quality of farm production and in the technologies utilised[99]. Fundamental to understanding the drivers of economic growth, productivity and environmental change is the documentation of investment (levels, changes and types) and governance patterns in agriculture as well as the outcomes of those actions. However, large-scale economic incentives may not be closely aligned with the condition of local ecosystems, making the drivers of change difficult to identify, monitor and manage (Box 12).[163,166,167]

Box 13: Requirements of adaptive governance in complex systems[166]

- **Providing information**: Environmental governance depends on good, trustworthy information about stocks, flows and processes within the resource systems being governed, as well as about the human–environment interactions affecting those systems. This information must be congruent in scale with environmental events and decisions.
- **Dealing with conflicts**: Sharp differences in power and in values across interested parties make conflict inherent in environmental choices. Designing resource institutes able to facilitate conflict resolution by bringing together people with different perspectives, interests and fundamental philosophies to spark learning and change.
- **Inducing rule compliance**: Effective governance requires that the rules of resource use are generally followed, with reasonable standards for tolerating modest violations.
- **Providing infrastructure**: Physical, technical and institutional infrastructure determines the degree to which natural resources can be exploited, the extent to which waste can be reduced in resource use, and the degree to which resource conditions and the behaviour of human users can be effectively monitored.
- **Be prepared for change**: Institutions must be designed to allow for adaptation because some current understanding is likely to be wrong, the required scale of organisation can shift and the biophysical and social systems change.

As ecosystems degrade and loss of biodiversity accelerates, it is becoming increasingly important to identify governance strategies that successfully mitigate these adverse impacts of human activities under particular conditions.[166,168] Yet, conservationists have been poor at building up and using an evidence base about the efficacy of potential interventions.[169,170] This lack of basic empirical evidence on performance of different management strategies has led to polarised debates among conservationists, wastage of scarce financial resources, and a risk of poorly designed and ineffective conservation programmes.[170] Climate change is a critical problem occurring at a large scale and involves non-local influences.[166] Promising strategies for addressing this problem include facilitating dialogue among interested stakeholders, government and scientists, and implementing designs that facilitate experimentation, learning and change.

Two indicators are recommended for assessing how well New Zealand's agro-ecosystems are buffered against future socio-economic pressures and shocks (**Table** 7) focusing on agro-environmental financial investments and governance.

Indicator 5.1: Agro-environmental financial resources

Definition	Sufficient public and private resources are available for sustaining and enhancing agro-environmental goods, services, research and conservation for improving environmental quality
Rationale	Documenting investment patterns (levels, changes, types) in agriculture is fundamental to understanding the drivers of economic growth, productivity and environmental change.[99] However, in New Zealand, information available on capital investment expenditure in agriculture is poor.
Reviewed schemes	37% of schemes, combination of performance and practice measures
Importance	Moderate–high
Readiness of indicator	High
Cost of indicator	Moderate
Measurability	High
Recurrence of monitoring	Continuous
Performance measures	Environmental outcomes in relation to public and private (including farm-level) agro-environmental expenditure
Practice measures	Farm-level agro-environmental expenditure in relation to net farm income (defined by OECD as the difference between the value of the gross output and all expenses, including the depreciation at the farm level from agricultural activities). Public and private agro-environmental expenditure on agro-environmental goods, services, research and conservation for improving environmental quality (e.g. number and value of corporate sponsorships in conservation)
Priority	Moderate, but context dependent

Indicator 5.2: Agro-environmental governance

Definition	Legal, institutional and economic framework is sufficient for sustaining and enhancing agro-ecosystem, conservation and climate change management
Rationale	Identification of governance strategies that successfully mitigate the adverse impacts of land management activities on the environment requires an evidence base about the efficacy of potential interventions.[168,169,170] A lack of such evidence leads to polarised debates among stakeholders, wastage of scarce financial resources, and a risk of poorly designed and ineffective environmental management programmes.[170]
Reviewed schemes	58% of schemes, mainly practice measures
Importance	Moderate
Readiness of indicator	High
Cost of indicator	Low
Measurability	High
Recurrence of monitoring	Occasional, escalated where alert found
Performance measures	Environmental outcomes assessed in relation to initiation and implementation of resource management policy and management actions
Practice measures	Implementation of resource management policy (e.g. environmental whole farm management plans for nutrient, pest, soil and water management, organic farming). Number of partnerships between different stakeholder groups (e.g. industry, government bodies, farmers and local community groups) and extent of participation. Education and advocacy effort to engage stakeholder participation
Priority	Moderate

Objective 6: Maintaining agro-biodiversity

Diverse agro-ecosystems are characterised by a high natural insurance function against changing environments because they decrease variance in crop yields and, thereby, the uncertainty in the provision of public-good ecosystem services.[152] Agricultural biodiversity may enhance a system's capacity to absorb and recover from perturbation, or build resilience, which in turn potentially reduces reliance on external inputs to maintain production.[171] The unique feature of agro-biodiversity (microbes, plants, and animals that provide ecosystem services) is the emphasis on its utility to human beings.[172]

Maintaining genetic diversity of crop-cultivars and livestock breeds is important for producing commercial products, as well as pest and disease management, pollination services and soil processes.[34,42,108,173] The monitoring of beneficial species representing different ecological functions (primary production, herbivory, pollination, predators) and a range of sensitivities to management activities at varying spatial scales is required, to ensure these important components of the system are being maintained.[18,46]

Agricultural intensification replaces heterogeneity in habitat structure, in time and space, with homogeneity[174] resulting in declines in agro-biodiversity at local and global scales.[60,72,175] The extent, structure, composition and management of non-crop habitats are of particular interest, because these habitats can provide important refuges for beneficial species on farms (e.g. Box 14).[35,36,118,176] Thus, maintaining habitat heterogeneity at multiple spatial scales (i.e. landscape, between-field and within field scales) is considered important for supporting biodiversity in agro-ecosystems. Key concerns include:

- At the landscape scale: consolidation of small farm units into larger ones, the replacement of mixed farming systems with specialised ones dominated by either tilled land or grassland.
- At the between-field scale: simplification of crop rotations, removal of non-cropped areas and removal of field boundary habitat strips.
- At the within-field scale: increased mechanisation of farming practices, agrochemical use, drainage/irrigation, more competitive crop breeds (creating monocultures) and grassland improvement as well as increased duration and intensity of grazing on improved fields.[177,178]

International examples of minimum requirements and thresholds for non-crop management applied either by law or certification schemes are:

- Ecological Compensation Areas (ECA, Switzerland) – Required to manage 7% of farm land area as ECA.[xxii,179] Features that qualify include hay meadows, traditional orchards and hedgerows. However, in addition to meeting regulations for management allowed on ECAs, there are also ecological quality criteria to which the ECA vegetation needs to conform.
- Conservation Grade certification (CG, UK) – Commit to at least 10% of farmed area to a range of managed wildlife habitats and meet specific management criteria. Two pollen and nectar sources should be provided (grass/wildflower

[xxii] Herzog et al. 2005 and Knop et al. 2006 cited in Henle et al. 2008[179]

mixtures and grass/legume mixtures) – specific thresholds and requirements need to be met.

- Sustainable Agriculture Standard (SAN, International) – farms in areas where the original natural vegetation is not forest (e.g. grasslands, savannahs, scrublands or shrublands) must dedicate at least 30% of the farm area for conservation or recovery of the area's typical ecosystems. These farms must implement a plan to establish or recover natural vegetation within 10 years.

