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Design criteria for effective assessment of sustainability in New Zealand's production landscapes

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About this report series

The New Zealand Sustainability Dashboard Report series is a publication of the ARGOS Group (www.argos.org.nz) – as part of the New Zealand Sustainability Dashboard project. All publications can be found on the website nzdashboard.org.nz. However, Internal Reports could not be published on the website.

The New Zealand Sustainability Dashboard project Research Partners

Executive Summary

The New Zealand Sustainability Dashboard (NZSD) provides monitoring tools and a sustainability assessment framework for learning, compliance and auditing, marketing strategy and networking within several host primary production sectors and wild food gathering practices to help each become more sustainable and resilient. Wine growers and makers, orchardists, farmers and foresters and kaitiaki (Māori environmental guardians) are customising the NZSD's multifaceted software package and online network to help facilitate communication amongst colleagues, industry champions and advisors within their own Community of Practice. NZSD sets up a unified sustainability monitoring framework, indicators and their measures so that producers can compare sustainability performance, share lessons and show their industry champions what they need. The growers themselves will score most of the indicators each year and upload them to an NZSD database so that trends in performance can be reported back to them instantly.

We primarily reviewed the general design criteria used by international agricultural and business sustainability assessments for selecting indicators and their measures. However we also identify optimum processes for the way a Community of Practice co-designs and participates in the overall sustainability assessment endeavour. Formation of the relationships and willingness to participate is just as important as smart choices of the actual content of prototype dashboards, their indicators and measures, or the way they link into a framework. Many sustainability dashboards sink without trace once the research team that created them have completed design. Therefore each NZSD host community will need to take full ownership of their dashboard for its use to be sustained and for its content to continually evolve to meet the ever-changing opportunities and challenges of the industry, its markets and the New Zealand public. Accordingly, this review does not offer a design prescription for 'ideal' goals, indicators and measures for sustainability assessment. Rather, it identifies issues for industry decision-makers to balance inevitable trade-offs between complexity and practicality, breadth and depth of measurement, and their level of investment in a dashboard compared to risk of not demonstrating sustainable practice.

The wide diversity of stakeholder values and world views undoubtedly makes it difficult to agree on how to define, plan and measure progress towards 'sustainability'. Nevertheless, all the approaches share a common concern for continuance: a goal to keep systems functioning; to avoid irreversible change so that the current agro-ecosystem and land remains both 'fit for current purpose'; and to take a long term view so that the land remains 'fit for future purpose'. Provided that these fundaments of all sustainability frameworks are retained, detailed debate and precise definition of sustainability would be ultimately futile, self-defeating and very distracting. We take the pragmatic view that NZSD goals must be broadly defined so that diverse and far-flung stakeholders use and trust the framework and the tools it creates.

Utility of the dashboard depends on it being 'action-oriented' i.e. to help growers, producers and industry make immediate decisions for sustainability. Dashboards provide a way for accelerating 'learning-by-doing' (adaptive management) by pooling data and comparing new against previous performance when a 'farming experiment' is trialled. The key to success of adaptive management is standardised, repeatable and efficient monitoring so that farmers can confidently track their own gains or losses from implementing new practices, and so they can objectively compare their performance against that of others. For many aspects for agriculture, this is a less expensive and more practically reliable approach to learn ways to improve outcomes.

'Responses-Pressures-Sate-Benefits' (RPSB) and 'Ecosystem Services' (ES) have been suggested as ways to structure sustainability assessments for targeting the main sustainability risks and benefits facing the industry. However we recommend that NZSD does not overtly structure its indicators and frameworks formally around RPSB or ES because they are somewhat abstract and generalised ways for prioritising what to measure. It would be better to break down the many facets of production into the logical and practical steps as perceived by the growers and processors themselves. However, both RPSB and ES provide a useful high level gap analysis for the scope of the NZSD sustainability assessment and underscore the value of quantifying some benefits of sustainable actions rather than simply focussing on risks or poor performance.

Appropriate indicator and measurement design will be crucial to build trust and participation among stakeholders, including farmers, industry facilitators, marketers and consumers. Optimal criteria identified for individual indicators and their measures include being:

- *Policy-relevant and meaningful* – they provide clear information at an appropriate level for policy and management decisions, preferably in relation to specified baselines, risk thresholds or action-oriented and realisable targets.
- *Broadly accepted* – they are selected objectively through collaboration with policymakers, key stakeholders and experts, unless serving specific local values.
- *Sensitive* - they detect changes in systems within the time frames and spatial scales relevant to decisions and risk management.
- *Specific* – they are affected by relatively few factors so any shift in their measures can be more directly linked to causes of change
- *Scalable* – measures and indicators can aggregated at a range of spatial, temporal, stakeholder levels
- *Performance based* – they measure actual performance towards outcomes (rather than practices expected to promote sustainability and resilience)
- *Clearly defined, quantified and repeatable* – they involve data collection where feasible, using quantitative, rather than qualitative, methods to provide comparable, verifiable and scientifically-acceptable information.
- *Affordable for monitoring and modelling* – they can be measured accurately but also cost-effectively to secure participation, regular monitoring and meaningful information on cause-and-effect relationships.

Optimal features of the entire suite of indicators and measures for sustainability assessment should include:

- *Minimum set required to be representative* – providing a balanced picture of pressures, states, responses, uses and capacity (coverage) that can be easily communicated.
- *Explicit declaration of values and goals* – making them interpretable in context and building consensus in management responses.
- *Wide scope and integration* – covering and cross-linking multiple dimensions of sustainability and values (environment, economics, social and governance); some should link to standards required for market certification.
- *Trade-off between generality and specificity* – allowing cross-comparison between sectors, regions, countries and diverse socio-ecological systems (i.e. requiring generalisable indicator structures). More locally-grounded indicators should be nested under these to guide sector-specific management issues.
- *Flexible and transparent analysis and reporting* – using well-documented and robust data management processes that allow aggregation, or disaggregation, of information at a range of spatial and temporal scales for different purposes.

The following strategies could be deployed to limit the number of indicators and time required to score them, yet maintain a wide scope to the NZSD monitoring:

1. Ensure that the indicators and measures can be calculated or scored rapidly. Use proxy measures and relative indices if they are reliable and sensitive, or if the absolute measures are too expensive or technically difficult to monitor.

2. Prioritise indicator and measures selection in collaboration with key stakeholders, using a transparent process (ideally a choice model).
3. Generate indicators from several components that span and report a wide range of issues at once – the growers themselves will have integrated many of these so that splitting them into component parts may not always be necessary.
4. Establish a rota of different indicators to be scored in successive years or blocks of years. Some core indicators may need to be repeated every year, but slow-moving ones or ones with high precision can be rested from time to time.
5. Trigger scoring of more indicators (or the same indicators scored more frequently) only when flags or thresholds come up to signal vulnerability or opportunity on a participant's own vineyard, orchard, farm or forest.
6. Present questions, or the sequence of individual components of an aggregated indicator, one by one from 'hidden' online lists.
7. Configure some of the scores in a hierarchical manner so that most respondents do not need to cascade through the whole sequence.
8. Rotate what is reported to emphasise only part of the bigger picture at once. Feedback should highlight just some of the indicators and measures at regular intervals, but make the complete set easily accessible by those that wish to delve further.
9. Configure reporting in a hierarchical manner so that those with a particular interest in part of the sustainability assessment framework delve deeper to get 'customised reports'.
10. Do much of the work behind the scenes by programming the software to automatically link to other data or score generic indicators from more specific measures.
11. Ensure that a given indicator only appears once at the data entry stage. It can then be reused in several parts of the NZSD by incorporating it into composite indicators or shifting it between domains where appropriate.

The scientific credentials of the dashboards depend on achieving high coverage and participation across each host industry. Around 95% of wine growers and processors are participating in WiSE, the Sustainable Winegrowing New Zealand dashboard. This immediately makes scientific interpretation of many of the results much more reliable:

- Normal constraints on statistical power from limited replication are released.
- Complete enumeration of indicators and their variation means representativeness of the information for the entire industry is no longer in question.
- Less precise indicators are needed to establish national-level average performance levels because so many growers or producers replicate the same metrics.
- More rapid feedback and benchmarking are possible because all neighbouring enterprises in the same sector are contributing.
- Management experiments are statistically powerful and so will detect even very small improvements in farming outcomes
- There is no doubt about the 'domain of inference' from analysing indicators – a virtually complete national picture has been revealed.

Maximising national participation of each dashboard should therefore be a primary goal of each host industry.

The use and reliability of the dashboards will grow and long-term data gathering allows analysts to distinguish trends from short-term perturbations. The challenge for the dashboard designers and decision-makers within industry is to maintain sufficient consistency in data streams (what is measured and how) while still updating monitoring to meet new challenges or capture new opportunities. A formal set of re-appraisal criteria would help judicious rotation of indicators to be measured in the coming growing or processing season (pause in measurement of some with reliable information of no immediate threat would allow space for the next most important measures to be instigated).

Host industries will need to invest heavily in database management if the long-term benefits of the dashboards are to be captured. It is extremely difficult for newcomers to interpret past data reliably, so there needs to be a meticulous log of any protocol changes and shifts in context variables of participating farms and processing plants.

Value can be added to the information entered to each dashboard by growers or processors by secondary manipulation and aggregation along the following continuum:

1. Primary raw data gathered for the NZSD or other monitoring agenda (e.g. change in agricultural land area on a farm).
2. Secondary measures calculated from simple formulas to link and cross-reference indicators from different parts of the dashboard (e.g. conversion of the quantities of several different fuel types into a common currency of energy content, or a common toxicity score for pesticides).
3. Aggregated or hierarchically-structured combinations of smaller indicators into a composite score for a given vineyard or orchard.
4. Recalculated indicators that scale data form the farm against information gathered elsewhere by other agencies (e.g. climate data from nearby NIWA weather stations could be used to calculate fruit production per 'degree day' or 'per mm rain' at a crucial time of the year).
5. Indicators predicted from technically complex models that use the raw scores from (1) above as input values (e.g. a nitrogen balance indicator calculated from Overseer®, which is calculated using a complete input–output equation determined from other research).

Combining metrics into single indicators on a common currency, as in (2) above, is extremely useful for benchmarking and comparisons between sectors and farming systems. 'Composite indicators' (aggregated scores) provide a coarse-scale indicator of overall progress towards very broadly stated goals or performance criteria. The aggregated indices may be particularly attractive to practitioners like farmers or customary harvesters who do not routinely reduce farming or wild food gathering to several disaggregated and quantified components in the way a scientist usually tries to do. Formal measures of the 'weight' (relative importance) of each component's measure are needed if such composite indicators are to retain sensitivity and reliably guide sustainability.

Indicators that measure outcomes provide specificity and measure current state of an agro-ecosystem, but by themselves are unlikely to incentivise change or add sustainability to farming unless they are coupled with equally specific and measureable targets. Sometimes the objective will be to achieve a new target state, or to maintain agro-ecosystem indicators within agreed and quite specific limits that safeguard sustainability. Meaningful and practical 'external reference' targets are still poorly developed in international sustainability assessment, so research on their development for NZSD should be given high priority once baseline indicators and measures are in place. In the meantime NZSD will have to rely more on 'internal reference' levels to incentivise improvement, such as benchmarking performance against neighbours or equivalent enterprises.

There is much more to science than just measuring. Good science and monitoring start with good questions, developed by: (1) using critical thinking, (2) building robust conceptual models of how agro-ecosystems work, (3) testing 'true' policy questions of management relevance, (4) promoting open dialogue between scientists and managers, and (5) evaluating both designed and opportunistic study manipulations critically. This signals a need for active management of each dashboard by its industry decision-makers and their co-ordination of its use by growers and processors.

To drive and demonstrate global best-practice among New Zealand growers, we recommend aligning NZSD with the Sustainability Assessment of Food and Agricultural (SAFA) framework, designed and promoted by the United Nations' Food and Agricultural Organisation (FAO) because:

- SAFA is the most cost effective and complementary of many international monitoring systems available and closest to the participatory approach sought by New Zealand stakeholders
- SAFA is a current and far-reaching initiative to harmonise a plethora of approaches.
- SAFA was designed and promoted by the FAO, a credible, scrupulously neutral and influential advocate for intergovernmental policy and action (trust and buy-in by stakeholders is more likely).
- SAFA was designed using a thorough and prolonged process of development of multiple stakeholders throughout the world.
- SAFA covers a more complete range of the drivers and spatial scales than covered by other frameworks.
- SAFA deploys inclusive indicators of a wide span of values and social, economic, ecological and governance contexts (this makes it more universal than most indicator frameworks designed by experts or professional monitoring agencies).
- SAFA is very flexible in its generic definitions of indicators (so that locally-tuned NZSD indicators can easily nest underneath the SAFA components).
- SAFA is particularly innovative in including several dimensions of governance that are usually not included in sustainability assessments in New Zealand because they are embedded in wider society and New Zealand's way of doing things (e.g. rule of law, equity, transparency, lack of corruption). SAFA therefore offers an inexpensive chance to demonstrate explicitly these advantages that are usually taken for granted in New Zealand.
- Other countries that are exporting into the same markets targeted by New Zealand are likely to use SAFA, so New Zealand growers can future-proof market advantages by participating in the same assessment.
- The NZSD researchers have had an influence on the SAFA design and succeeded in making it more relevant to New Zealand agriculture.
- Four pilot runs using the preliminary SAFA framework and indicator guidelines showed that New Zealand scores very favourably against the international benchmarks used by SAFA.
- Those pilot tests showed that a knowledgeable expert can perform a SAFA assessment rapidly and with little expense.
- Participation in SAFA is voluntary and free, so there is no requirement for an expensive accreditation process to claim compliance. Any New Zealand industry audit processes that are currently used for their market accreditation protocols can simultaneously serve the SAFA needs.

New Zealand's ecology (e.g. presence of threatened indigenous biota, prevalence of invasive species) and social-political orientation (e.g. deregulated, non-subsidised, export oriented agriculture) require special emphases if the dashboards are to be locally relevant. This highlights the importance of alignment to a coordinated biodiversity monitoring and reporting system currently being developed by the Department of Conservation and regional councils. Successful integration of the NZSD, DoC and regional council sustainability framework, indicators and measures will support formation of more integrated national environmental policy. Growers and processors could then contribute to 'state of the environment' reporting and better safeguard their own sustainable land management practices.

The complexity and breadth of sustainability assessment risk precipitating 'paralysis by analysis, so we advocate an iterative design process that starts small and gradually spreads and deepens the NZSD coverage. Designing an effective monitoring tool is rather like building a model of a system – the key challenge is to reduce complexity to the barest minimum yet still be able to describe the system adequately. It will be important to keep expectations realistic: monitoring alone cannot achieve sustainability. However, turning compliance into a learning tool using a sustainability dashboard is a first step in an important and long-term journey.

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Introduction

The New Zealand Sustainability Dashboard

This report supports the development of the New Zealand Sustainability Dashboard (NZSD), an online sustainability assessment and reporting tool for the country's primary industry sectors.[1] 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 growers 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.*

Internationally recognised frameworks and their key generic sustainability performance indicators will be co-opted to ensure that overseas consumers can benchmark and verify the sustainability credentials of New Zealand exported products. It is a participatory, industry-led approach to measuring and reporting sustainability allowing farmers to log mainly self-assessed sustainability measures into an online network. The Sustainability Dashboard will allow for instant benchmarking, trend analysis, progress towards targets and provide warnings when trigger points indicate a need for intervention. The Dashboard will also be equipped with an automated reporting system to benchmark a participating farmer's performance with that of others producing similar goods, or using similar farming technologies (eg. irrigation). Relatively standardised measures of farming performance will be shared between farmers, industry advocates, policy makers and consumers. A basic version of the dashboard is currently being customised and extended to meet the needs of New Zealand growers and food processors so they can formally measure and demonstrate their performance against many of the sustainability criteria demanded by competing market assurance programmes.

Over the next five years, the proposed framework will be developed and adapted progressively to meet the specific needs of participating stakeholders, including production sectors (kiwifruit, wine,[2] pastoral, forestry and aquaculture), related Māori initiatives (e.g. Ahikaa kai) and regulatory bodies (e.g. regional councils, Statistics New Zealand) and international policy and advisory institutes (e.g. Organisation for Economic Co-operation and Development [OECD], Food and Agriculture Organisation [FAO]; Figure 1).

This report focuses on the general design criteria for monitoring sustainability within separate dashboards for all these sectors (see steps ❶–❸ in Figure 1). Although we mainly draw on environmental examples to illustrate key points throughout the report, the general design criteria should be equally relevant to other sustainability dimensions; accompanying reports to this one consider specific goals and indicators for the different components of sustainability (environment,[3] social well-being[4] including Māori culture,[5] economic resilience,[6] good governance and farm management[7]), the three key main drivers for sustainability reporting (market,[8] regulatory[9] and business improvement[10] drivers) and tools for communication and learning.[11]

Design roadmap

Effective design of monitoring frameworks proceeds by answering three important and interrelated questions:[12,13] (1) **Why** monitor? (2) **What** to monitor? and (3) **How** to monitor? The last identifies the specific 'measures' (methods and sources of information for the indicator) and elements (e.g. data layers to support a measure) used to quantify the indicators. A common criticism of indicator monitoring programmes is that they accelerate and operationalise measuring itself without giving sufficient attention to the desired outcomes and what exactly the proposed indicators will tell managers about progress toward a programme's goals. These higher order goals are therefore incorporated into an overall sustainability assessment 'framework' which in the NZSD case is defined as a nested hierarchy of 'Pillars', 'Outcomes', 'Objectives' and 'Indicators'[7]. It is important to continually distinguish a 'measure' (the metric or way a property of an agroecosystem is scored) from an 'indicator' (the property of the agroecosystem itself that is being monitored because it drives or reflects sustainability). An indicator might have several measures, but a measure must always be linked to an indicator, which in turn is mapped to a higher objective, outcome and pillar goal within the sustainability framework. The importance of tight linkage to sustainability goals is also underscored by focus on 'outcomes' rather than on 'outputs' of a farming system. Outputs indicate little more than efficiency, unless they are reliable proxy measures of progress towards outcomes where measuring the latter is too difficult or expensive.