Three indicators are recommended to assess the status of agro-biodiversity in New Zealand's production lands: genetic stock, beneficial species and landscape functional heterogeneity (**Table** 8).

Box 14 Agro-biodiversity indicators for New Zealand agro-ecosystems

Shelterbelts as refuges for beneficial species[180]

Spiders (Araneae) and beetles (Coleoptera) comprise more than one-quarter of world biodiversity and provide crucial ecosystem services. Spiders and predatory beetles are important natural enemies of many pasture pests; many detritivorous beetles facilitate nutrient cycling. They are also an important food source for birds and have potential to be used as indicators of agro-ecosystem health. However, agricultural intensification has caused rapid declines in invertebrate biodiversity worldwide, due to increased input of inorganic pesticides, herbicides and fertilisers, and removal of woody vegetation.

A recent study focusing on the North Island dairy sector found organic farms and fenced shelterbelts supported 40% and 67% higher densities of spiders than conventional farms and unfenced shelterbelts, respectively. Shelterbelts of native plant species supported higher species richness of native spiders and beetles than shelterbelts of exotic plants. A combination of converting to organic farming, fencing off shelterbelts and planting more native shelterbelts is likely to provide increased ecosystem services and biodiversity conservation on New Zealand dairy farms.

Native birds in kiwifruit orchards[155]

A recent study in New Zealand kiwifruit orchards observed native bird densities (for common and widespread species) were negatively associated with pesticide toxicity ranking and/or positively associated with woody vegetation cover. Native bird species are, therefore, likely to be suitable indicators for monitoring the impact of changes in land management practices within kiwifruit orchards. Although only relatively small differences between bird densities were associated with the different management systems, the alignment of these differences with previously observed benefits of organics in terms of higher plant and invertebrate biodiversity and soil quality[181,182,183] means that they are likely to reflect large differences at the total biodiversity scale.

Threatened falcons in vineyards[144]

The New Zealand falcon (*Falco novaeseelandiae*) is listed as a threatened species by the Department of Conservation. Introduction of this species to vineyards in Marlborough was associated with a significant decrease in the abundance of introduced passerines considered vineyard pests and with a 95% reduction in the number of grapes removed relative to vineyards without falcons. Also, relative to damage in vineyards without falcons, the presence of a falcon could potentially result in savings of US$234/ha for the Sauvignon Blanc variety of grapes and $326/ha for Pinot Noir variety of grapes.

Indicator 6.1: Genetic stock

Definition	The diversity of domesticated species living in agricultural, forestry and fisheries ecosystems, as well as the diversity of varieties, cultivars and breeds of domesticated species, is sustained and enhanced.
Rationale	A wide variety of species and their genes contribute to commercial products in agro-ecosystems.[42] Farmers and breeders have developed a multitude of crop varieties and animal breeds to suit their needs, and to stabilise and increase productivity.[118] Molecular genetic methods for characterising genetic variation are technologically demanding, expensive and require further development for general application. International schemes (e.g. OECD, BIOBIO) recommend on simple, indirect measures based on crop-cultivar and livestock breed information to assess genetic resources.
Reviewed schemes	21% of schemes
Importance	Low
Readiness of indicator	High
Cost of indicator	Low
Measurability	High
Recurrence of monitoring	Intermittent
Performance measures	Number, amount and origin of different breeds and varieties and the number and proportion of those that are endangered. Genetic diversity of aquaculture/crop/livestock/tree production is enhanced
Practice measures	Number of varieties or breeds that have registered and certified within the main crop/livestock categories for marketing. Share of key crop varieties in total marketed production for individual crops and key livestock breeds in respective categories of livestock numbers
Priority	Low

Indicator 6.2: Beneficial species

Definition	The status of species (or animal guilds) that are beneficial to agricultural, forestry and fisheries ecosystems is sustained and enhanced.
Rationale	Agricultural biodiversity may enhance a system's capacity to absorb and recover from perturbation, or build resilience,[158] which in turn potentially reduces reliance on external inputs to maintain production.[171]
Reviewed schemes	47% of schemes
Importance	High
Readiness of indicator	Moderate
Cost of indicator	Moderate–high
Measurability	Low–high
Recurrence of monitoring	Intermittent
Performance measures	Diversity and/or abundance of species guilds considered important for production, including pollinators (e.g. wild bees and bumblebees), natural predators (e.g. spiders) and ecosystem engineers (e.g. earthworms)
Practice measures	Implementation of key management actions (e.g. spraying, mowing, grazing, weeding) likely to affect the status and trend in beneficial species populations
Priority	High

Indicator 6.3: Landscape functional heterogeneity

Definition	The diversity, functional integrity and connectivity of ecological refuges in agro-ecosystems are sustained and enhanced.
Rationale	Elements of landscape heterogeneity can influence a variety of ecological responses, including animal movement, population persistence, species interactions and ecosystem function[184]. Agricultural landscapes vary widely in their degree of spatial heterogeneity, in part, controlled by patterns of land tenure and cumulative effects of cropping, grazing and other decisions made by individual farmers. More heterogeneous landscapes contain many different production cover types which are distributed in a complex pattern and interspersed with other, more 'natural' cover types. Of particular interest are habitats providing refuges for agro-biodiversity. Landscape functional heterogeneity identifies different land cover types based on differences in resource dependencies of species or species groups of interest[184,185,186] (e.g. pollinators, natural predators, ecosystem engineers) at different spatial scales[187] (field, farm or landscape scale). It also takes into account subtle non-structural distinctions among habitat types relevant to a species response (i.e. management actions that can affect patch quality such as pesticide use, soil management or crop history.[177,178]
Reviewed schemes	74% of schemes, mainly practice measures with performance measures often focusing on habitat diversity rather than directly aiming to assess functionality
Importance	High
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Occasional, monitoring escalated if event/change signalled
Performance measures	Status and trends of landscape functional heterogeneity assessed for key species or groups of species of interest and changes in these metrics of over time. Status and trends in bird communities as surrogate indicators of environmental health indicators
Practice measures	Implementation of key management actions likely to affect the value and continuity of ecological refuges for agro-biodiversity within the farm boundary including (1) proportion protected from grazed animals and other forms of ecological disturbance; (2) number of native and exotic trees planted or removed on the property; (3) share of utilised area and stock with certified organic production; (4) area set aside for protection purposes (e.g. riparian corridors); and (5) other non-crop habitats like field margins or understorey for vineyards and orchards.
Priority	High

Outcome 3: 'Enhanced natural heritage' goal supported

This outcome focuses on New Zealand's national goal to enhance its natural heritage. It aims to address three key objectives within production landscapes: (1) maintaining ecosystem representation and composition; (2) preventing extinctions and declines; and (3) reducing conservation pest threats.

A high proportion of New Zealand's species are endemic (i.e. found nowhere else in the world) – making these species both valuable and highly vulnerable (Box 1). Better information is required about drivers of change (including threats posed by exotic weeds and pests, habitat loss and land-use intensification) and the extent to which New Zealand's native biodiversity is being protected and sustained (Box 14).[130] In the past, biodiversity indicators employed in New Zealand focused on recording management activity inputs, as these are often easily and accurately measured (e.g. area of possum control, number of litres of herbicide used over a given area). However, these do not directly measure the actual biodiversity outcomes achieved from the management activities.[12,98,149] This makes it difficult to demonstrate whether biodiversity representation or persistence is improving or not.

Box 15: Enduring questions posed in New Zealand's Environment Domain Plan[130]

Ecosystems and Biodiversity

To what extent is the native (indigenous) biodiversity of New Zealand being protected and sustained?