This report reviews international best practice, and incorporates nine best-practice principles of monitoring (Box 1), to identify five key considerations when designing the New Zealand Sustainability Dashboard, before discussing the overall prospect for success, i.e.

- Clarifying goals: where do we want to get to?
- Co-discovery by multiple stakeholders
- Accelerating learning through active adaptive management
- Improving the New Zealand Sustainability Dashboard step-by-step
- What makes an ideal indicator and framework?
- Prospects for an effective New Zealand Sustainability Dashboard.

Box 1. Nine principles of monitoring[14]

1. Define the problem you are trying to solve and set goals for monitoring.
2. Build on the past available information, even if fragmentary or statistically weak. It can help you design optimal monitoring.
3. Don't be preoccupied by current perceptions about what is most important to measure – it pays to keep the scope of monitoring wide to inform new and unexpected issues arising later.
4. Ensure comparability. Changing methods too much or not calibrating new against old ways of monitoring undermines detection of change and interpretation of the long-term database.
5. Utilise repeat measures. Trends are easier to detect if sampling sites are fixed.
6. Establish baselines. These can offer targets for restoration and more solid benchmark comparisons to assess current state of the environment.
7. Collect complementary interpretive data that provide context for what you monitor and help pinpoint why changes are observed.
8. Ensure long-term commitment. A combination of inspired leadership, opportunity and funding is needed to maintain monitoring to detect the crucial slow long-term changes.
9. Commit to data management. Archive your data in annotated, checked and retrievable form so that others can interpret it confidently later. Add value by combining your own data with new datasets to help interpret the results.

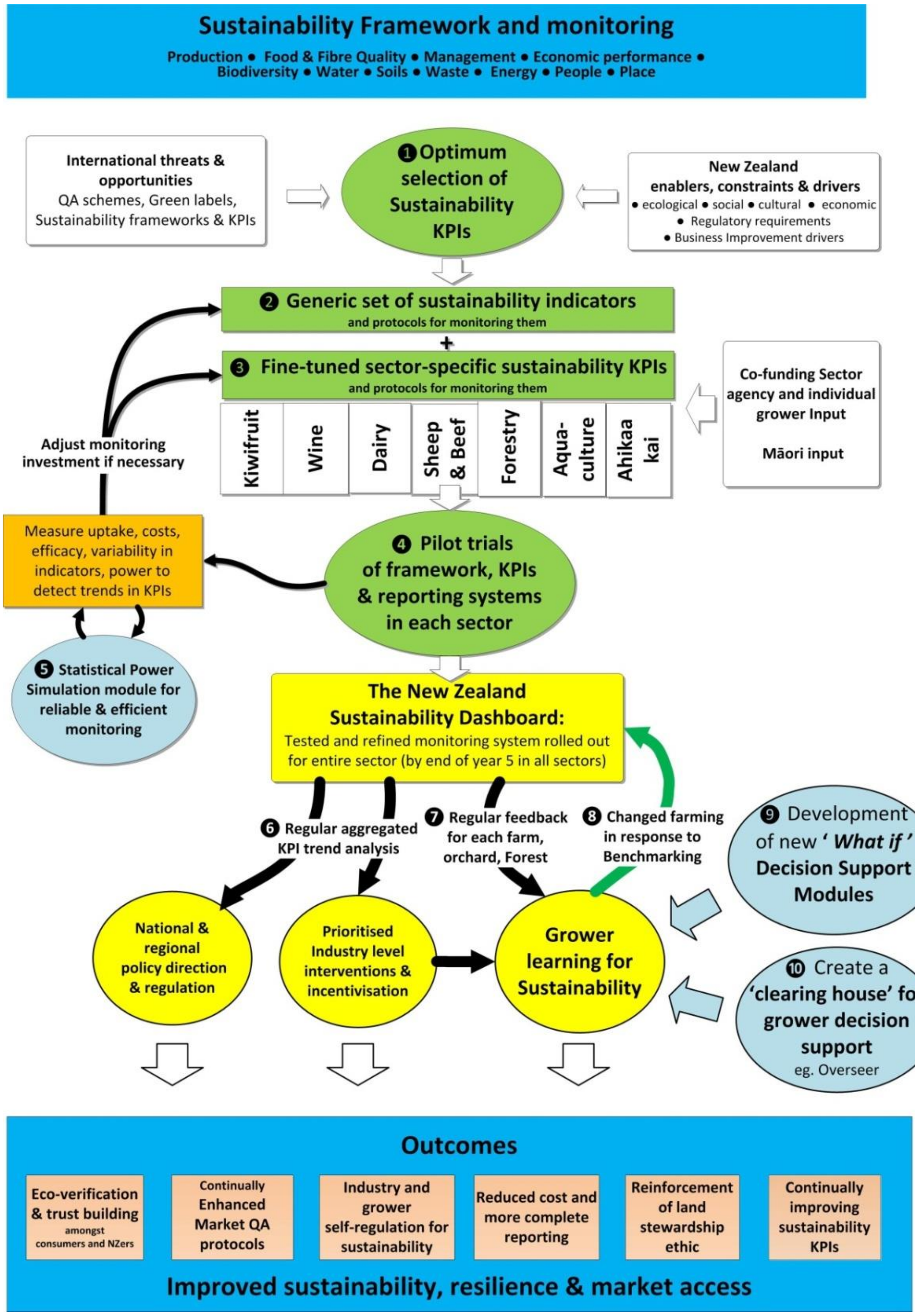


Figure 1: The New Zealand Sustainability Dashboard project map.

Clarifying goals: where do we want to get to?

What is sustainability?

The very first step in goal definition is to clarify what is meant by 'sustainability'. The concept of sustainability has broad political appeal and provides the basis for several international monitoring frameworks.[15,16] However, despite concerted academic effort by dedicated transdisciplinary teams, the concept of sustainability is difficult to define in precise terms. Some argue that 'defining sustainability is ultimately a social and somewhat arbitrary choice about what to develop, what to sustain and for how long'.[17] There is sometimes strident disagreement on which domains should be included in sustainability assessment. For example, a predominating emphasis on farm production could measure whether New Zealand farmers can continue to efficiently produce food and fibre for export. Emphasis of a need to avoid environmental degradation recognises that much of primary production is underpinned by biological processes like nutrient cycling, pollination and natural pest control. A focus on 'multifunctional agriculture[18-23] recognises that New Zealanders enjoy production landscapes for recreation, tourism or aesthetic reasons. Socially acceptable farming methods include sound and ethical labour conditions, and for increasing numbers of consumers, that animal welfare is safeguarded demonstrably.

Debate on how best to manage and monitor sustainability remains, even when only considering environmental domains. Ecologists who seek to protect or restore ecosystems to more natural states will drive land and wildlife management towards a relatively defined and fixed end-point.[i, 24-26] In sharp contrast, resilience thinkers emphasise multiple stable states in a complex, adaptive system.[27-28] They focus more on maintaining systems linkages that enable change and continuance in the face of drivers and shocks.[29,30] In their paradigm, one could never judge, let alone measure, whether New Zealand agriculture is sustainable. What sustains farming now may not be what is needed in future conditions of, say, climate change or high fuel costs. Similarly, what works in one place now cannot be expected to work elsewhere. Social–ecological resilience is increasingly complementing and supplanting sustainability as a guiding paradigm.[30]

The wide diversity of stakeholder values and world views undoubtedly makes it difficult to agree on how to define, plan and measure progress towards 'sustainability'.[32] Nevertheless, all the approaches share a common concern for continuance: a goal to keep systems functioning (Box 2). This in turn leads to an imperative to maintain natural, economic, social and human capital by optimising flows between them.[33] In the case of agriculture and the NZSD, the primary immediate focus is to maintain the land and its ecosystems to be 'fit for current purpose', i.e. primarily to produce high quality food and fibre in a cost-efficient way.

An additional common feature of all sustainability approaches is that they take a long-term view – thus it is important to not degrade or change land and agro-ecosystems irreversibly in ways that will make them no longer 'fit for future purposes'. In an internationally turbulent and globalised world, it is difficult to predict future challenges facing New Zealand farmers and society and how they might wish or need to farm 20, 50 or especially 100 years hence. Therefore, sustainability strategies must keep options open and maintain crucial social–ecological linkages to allow transformation to new ways of farming should circumstances demand them. Irreversible change (e.g. species' extinction, severe erosion, habitat destruction) must be avoided if this future flexibility is to be retained.

[i] The goal is normally to restore habitats, ecosystems and associated ecological communities to a defined previous state, normally that before humans changed it. Maintaining a representative and complete association of indigenous species is the key part of this 'preservation' approach to conservation.

Box 2: Sustainability definitions and criteria

Sustainable development[34]:

'*…the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable'.*

Sustainable agriculture:

'Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimising natural and human resources.[35,36]

'The use of farming practices which maintain or improve the natural resource base of agriculture, and any parts of the environment influenced by agriculture. Sustainability also requires the agriculture is profitable; that the quality and safety of the food, fibre and other agricultural products are maintained; and that people and communities are able to provide for their social and cultural well-being.[37]

Sustainable agriculture should[29]***:***

Produce crops with high yield and nutritional quality to meet existing and future needs, while keeping resource inputs as low as possible.
Ensure that any adverse effects on soil fertility, water and air quality, and biodiversity from agricultural activities are minimised, and positive contributions are made where possible.
Optimise the use of renewable resources while minimising the use of non-renewable resources.
Enable local communities to protect and improve their well-being and environment.

Environmental sustainability should 'maintain and enhance natural capital',[38] ***by:***

Regeneration: using renewable resources efficiently and not permitting their use to exceed their long-term rates of natural regeneration.
Substitutability: using non-renewable resources efficiently and limiting their use to levels that can be offset by substitution by renewable resources or other forms of capital.
Assimilation: not allowing releases of hazardous or polluting substances to the environment to exceed the environment's assimilative capacity.
Avoiding irreversibility: avoiding irreversible impacts of human activities on ecosystems

Provided that these fundaments of all sustainability frameworks are retained, detailed debate and precise definition of sustainability would be ultimately futile, self-defeating and very distracting. We take the pragmatic view that NZSD goals must be broadly defined so that diverse and far-flung stakeholders use and trust the framework and the tools it creates.

We envision deployment of a set of generic and universally applicable sustainability indicators and their measures (❷ in Figure 1) that give space for pluralism and broadly defined multiple values that underpin sustainability. This leads to an emphasis on the value of 'and' rather than 'or' as a guiding design criterion for more effective environmental care.[39] However, a broad and generalised framework must be complemented by selecting detailed, defendable and locally-grounded indicators that are defined precisely and well linked (❸ in Figure 1). Designing a sustainability framework that is wide and inclusive does not create a warrant to measure everything or anything – the NZSD needs to avoid measurement for measurement's sake and must prioritise between a huge range of potential indicators. Our framework is designed to provide generalisability and coherence, whereas the indicators and their measures themselves must be described precisely with clear bounds for what they can and cannot tell us about the health, resilience or sustainability of a specific compartment of a wider agro-ecosystem.

Why is achieving agricultural sustainability so important?

Producing food while maintaining biodiversity and 'ecosystem services' is one of the greatest challenges facing humanity (Box 3).[40-43] With more than 40% of the Earth's surface being used for agriculture,[44] farmers and herders manage vast tracts of land and the natural resources within them, shaping ecosystems, habitats and landscapes.[45] Farms are vital in securing human survival, both directly by producing food and fibre, and indirectly by producing amenities and maintaining social and cultural services (Box 3).[46] The global human population is projected to peak at approximately nine billion by 2050, two billion greater than the present population. Much of the production in industrial-scale agriculture and the world food systems it supplies are subsidised by inexpensive energy from fossil fuel, despite recent 'peak energy' projections asserting that supplies are already declining.[47] Food and fibre production failure will lead to humanitarian crises, as well as political instability on a global scale. New Zealand can make an important international contribution to food security through efficient production. The NZSD can help assess sustainability and share knowledge about how to improve sustainability of high intensity agriculture in other countries.

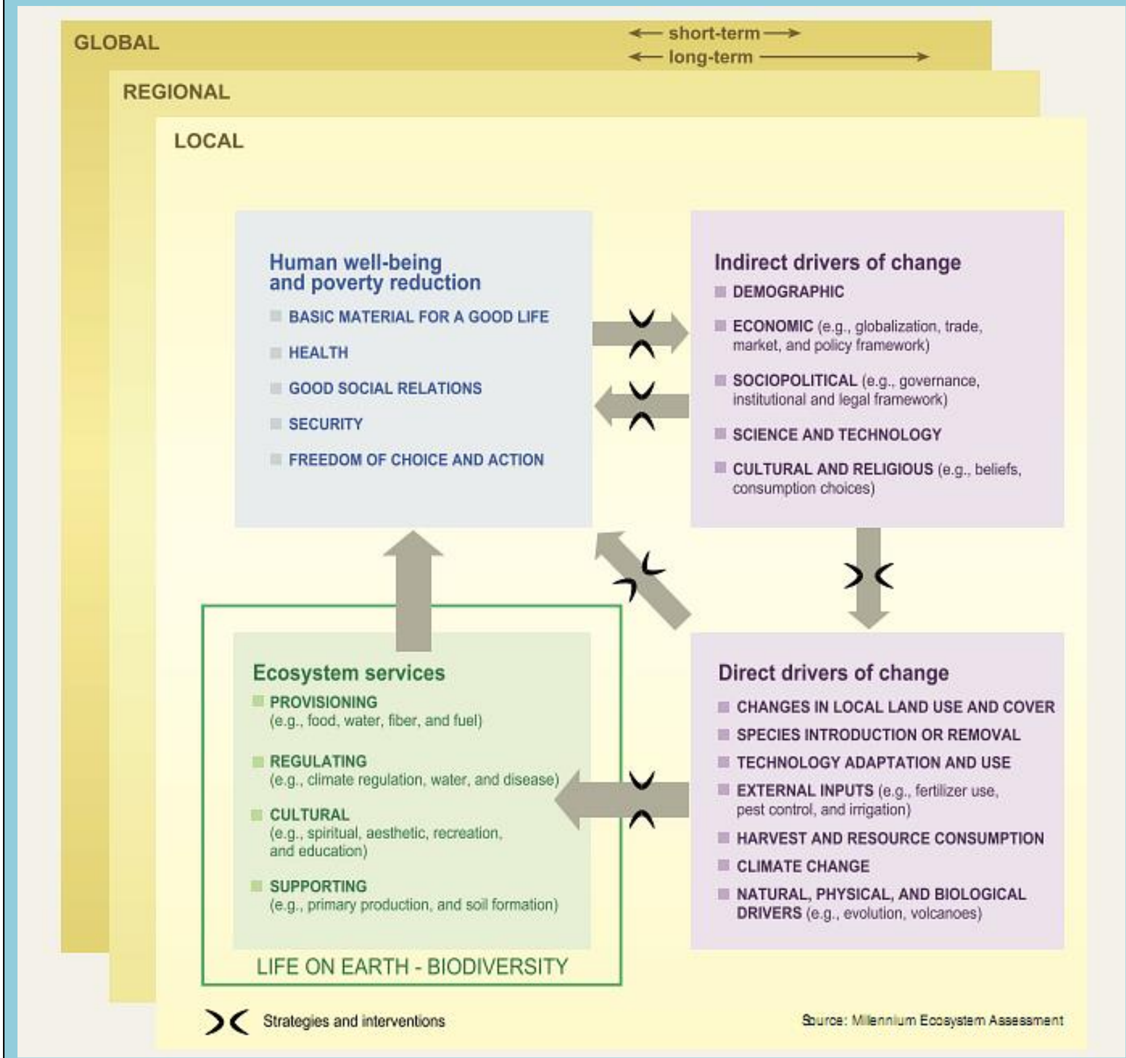
The Millennium Ecosystem Assessment concluded that some 60% of the basic ecosystem services that support human well-being have been degraded, with particularly strong losses in the past half-century.[41] Agricultural land use change is considered a major driver of this degradation.[48] Many farming practices affect ecosystems negatively both on- and off-farm, sometimes over large distances, through importing ecological subsidies[49] such as nutrients and energy derived from other ecosystems, and by exporting pollution.[20] Agriculture is a major cause of environmental pollution (waterways, coastal zones, soil and the atmosphere), including large-scale nitrogen- and phosphorus-induced environmental change and greenhouse gas emissions that influence global cycles.[49,50] The contribution of agriculture to global climate change through greenhouse gas emissions and heavy consumption of fossil fuels has led to calls for the transformation of agricultural production.

Although there are clear indications that humanity has already overstepped three environmental planetary boundaries (climate change, biodiversity loss and changes to the global nitrogen cycle[50]), there is little systematic information available to track how these are changing over time in many countries, including New Zealand.[49] The NZSD tool is being designed to measure trends in key indicators and to guide learning on how best to transition to more sustainable production systems (Figure 1).

Concern for the sustainability of agricultural systems at interlinked local, national and international levels is spreading well beyond an academic community of 'whistle blowers' to become a well-organised mainstream consumer and environmental movement. This trend is evidenced by a growing number of popular books, websites, films, newspaper, radio and television items about the agricultural sustainability crisis, food security and food sovereignty.[51-58] There is a clear need for sound and accessible agricultural monitoring systems to link consumers, growers and policymakers to guide this growing popular movement for transitions to more sustainable and equitable food production (Figure 2). For example, the value of biodiversity monitoring for documenting ecosystem change has been demonstrated clearly in recent years,[59-61] engaging public awareness in environmental issues and providing the necessary evidential basis for environmental legislation.[62]

Box 3: Ecosystem services

Ecosystem services are the benefits that people obtain from ecosystems; where an ecosystem is defined as a dynamic complex of plant, animal, microorganism communities and the non-living environment interacting as a functional unit.[41]



Over 50% of New Zealand's export earnings are derived from primary production,[ii,63] so maintaining an efficient and internationally acceptable food and fibre production stream is paramount for New Zealand's economic prosperity. New Zealand's neoliberal socio-political system relies predominantly on export markets to sustain productive land use. Demonstration of sustainable and ethical food and fibre production attracts ongoing access to premium high quality niche markets and attracts premium prices from consumers in the United States, Australia, Europe and, increasingly, Asia.[64-65] The NZSD can help secure market access and premium prices by assuring distant consumers that our exported products are safe, of high quality and have been produced in ethical and environmentally friendly ways. This can only be achieved by improved connection and communication between far-flung stakeholders (Figure 2).

New Zealand is a signatory to multiple international policy agreements (Appendix 1) that aim to halt adverse impacts of land use change on biodiversity and the wider environment.[66,67] This requires New Zealand to promote conservation and sustainable use proactively and to also monitor and report on its progress towards specified sustainability goals. An immediate and practical need is to engage with several international monitoring frameworks, standards and accreditation systems (Table 1) developed to assess and demonstrate whether producers' practices are sustainable. It is important, therefore, for New Zealand's production sectors to meet customers' and consumers' expectations by using rigorous and credible monitoring and reporting methods and avoiding making unsubstantiated environmental and/or ethical marketing claims. Wider New Zealand society is also increasingly demanding better environmental care in its production landscapes to protect its aesthetic, recreational and biodiversity values.[68-71]

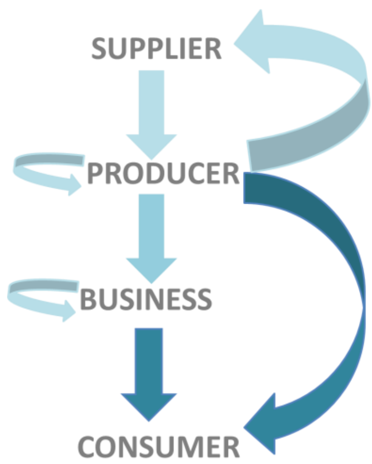


Figure 2: Co-dependence and communication pathways among multiple stakeholders.

[ii] In 2012 the sum of exports from dairy, meat and arable farming represented 44% of New Zealand's overseas earnings; and forestry, wine and fish approximately a further 13% (p.107 and figure 5.1 of Hendy & Callaghan 2013).[63]

Design the framework to guide actions

Environmental monitoring may be initiated for many different proximate reasons even if the ultimate goal – sustainable resource management – is the same (Table 1). Immediate goals range from those focused on enhancing knowledge of the system, to early warning, to raising awareness of stakeholders and, ultimately, to inform management actions (Figure 3). Monitoring for sustainability and resilience is an integral part of risk management.

The value of monitoring for building general public support for environmental care should not be underestimated. For example, on the basis of population monitoring demonstrating farmland bird decline in the United Kingdom,[84-88] media and public interest was successfully engaged,[89-90] targeted research to understand the mechanisms of decline (and thus identify approaches to reverse decline) was motivated,[91-92] and initiatives put in place to foster the uptake of management solutions by farmers.[93] Although the NZSD is hosted primarily and will be used most by growers and industry, its indirect influence through wider stakeholders, policymakers and regulators may build lasting benefits for farmers and protect their licence to farm and freedom to farm in their own way without undue regulation (Figure 1 and Figure 2).

Figure 3: Reasons for setting up a monitoring programme (adapted from Jones et al. 2011[13,83]**).**

Table 1: International monitoring initiatives reviewed to inform the design of New Zealand's Sustainability Dashboard's environmental monitoring framework[3], including their scope, key drivers (■) and spatial scales (•) for implementation.

			Key drivers			Spatial scales				
Code	**International initiative**	**Scope**	**Policy**	**Market assurance**	**Business improvement**	**Farm**	**Industry**	**Regional**	**National**	**International**
OECD	Organisation for Economic Co-operation & Development[15]	Sustainability	■						•	•
SAFA	Sustainability Assessment of Food & Agriculture Systems[16]	Sustainability	■	■	■	•	•	•	•	•
MP	Montreal Process Criteria and Indicators[72]	Sustainability	■	■	■		•		•	•
SAN	Sustainability Agriculture Network[73]	Sustainability	■	■	■	•	•			•
COSA	Committee on Sustainability Assessment[74]	Sustainability	■	■	■	•	•	•	•	•
UNIL	Unilever[29]	Sustainability		■	■	•	•			
FA	Food Alliance[75]	Sustainability		■		•	•			
LEAF	Linking Environment and Farming[76]	Sustainability		■	■		•		•	•
GRI	Global Reporting Initiative[77]	Sustainability			■		•			
RISE	Response-Inducing Sustainability Evaluation[78]	Sustainability			■	•	•			
EPI	Environmental Performance Index Framework[79]	Environment	■						•	•
BIOBIO	Biodiversity Indicators for European Farming Systems[80]	Environment	■			•	•	•	•	
BWI	WWF Biodiversity & Wine Initiative[81]	Environment		■	■	•	•			
CG	Conservation Grade[82]	Biodiversity		■					•	•

With increased pressure for accountability from the public, audits can be important for addressing multiple environmental governance issues.[13] Information on successes and failures of past interventions in relation to agreed goals and targets is necessary for improving future decision making. Conservationists have generally been poor at generating and using an evidence base about the efficacy of potential interventions.[94] Monitoring results can also be used by Non-Governmental Organisations (NGOs) to hold governments to account when national or international biodiversity commitments are broken; conversely, government agencies can use them to ensure a private company fulfils any statutory responsibilities with respect to local impact on the environment,[95] or to determine whether a landowner has delivered environmental benefits promised in exchange for payments under an agri-environment scheme. Information on the outcomes of management actions is also important to advocate for, inform and review policy, but is often lacking. For example, the European Court of Auditors recently found only patchy information was available for an assessment of the design and management of agri-environmental support measures.[80]

Environmental audits are useful for access to finance, internal business processes, membership of trade bodies and certification of products and services.[96] There is mounting public and consumer pressure to avoid 'greenwash' i.e. a form of spin in which green Public Relations or green marketing is deceptively used to promote the perception that an organization's products, aims or policies are environmentally friendly[188]. Tools and processes for independent environmental assessments of farm management practices and food products are therefore becoming increasingly important for 'eco-verification' and facilitating efficient business-to-business and business-to-consumer communication (Figure 2). Such tools also offer an opportunity for business improvement,[10] providing feedback and learning opportunities for industry- and grower-led initiatives, as well as prospects for enhancing efficiency and publicising achievements (e.g. zero-discharge targets or successful outcomes for restoration work).[iii] The NZSD is dedicated to achieving environmental sustainability, partly by improving business performance, so farmers can invest more in environmental protection and restoration, and partly by enhancing the marketability of those investments.[6]

A combination of environmental monitoring, diagnostic research, process-oriented research and the testing of management solutions would be ideal,[12,94,97] especially as New Zealand's agro-ecosystems have received comparatively little research at systems levels that transcend smaller-scale, focused inquires for maximising production and farming efficiency.[49,98] NZSD research is predominantly focussed on providing tools and information for immediate decision making, but it also incorporates strong learning-by-doing components. The development of decision support software (called 'What-if' decision support at ❾ in Figure 1) will also demand innovative model building, underpinned by inquiry about how sustainability indicators affect each other. Around 15% of the budget is retained for biodiversity process-oriented research in particular because meaningful indicator systems are generally less developed for biodiversity than biophysical components like carbon and water footprinting.[99-101]

Even though NZSD is focused primarily on immediate choices for more sustainable growing and production, we expect fundamental knowledge to emerge naturally and perhaps in surprising ways. While developing a sustainability assessment framework for audits, Unilever found the main advantage was not the emergence of a sustainability index itself, but increased knowledge and understanding of the agricultural and environmental interactions that emerged from discussion and assessment of the indicators.[29] The ARGOS programme also concentrated initial investments in monitoring what was happening on some 100 New Zealand farms chosen across a continuum from low to high production intensity and gradually shifted inquiry to understanding why differences were observed.[102,103] Shortage of research funds forces even sharper prioritisation of investments in the NZSD research. We view this as a useful driver to force applied relevance for farmers, industry

[iii] The Global Reporting Initiative[77] provides a useful example of using business incentives for driving sustainability.

managers and policymakers. We also are confident that useful knowledge, extending well beyond monitoring results and New Zealand's agriculture, will emerge.

Co-discovery by multiple stakeholders

Embracing diverse values and goals can only succeed if the process used to develop the framework and indicators is inclusive and collaborative.[104] Mostly quantitative measures will be selected to assess progress toward or away from shared land use, economic, ecological, social and governance goals.[17,105] Measures of indicators communicate information in a summary form about issues that are important to stakeholders. Therefore, the indicators and measures must not only match public and political needs, but also be analytically sound, measurable and easy to interpret. What works for one sector or ecological landscape may not help sustainability of a different sector. Taking a 'one size fits all' approach to designing a single NZSD would be risky, especially if it is generated mainly by consultants and researchers. NZSD's research plan and this report therefore focus initially on developing three prototype dashboards (kiwifruit, wine and Ngāi Tahu *Ahi Kā Kai* enterprises). They will be developed in a relatively independent way and will experiment with different software designs and tools. Creating a single NZSD and attempting to insert it within different sectors could undermine crucial participation and ownership of the participants and hosts who are co-designers rather than simple end-users. As lessons emerge, we expect subsequent development of dashboards for forestry, aquaculture, dairy, sheep & beef and organic farming (Figure 1) to be more efficient because they will incorporate successful core features developed for earlier dashboards. However, even the last one will have to involve new collaborators actively to tailor their dashboard to meet their needs.

Throughout the six-year NZSD project, we will advocate a co-discovery approach where scientists, consultants, industry facilitators and especially growers combine forces for an evolutionary design approach. Interaction and networking (Figure 2) ensures that the framework and its indicators will be: (1) locally grounded, (2) internationally relevant, (3) useful, relevant and affordable to insiders (especially growers their industry supporters) and (4) scientifically credible for reliable learning and engendering trust of insiders and outsiders alike.

The unusual feature and potential power of the NZSD is that it will provide a mechanism for aggregating and incorporating the knowledge and experience of practitioners, especially the growers, but also the industry representatives (policymakers, analysts, planners, managers).[iv] Practitioners can often know best how to manage land, plants, animals and people in production landscapes (**Error! Reference source not found.**). As stated in a 2007 *Nature* editorial:[106]

> *'Practitioners buy land, put up fences, set fires, put out fires, lobby politicians, negotiate with farmers, spray invasive weeds, poison rats and guard against poachers. These people are generally not conservation biologists: they are civil servants, environmental consultants, park managers or environmental lobbyists. Typically, practitioners make decisions based on personal experience and intuition. Their knowledge usually stays untapped by others — and can be impervious to fresh scientific findings'.*

The practical knowledge of farmers is rarely gathered together in systematic ways to challenge and augment lessons from agricultural science professionals. The NZSD is a recent example of a growing number of tools that can help bridge these divergent knowledge systems. "Citizen scientists" can amass lots of local information and, if channelled through appropriate crowd-sourcing tools, provide a bigger picture and more immediate information about biodiversity (Figure 5: Different ways of learning what to do). 'Participatory Action Research' (PAR)[107,108] formalises and accelerates ways

[iv] The industry facilitators are a valuable and special type of practitioner – ones that have an important influence on decisions and actions for securing ecosystem services, yet there are usually few ways that their knowledge is gathered, combined with formal research and communicated to everyone for improved environmental outcomes.

of learning directly from practitioners. NZSD is a very unusual form of PAR because it collects, integrates and feeds back structured information through computer-aided networking tools. Participation in monitoring and decision-making for biodiversity and ecosystem service enhancement is also the key to making long-term 'environmental citizens' from all types of knowledge holders.[109] Their environmental values, beliefs and awareness are key components of the social capital that is needed to protect and restore biodiversity and ecosystem services.

NZSD will gain strength from diversity, especially by pooling knowledge of different types. Different users (e.g. farmer, industry, government, NGO, consumer or academic body) tend to ask different questions of monitoring, depending on their needs or interests, with the purpose, in turn, defining which different approaches (i.e. what is measured) and methods (i.e. how it is measured) are more or less appropriate.[110] For example, some users may be interested in a specific aspect of biodiversity (such as a rare or threatened species), while others may be interested in the productive capacity of the agro-ecosystem (e.g. focusing on soil health or pollination status[111]).

Farmers, like many indigenous and local knowledge (ILK) holders, are immersed in the detail and nuances of a local place, community, culture and language[112] and are naturally motivated to sustain them.[113] This enables them to provide a grounded and deep critique of science from an insider's (emic) perspective and knowledge base. ILK holders are sometimes the only ones privy to crucial local or culturally/politically-sensitive information that determines whether anything will be done for biodiversity and ecosystem services or to mitigate poor land stewardship. Many scientists are extremely sceptical of ILK and involving practitioners in self-monitoring. Others may reframe this as an innovative strength of the whole NZSD that will strengthen rather than weaken scientific inference and help build what Arun Agrawal called 'environmentality': a shared governance and individual responsibility for more sustainable resource management[109].

Accelerating learning through active adaptive management

Farmers, like many practitioners, 'learn by doing' (scientists often call this 'adaptive management'). The idea is to place strong emphasis on learning about the effectiveness of farming while you are actually getting on with the job,[114-116] whereas science and agronomy make a job out of the learning itself. Adaptive management can lead to much more widespread testing of strategies and experimentation in more realistic settings (whole farms compared with experiments in some kiwifruit bays or vineyard blocks).[102] Management experiments can be mounted on much larger spatial scales than, say, sampling plots that are treated in different ways within a single paddock.[117] The costs of learning can be minimised[v] by integrating the interventions into day-to-day farming activities. Uptake and immediate application of lessons is already in place by the time the farmers have tried a range of options and chosen the winner that suits them or their land best. A potential advantage of adaptive management for sustainability is this 'local tuning' of solutions that are matched to the crucial 'sites of action' and governance: the whole farm, the owners and key decision makers, the capacity of the land, infrastructure and the skill of the farmers themselves.

[v] This applies as long as no large mistakes are made over wide areas. Most farmers experiment with new land management strategies in small parts of their farm and gradually shift their farming to the new way if things seem to work out.

Formal science most often takes a 'synchronic' approach to learning, within which lessons are divined from comparing short runs of data from a lot of different places. Farmers, a special type of ILK holder, most often learn from 'diachronic' data – long runs of information (sometimes spanning generations) from a relatively small area (their farm or neighbourhood). They may not learn much from faraway farms, but they will gain a much more nuanced and fine-grained understanding of what they need to do (or not do!) to be good farmers of their place. Synchronic and diachronic information are complementary.[118] The NZSD is an innovative tool for trying to harness the best from these two ways of learning. The feedback loop between regular monitoring and changed farm management (❽ in Figure 1) is the local source of learning: this is a diachronic approach. However, the progress and performance of faraway growers is brought to the attention of farm manager or owner by the instant reference to industry and regional benchmarks when they enter their own results (❼ in Figure 1): this is a synchronic approach.[vi]

The key to success of adaptive management is standardised, repeatable and efficient monitoring so that farmers can confidently track their own gains or losses from implementing new practices , and so they can compare their performance against that of others confidently and objectively. The very existence of the NZSD should encourage more experimentation and transition to improved performance by building confidence that both the costs and benefits of new approaches are being monitored and analysed by the software and industry champions.

Each sector's professional body[vii] will be another important site of learning for sustainability. Sector-level strategies for sustainability will drive the nature and shape of many of the new growing and marketing methods being honed by adaptive management within the various dashboards. A survey and choice modelling tool will be incorporated into the NZSDs to identify and quantify costs and benefits of competing strategies by polling consumers, growers, policymakers or scientists. However, the main lessons for the industry facilitators will come from interrogating, modelling, interpreting and reporting the aggregated sustainability KPIs (❻ in Figure 1). An overarching structure greatly hastens learning by doing. Experts distinguish between 'active adaptive management', in which a variety of competing interventions are trialled and replicated, and 'passive adaptive management', where experimentation is relatively *ad hoc*, sporadic and potentially localised.[119] The way farmers learned in the past has mainly been by passive adaptive management. ILK and Traditional Ecological Knowledge are considered to result from accumulation of a multitude of passive adaptive management lessons that are passed down over the generations by practitioners.[112,120] The NZSD provides an opportunity for the host industry body to formalise and accelerate this learning process for faster learning, risk management, collective safety and preparedness for their industry as a whole. This will be achieved in part by linking monitoring to existing smart-business strategic planning. However, tight linkage of precise indicators to inform those strategies can make learning faster and more reliable because of the far reach and efficient information gathering of each dashboard.

[vi] Similarly, decision support tools will guide farmers on optimal options for changing their farming (❾and ❿ in Figure 1). These tools are mainly generated from a synchronic research process deployed by agricultural scientists and consultants.