Supplementary enduring questions

- How and where is the biodiversity and condition of indigenous species changing?
- How and where is the diversity and condition of indigenous ecosystems changing?
- What impact does change to the diversity and condition of indigenous species and ecosystems have on natural capital and the provision of ecosystem services?
- What is driving the change to the diversity and condition of indigenous species and ecosystems, where does it occur, and how is it changing over time?
- What ecosystem services are currently provided by New Zealand's terrestrial and freshwater environments and how are these predicted to change in the future?
- What and where is the impact of change to culturally significant indigenous taonga (treasured) species, mahinga kai (customary food gathering areas and practices), and ecosystems, and what is being done to protect and sustain them?
- What and where is environmental protection effort being undertaken to protect and sustain the diversity and condition of indigenous species and ecosystems, including people and agencies, time and capital and how effective are the different efforts?

Objective 7: Maintaining ecosystem representation & composition

Ecosystems can be defined by abiotic and biotic factors.[9] Ecosystems occupy a range of environments (defined at different scales by climate, soils, topography, and disturbance regime factors) and their composition can vary according to species, functional groups, life-history stages, trophic diversity and structural complexity.

Focusing on higher levels of biological organisation (e.g. the ecosystem rather than species) may provide a pragmatic and cost-effective means of conserving multiple levels of biological diversity. A key challenge for biodiversity conservation is to identify and conserve areas of natural habitat that contain unique and diverse biological assemblages.[45] New Zealand's rare ecosystems, for example, frequently occur outside existing conservation areas, with opportunities for improvements in their protection and management recently being highlighted using an international threat classification system (Box 16).

Three indicators are recommended for monitoring whether ecosystem representation and composition is improving (**Table** 8). These focus on (1) environmental representation and protected status; (2) ecosystem composition; and (3) occupancy of environmental range.

Box 16: Classification and protection New Zealand's naturally uncommon ecosystems

Naturally uncommon ecosystems represent a distinct set of environmental conditions often associated with rare and threatened endemic species. IUCN recently developed some Ecosystem Red-List criteria that can be used to assess changes in the extent of these ecosystems and any reductions in their ecosystem processes.[188] By providing a rational basis for identifying which ecosystems are the most threatened, this classification system can inform conservation priority setting.[189]

New Zealand's naturally uncommon ecosystems:

- Are classified into 72 different types[190] (e.g. basaltic outcrops and coastal turfs).
- Eighteen are critically endangered, 17 endangered and 10 vulnerable naturally uncommon ecosystem types.[189]
- Contain 145 (85%) of mainland New Zealand's taxonomically distinct nationally critically, endangered or vulnerable plant species, 66 (46%) of which are thought to be endemic to naturally uncommon ecosystems.
- Frequently occur outside existing public conservation areas and have been included in national conservation policy.[191,192]
- Of the seven threatened ecosystems currently mapped, four have <20% of their total area under formal protection.[11]

Table 8: Review of practice (■) and performance (●) indicators relevant to the 'contributed to the national natural heritage goal' outcome used by local and international monitoring initiatives (full names provided in Table 2).

Objective	Indicator	Local					International													
		LEP	ARGOS	BMRS	TBMF	LUCAS	SAFA	OECD	MP	COSA	SAN	UNIL	FA	LEAF	RISE	GRI	EPI	BIOBIO	BWI	CG
7. Maintaining ecosystem representation & composition	7.1 Environmental representation & protected status			●	●		●			■	■				■	■ ●			■ ●	
	7.2 Ecosystem composition	■ ●		●	●		●		●	●	■	●	■	■		■ ●			■ ●	■
	7.3 Occupancy of environmental range			●																
8. Preventing extinctions & declines	8.1 Status of threatened species[xxiii]		●	●	●		■ ●		■ ●		■					■ ●				■
10. Reducing conservation pest threats	10.1 New conservation weed & pest species			●	●		●						■							
	10.2 Conservation weed & pest dominance		●	●	●		■	●	●				■						■ ●	

[xxiii] Note that the majority of schemes specify direct measures of species status rather than indirect measures of habitat status for threatened species.

Indicator 7.1: Environmental representation and protected status

Definition	Sustain and enhance the extent and protection of indigenous cover and habitats or naturally uncommon ecosystems.
Rationale	Very widely reported internationally to assess the survivorship of intact ecosystems relative to their original extent and protection status. In New Zealand, such measures are expected to change slowly but are generally limited to coarse-level assessments[9] (but also see Box 16).
Reviewed schemes	42% of schemes
Importance	High
Readiness of indicator	Moderate
Cost of indicator	Moderate–high
Measurability	Moderate
Recurrence of monitoring	Occasional, monitoring escalated if event/change signalled
Performance measures	Extent, transformation and type of natural and near-natural ecosystems and habitats within production landscapes (including indigenous cover or habitats and naturally uncommon ecosystems)
Practice measures	Production does not occur in areas where natural habitat was destroyed during the last five years. Area and type of natural or near-natural ecosystems and habitats protected from human interventions. Implementation of best-practice management to mitigate damage risk of transformation or loss of existing habitats (e.g. through fire or aerial spraying) and to contribute to habitat restoration initiatives.
Priority	High

Indicator 7.2: Ecosystem composition

Definition	A balanced composition of plant and animal species typical and important to the region in natural and semi-natural ecosystems is sustained and enhanced.
Rationale	This indicator addresses a major conservation goal for New Zealand and is widely used in North America and Europe.[9] Early warnings of long-term changes/problems can be indicated by (1) changes in vegetation structure or functional groups; (2) local/regional extinctions of previously widespread and common animals; or (3) changes in functional communities or guilds of animals.
Reviewed schemes	68% of schemes, mainly practice measures
Importance	Moderate
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	Low to Moderate
Recurrence of monitoring	Occasional
Performance measures	Structure and composition of vegetation and animal communities and vulnerable ecosystems have not been affected in your sphere of influence
Practice measures	Implementation of best-practice management actions to mitigate risks
Priority	Low

Indicator 7.3: Occupancy of environmental range

Definition	Sustain and enhance the extent of potential range occupied by focal indigenous taxa.
Rationale	Species that are limited by adverse ecological factors (e.g. predators or habitat disruption) typically have very much smaller, atypical and fragmented ranges than those less affected.[9] The extent to which they occupy their potential range can be regarded as a surrogate for cumulative pressure up on them, and this indicator is therefore widely used internationally. The ultimate baseline for species' occurrence is its potential ecological range. However, as this potential range is often effectively unbounded, it is more common to use some version of its historical range, or modelling based on its historical range.
Reviewed schemes	5% of schemes, only in one locally
Importance	Low
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Occasional
Performance measures	Extent of potential range occupied by focal indigenous taxa
Practice measures	Implementation of management actions to facilitate the maintenance or enhancement of focal taxa ranges
Priority	Very low

Objective 8: Preventing extinctions & declines

Preventing extinctions and population reductions is fundamental for maintaining biodiversity.[9] Indicators reporting on conservation status of threatened taxa attract high public interest not only in New Zealand, where many endemic species are highly threatened, but also internationally.[193,194] Many small natural-habitat remnants across a large geographical area protect more species than a single large remnant of the same area.[152] However, fragmented populations experience high extinction rates, and many of the most endangered plants and animals need very large areas to survive. One indicator is recommended for reporting on the status of threatened species in New Zealand agro-ecosystems.