[vii] In the NZSD project these key bridging organisations include: ZESPRI and packhouses; New Zealand Wine and Sustainable Wine New Zealand; Ngāi Tahu; Aquaculture New Zealand; Biogro; Beef+Lamb

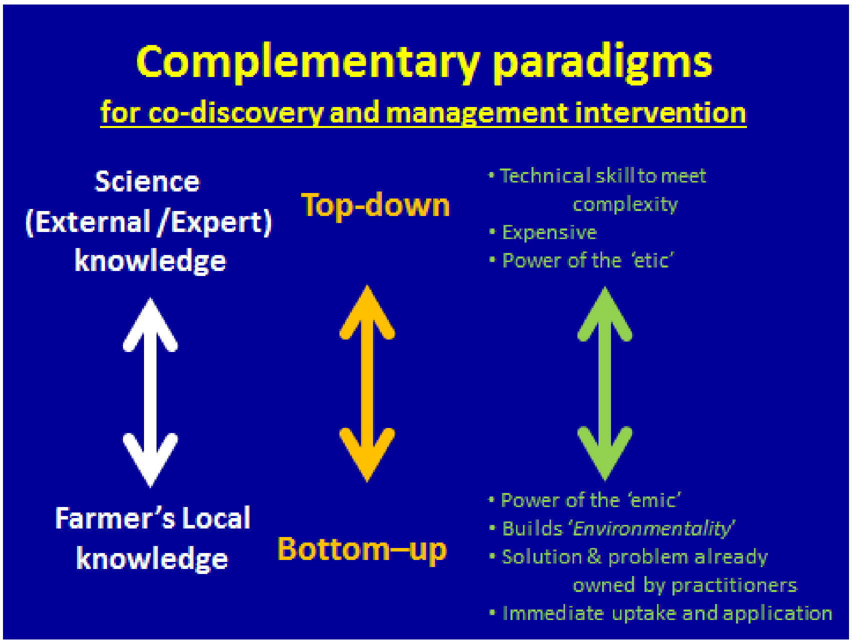


Figure 4: Combining the strengths of different ways of seeing and knowing

Partnership between indigenous and local knowledge holders and science can benefit both from emic/etic and top-down/bottom-up contributions. Partnership increases understanding and motivates active intervention to support or restore biodiversity and ecosystem services. (Adapted from Moller & Lyver in press.[114])

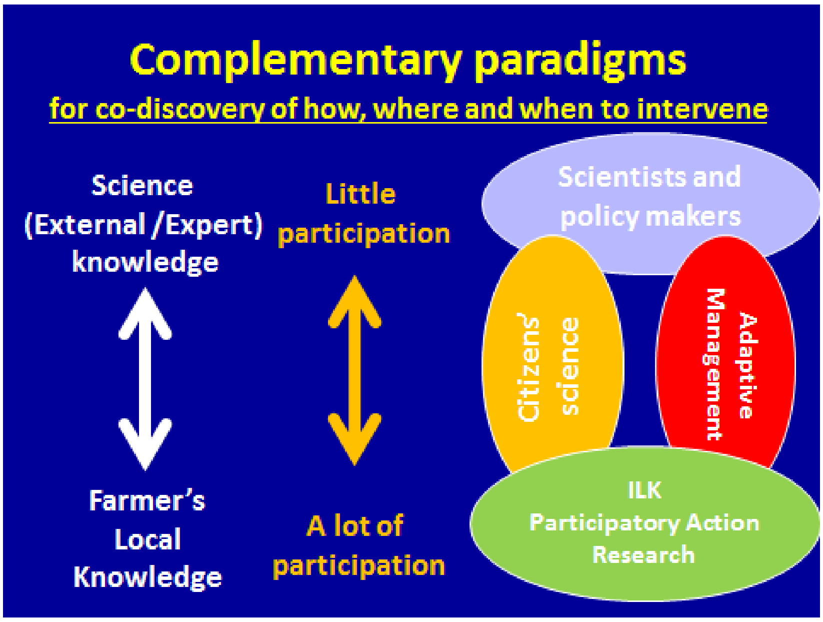


Figure 5: Different ways of learning what to do

A key to individual and local community support for biodiversity and ecosystem services is participation in ecological monitoring and application of their Indigenous and Local Knowledge to decide what to do, and then to learn from active intervention. The same learning-by-doing guides environmental managers, and citizens science contribute with local information. (Adapted from Moller & Lyver in press.[114])

Common criticisms of adaptive management by scientists include disappointment that management interventions (the 'experimental treatment' in a scientist's language) are not maintained for long enough, nor sufficiently replicated under similar conditions for the inferences to be reliable. The NZSD can be coupled with coherent industry-level interventions to drive a well-networked and complete group of growers in a certain direction, or to trial competing directions for a while before to identify the best management choice. It can also optimise industry-level investments for sustainability by showing what is working well now, or identifying when current attempts to transition in a desired direction are not happening. Hosting by the parent industry body, which will apply sound business planning principles to their NZSD, is likely to drive active experimentation, coherence, persistence and replication – all the features that are often missing from adaptive management programmes promulgated by government and administrative agencies.

The framework and its indicators must be updated continually if it is to help the dashboard's host industry prepare for future challenges. Monitoring for sustainability and resilience is fundamentally future-focused even though it learns by looking at current states and past trends. Resilience to ride out turbulence in world food supply and agricultural systems demands early warning. The best way of achieving that is by fostering a far-reaching and responsive information network, of which the dashboards can be part. Therefore, regular review of the indicator suite and dimensions of the sustainability framework is needed. Preoccupation with current perceptions of what is important to monitor may run the risk of being blindsided by the new threats (Box 1), or of missing opportunities and market leads when they first appear. Industry and government analysts, scientists and economists all play a valuable role in maintaining the wider watch in partnership with the growers monitoring at the local scale.

In summary, we expect that growers and key industry facilitators will provide the deeper 'emic' (insider) knowledge and action on the vineyard, orchard or farm and smarter strategic decision making in industry board rooms. If the growers and their industry champions are not in the driver's seat, the NZSD is most unlikely to last or be honed to the practical needs of the growers, and it most certainly will not trigger widespread learning for sustainability (Figure 4 and Figure 5).[viii] Researchers and consultants help complete the package by providing valuable 'etic' (outsider) guidance on threats and opportunities way beyond the farm, region and New Zealand.

Improving the New Zealand Sustainability Dashboard step by step

We have taken an iterative approach to developing the framework, indicators and measures for the dashboards (Figure 6). This allows staging and adjusted pacing for sustainability transitions and innovation. Abrupt and whole-scale change could unsettle many actors and challenge confidence and pride in progress to date (Box 1), and ultimately build apprehension and resistance. Going too fast is likely to invite mistakes and undermine credibility. Going too slow will build frustration and could even undermine collaboration in the monitoring endeavour, as well as expose the agriculture sector to existing and escalating risks from unsustainable practice. Nor can we assume we have got it right from the start.

[viii] Darnhofer et al. (2010)[30] argue that the local farm is the keystone for resilience even in a turbulent globalised world. The practical reality is that farm owners are the key decision makers. They may not be able to fully control what happens in far-off markets or national policy initiatives, but they are in charge of local responses and adaptive strategies to be better prepared and make the best of what comes at them from beyond their gate.

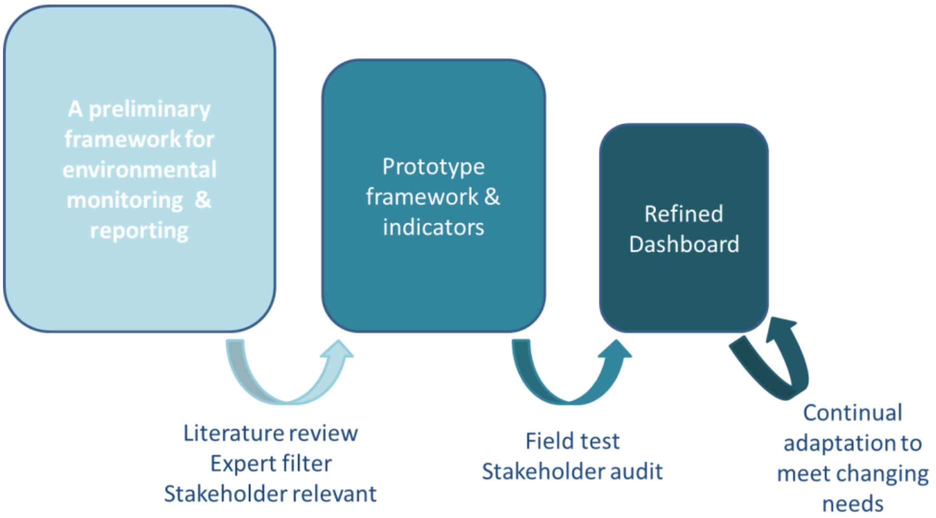


Figure 6: An iterative and interactive process of reviewing and filtering the monitoring framework and indicators design among researchers and stakeholders

(adapted from Herzog et al. 2012[80]).

Ultimately, monitoring is a practical activity that needs to blend as seamlessly as possible with efficient food and fibre production, so indicators need to be road-tested by the practitioners themselves. Accordingly, the NZSD has planned a set of milestones to mark progress towards development of prototype dashboards, followed by formal investigation of their strengths and weaknesses. Polling of the participants through the NZSD itself will focus on how to improve its performance and usefulness to the growers. These polls will be complemented by in-depth interviews before and in successive stages after deployment as the NZSD prototypes are perfected. Participation rates will be monitored automatically by the software to measure how many growers visit the NZSD site, which pages they consult and for how long and ultimately whether those using the NZSD change their farm management and outcomes more than those who hardly use it. Should the system indicate low levels of uptake, targeted interviewing and polling could be used to investigate causes and suggest solutions.

A gradual deepening and broadening of the scope of the dashboards is anticipated, but the formation of the relationships, trust and willingness to participate is just as important making smart choices of the actual content of prototype dashboards, their indicators, or the way we link them into a framework. A review of sustainability dashboards overseas identified many that seem to have sunk without trace once the research team that created them had completed design.[11] Embedding the dashboard into the 'community of practice'[121] and having that community take full ownership of its subsequent use and evolution is the key to the sustained use of the tool (Box 1).

What makes an ideal indicator and its measures?

Our review of selection criteria for indicators and their measures identified 23 main recommendations (Table 2). This next section considers the most important of these and their implications for the NZSD sustainability framework and indictors, and the measures chosen for each indicator.

Table 2: Quality design criteria of environmental indicators and their measures proposed for the New Zealand Sustainability Dashboards.

Section 'a' (this page) focuses on optimal criteria for individual indicators and their measures; Section 'b' (next page) focuses on optimal features of the entire set of indicators that are then incorporated into an assessment framework. (Sources – adapted and augmented from: OECD 2001;[15] Lee et al. 2005;[122] Sommerville et al. 2011;[123] Jones et al. 2012;[95] Herzog et al. 2012[80]).

Indicators	Criterion	Description
(a) Individual indicators and their measures	Policy-relevant and 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).
	By 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.
	By preference performance based	Where available and practical, it is better to measure performance towards target 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 and 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 specific, measurable, achievable, realisable and time-delimited (SMART) outcomes or critical thresholds of risk, performance or best professional practice.

Table 2 continued.

Indicators	Criterion	Description
(b) Sets of indicators	Representative	The set of indicators provides a representative picture of the pressures, status, responses, uses and capacity (coverage).
	Declare values and goals	Explicit definition of outcomes measured by 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 and 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 and 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.

Maximising relevance: Target monitoring at risks and benefits

One of the common ways of locking in relevance and prioritising what is to be measured is provided by the 'Response–Pressures–State–Benefit' (RPSB) framework, i.e.

- **Responses** – actions to prevent or reduce adverse environmental impacts (e.g. variation in agri-environmental expenditure aiming to reduce biodiversity loss).
- **Pressures** – threats to the environment that your responses aim to address (e.g. changes in the availability of farm management practices and the use of nutrients, pesticides, land and water).[ix]
- **State** – the condition of biodiversity and how it is changing (e.g. for soil, water, air, biodiversity, habitats and landscapes).
- **Benefits** – amount and change in the benefits and services that humans derive from biodiversity.

Although the RPSB framework provides a structure within which individual indicators can be placed in context (Box 1), indicators can sometimes overlap categories.[111,122]

A significant advantage of the RPSB framework for the NZSD is that it will lead farmers and facilitators to identify potential threats and what might be done about them to capture benefits of all sorts, including sustainability. Figure 7 provides an example for biodiversity conservation, but the system could equally guide policy and planning for market access preparedness, or rural community resilience. For example, the Agriculture Research Group On Sustainability has researched the use of iconic 'Market Flagship' species (in this case bird species) to promote consumer confidence in buying New Zealand produce.[125,126] New Zealand falcons support both marketing and pest control functions on vineyards in a similar way.[127]

The RPSB framework emphasises the need to include monitoring of benefits in order to incentivise monitoring investments and raise consciousness among all actors about the need for sustainability. The dashboards will ensure benefits by tight linkage of measures and indicators to higher order objectives, outcomes and pillar goals, but inclusion of some measurement of benefits could encourage participation and engagement in sustainability amongst some growers and processors that are initially sceptical of the business case for sustainability. An ultimate goal of the NZSD research team is to use the choice modelling and network of stakeholders connected by the NZSD to calculate the overall value of sustainability monitoring and management so as to incentivise ongoing use and adaptation of the tool.

Another relatively recent focus on the benefits of sustainable resource use and wise environmental management is provided by the 'Ecosystems Services' framework (Box 3). A sharp and apparently ongoing increase in the number of papers published in recent years[129] suggests that use of the ecosystems services terminology and categorisation of benefits is attracting interest within agricultural landscapes in particular.[130-135] Linking sustainability indicators to ecosystem services frameworks has been advocated.[136] Nevertheless some people have criticised the ecosystems services framework as being difficult to put into practice for land use decision making.[137-142] It has proved especially difficult to quantify the value of the services in monetary terms.[123,143-151]

[ix] Related frameworks are 'Driving–Force–State–Response'[15] 'Driving–Forces–Pressures–States–Impacts–Responses'. They distinguished between drivers, pressures and impacts, but these have now been combined into this single category 'pressures' within RPSB.

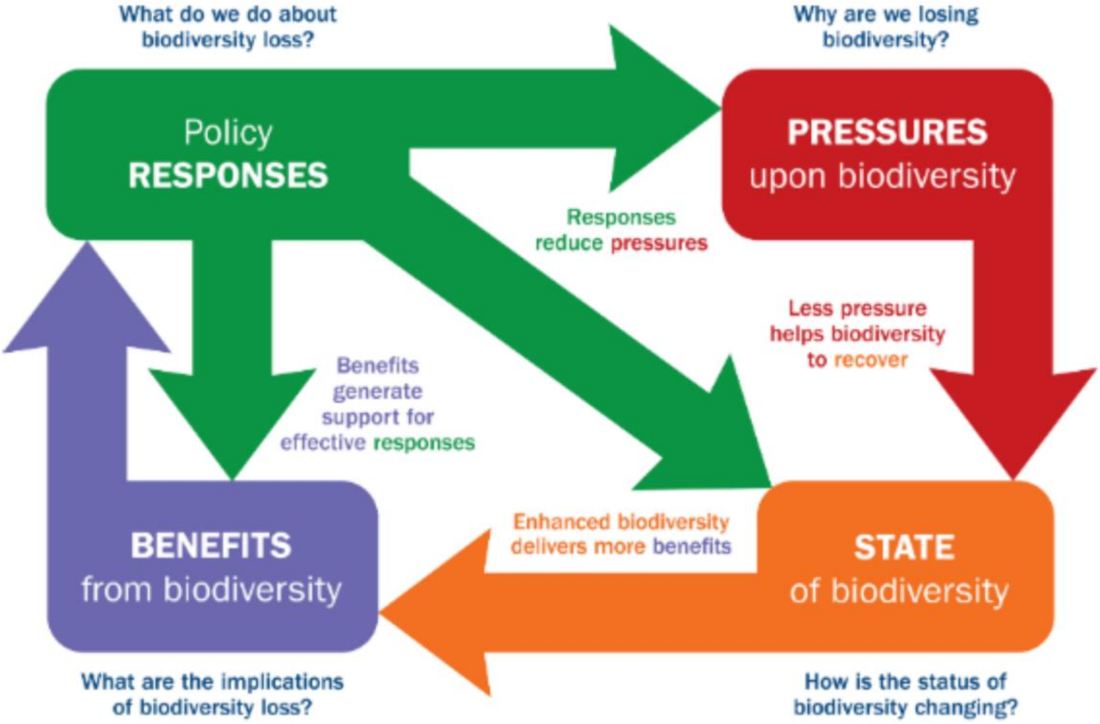


Figure 7: Linkages between policy and management actions and the state of and benefits derived from biodiversity.[128]

The NZSD will not structure its indicators and frameworks formally around RPSB or ecosystems services because we think they are somewhat abstract and generalised ways for prioritising what to measure. Ideal indicators need to be both relevant and meaningful to the main actors (Table 2). We would rather encourage farmer and stakeholder participation by defining indicators in farming and marketing terms that link to their own goals. Nevertheless the general principles of ecosystem services and RPSB typologies are useful for making sure that the NZSD indicators cover the bases and can be directly mapped to these international frameworks – it is just that we prefer to match the categories and language of the elements to be monitored to the way a grower and industry facilitator divide up the multiple challenges of growing grapes, kiwifruit or trees.

Another barrier to using the ecosystem services approach directly is that, apart from three brief studies,[152-154] very little research has been done in New Zealand to apply the approach. Until more research is done and methods of quantifying benefits are made simpler, we cannot quantify the direct benefits arising from ecosystem services in a holistic or sufficiently inclusive way within the dashboards. We hope that eventually ecosystem services will be quantified in direct terms for inclusion in future dashboards so that direct benefits can be quantified in dollar terms. In the meantime we deflect explicit use of that framework other than for a general-level gap analysis to make sure our simpler indicators and goals are aligned broadly with the ecosystem services recognised overseas.

Scientifically sound inferences for broad acceptability

Scientific inference begins with measurement in different places and times to test whether patterns or trends recur; and then proceeds to test ideas on why that pattern recurs. As far as practicable, scientists standardise how they measure things so that results are repeatable and comparable, no matter who does the measuring, where or why. There is broad-scale confidence that science is objective, so that the results have a verifiable 'truth' that transcends vested interests. The NZSD will contribute to 'eco-verification' of sustainability credentials by declaring methods and showing metrics to diverse and widespread stakeholders. The tool is dedicated to banishing 'greenwash' and thereby building trust and commitment of stakeholders ranging from New Zealand farmers and communities, to consumers in other countries or cultures, and all the actors along the world's food supply chains that join them together. Measurement and scientific interpretation accelerates learning and garners most trust from diverse stakeholders. Therefore NZSD will promote rigorous measurement of indicators whenever practicable and attempt to codify how they can be standardised. This is not to say that qualitative inferences are unreliable and have no place in the NZSD framework – indeed, several important aspects of sustainability will be unmeasurable in the sense that they cannot be reduced to a number or rank, yet still detectable by a whole suite of formal, respectable and useful qualitative methods. The latter must be included amongst sustainability assessments of NZSD host industries, even if they cannot be formally incorporated into the bulk of the dashboards' metrics. We are simply asserting that where an option to measure is available and practicable, we should seize the opportunity to measure it. Where measurement is unreliable, too costly, or cannot capture the essence of a factor, semi-quantitative and wholly qualitative scoring is more appropriate and far preferable to forcing quantification of the unquantifiable.

There is much more to science than just measuring. Good science and monitoring start with good questions, developed by: (1) using critical thinking, (2) building robust conceptual models of how ecosystems work, (3) testing 'true' policy questions of management relevance, (4) promoting open dialogue between scientists and managers, and (5) evaluating both designed and opportunistic study manipulations critically.[116] The NZSD focuses on farming transitions, on learning what needs to be changed or maintained to keep New Zealand agriculture resilient and sustainable – so the 'study manipulations' under consideration in our agenda are mainly changes in farming practice, industry interventions or government policy. We expect the dashboards to initially focus on meeting compliance requirements of production accreditation schemes and strategy development by industry (Figure 8). Later the dashboards could be used as a tool for efficient, scientifically defendable and well-structured management experiments to compare outcomes between panels of growers that test new production methods or sustainability interventions.

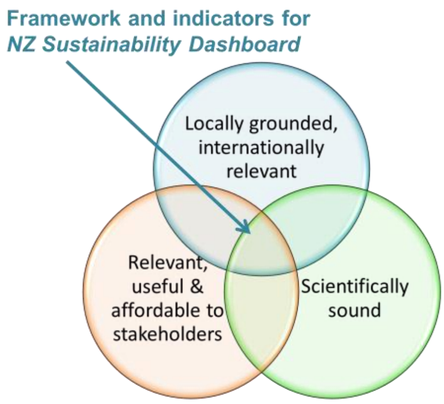


Figure 8: Criteria used to select environmental monitoring framework and indicators for the New Zealand Sustainability Dashboard.

Use just enough indicators

Several commentators have warned of the need to not saturate users by deploying too many indicators (Table 2). Information overload can weaken focus and confuse rather than assist management. Monitoring becomes time-consuming and understanding the nuances of many ways of scoring could be exhausting. Subtly different but similar indicators may appear to be asking the same thing and invite cynicism and belief among farmers that the system is wasting their valuable time. The design trade-off is to maintain wide coverage and relevance, yet keep the number of indicators to a minimum selection.

The need to have a small number of indicators is particularly acute in the NZSD case. If farmers are faced with a long list of reporting requirements they will be quickly discouraged, fatigued and are likely to become resistant rather than enthusiastic users of their NZSD. Worse, they may not take the multitude of indicators seriously and quality of scoring is likely to decline. New Zealand sheep & beef farmers and kiwifruit growers were found to be particularly sceptical and alienated by the large number of seemingly irrelevant compliance standards demanded by the EurepGAP supermarket audit scheme.[155,156]

The co-funders of the NZSD have been adamant that the tool must reduce rather than add to their members' reporting requirements.[157] It will be helpful to set a target limit on the time required per online session, month or year by each grower and then to use the automatic monitoring facilities of the software to measure how long each one actually took. Although the main risk is overloading growers, industry analysts also need to be protected – it is enormously time consuming and technically difficult to analyse, interpret and report swathes of interconnected data – so firm prioritisation and discipline is needed to collect just enough data on what is actually needed and then used.

Affordability and accreditation to maximise participation, coverage and statistical power

While some of the NZSD monitoring is likely to require skill and instrumentation to gather complex data, a strong emphasis will be placed on self-monitoring wherever feasible. Self-monitoring could provide unreliable information if farmers have a self-interest in reporting favourable outcomes or lack objectivity to score reliably. Building trust among external stakeholders depends on demonstrated neutrality in the way the indicators are framed and measured (Table 2). However, farmer-monitored indicators and associated networking with practitioners provide an unusual and potentially very valuable type of information for local tuning of sustainable management.

Participation in the NZSD will be linked to affiliation with a particular brand or market accreditation protocol. For example, accreditation by Sustainable Wine New Zealand[2] (SWNZ) already forces reporting of 'scorecards'[158,159] and 'spray diaries'. This will now be automated via NZSD. Compliance with ZESPRI's KiwiGreen accreditation is mandatory for growers that wish to export their kiwifruit. We hope that many of the functions of the NZSD being developed for ZESPRI and several packhouses will assist KiwiGreen compliance and reporting needs. Ngāi Tahu will use their dashboard to underscore and add market value to their whānau businesses by certifying the cultural authenticity of their products. The industry and market networks will therefore incentivise enrolment and greatly accelerate use of the dashboards. Already over 95% of wine growers and processors are affiliated to SWNZ, so we can expect instant and national coverage in monitoring using their NZSD. This immediately makes scientific interpretation of many of the results much more reliable:

- Normal constraints on statistical power from limited replication are released.

- Complete enumeration of indicators and their variation means representativeness of the information for the entire industry is no longer in question.
- Less precise indicators are needed to establish national-level average performance levels because so many growers or producers replicate the same metrics.
- More rapid feedback and benchmarking are possible because all neighbouring enterprises in the same sector are contributing.
- Management experiments are statistically powerful and so will detect even very small improvements in farming outcomes i.e. the dashboard's database and longitudinal model provides strong statistical power to measure shifts in farm outcomes by using a Before-After-Control-Impact (BACI) analysis. The complete coverage of sampling by the dashboard allows very strong inference because the control group within the BACI is virtually complete.
- There is no doubt about the 'domain of inference' from analysing indicators – the complete national picture has been revealed.

Technically demanding or time-consuming measurements cannot be performed by farmers and so will be relatively expensive. The NZSD researchers will prioritise investments in these more complex indicators and suggest a subset of orchards, vineyards and farms for monitoring. Investment in deployment of expert monitoring teams on vineyards, orchards, forests and farms may be needed for these specialised indicators. Collaboration with regional councils and Department of Conservation and other agricultural sector groups could help defray these costs.

Mix performance, practice and proxy indicators to improve affordability

Indicators can be broadly divided into three types: performance, practice and context indicators. The first group is sometimes further divided into 'Key Performance Indicators (KPIs)' and other less important performance measures[x]; 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.[xi]

Performance-based indicators quantify progress towards outcomes and so are considered by most observers to be more reliable guides for sustainability. However, they are often expensive and technically demanding to measure, and full statistical analysis for reliable interpretation requires specialised skills. In many circumstances, especially when guiding smaller farming enterprises and where self-monitoring by growers is the only available approach, performance-based indicators will be impractical. Also, performance indicators are usually narrowly focused on single components of a farming system.[xii] Sometimes there is value in monitoring the practice of growers at a more holistic and generalised level, usually by scoring the actions that are expected to promote 'good' or sustainable outcomes.[xiii] For example, OECD considers that having a farm plan promotes

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[x] Some sustainability assessmsnt professionals prefer to use the term 'outcome-based' indicators rather than performance-based indicators because the former can precipitate defensiveness amongst some participants (C. Jones, pers. comm.).

[xi] Other ways of distinguishing between indicator types have been suggested. For example, Gasparatos and Scolobig (2012)[32] argue that there are three broad categories of assessment tools – monetary, biophysical, and indicator-based – and warn that guidelines and criteria on how to choose between these tools are lacking. Assumptions made by each type are highly value laden. We have not used this approach because we think it confuses detail of the currency used (a how-to-monitor issue) and targets of measurement as though they themselves are not indicators of bigger agro-ecosystem interactions.

[xii] Measurement drives a form of scientific reductionism which is by nature very different from the integrated and practice-based approach that farmers and industry facilitators apply to the world.

[xiii] Deployment of precision agriculture, minimum till, soil tests or nutrient budgeting to plan soil fertilisation are all examples of potential practice-based indicators.

sustainability and so scores the presence or absence of a plan as an indicator in itself. This begs the questions of what sort of plan is used, whether the actual actions nominated in the plan are put into practice, and whether those actions genuinely trigger improved outcomes.

By their nature, practice-based indicators are monitoring farm management inputs and activities, not necessarily outputs or outcomes. Aside from ease of monitoring, their advantage is that they are configured in the way that farmers see the world and organise their decision making. This makes them holistic or at least multifaceted and, in the minds of growers, directly linked to expected beneficial outcomes and planning. Scoring practice-based indicators is therefore likely to be satisfying for the growers and will reinforce sound practice and raise consciousness about sustainability principles in general. Incorporating some broad practice-based scores can maximise coverage of the overall sustainability framework while avoiding saturation and complexity and so help keep the overall number of indicators as low as possible (Table 1).

Practice- and performance-based indicators can be combined (as illustrated by the hypothetical example in Figure 9) to ask generalised questions like:

1. What proportion of farmers in different sectors and soil types use quantitative soil tests and follow their recommendations?
2. Do farmers that follow soil testing recommendations more closely than others:
    a. Produce more?
    b. Profit more (i.e. is the cost of soil fertilisation more than recouped by extra production?)?
    c. Pollute more?
3. Are farmers more likely to invest in fertilisers in times of financial buoyancy?

The highly quantified indicators from soil tests (Figure 10 and Figure 11) are performance based and sufficiently detailed to fine-tune soil management, to optimise short-term production and/or guide longer term strategies, to build soil quality on their specific property.[160,161] However, the soil test data are very much linked to local soil type and climate and therefore cannot be reliably used to benchmark performance against that of other farmers. The mix of performance- and practice-based scores like those in Figure 9 loses specificity but gains generalisability and universality for wider benchmarking.

NZSD will deploy a judicious mix of performance- and practice-based indicators as directed by the dashboard host industries to best meet their participants' needs. Expected associations between KPIs and practise-based indicators will be tested as the NZSD database deepens. However, eco-verification will demand that we also cross-check whether the most important performance-based indicators are genuinely correlated with desired outcomes for sustainability expected from best practice activities. This will require detailed and in-depth study on a subset of orchards, vineyards and farms that form the test panels for perfecting NZSD prototypes.

Sometimes indicators are a type of proxy measure to track a much bigger aspect of an ecosystem that is more difficult to measure directly. Particular 'indicator species' are sometimes monitored as proxies for a whole suite of biodiversity.[162,163] For example, forest managers in the north-west United States measure woodpeckers,[164] a conspicuous bird that makes tree holes and so whose numbers are closely correlated with the number of tree hollows. The latter are extremely difficult to quantify, but are crucial components of forest habitat quality for retaining the woodpeckers themselves, endangered spotted owls and supporting a whole raft of other biota.[165] Sometimes particularly conspicuous and sensitive guilds of species are monitored as a way of detecting change in parts of food webs that are more difficult to measure. For instance, insect-feeding birds are top predators in food chains and easier to monitor than the vast array of invertebrates that they

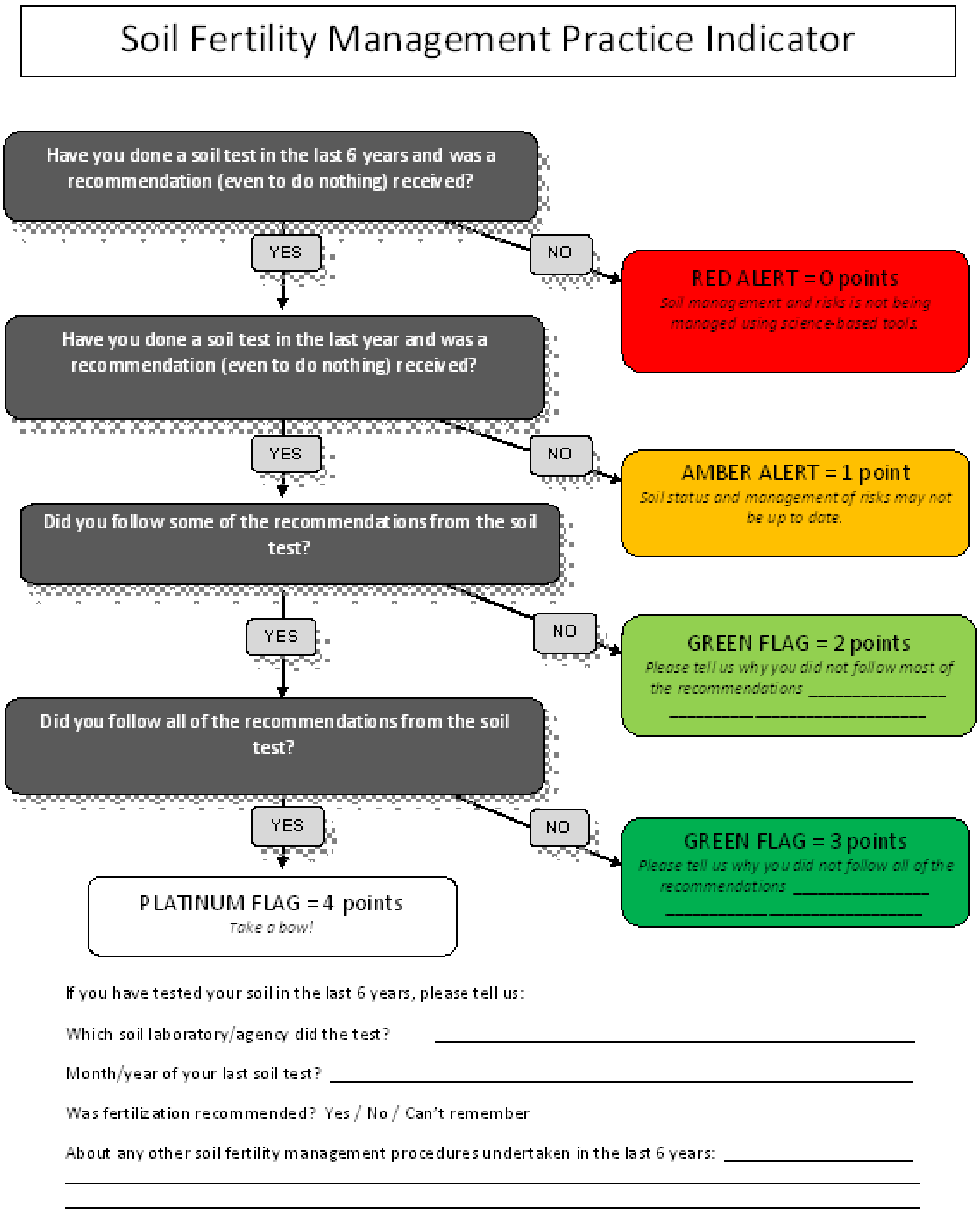

Figure 9: An example of mixing quantitative and qualitative processes in a practice-based indicator.

This generalises the indicator and focuses the grower onto keeping soil quality measures up to date and responding to the results of several quantitative soil indicators. Some of the relevant data may be uploaded automatically from soil test laboratory databases provided that the growers permit access.

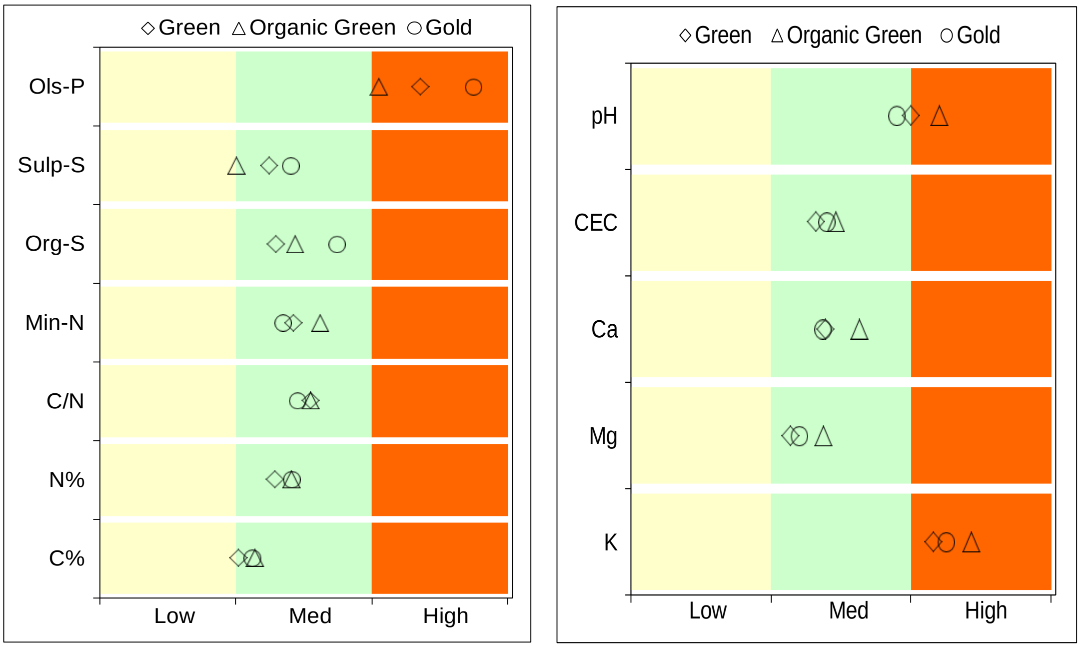

Figure 10: Soil quality results for kiwifruit orchards in the ARGOS programme, relative to established benchmarks for New Zealand agriculture.