Indicator 8.1: Status of threatened taxa

Definition	Sustain and enhance the status of threatened taxa and their habitats.
Rationale	Threatened biota status is probably the most widely used conservation index.[9] For example, protection measures for species are common biodiversity requirements of standards and certification schemes (94% of 36 standards reviewed across eight sectors), with a strong emphasis on measures to protect or manage threatened species.[45]
Reviewed schemes	42% of schemes
Importance	High
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	Low, specialised
Recurrence of monitoring	Occasional, escalated if threatened taxa found
Performance measures	Number of threatened taxa, extent and transformation of their habitats and the number responsive to management actions within sphere of influence; changes quantitative genetic characters
Practice measures	Number of threatened taxa and their habitats being actively managed within sphere of influence
Priority	Moderate

Objective 9: Reducing conservation pest threats

Biological invasions are a major cause of indigenous biodiversity loss and ecosystem function both globally and locally.[9,148,195] Mammal predators have caused extinction and reductions in many indigenous animal species, while mammalian herbivores have caused shifts in vegetation composition and structure. Invasive species alter disturbance regimes, displace native species and vegetation, and modify ecosystem processes.

Agro-ecosystems and neighbouring vegetation can be a source of environmental invasive weeds and pests. In New Zealand, about 80% of environmental weed species that are managed by government agencies arise from garden dumping in marginal habitats, or through the naturalisation of economic plant species outside of cultivation.[196,197,198,199] Naturalised populations of wild kiwifruit, for example, emerged in native and exotic forest patches near orchards; this spread was likely facilitated by birds dispersing seed after feeding on waste fruit, and producers dumping vines or fruit into surrounding bush patches.[200,201] Improvements in the industry's waste management practices, coupled with proactive control of wild kiwifruit populations by the regional council, are required to significantly reduce the risk posed by this invasive species.[200]

Two indicators are recommended for monitoring the status of conservation pest populations. One focuses on new pest species incursions, the other on distribution and abundance of established pest species.

Indicator 9.1: New conservation weed and pest species

Definition	Minimise the number and risk of new incursions and/or sites of nationally listed conservation weed and pest species.
Rationale	Central and local government have good border security and effective surveillance mechanisms in place to make this a reliable indicator of the size and potential threat of new conservation weed and pests.[9] Early detection and management of novel weeds and pests is considered the only feasible way of preventing spread.
Reviewed schemes	21% of schemes, mainly performance measures
Importance	Moderate–high
Readiness of indicator	Moderate
Cost of indicator	High
Measurability	Moderate
Recurrence of monitoring	Continuous, escalated if threat found (driver or shock)
Performance measures	Occurrence and elimination of self-maintaining populations of new potential conservation weeds and animal pests
Practice measures	Implementation of management practices to control or eliminate target species
Priority	Moderate, but context dependent

Indicator 9.2: Conservation weed and pest dominance

Definition	Minimise the risk, distribution and abundance of conservation weeds and nationally listed animal pests.
Rationale	Exotic environmental weed and pest dominance are important measures of the threats posed to indigenous persistence, realignment of ecosystem processes and the destruction of socially valued aspects of ecosystems.[9] However, while invasive species are considered a major threat, standards and certification schemes provide little evidence this threat is being reduced by management, with the management requirements varying greatly among schemes.[45] This indicator will provide a useful tool for priority setting and quantifying threats to ecological integrity.[9]
Reviewed schemes	42% of schemes
Importance	Low–high
Readiness of indicator	High
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Intermittent
Performance measures	Distribution and abundance of exotic conservation weeds and pests considered a threat. Change in the abundance of indigenous plants and animals susceptible to introduced herbivores and carnivores
Practice measures	Implementation of management actions that contribution to weed and animal pest control and reductions in ecological refuges on or adjoining farms
Priority	Context dependent

Outcome 4: Global environmental change obligations met

This outcome sets out to address two key objectives for New Zealand to meet its global environmental change obligations: (1) reducing emissions; and (2) increasing carbon sequestration.

Agriculture releases significant amounts of greenhouse gas (GHG) emissions to the atmosphere, which are expected to drive global warming (i.e. rising average surface temperatures) with large-scale and irreversible consequences.[8,202] Carbon dioxide is released largely from microbial decay or burning of plant litter and soil organic matter. Methane is produced when organic materials decompose in oxygen-deprived conditions (particularly from fermentative digestion by ruminant livestock, and stored manures). Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available nitrogen exceeds plant requirements, especially under wet conditions. Land-use change associated with agriculture is also a significant but indirect driver of emissions. Agriculture will also likely be adversely affected by global warming, due to changes in temperatures and rainfall patterns and dramatic weather events. A number of mechanisms for increasing carbon sinks and reducing carbon dioxide and other greenhouse grass emissions in agricultural systems have been proposed (Box 17).

The 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change established an international policy context for the reduction of carbon emissions and increases in carbon sinks in order to address the global challenge of anthropogenic interference with the climate system.[203] New Zealand's Land use and Carbon Analysis System[204] (LUCAS), administered by the Ministry for the Environment, was established in 2005 to support international reporting requirements (Box 18). It is envisaged the recommended indicators will closely align to those being used or considered for LUCAS, hence supporting national and international reporting initiatives (Table 9).

Box 17: Mechanisms for increasing carbon sinks and reducing CO_2 and other greenhouse gas emissions in agricultural systems[xxiv]

Increase carbon sinks in soil organic matter and above-ground biomass

- Replace inversion ploughing with conservation- and zero-tillage systems.
- Adopt mixed rotations with cover crops and green manures to increase biomass additions to soil.
- Adopt agroforestry in cropping systems to increase above-ground standing biomass.
- Minimise summer fallows and periods with no ground cover to maintain soil organic matter stocks.
- Use soil conservation measures to avoid soil erosion and loss of soil organic matter.
- Apply composts and manures to increase soil organic matter stocks.
- Improve pasture/rangelands through grazing, vegetation and fire management both to reduce degradation and increase soil organic matter.
- Cultivate perennial grasses (60–80% of biomass below ground) rather than annuals (20% below ground).
- Restore and protect agricultural wetlands.
- Convert marginal agricultural land to woodlands to increase standing biomass of carbon.

Reduce direct and indirect energy use to avoid greenhouse gas emissions

- Conserve fuel and reduce machinery use to avoid fossil fuel consumption.
- Use conservation-zero-tillage to reduce CO_2 emissions from soils.
- Adopt grass-based grazing systems to reduce methane emissions from ruminant livestock.
- Use composting to reduce manure methane emissions.
- Substitute biofuel for fossil fuel consumption.
- Reduce the use of inorganic nitrogenous fertilisers (as manufacturing is highly energy intensive), and adopt targeted- and slow-release fertilisers.
- Use IPM to reduce pesticide use (avoid indirect energy consumption).

Box 18: Tools for New Zealand's global environmental change obligations

New Zealand's Land Use and Carbon Analysis System (LUCAS) was established in 2005 to meet UN Framework Convention on Climate Change (UNFCC) and Kyoto Protocol reporting requirements.[107]. It tracks and quantifies changes in New Zealand land use, (particularly since 1990), as well as compiles information on greenhouse gas emissions and removals. Method development for the carbon accounting system focuses principally on carbon inventory and modelling in natural forest, planted forest and soils. It draws on information collected using a combination of field surveys, LiDAR and remote-sensing.

[xxiv] (Adapted from Pretty 2008)[203]

Table 9: Review of practice (■) and performance (●) indicators relevant to the 'global environmental change obligations met' outcome used by international and local monitoring initiatives (full names provided in Table 2).

		Local				International														
Objective	**Indicator**	**LEP**	**ARGOS**	**BMRS**	**TBMF**	**LUCAS**	**SAFA**	**OECD**	**MP**	**COSA**	**SAN**	**UNIL**	**FA**	**LEAF**	**RISE**	**GRI**	**EPI**	**BIOBIO**	**BWI**	**CG**
12. Reducing emissions	12.1 Greenhouse gas emissions					■ ●	●	●	■	■	■	■		■	●	■	■			
13. Reducing carbon emissions	13.1 Total carbon pools and fluxes		●			■ ●	■		●	■ ●	■			■		■ ●	■			

Objective 10: Reducing emissions

Agricultural greenhouse gas fluxes are complex and heterogeneous.[202] In New Zealand, for example, there are large year-to-year fluctuations in emissions, which are partly driven by changes in agricultural productivity and livestock numbers associated with droughts.[204] However, active management of agricultural systems offers possibilities for mitigation, using current technologies to manage more efficiently the flows of carbon and nitrogen in agro-ecosystems.[202] For example, managing livestock to make most efficient use of feeds often suppresses the amount of methane produced. Approaches that best reduce emissions depend on local conditions and therefore vary from region to region. Emissions of GHG, in particular carbon dioxide, can be avoided by implementing agricultural practices that prevent the cultivation of new lands now under forest, grassland or other non-agricultural vegetation.[205] The net benefit of a particular action will depend on the combined effects on all gases, as that practice will often affect more than one gas, by more than one mechanism and sometimes in opposite ways.[202] One indicator is recommended focusing on monitoring industry efforts to mitigate greenhouse gas emissions.

Indicator 10.1: Greenhouse gas emissions

Definition	Emission of greenhouse gases is slowed, stabilised and eventually reduced.
Rationale	Greenhouse gases facilitate climate warming. At the global scale, 20% of CO_2 emissions (in the 1990s) originated from changes in land use and land management, primarily deforestation.[42] At the same time, agriculture was responsible for 30% of methane and 35% of nitrous oxide emissions.
Reviewed schemes	58% of schemes, typically practice measures
Importance	Low
Readiness of indicator	Moderate
Cost of indicator	Low
Measurability	Moderate
Recurrence of monitoring	Intermittent
Performance measures	Change in the gross total agricultural emissions of carbon dioxide, methane and nitrous oxide, expressed in CO2-eq. GHG intensity of products as compared to similar products produced elsewhere is reduced. Margin for potential reduction in GHG emissions to reach the best achievable target in the region/sector
Practice measures	Share of operations covered by GHG prevention and mitigation measures. Reduction of GHG emissions through prevention and mitigation measures (kg of CO2-eq)
Priority	Low

Objective 11: Increasing carbon sequestration

Carbon sequestration is defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere.[203] Agriculture can contribute to carbon storage, when organic matter is accumulated in the soil, and when above-ground biomass acts as either as a permanent sink or is used as an energy source that substitutes for fossil fuels and avoids carbon emissions. Changes in land use and management can facilitate increases in carbon storage. One indicator is recommended, focusing on measuring total carbon pools and fluxes in agro-ecosystems.

Indicator 11.1: Carbon storage and fluxes

Definition	Total amount of carbon stored in agro-ecosystems is enhanced. Changes, fluxes or flows in carbon between agro-ecosystems and the atmosphere are slowed, stabilised and eventually reduced.
Rationale	Carbon sequestration is advocated to minimise potential impacts of GHG emissions on the global climate. Sequestering carbon in agriculture requires a change in management practices (Box 17).[202,203]
Reviewed schemes	47% of schemes, typically practice measures
Importance	Moderate
Readiness of indicator	Moderate
Cost of indicator	Moderate
Measurability	Moderate
Recurrence of monitoring	Occasional
Performance measures	Status and trend in total amount of carbon stored in agro-ecosystems. Changes, fluxes or flows in carbon between agro-ecosystems and the atmosphere
Practice measures	Implementation of education and best-practice management to increase carbon sequestration on farms
Priority	Low

Next steps for framework and indicator development

Integrating agro-environmental integrity monitoring

This report provided context to optimise monitoring of just the environmental dimensions of sustainability. However, we also cast it in ways that will naturally couple with economic, social and governance concerns that are equally crucial for the success of the NZSDs. That integration will broadly follow the SAFA structures about to be launched by FAO. SAFA was chosen as the most wide ranging and flexible framework available under which the more local focus of the NZSD can nestle.[xxv]

The first stage of achieving integration will be to formulate a common goal for the entire NZSD sustainability initiative. We will then map indicators that are measured for one dimension that can usefully be combined with data from other dimensions. For example, many of the environmental indicators can most usefully be expressed on a production area basis, which is gathered under the suite of farming statistics entered via the Governance section of the NZSD.

Although the NZSD framework and associated software tool provides the opportunity to integrate across sectors, landscapes and institutional jurisdictions, such cross-scale linkage is unlikely to happen without active facilitation by a steering group. It is fortuitous and potentially enormously beneficial that DOC and regional councils are developing and beginning to road-test monitoring frameworks at the same time as the NZSD finds its feet. We urge that a working party is convened as soon as possible to maximise integration of frameworks and information sharing between the groups. A test-drive of an integrated approach could provide evidence of mutual benefit. The most likely test case could combine remote sensing by the regional councils with ‘ground truthing’ and monitoring on orchards, vineyards and farms and on the DOC estate. Vegetation cover, flows of water and changes in water quality, or biosecurity risk management[xxvi] across catchments are likely to be the most practical examples of the value of integration.

Cross-cultural partnership will be needed for any distinctive and integrated New Zealand agro-environmental integrity monitoring. We have chosen not to separate Māori-oriented environmental management priorities from those of Pākehā throughout the preceding review of sustainability monitoring in general[3] and development of a rationale for the agro-environmental integrity framework in this report. Nevertheless there is growing evidence that Māori set land and environmental priorities differently, target different species of particular cultural importance, and see ecological restoration as bicultural restoration – the restoration of people’s links to the land and each other as much as reinstatement of the plants and animals themselves.[206] Māori may choose to monitor different things and to monitor in different ways.[xxvii] These needs will be incorporated by including inclusive and culturally appropriate processes[207,208] to refine the NZSDs’ designs and how they are operationalised. The agro-environmental integrity framework proposed here is sufficiently broadly cast that we expect any distinctive Māori approaches to be easily enveloped within it.

[xxv] See Moller & MacLeod (2013)[3] for a more detailed description of the advanatges and disadvantages of linking to SAFA.

[xxvi] For example, distribution and abundance and flows of established pest and weed populations.

[xxvii] For example, see Moller & MacLeod (2013) for a description of Marine Cultural Health Indices[3].

Preliminary indicator selection

NZSD researchers, industry facilitators and other key stakeholders[xxviii] will next co-design tightly prescribed metrics for each of the indicators proposed here[xxix]. Several composite indicators can be deployed to summarise large quantities of information and spread the scope of the framework. A wider mapping exercise will automatically link to databases outside the NZSD (e.g. climate records, soil maps, LCDB3). Careful selection of all measures will ground the more conceptual considerations outlined by Moller & MacLeod[3] for sustainability monitoring in general, and for New Zealand environmental conditions in this report. Defining what is measured or how an indicator is scored forces fine tuning of monitoring to serve the practical needs, opportunities and challenges that confront New Zealand's orchardists, wine producers and makers, foresters and farmers.