(Source: Benge et al. 2010.[168])

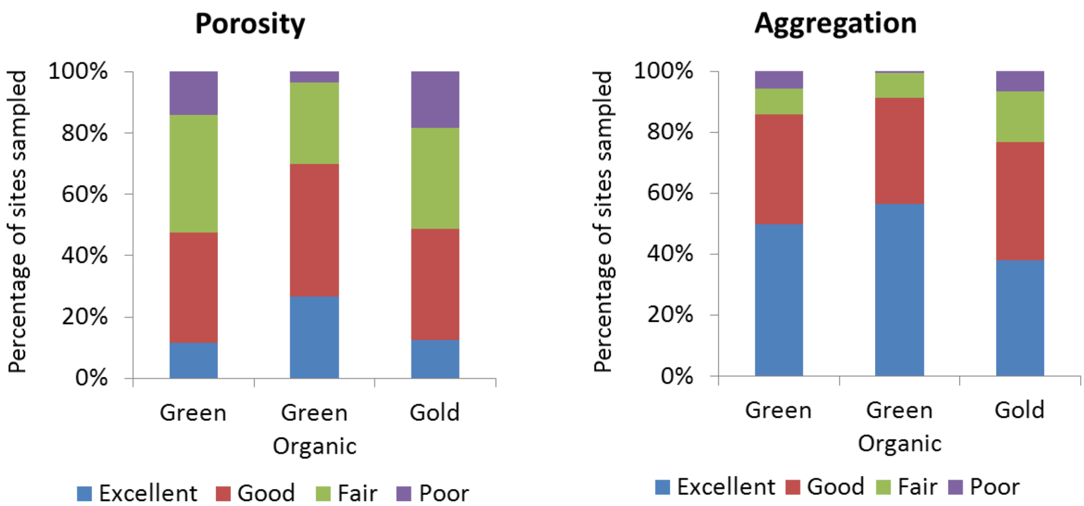

Figure 11: Soil structure results for kiwifruit orchards in the ARGOS programme using visual soil assessments.

Soil quality is scored on very simple ordinal scales that are linked to broad-scale normative claims of 'excellent' through to 'poor' status. (Source: Benge et al. 2010.[168])

eat, and, similarly, measures of plant biodiversity can be used as indirect predictors of invertebrate abundance.[166,167]

The NZSD researchers and participating industries will identify proxy indicators to short-circuit measurement and lighten the burden on growers. Some follow-up process-oriented research on a set of focal vineyards, orchards and farms will be needed to check that any such proxies are reliable indicators of the target agro-ecosystem process. Consultation with the dashboard hosts and research will start in 2014 on developing proxy measures for biodiversity based on broad-scale habitat characteristics measured at landscape levels and perhaps informed by remote sensing.

Adding value by combining data, modelling and qualitative research

An agri-environmental indicator is 'a summary measure combining raw data on something identified as important' to stakeholders (e.g. soil erosion rates) and combining those data with other context information to make them interpretable and useful'.[xiv] The complexity of indicators is spread along a continuum:

1. Primary raw data gathered for the NZSD or other monitoring agenda (e.g. change in agricultural land area on a farm).
2. Secondary measures calculated from simple formulas to link and cross-reference indicators from different parts of the dashboard (e.g. conversion of the quantities of several different fuel types into a common currency of energy content,[169] or a common toxicity score for pesticides[170]).
3. Aggregated or hierarchically-structured combinations of smaller indicators into a composite score for a given vineyard or orchard.
4. Composite indicators that scale data form the farm against information gathered elsewhere by other agencies (e.g. climate data from nearby NIWA weather stations could be used to calculate fruit production per 'degree day' or 'per mm rain' at a crucial time of the year).
5. Indicators predicted from technically complex models that use the raw scores from (1) above as input values (e.g. a nitrogen balance indicator calculated from Overseer®, which is calculated using a complete input–output equation determined from other research).

Combining metrics into single indicators on a common currency, as in (2) above, is extremely useful for benchmarking and comparisons between sectors and farming systems.[15] Scientific methods may be needed to establish equivalencies to a common unit of measure, but several standard conversion factors are already available for energy and nutrient contents to allow calculations of nutrient fluxes. Other common currencies used by ecologists include biomass[xv] and land area itself as an input variable. Dollar values can bring divergent investments into common metrics, and output per hour of a farmer's working day is a comparatively neglected but potentially important universal currency for calculating composite indicators.[171]

An advantage of the online feature of the dashboards is their ability to calculate these secondary or aggregate indicators behind the scenes and instantly reflect them back to the growers for benchmarking and interpretation. The software will interface with other databases to automatically gather useful contextual or interpretative data[172]. The grower is then able to see a much more comprehensive and integrated set of indicators from the raw data that she or he enters for their own

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[xiv] as defined by OECD.[15]

[xv] Sometimes a 'Biomass Return Ratio' is calculated. It measures the proportion of biomass on a farm that is returned to the land rather than extracted as produce or transfered off the farm as waste. Decomposition of the retained biomass supports nutrient cycling and biodiversity on the farm.

farm. The industry can formalise, declare and defend the precise way that the secondary and aggregated indicators are calculated and time is saved for all participants.

Context indicators reflect the state of the economic, social or environmental situation of the territory in which a farming/fishing/ forestry enterprise is situated.[xvi] They underpin standards that establish 'limits' for an enterprise operating within a territory. For example, each territory will have different limits for water use based upon the rainfall, water storage capacity, soils, etc., specific to the territory. However, each territory may also establish standards common to other territories nationally, or internationally. For example standards for greenhouse gas emissions or labour have international consistency and relevance.

Many context indicators to be used in the dashboards are specific data for each farm (e.g. their regional or production area, the type of produce grown, area of the farm, altitude, soil type, ownership model). We need a large number of extra pieces of information to interpret results, benchmark performance and build models of what determines key components like farming efficiency or profit.[xvii] Fortunately, many of these added data will only need to be answered once, or at least very occasionally, so we envision a slightly added burden in reporting when growers first enrol in the NZSD. Thereafter they would only be prompted every year to indicate if anything has changed. The vast majority of participants could skip that section of reporting, and only the few that have modified their land use or grape or fruit varieties would be drawn into detailed description of their new circumstances.

Formal interviewing and subsequent qualitative analysis provides a rich context for why farmers act in a given way, how they interpret information (including indicators and sustainability frameworks) and what their individual management goals are. Semi-structured interviews can be used to score semi-quantitative indicators, or more simply to gather crucial information to interpret other indicators. For example, the BioBio Indicator project used interviews to learn about details of genetic and farm management strategies.[81]

Aggregating multiple measures into a higher level measure

Composite measures are increasingly used in monitoring programmes as a way of simplifying a lot of information into fewer and more holistic indices.[173-175] Sometimes these go as far as to combine disparate measurement systems into a single overall score like an environmental sustainability index[176] or an ecosystem well-being index.[177] Farmers in Switzerland can use a 'scoring with biodiversity' system that totals credit points by applying 34 different biodiversity-favouring farming measures.[178]

A default option is to give each contributing score, however trivial its subject, equal importance in determining the final aggregate score. However, more useful aggregates may result from weighting those components considered most critical for attaining the monitoring framework's goals.[111] Sometimes the total for several less important scores is <u>multiplied</u> by (rather than added to) the score allocated to a more important component. For instance, interviews with 100 customary fishers in Te Waipounamu (South Island, New Zealand) emphasised that contamination with sewage trumps all other considerations of the cultural health of near-shore marine ecosystems as far as the kaitiaki (Māori environmental guardians) are concerned (Box 4).[179] Even if there are abundant pāua[xviii] and

[xvi] This and the following description of context indicators was provided by Dr John Reid (*In litt*., 5 April 2013).

[xvii] The logical place to gather such contextual variables into the dashboards is via the Governance indicator sections.

[xviii] Abalone, *Heliotis iris*

sign of the population replacing itself, the locals consider the population completely soiled and of zero cultural value if contaminated by human waste.

Some of the hierarchical scoring systems, like the one illustrated in Figure 9 for instance, build in weightings indirectly. In that instance, having done a recent soil test, even if the recommendations were not followed, scores higher than an old one that might well have led to fertiliser application. Weighting itself introduces subjectivity and either assumes systems' certainty or implicit relative value statements about what contributes most to environmental health or sustainability. Many kaitiaki (Māori environmental guardians) emphasise the importance of particular 'taonga' (treasured) species,[xix,180,181] so the Ngāi Tahu Marine Cultural Health Index weights the scores of the taonga species as being more important than secondary kai (food) species when calculating a 'Cultural Species Richness' index of biodiversity (Box 4). It is standard practice to consult with stakeholders about any weights to be assigned.

The goal of aggregated scores is to provide a coarse-scale indicator of overall progress towards very broadly stated goals or performance criteria. The aggregated indices may be particularly attractive to practitioners like farmers or customary harvesters who do not routinely reduce farming or wild food gathering to several disaggregated and quantified components in the way a scientist usually tries to do. Critics highlight the danger of placing too much confidence in a single figure generated by several subjective methods, or a grade with no associated units. Normally these scores are ranged along an 'ordinal scale' (we can assert that 3 is more than a 2, but not by how much). They must be treated with extreme caution in statistical hypothesis testing and interpreted within very broad limits.[182] Some critics assert that they never should be added together or multiplied.[xx] As different stakeholders emphasise different dimensions of sustainability,[15] professional practice or underlying values,[32,111] aggregating the scores into a few holistic indices could undermine pluralism, trust and participation.

There is value in monitoring 'first order variability' in all indicators[13,15] to understand the system in detail even if aggregated scores are calculated later. At the very least, the dashboards must standardise individual component scoring methods as much as practicable and store the component results so that they can be treated separately, weighted differently or combined in new and more appropriate ways later (Table 2).

We expect that simple aggregated indices have considerable potential utility in motivating practitioners to take steps in broadly sustainable directions. Therefore we recommend that some are trialled and interviews with stakeholders are directed towards understanding their acceptance and trust of such coarse indicators. In view of the strong scientific criticisms of the way they have been abused, we advocate a careful empirical approach to calibrating them against a whole host of continuous quantitative indicators and deeper qualitative inferences to test their veracity. Here we will be using the NZSD as a Participatory Action Research platform to test, calibrate and refine aggregated semi-quantitative scoring systems. A panel of intensively studied vineyards, orchards, farms and forests will be used to calibrate and test the courser aggregated and semi-quantitative indicators that use ordinal scales.

[xix] Cristancho & Vining (2004)[180] and Garibaldi & Turner (2004)[181] term these particularly important animals and plants as 'cultural keystone species', i.e. species that maintain social and cultural links between local communities and their place, reinforce kinship, promote identity and trigger continuance of knowledge and environmental care.
[xx] Hubbard (2009)[182] broadly labels such schemes for semi-quantitative risk assessments as 'worse than useless'.

Sensitive indicators to maximise control, learning and verification

Learning and reliability of farm management changes for sustainability will increase if indicators and their measures are 'sensitive', i.e. if change in the indicator is large and immediately detectable following change in practice even though the alteration in a state variable(e.g. land use, productivity, economic performance, or biodiversity, etc.) is relatively slight . Thus sensitivity concerns the strength of the signal to those monitoring an agro-ecosystem.

High sensitivity is determined by three main criteria: (i) the precision of the method used to measure an indicator, (ii) the 'specificity' of the response of the indicator and (iii) the immediacy of the response to the perturbation. If the indicator is affected by only one factor and that is the key process that managers are wishing to monitor, the indicator can be considered quite specific. If response in the indicator immediately follows a perturbation, it will closely track and give early warning of the threat or opportunity. In practice many ecological interactions are indirect, delayed or buffered by a myriad of feedback loops and emergent properties of ecosystems.[186,187] Therefore (i) changes in one element of an ecosystem (perhaps a chosen indicator) can by caused by changes in several other elements (not necessarily what the farmer or industry wish to track); and/or (ii) the effect on the indicator may be quite delayed so that the signal for learning or warning is lost and intervention may be too late to prevent environmental degradation;[xxi] and/or (iii) the degree of change in an indicator may not be directly proportional to the degree of change that is of primary concern to farmers.[xxii, 118] This last complication is potentially troublesome because a slight change in the indicator may actually be signalling a huge change in the system at one time or place, but the reverse elsewhere or at a different time on the same farm.

Targets and thresholds: keys to raising sustainability performance

Like most effective management systems, clever farming demands effective planning and predetermined trigger points for investment interventions where and when needed.[189] Higher order vision statements set the general direction and build consensus and collaborative effort among all actors. Strategic goals are slightly more specific but still not sufficiently detailed to lay out a roadmap of how to achieve the goals. The Convention on Biological Diversity's (CBD) nested arrangement of planning statements to restore biodiversity is an excellent example of higher level goal setting (Box 5). However, short-term tactical decision-making to transition towards those goals requires declaration of much more specific objectives (the CBD lists 20 of them). 'SMART' objectives are **S**pecific, **M**easureable, **A**ction-oriented, **R**ealisable and **T**ime-delimited.[xxiii] Best-management-practice sets slightly ambitious but still realisable objectives so as to stretch actors and draw them on to improved performance – a gradual 'raising of the bar' for sustainability. If objectives are too ambitious, confidence and credibility of actors is undermined; if objectives are too easy to achieve, they put agriculture at danger by planning for mediocre performance and making actors overconfident and complacent.

[xxi] Considerable blurring of associations between an indicator and some critical component for resilience and sustainability can therefore be expected and fundamental research and understanding of the agri-ecosystem is required to assess the specificity, immediacy and overall sensitivity of each indicator. Calibration studies that measure precision, specificity, proportionality and overall sensitivity are important and may be needed for scientific evaluation of the most important indicators adopted by the NZSDs.

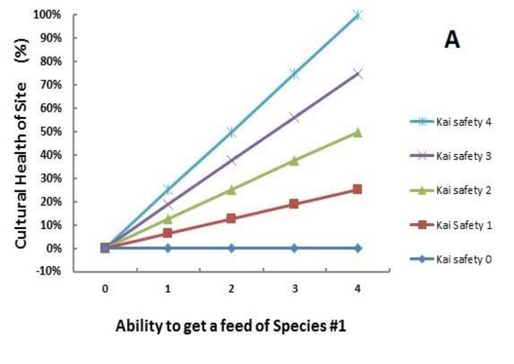
[xxii] By directly proportional we mean that a 60% change in an indicator would be registered if there was a corresponding 60% change in the agro-ecosystem state variable of interest. One way of detecting non-proportionality is to research and describe a 'calibration curve' between the indicator and the thing it is trying to estimate. If that calibration curve is not linear, the indicator will not change in an even (proportional) way over the range that it is seen to vary. See Moller et al. (2004)[118] for examples of common departures from linear calibration functions.

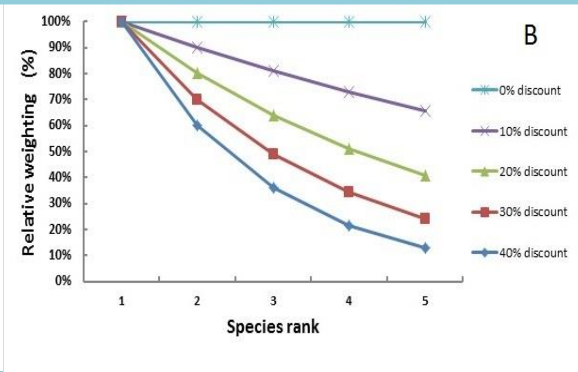
[xxiii] These criteria are outlined by Perring et al. (2011)[66] from earlier management best practice guidelines, except they substituted 'ambitious' for 'action oriented'.

Box 4: The Ngāi Tahu Marine Cultural Health Index[179]

Kaitiaki (environmental guardians) from across New Zealand have voiced deepening concerns about the depleted state of some in-shore fisheries and ecosystems, especially diminishing abundance of some *taonga* (treasured) species.[183,113] A Marine Cultural Health Index (MCHI) monitoring toolkit has been developed to enable Ngāi Tahu to establish restoration targets and sustainable *mahinga kai*[xxiv] harvest strategies within their *taiāpure*, *mātaitai*, and other coastal protection areas.[xxv,184,185] The toolkit, derived from local and traditional knowledge of 100 informants, will allow communities to independently, inexpensively, and robustly assess the state of their *rohe moana*, monitor changes in marine ecosystem health over time, and measure effectiveness of local fishing rules and reseeding strategies. The indicators link to cultural health and continuance as well as ecosystem health as part of a wider paradigm of 'biocultural conservation'.

The Key Cultural Indicators are set in a hierarchical structure, each being given a score (0–4) that signals varying degrees of alerts. '*Kai safety*' and '*Ability to get a feed*' are the highest weighted indicators, followed by *'Taste and condition of kai (food) species'*, and '*Replacement of kai'*. '*Habitat Threats and Quality Indicators'* include supplementary threats such as water clarity, sedimentation and invasive species. The main determinant of an aggregated score of the 'Species Cultural Health' is availability of healthy food for harvest by everyone, including elders and people without specialised equipment (Figure A).





Marae (traditional Māori meeting places) have particular species that are linked to their identity and *manaakitanga* (hosting and providing for guests), so surveyors are asked to choose their most highly prized kai species for this evaluation. 'Cultural Species Richness' is scored as the number of those favoured species present at a gathering site. An overall 'Cultural Health' score for each traditional gathering site depends on an assumed discount rate when further kai species are included (Figure B). At zero weighting, the health of the most important cultural species is given the same importance as the 5th ranked species when calculating the overall site's cultural health; if a 40% discount rate is used, the 5th species has only a 13% influence on the overall cultural health of the site, i.e. it may be abundant and showing signs of recruitment, taste good and be thriving in a secure habitat, but if the most favoured species is depleted or failing, the health of the 5th species has little effect on the perceived health of the site. Appropriate weightings will be discovered retrospectively once the main users have trialed the MCHI and its correspondence with their overall sense of the ability of the site to sustain their culture, community and people.

Once the stand-alone prototype MCHI has been sufficiently field-tested it will be fully incorporated into the Ngāi Tahu *State of the Takiwā* database and reporting procedures. These types of culturally nuanced indicators are ideologically based, subjective and can only be scored by locals with an intimate knowledge of their place. This makes them very different in design and operation from indicators following the design criteria in Table 2, but ideally suited for guiding local management seeking to protect and restore highly prized cultural values.