Our preliminary screening of the relative importance, costs, measurability, readiness and recurrence of the indicators (Table 10) is extremely broad brush and reflects judgements by two ecologists who considered national priorities. We expect facilitators and producers from each host industry to check each of these scales and adjust ranks according to specific opportunities and threats confronting their own sector and regions where their production is concentrated. Whatever the sector-adjusted ranks for individual indicators, we suggest that preliminary indicator selection considers all the design criteria set out in Table 3 (pages 24–25), and is further prioritised as follows:

1. *Start by working with what you've got already:* An iterative process of perfecting the framework should start by co-opting some of the more fragmentary indicators already being monitored by each sector and then gradually migrating and broadening the scope of monitoring into a long-term and more comprehensive package. Linking to existing standards, thresholds and protocols will help. Smaller steps and smoother transition will be less disruptive than major redesign.
2. *Importance of the indicator:* Policy relevance and direct link to keystones of the agro-ecosystem is paramount, but it must also be meaningful and acceptable for the producers.
3. *Costs:* Time and monetary costs for both the individual producers and the industry.
4. *Readiness of the indicator:* Only indicators that are already proven and accepted should be immediately deployed across the entire sector.
5. *Measurability:* Qualitative scores are valuable and entirely appropriate for some aspects of sustainability, but where a choice exists, semi-quantitative and especially quantitative approaches should be selected.

[xxviii] Including regional councils, Ministry for Primary Industries, Ministry for the Environment, Department of Conservation, Environment Protection Agency, Statistics New Zealand.

[xxix] A preliminary spreadsheet of over 150 metrics has been drawn up for consideration by the partipating producers and industry advisors.

Table 10: Summary of approximate national rankings of indicators for importance, cost and other design issues (Table 3).

Outcome	Objective	Indicators (% of reviewed schemes)	Importance	Cost	Readiness	Measurability	Recurrence	Priority†
Natural capital maintained	1. Maintaining ecosystem processes	1.1: Soil status (74%)	High	Low	High	High	Intermittent	High
		1.2: Water quality and yield (79%)	Moderate-High	High	Moderate	High, Specialised	Intermittent	(Low)
		1.3: Land cover (63%)	High	Low	High	Moderate	Occasional	High
		1.4: Ecosystem disruption (16%)	Moderate	Low	Moderate	High	Continuous, escalated if an alert	Moderate
		1.5: Pollination (11%)	Low-High	Moderate	Moderate	Moderate, Specialised	Intermittent	Variable
	2. Reducing agricultural pest threats	2.1: New agricultural diseases, weed and pest species (26%)	Moderate - High	High	Moderate	Moderate	Continuous, escalated if an alert	(Low)
		2.2: Agricultural disease, weed and pest dominance (74%)	Low-High	Moderate	High	Moderate	Intermittent	Variable
	3. Limiting environmental pollutants	3.1: Environmental risk of toxins (53%)	Moderate	Low	Moderate	High	Continuous	Moderate
		3.2: Ecosystem level of persistent toxins (53%)	Low	High	Moderate	High, Specialised	Occasional	Very low
Resilience secured for future use	4. Minimising materials and energy subsidies	4.1: Non-renewables materials (53%)	Moderate	Moderate	Moderate	High	Intermittent	(Low)
		4.2: Energy use (42%)	High	Moderate	Moderate	Moderate	Continuous	High
	5. Buffering against socio-economic pressures and shocks	5.1: Agro-environmental financial resources (37%)	Moderate-High	Moderate	High	High	Continuous	(Moderate)
		5.2: Agro-environmental governance (58%)	Moderate	Low	High	High	Occasional, escalated if an alert	Moderate
	6. Maintaining agro-biodiversity	6.1: Genetic stock (21%)	Low	Low	High	High	Intermittent	Low
		6.2: Beneficial species (47%)	High	Moderate-High	Moderate	Low-High	Intermittent	High
		6.3: Landscape functional heterogeneity (74%)	High	Moderate	Moderate	Moderate	Occasional, escalated if an alert	High

Table 10 continued:

Outcome	Objective	Indicators (% of reviewed schemes)	Importance	Cost	Readiness	Measurability	Recurrence	Priority
Contributed to national 'natural heritage' goals	7. Improving ecosystems representation and composition	7.1: Ecosystem representation and protection (42%)	High	Moderate-High	Moderate	Moderate	Occasional, escalated if land use change signalled	High
		7.2: Ecosystem composition (68%)	Moderate	High	Moderate	Low-Moderate	Occasional	Low
		7.3: Occupancy of environmental range (5%)	Low	Moderate	Moderate	Moderate	Occasional	Very low
	8. Preventing extinctions and declines	8.1: Status of threatened taxa (42%)	High	High	Moderate	Low, Specialised	Occasional, escalated if threatened taxa found	Moderate
	9. Reducing conservation pest threats	9.1: New conservation weed and pest species (21%)	Moderate-High	High	Moderate	Moderate	Continuous, escalated if alert signalled	(Moderate)
		9.2: Conservation weed and pest dominance (42%)	Low-High	Moderate	High	Moderate	Intermittent	Variable
Global Environmental Change obligations met	10. Reducing emissions	10.1: Greenhouse gas emissions (58%)	Low	Low	Moderate	Moderate	Intermittent	Low
	11. Increasing carbon sequestration	11.1: Carbon storage and fluxes (47%)	Moderate	Moderate	Moderate	Moderate	Occasional	Low

† See Table 4 (p. 26) for explanation of priority ranking and colour codes.

Our very crude priority ranking of indicators (Table 3) suggests rapid deployment of soil status, land cover, energy use, beneficial species, landscape functional heterogeneity, and ecosystem representation and protection. The latter two will often need to be managed and monitored well beyond the individual vineyard, orchard, farm, or forest-patch level so they are likely to be high priority for collaborative work between farmers, regional councils and DOC.

We expect agricultural and conservation weed and pest issues to be of high priority in some catchments but not others, so we recommend that collaborative trials with regional councils and DOC target those catchments to maximise the benefits of the collaboration. There seems to be no reason why an NZSD needs to deploy all indicators everywhere, so some targeting to meet regional priorities should be considered.

Reliability checks once NZSD prototypes are operating

Indicators will only make a difference if they are trusted. We therefore urge the development of a rigorous field testing and independent auditing of the prototype NZSD measurements and each subsequent additional measure as they are introduced. These checks must reflect the international best-practice criteria outlined in Table 3 and reviewed in detail by Moller & MacLeod (2013[3]). For each indicator, we will need to demonstrate and quantify levels of:

- Honesty in reporting
- Repeatability
- Sensitivity and specificity
- Scale appropriateness and scalability
- Precision and, where required, accuracy and bias
- Statistical power to detect trends and accurate benchmarking between similar orchards, vineyards, wineries, farms and forests.

Where relative or proxy indicators are deployed, detailed calibration studies may be needed to describe the shape of the relationship between the indicator and what it purports to predict in the agro-ecosystem. An equivalent verification of the reliability of qualitative and semi-quantitative indicators is particularly important, starting with an realistic assessment of whether an indicator can be used at all. The ultimate goal is to track nuanced but fundamentally important determinants of social sustainability that drive sustainable practice by farmers, their families and their communities. Deployment of a forced, abstracted or non-repeatable indicator will be worse than useless – it adds rather than reduces risk.