[xxiv] *Mahinga kai* literally means the places where food is collected, but it is increasingly generalised to refer to the kai (food) resources and the practice of customary food gathering itself.

[xxv] Taiāpure and mātaitai are established and managed by local communities primarily for customary harvest, but the locals assume a multitude of environmental health restoration and advocacy strategies as well.

Box 5: Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets

Biodiversity is 'the variety of life on Earth and the natural patterns it forms'. Parties to the Convention on Biological Diversity, gathering in 2010 in Nagoya, Japan, adopted a 10-year framework for action by all countries and stakeholders to save biodiversity and enhance its benefits for people.[191] The strategic plan comprises a shared vision, a mission, five strategic goals and 20 'ambitious yet achievable' targets.

Vision:

'By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people.'

Mission:

'Take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the variety of life and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of the utilisation of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values are mainstreamed, appropriate policies are effectively implemented, and decision making is based on sound science and the precautionary approach.'

Strategic Goals:

Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society.

- Reduce the direct pressures on biodiversity and promote sustainable use.
- Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity.
- Enhance the benefits to all from biodiversity and ecosystem services.
- Enhance implementation through participatory planning, knowledge management and capacity building.

Examples of Targets:

- By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes.
- By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.
- By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
- By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas.
- By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

Indicators that measure outcomes provide specificity and measure current state of an agro-ecosystem, but by themselves are unlikely to incentivise change or add sustainability to farming unless they are coupled with equally specific and measureable targets. Sometimes the objective will be to achieve a new target state, or to maintain agro-ecosystem indicators within agreed and quite specific limits that safeguard sustainability.[190] Soil quality measures are commonly-used examples of the latter (Figure 10).

In some circumstances progress towards a target itself becomes an indicator. For example, the OECD suggests that tracking the rate of progress towards achieving nationally agreed targets is a more universal and reliable benchmark to compare performance of different countries than tracking more specific metrics that only apply or have relevance to a particular social, economic or farming system.[15] A similar 'progress towards goals' indicator has been advocated for monitoring success in restoring diverse ecosystems.[115]

Measuring indicators without reference to targets, safe boundaries or thresholds could simply measure our progress towards collapse of agriculture's sustainability or resilience. A lack of scientifically defendable and explicit targets and thresholds for indicators is one source of scepticism that monitoring sustainability is just measurement for measurement's sake.[1,105] The dilemma is that erecting meaningful and defendable targets demands a lot more systems-level knowledge than is currently available. Some commentators have asserted that humanity has already passed 'tipping points' in three planetary boundaries (climate change, biodiversity loss and disrupted nitrogen cycling) so that widespread and unstoppable systems-level change is now inevitable.[50,192] However, these broad claims for having breached systems limits are not coupled with verifiable and quite specific indicator thresholds that could signal tipping, transformation or collapse.

There are internationally accepted thresholds for species conservation risk and ecosystem restoration interventions (Box 6)[193-195] but the rationale for setting these is somewhat arbitrary. Most require more detail than currently is available to apply them immediately to New Zealand's agro-ecosystems. The brown kiwi is a threatened species that is partially dependent on a mosaic of pine and native forest patches embedded within production landscapes of the North Island. Its recovery is guided partly by formal population modelling, but even here the risks being managed are predominantly predation of chicks by introduced small mammals rather than potential impacts of farming on the kiwi.[196,197] We know of no formal population viability analysis for threatened species (or valued agro-biodiversity) in New Zealand's production landscapes and only a few are in place for endangered (mainly bird) species elsewhere in New Zealand, so the types of dynamic thresholds deployed overseas (Box 6) cannot yet be operationalised in the dashboards.

The NZSD research team may need to invest more in researching targets and thresholds in future, but in the first instance will suggest simple, realisable but slightly optimistic targets for change in the direction considered to be generally desirable according to normative claims of what is 'good' and 'bad' farming. Setting these targets will rely a lot on the practical knowledge and experience of the growers and industry facilitators of what can be achieved rather than by reference to externally derived and scientifically-based knowledge (Figure 4 and Figure 5). We will force declaration of 'Green', 'Amber' and 'Red' alert levels from the outset, but we expect continuous adjustment of these as better information becomes available, partly from NZSDs themselves. Although there is a huge international literature on environmental indicators that we have reviewed here for NZSD development, the sobering reality is that rationales and generic models for setting the targets and thresholds to drive transition are either impractical, or inappropriate or unknown.

Box 6: Setting thresholds and timelines for raising conservation alerts

Static approaches include measures of 'population status' (e.g. population size and range) against threshold measures and, at a community level, proportions of species that meet specified management targets.

For example, classify species according to thresholds specified under the IUCN Red List classification system. New Zealand's Department of Conservation operates a New Zealand threat classification system[198] that integrates information on current population size and trends in abundance over the past 10 years.[199] It is necessarily based on broad criteria rather than formal quantification of extinction risk, so it is mainly useful for prioritising interventions.

Dynamic approaches include the tallying of such numbers or proportions of species in various categories and monitoring changes in status of these assemblages over time. It is important to specify what levels of trend and within what confidence intervals the system aims to detect.

The IUCN system, for example, raises an 'amber' alert about a population if it declines by 25% over 25 years and a 'red' alert if it declines by >50% over 25 years.
The NeoTropical Migratory Bird Conservation Program, for example, defined an effective monitoring system as one that has 90% chance of detecting a 50% decline in a species' abundance over 25 years.

Assessments with respect to previously identified thresholds can also **combine both static and dynamic variables**, such as in 'Alerts' approaches where sets of quantitative population criteria are used to place species on a 'red', 'amber' or 'green' alert.

The UK bird 'Alert' listing criteria, for example, assess global conservation status, historical population decline, recent population decline (numbers and geographical range), European conservation status, rarity, localised distribution, and international importance of populations.

Linking indicators to standards: increasing relevance or dumbing down monitoring?

Standards are established, explicit and precise sets of requirements for business practice and product quality (Box 7).[95] Most agricultural industries have adopted standards to mitigate their impact on the environment, assure quality and meet statutory requirements (like operational health and safety standards for their employees). As farmers are increasingly expected to meet these standards, there is an obvious need for dashboards to incorporate and embrace the standards, reinforce them and communicate compliance levels.

The fastest and most efficient way to integrate NZSD indicators with standards is to build them into practice-based scores around compliance. For example, a kiwifruit grower could be asked directly 'Did you meet all the KiwiGreen™ integrated pest management procedures in the past season?' More usefully, the industry facilitators and auditors could automatically populate or interface their compliance inspection results with their NZSD. The scope of the Dashboard's coverage will thereby be greatly increased because the standards themselves are wide ranging. The Dashboard can also report to the individual growers and aggregate compliance scores at regional and industry levels or for different aspects of fruit production (e.g. soil management, phyto-sanitary needs, labour relations). An overall score for meeting the required and optional best practice standards will greatly spread the scope of the issues covered by an NZSD without adding time and reporting burdens on the growers themselves. The instantaneous feedback of a grower's compliance score benchmarked against industry levels will help reinforce the relevance of the standards.

The second major way of integrating compliance needs into NZSD's framework is to use the standards as the very same critical thresholds or targets for specific indicators to guide management, score performance or trigger interventions.

We expect integration with standards to begin by using them as practice-based indicators, but then to be followed by working towards rewriting standards in ways that link them to specific KPIs.

It is important to remember that all food and fibre production standards by themselves are not necessarily indicators of sustainability. They have normally been chosen for a mixture of legislative and practical marketing reasons that support narrow regulatory and administrative agendas. The need to define a standard in very precise and static terms makes them rigid and binary scores (did a farmer meet the standard or not?) which have relatively limited power for learning and monitoring progress compared with continuous variables used for many other sustainability indicators. The NZSD therefore needs to go well beyond mere scoring and communicating compliance with regulations, even though it can start by mapping its selection of indicators to the traditional milestones codified by the industry as minimum performance thresholds. A fundamental strategy of the NZSD is to turn compliance into a learning activity and this will require indicators that build off, but not be imprisoned by, the existing standards. New Zealand hosts of NZSD could consider having their systems accredited by some of these international systems to assist trust building.

Measuring trends is often enough

Nearly all monitoring systems assess sustainability primarily by monitoring trends in KPIs.[203,204] Proxy indicators or 'relative indices'[xxvi] may be all that is needed to detect trends. Measures of absolute value will always be the scientific ideal because there is less chance that confounding variables have

[xxvi] For example, wildlife managers often measure abundance of pests as a relative index (e.g. the number or rats caught per 100 trap nights) rather than the absolute abundance (rats per hectare).

Box 7: Standards and certification procedures for improved sustainability

The international Organisation for Standardisation[200] has provided a wide array of voluntary environmental and food and fibre production standards which help inform the NZSD design.

Environmental claims made by companies themselves must meet the requirements of ISO 14021, which covers the use of particular words and symbols and specific requirements about accuracy, relevance, explanation and verification of claims.

- Independently-audited ecolabels that meet ISO 14024 standards are given a 'seal of approval' and issued a licence to use their ecolabel logo on products or services.
- Environmental declarations are ecolabels that meet ISO 14025 standards that codify principles and procedures. They provide 'eco-profiles' or 'report cards' allowing buyers to compare the performance of competing products. They are based on publicly available product category rules, operated by third parties and involve independent audits.

A recent review[97] of 36 environmental standards over eight business sectors, including 12 agricultural standards, highlighted the challenge that standard-setting organisations face when trying to safeguard biodiversity in particular: they need to go into sufficient depth for a wide range of issues without producing excessively complicated schemes which themselves create barriers to compliance. For biodiversity they advocate:

- Adopt internationally recognised definitions (e.g. IUCN Red List of Threatened Species)
- Avoid the displacement of threats
- Include modified habitats
- Provide guidance on operation inside protected areas
- Recognise Indigenous and Community Conserved Areas
- Safeguard priority conservation areas
- Adopt the mitigation hierarchy and 'no net loss' approaches
- Certification

There is growing scientific evidence that eco-labelling can lead to improved sustainability through ethical consumer choice, but several challenges remain:[201]

- Criteria of the labels too often focus on single attributes and impact areas
- Lack of consideration of holistic effects can lead to unintended and unwelcome social, economic and environmental effects
- Labels focus on short-term impacts but need to consider an LCA approach
- Too few consumers are aware of subtle distinctions between criteria and differential impacts
- There is a lack of eco-verification of claimed benefits
- There are too many ecolabels to track
- There is a need to transition from single-attribute of highly specialised products to multi-attribute indexing of heterogeneous product categories
- Communication, marketing and verification must be led by an international coalition of government, industry, NGOs and consumers.

New Zealand primary producers are rapidly adopting a wide range of market accreditation systems.[202] The NZSD will help integrate a wider range of these into an overarching framework and hopefully will allow stronger benchmarking between their systems.

altered the association between an index and the absolute value[xxvii,205] and because they can be used in many additional ways for modelling and prediction. However, measuring absolute values[xxviii] is usually much more expensive and technically difficult compared with measuring relative indices or proxy indicators. In the interests of affordability (Table 2) and promoting participation by practitioners (Figure 5), the NZSD prefers relative and simple indices of current state variables and will concentrate most on detecting whether these change at sufficient rates to capture opportunity and warn of threats to sustainability. Where a relative index is considered important for measuring farming

[xxvii] For example, mice increase their activity and so are caught more often when rats are removed (Brown et al. 1996),[205] so the relationship between mice caught per 100 trap nights and absolute density (mice per hectare) is very different according to whether rats are present and abundant or not.
[xxviii] Or say a complete energy budget rather than a proxy for them.

sustainability, we will build in ‘calibration’ studies that cross-check the index against what it purports to measure.[120,205]

Both relative indices and absolute measures are powerful tools for detecting trends provided that they are relatively precise (Figure 12). Bias has little meaning in the context of using a relative index for detecting trends in sustainability KPIs because it is never expected that they measure an absolute value. An absolute measure must be both accurate and not biased if it is to be used for prediction or benchmarking, but even a biased absolute measure is useful for trend detection provided it remains precise (i.e. constantly biased). For example, ‘Five-minute bird counts’, the most commonly applied bird monitoring technique in New Zealand,[206] cannot measure differences in bird abundance and diversity between habitats reliably, but it can detect long-term changes in one place if done consistently.[207] Absolute bird abundance measures are much more technically difficult to deploy,[208] but they can be better compared across habitats or between farming systems.[209-211]

It will nearly always pay to fix sampling sites in place and use repeated measures if the primary goal is to estimate trends (Box 1). This arises because sampling over and again in the same sites reduces the scope for spatial variation in confounding factors to interfere with interpretation of change. Sometimes the suite of sites needs to be refreshed or augmented to account for changing circumstances (e.g. distributions of biodiversity or land uses), or to track ecological succession that is patchy or cyclical.[xxix]

Repeating measurement by the same individuals (rather than just at the same places) also increases power to detect trends. One wine grower may well score a given semi-quantitative indicator in a slightly different way from his/her neighbour, but provided those differences remain about constant over the years, each can detect trends reliably on his/her own place and even compare the rates of change each is experiencing. However, they cannot compare their own performance with each other reliably by using the indicator score.

Trend detection across the whole sector can tolerate a lot more scatter in the results provided the panel and measurers remain consistently different from each other in the way they score and provided that the panel of measurers remains about the same. The most important safety feature of the NZSD is the way that nearly all, or at least a large number of growers will participate from within each sector, so the emphasis shifts away from maximising accuracy and precision to maintaining consistency.

Reliable detection of trends is partly dependent on sample precision, partly on spatial and temporal variation (e.g. interannual variation in weed abundance or biodiversity), and partly on how long the monitoring has been maintained. The NZSD is putting considerable emphasis on developing a ‘Power Analysis Tool Pack’ (❺ in Figure 1) so that sampling investments can be optimised by balancing several competing priorities:

- Detecting trends early enough (amber alerts) to avoid irreversible or expensive damage to agro-ecosystems
- Demonstrating reliably that compliance boundaries (red alerts or trigger points for interventions) have or have not been breached
- Avoiding false alarms or complacency

[xxix] For example, if plots are established across a mosaic of patches at different stages of succession, directional change will inevitably be detected by repeated measures. Appearance of new patches at first stages of succession in disturbance sites will not be included if only the original stratified selection of monitoring sites is sampled over the years. Similarly, a new land use or farm operation may enter the industry and not be captured by the original selection of repeated sampling sites. A rota or regular schedule of review and updating of sampling sites is needed even if most of the sampling uses the repeated-measures approach to more effectively detect trends.

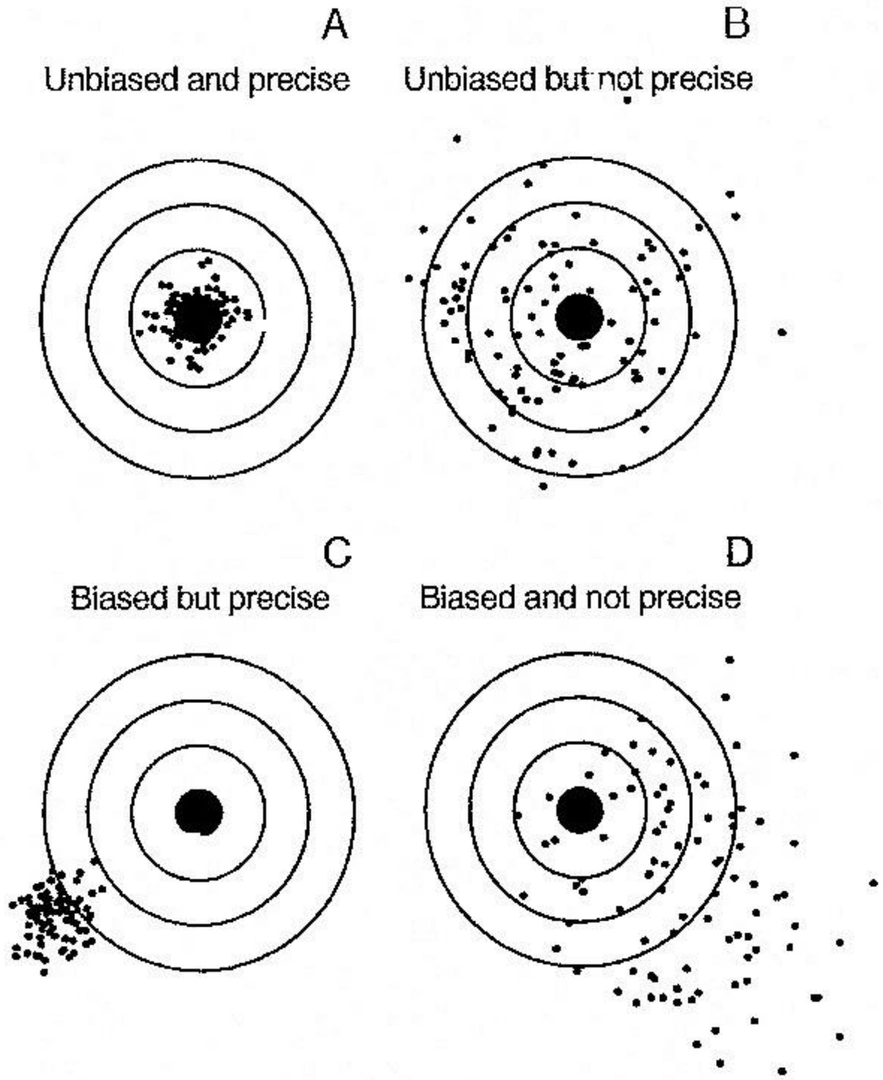


Figure 12: Accuracy and precision are quite different things – sometimes precision is more important than accuracy of an indicator for understanding agro-ecosystem change.