Practice-based indicators are likely to be incorporated because they are likely to be affordable, easy of score, integrate and cover a wide scope of issues and match the way farmers organise their work planning.[xxx] However, usually they are only assumed to trigger desired sustainability outcomes. Researchers must check any important practice-based indicators deployed in the NZSD to critically evaluate whether they deliver the expected gains for sustainability and resilience. This may require quite detailed research of

[xxx] See Moller & MacLoed (2013)[3] for more detailed comparisons of practice- and performance-based indicators.

ecological processes and feedbacks on a subset of orchards, vineyards, forests and farms.

Refining indicator selection and measures

Just as farmers mainly learn to farm by getting out there and doing it, the NZSD coalition of practitioners, industry facilitators, consultants and researchers must now learn how to monitor effectively by doing it. Our recommendations are:

1. *Broaden scope of monitoring to fill gaps:* Start substituting or adding indicators to achieve the protection of the emerging multidimensional sustainability criteria. Our review showed that some of the indicators we have proposed only occur in 5% or other schemes, while others appear in 79% of schemes. The international trends are clearly for broadening the scope of sustainability themes so the goal should be to eventually have at least one indicator in each theme as soon as is practicable. Gap analysis to guide this broadening should (a) first prioritise existing sector risk and opportunity management plans, and then address higher level gap analyses to cover (b) the Response-Pressure-State-Benefits and (c) all ecosystem services categories.
2. *Eliminate unreliable indicators:* Any indicators that fail the reliability checks outlined above should be rapidly modified to fix the problems or immediately eliminated from the NZSD framework.
3. *Don't overburden your producers:* Check the time and costs committed to the programme. If near their limit, start eliminating indicators that (a) are not judged important or relevant, (b) that change slowly, (c) where a formal power analysis has demonstrated that reliable information or baselines have been obtained already, or that sampling can be rested for a while.
4. *Consult the producers and other stakeholders to refine the indicators:* We stress that the mandatory participation in NZSD reporting forced by marketing accreditation is both an opportunity and a threat: it will greatly accelerate initial engagement and spread of the network; however it risks resistance and low quality reporting if producers do not adopt the tool as 'theirs' and make it work primarily for their needs. A series of repeated interviews with owners and managers of a subsample of vineyards, wineries orchards and farms will guide refinement of the framework and software. The survey module has been incorporated into the software so that responses to the NZSD and monitoring framework can be elicited regularly from all participants in each agricultural sector.
5. *Consider formal choice modelling to guide indicator refinement:* One way of building ownership of the tool by the host industry is to involve them as much as practicable and as early as possible in its design. A choice modelling approach using the *1000 Minds* software could be used to formally evaluate the optimum shape and scope of the framework and selection of the indicators themselves. It would be ideal to involve farmers, industry champions, regional and national policy analysts and consumers in such choice modelling inquiries so that strategy is based on an amalgam of stakeholder needs and preferences. The choice modelling can directly measure producers' preferences for what to include in the

beta-generation NZSDs and demonstrate to the farmers that they are in the drivers' seat.

6. *Start with least sensitive information to build trust:* Security of confidential data will have to be managed and demonstrated if the producers are going to feel safe about providing information. As the scope of the NZSD's monitoring widens and deepens, gradually more intimate information could be requested. We recommend that proof of the NZSD product and inevitable teething problems in getting it up and running are negotiated first before more sensitive information is requested from producers.
7. *Substitute performance-based indictors in the place of practice-based indicators where practicable:* Outcomes from farming provide more certain inference of sustainability than inputs like best professional practice (the latter are assumed to deliver better outcomes).
8. *Substitute measureable indicators in the place of qualitative indicators where practicable:* Trust of wider stakeholders is enhanced if indicators are quantified and repeatable. Nearly all the indicators proposed for agro-environmental integrity are measureable, at least in part (Table 9), but we expect relatively few of the social well-being indicators in NZSD to be similarly quantifiable.
9. *Research important indicators that are not yet ready for sector-wide deployment:* Some workable measures exist for all indicators, but we also scored 17 (71%) of proposed indicators as 'moderately ready' for deployment (Table 9). Careful selection and follow-up work on developing workable indicators is still needed. An associated research programme should test new indicators for critical gaps in the framework. Trials on a test panel of vineyards, wineries, orchards, farms and forests should be completed before sector-wide roll-out.

Continual refinement of the NZSD software will be needed to improve a farmer-friendly interface that is fundamentally important for efficient, repeatable and scientifically defensible monitoring. Participation metrics will be automatically recorded by the software[xxxi] to guide the researchers to what is useful for the producers and which features of NZSD are being ignored. Interviews and online surveys should be used for much more than to just select indicators – they should also explore the barriers and enablers to lift participation rates and particularly the processes by which producers and industry champions interact to co-design and improve their dashboard.

Although the main indicator of success of the NZSD is whether it is enthusiastically adopted and used by the producers, the industry facilitators have crucial roles to structure and guide the learning by doing. Their continuous queries and direction of their NZSD will turn 'passive adaptive management' into 'active adaptive management' and thereby accelerate learning and focus attention on the most important vulnerabilities and opportunities faced by the industry as a whole.[3] Vertical integration into industry plans and risk management strategies will assist uptake and guide investment, but active driving of the dashboard from within the industry bodies by key sustainability champions will be needed. Too many sustainability monitoring frameworks and tools sit moribund because they were not fully integrated into day-to-day industry practice.[7]

[xxxi] Examples of queries include: How many farmers visited the site? What pages did they look at and for how long? Which Decision Support tools did they access? Did they change their farming practice in the longer run?

Biodiversity indicators (to meet Objectives 6 and 7) are particularly expensive and often technically complex to measure (Table 10). They are not yet generally present in agricultural sustainability accreditation schemes within New Zealand, but are increasingly being required overseas. They also vary enormously between taxa and the ecological level of organisation concerned (species, communities, ecosystems, habitats, ecological landscapes).[3] Retention and restoration of biodiversity depends on integrated management of forces operating at all these scales.

We expect and encourage continual challenge and refinement of the agro-environmental integrity indictors proposed in Figure 3, and especially rapid evolution of the metrics used for each indicator as the NZSDs are operationalised. Nevertheless we have proposed a general framework that we hope is sufficiently complete and flexible to confront global and national needs, while still being cast in locally grounded and relevant terms for producers and agricultural industry sectors to future-proof what they do best: the efficient production of high quality food and fibre in a way that maintains the natural capital of the land and contributes to shared national and global goals for environmental care.

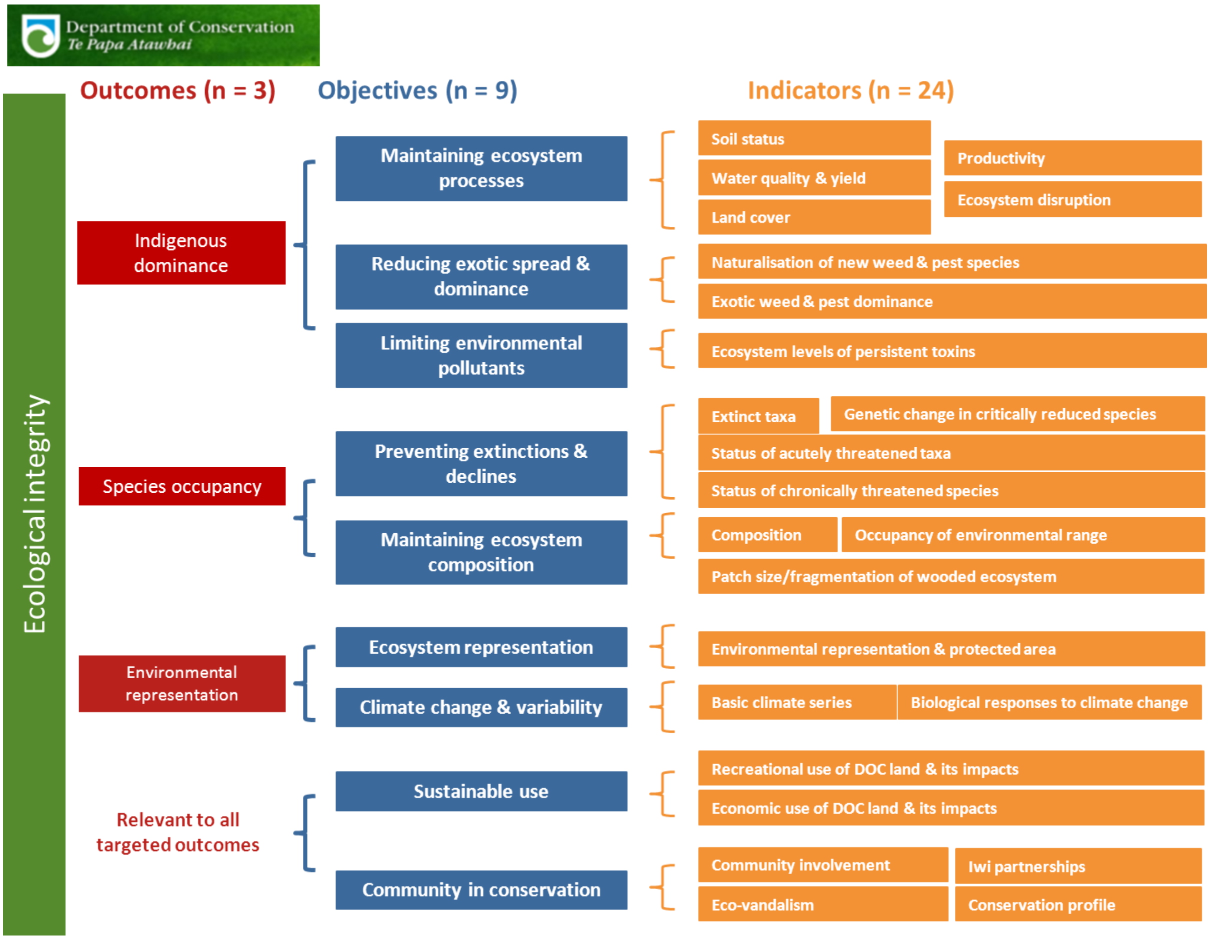
Appendix 1: National monitoring and reporting systems

Sustainability Dashboard

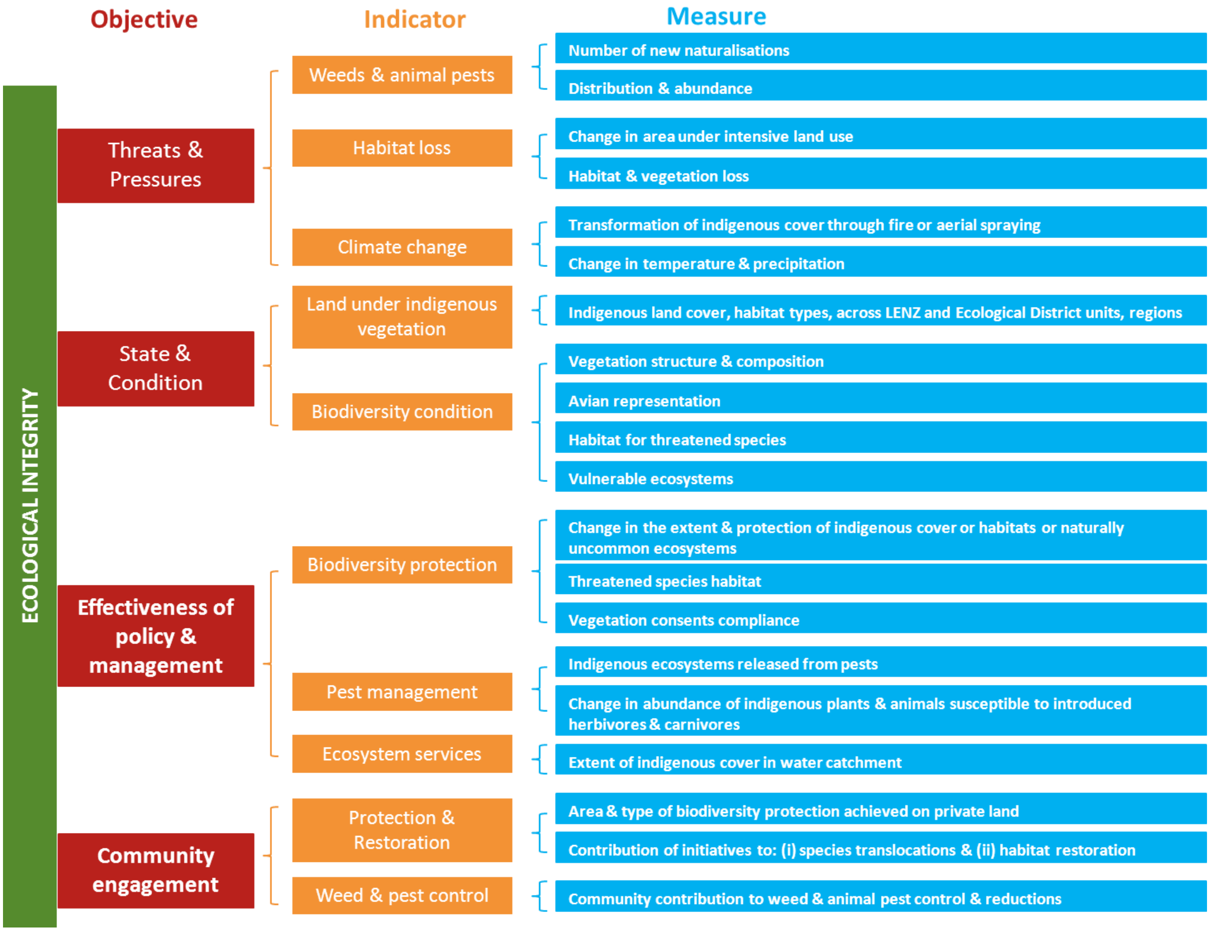
The project's vision at the completion of the six-year research project by September 2018 is that:

> *The New Zealand Sustainability Dashboard is unifying sustainability monitoring and reporting of internationally recognised metrics across five primary production sectors. Fine-tuned monitoring has been designed, tested and integrated into the framework. A web-application tool enables (i) users to directly upload their sustainability Key Performance Indicators (KPIs) to industry databases, (ii) smart visualisation of trends and benchmark comparisons between farms and sectors, (iii) semi-automated reporting at regional, industry and farm levels, and (iv) a 'clearing house' for access to decision-support tools for improving KPIs. The Dashboard is used throughout product supply chains by market assurance programmes and is providing regular feedback to producers for learning, and to government for policy formation. The system has reduced monitoring and regulatory costs, built consumer trust, secured market access and garnered support from wider New Zealand society by verification and regular reporting of standardised sustainability criteria.*

DOC biodiversity monitoring and reporting system



Regional Council Terrestrial Biodiversity Framework



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