Accuracy is usually also more expensive to achieve and may not be needed for many management issues. The key is to understand and measure accuracy and precision and to interpret results within the NZSD in the light of their reliable limits. (Source: Morrison et al. 2001.[212])

- Maximising the precision of benchmarking of the performance of a vineyard, orchard, farm or forest
- Remaining aware of uncertainty by estimating its bounds rigorously
- Minimising cost of monitoring by making it just sufficiently frequent and intensive to gain sufficiently reliable inferences
- Minimising the amount of time and effort that growers and industry representatives put into monitoring
- Predicting which indicators need more repeated measures than others, and which ones can be dropped for a while to concentrate on the next most important indicators, i.e. we recommend that an optimal rotation of indictors is designed using the Power Analysis

Tool Pack so that the overall scope of the indicators and framework can be maximised while containing the impost on the participants.

The intensity of sampling chosen will be a trade-off between the statistical constraints measured by the power simulation tool and variation in how fast the focal process changes or varies. Fluctuation in nutrient and pesticide runoff from agricultural land into rivers, lakes and marine water can occur rapidly within hours/days. However, accumulation over much longer periods in groundwater (months/years) must be captured. Parts of soil quality change only very gradually, so sampling can be less frequent but still safe.

Sometimes the variability in a key variable is an indicator in itself, such as the frequency and intensity of shocks like floods, drought and fires. In those instances a near-continuous sampling watch will be needed in order to score the frequency of rare but important events.

Complete enumeration of a particular indicator in all vineyards greatly reduces the need for precision and/or accuracy for some monitoring agendas. Nevertheless it will be important to maximise accuracy and precision of indicators for benchmarking and learning, model building and trend analysis, to understand how the system works, or to guide individual farms, orchards and vineyards on optimal interventions. The next phase of the NZSD is development and field testing of field instructions and manuals to make measurement by different growers as standardised as possible to facilitate benchmarking between growers.

Long-term datasets are extremely valuable

The longer measurement of a standardised set of indicators is maintained, the more valuable the database is for detecting gradual degradation or threats, and putting rare or unexpected events into context (Recommendations 2, 6, 8 and 9 in Box 1; Figure 3). The costs of setting up a monitoring framework are usually high and there is some delay before benefits from long-term data acquisition can be realised. Consequently there is a vulnerable intermediate period where commitment to the ongoing monitoring is more likely to falter (Figure 13). The NZSD will manage this risk by building in some historical data that so far have been relatively inaccessible to individual growers and industry (Box 1). For example, soil monitoring results are archived in databases by soil testing laboratories that may be accessible to the NZSD so that current soil quality can be compared with trends over the past decade or longer.[213] A clear and effective demonstration of the anticipated benefits of long-term monitoring effort will be sought from the outset to ensure stakeholder support through this potentially ‘vulnerable’ stage. Strong leadership and a tight focus on core questions or business are needed to maintain long-term monitoring.[214,215] Long-term records are only interpretable if they are continuous and if measurement methods, definitions of categories and stipulations of what is to be included or excluded from calculation are kept consistent. For example, interpretation of long-term changes in macro-indicators of New Zealand agricultural intensity between 1960 and 2000 was severely hampered by changes in definitions and inadequate historical records of the methodological shifts.[216] If the records are discontinued, some longer term trend analyses can be severely compromised.[217]

Invest heavily in careful database management

A common mistake is to commit too few resources to database management.[214,218,219] A rough rule of thumb is that 25% of the budget for long-term monitoring programmes should be dedicated to data management and archiving (Table 2).

It is extremely difficult for newcomers to interpret past data reliably, so there needs to be a meticulous log of any protocol changes and shifts in context variables of participating farms. Constant referral to and use of the indicator databases being incorporated into the dashboards reduces the risk that the archives go cold and cannot be interpreted later. A large part of the commitment of host industries to their NZSD will be in ongoing maintenance and enrichment of the underlying database and this will best be managed by their in-house IT support teams.

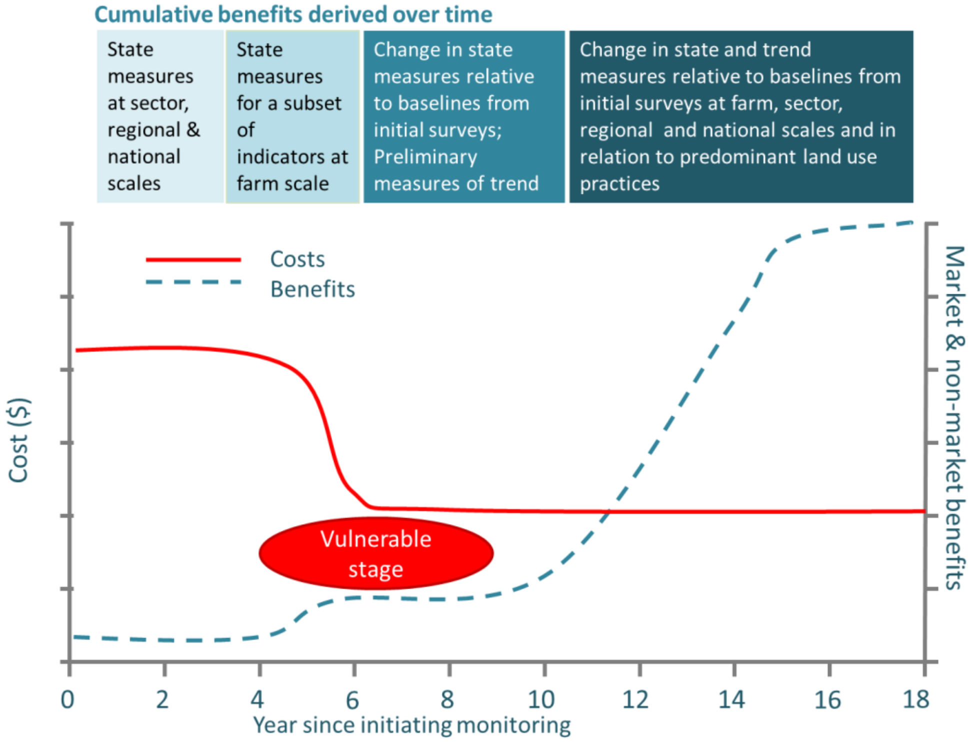


Figure 13: Stylised timeline of costs and benefits for environmental monitoring, assuming that sampling will start in earnest in the fourth year and the first change data are available in year 6.

Start-up costs are higher than ongoing costs, with the vulnerable stage being from year 4 to 8 when the sampling locations are being set up but the change information is not yet available. Benefits increase rapidly as the locations are reassessed, but reach an asymptote at some stage in the future. (Figure adapted from Watson & Novelly 2004.[219])

Nested spatial scales: internationally relevant and locally grounded

The spatial scales of interventions and policy setting need to match the scale of the social–ecological forces that determine outcomes. Ecological processes, for example biodiversity status, on a farm may be determined more by what happens in the surrounding ecological landscape than what the farmers do on their land[220-222]. Management and policy must therefore focus on the wider landscape if intervention is needed.[223-227] For example, there is little point in a farmer investing in pest control in a bush remnant to promote native plants and animals if removal of bush from the whole surrounding catchment or region has severed ecological flows to and from that local bush patch. Local farmers may well change their farming to reduce greenhouse gas emissions for ethical, moral or marketing reasons, but the practical reality is that no matter what they do, tangible changes to climate change impacts on their prosperity and productivity will happen (or be mitigated) because of actions (or inaction) in societies and economies well beyond their orchard gates (Figure 14).

The spatial scale of ecological capacities and flows will ultimately trump governance considerations (like ownership, regulation and rule of law, policy spheres of influence) to determine potential outcomes for biodiversity, land care and biophysical capacity for production of food and fibre. However, social and political scales of influence set policy interventions like subsidisation or instigation of agri-environmental schemes. In the New Zealand neoliberal paradigm, a private land ownership model leaves farmers to carry nearly all the costs of environmental care even though some of the benefits are undoubtedly public, but also vast freedom and responsibility with farmers to decide how much (or little) they spend to provide environmental care.[39]

Unified and integrated control of environmental threats and opportunities can be most effective when economic, social and ecological scales of influence match each other and are managed together.[224,228] In practice they are nearly all operating at different spatial levels and interventions and responses to them work at very different paces. Indicators and frameworks can provide important ‘cross-scale linkage’ to facilitate this integration and identification of effective management responses. For example, the abundance and diversity of stream invertebrates is partly determined by local (farm scale) management[229] and partly by catchment-level landscape features in South Island sheep & beef farms.[230] The indicators must work over large areas and the compartments nested within them. They must be sensitive to monitor both fast and slow system feedbacks. Nested hierarchies (small areas embedded within large ones, fast responses embedded within slower cycles of change) force a need for dashboards to use indicators that can be aggregated upwards from farm level to inform catchment, regional, national and sometimes even international scales; and for daily, seasonal, annual or decadal trends to be calculated from databases. Our indicators and framework must be internationally relevant, yet locally grounded (Figure 8). Selection of locally appropriate goals, indicators and audit processes are needed to assess whether a specified management goal is being met or not.[231] Locally grounded frameworks and indicators are particularly important in the NZSD case because full participation by growers is needed and will not last unless they see its relevance to themselves and their land and ecology.

Aggregation demands standardisation and consistency at the lowest relevant spatial and temporal scales being monitored, maintenance of consistent long-term procedures, and efficient data manipulation and statistical rigour. Aggregation upward is usually not simply a matter of calculating averages over successively larger areas or longer periods. Sampling indicators must be appropriate and representative within each scale and this often requires stratification of where information is gathered and how measurements are taken. Additional information is sometimes needed to scale upwards. For example, measuring forest bird abundance in a catchment or region requires appropriate bird monitoring to be accurate even in small patches like those commonly found on farms. This requires a very different statistical treatment and counting method than that used in continuous forest.[208,210,232] Successful aggregation requires additional catchment-level measures of forest cover and monitoring of how those mosaics of habitat types change over long periods.

Up-scaling also forces deployment of more generally defined indicators. For example, habitat mapping surveys should include standardised and generic typologies that cover many land uses.[234] Standardised landscape-level indicators of habitat connectivity have been developed.[235,236] Remote-sensing methods can capture and calculate indicators at landscape and regional levels (Box 8), so it is important that the NZSD calibrates many of its own vineyard, orchard and farm-level measurements with coarser indicators derived from satellites. The power of remote sensing is well recognised for its role in monitoring at large spatial scales where ground-based monitoring would be prohibitively expensive.[13]

Technology to support interpretation and measuring of habitat features from these data are improving, but there is a gap between what can be sensed remotely and the data available in New Zealand so far. For example, measures of trends in extent or composition of woody vegetation are not current available. Certainly, aerial and satellite-based remote-sensing means we can accurately measure extent and spatial configurations of distinctive landscape elements (e.g. forest, grassland and wetlands) and provide important contextual information.[122]

Several spatial models and associated indicators of land-cover and habitat configurations have been developed and tested over the past 15 years.[236-238] Indigenous and Local Knowledge systems have emphasised the need to manage the entire landscape,[237,238] e.g. Māori stress the need to monitor and manage *Ki uta, ki tai* – from the mountains to sea.[239]

The NZSD will facilitate automated aggregation and reporting to regional and national agencies (❻ in Figure 1), but it is targeted primarily at informing what is happening (❼ and ❽) and what to do (❾ and ❿) on individual vineyards, orchards, farms and forests. Where possible, we will design indicators that can be successfully upscaled, but where compromise is forced, optimal design for serving growers and agricultural sector needs must take precedence.

Prospects for an effective New Zealand Sustainability Dashboard?

This review and similar ones completed recently by our colleagues in the NZSD research team[3-10] have all highlighted considerable challenges and opportunities for designing and implementing effective sustainability monitoring of New Zealand agriculture. New Zealand agro-ecosystems, global food supply chains and international economic forces are linked to form a complex adaptive system. This system is turbulent, poorly understood and lacks coordinated communication and risk management. The NZSD will reconnect multiple 'layers and players'[246] and attempt to combine compliance, reporting and learning into a complete package.[157]

Avoiding getting bogged down by complexity

The complexity and breadth of the exercise could precipitate 'paralysis by analysis,' so we advocate an iterative design process that starts small and gradually spreads and deepens the NZSD coverage. Designing an effective monitoring tool is rather like building a model of a system – the key challenge is to reduce complexity to the barest minimum yet still be able to describe the system adequately (Box 9). There are hundreds of potential sustainability indicators,[xxx] but how few can the NZSD get away with? What is the optimum trajectory to build the indicator set for NZSD without overwhelming the main participants (the growers and industry facilitators)? The exacting scientific disciplines of prescription, measurement and reductionism are both opportunities (for trust building and more reliable knowledge for learning) and threats to success of dashboards (by wrenching its processes out of the hands of farmers and their more naturally integrated and holistic way of looking at the world). Over-prescribing the design criteria will undermine the tool's applicability and adaptability, just as relaxing scientific rigour too much will risk standardisation and 'greenwash'.

Sustaining participation by keeping costs down and rapid feedback

The NZSD is as much a social networking tool as an eco-verification, marketing, communication and learning device.[248,249] It may take time to build trust and participation among some farmers, industry facilitators, marketers and consumers. Full participation and lasting engagement depends primarily on the Dashboard's benefits outweighing its costs for the growers and industry. Compulsory participation in Dashboard reporting to earn membership of an accreditation system will facilitate start-up and greatly assist scientific interpretation of data. However, forced participation could quickly turn to resistance and cynical form filling rather than critical self-analysis and learning by the growers if they do not see the NZSD as relevant and practical.

[xxx] Our preliminary list of ones for consideration in the NZSD included more than 150 potential measures.

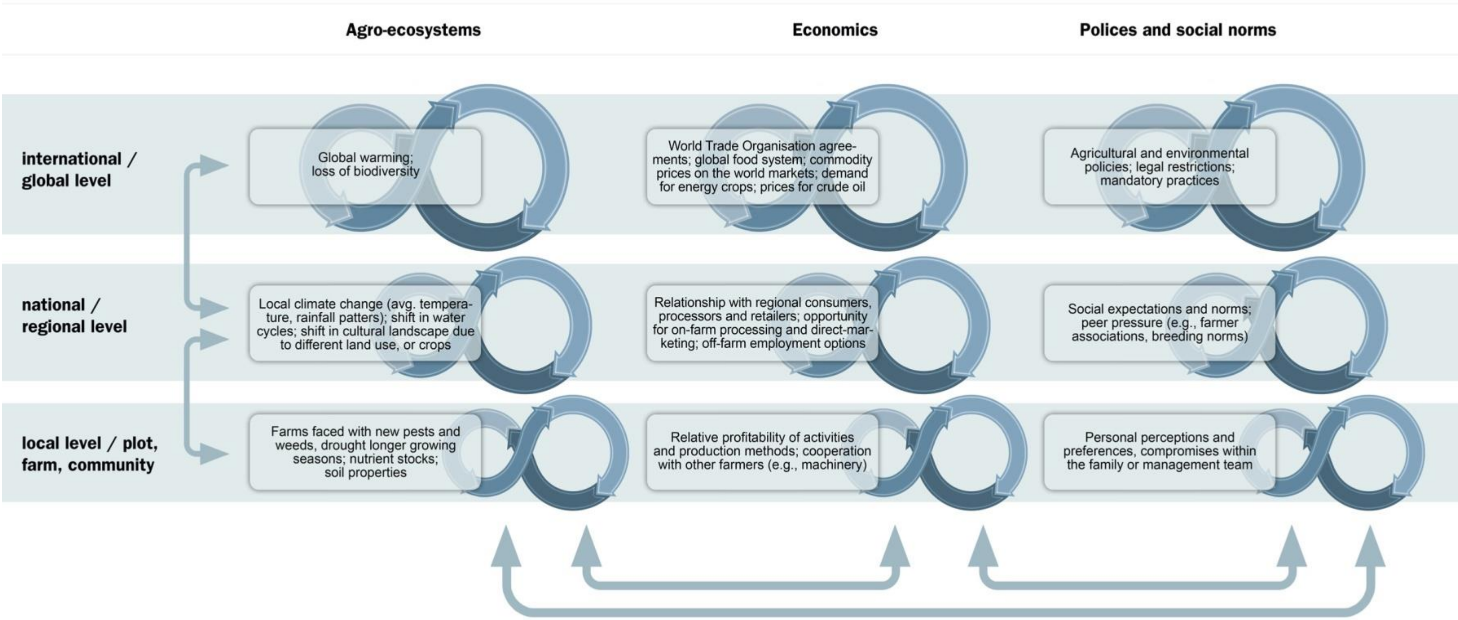


Figure 14: Interactions between hierarchies of nested adaptive systems within the ecological, economic and social domains.

The adaptive systems are semi-autonomous but they influence each other, both within and between domains. (Source: Darnhofer et al. 2010[30].)

Eleven main strategies have been identified in this report for keeping the time and costs of participation by growers to a minimum (Box 10). Similar discipline is needed to minimise the imposition on busy industry facilitators. Our team's review of sustainability-oriented IT tools identified a large number of apparently moribund initiatives that clearly had not become embedded in ongoing industry practice.[11] Hosting and branding of their version of the NZSD genre will help build industry ownership, lock in relevance and ensure adaptation of the tool as industry priorities change. However, there is a need for regular interaction between the industry facilitators and researchers, particularly at the outset and then in episodes as it is adjusted and tested. The ultimate indicator of success of the NZSD research programme would be when the sector-specific dashboards are being operated and adapted entirely by the host industry management teams. Similarly, the online interface with growers must give space and opportunity for them to provide

Box 8: Integrating the NZSD with remote-sensing data and national GIS databases to upscale agro-ecosystem indicators

Remote sensing and integration of data layers within Geographic Information Systems (GIS) are steadily being improved in New Zealand and offer huge potential for integrating and interpreting NZSD monitoring at whole catchment, regional and national levels.

New Zealand Landcover Databases

Successive improvements to the landcover database (LCDB1, LCDB2, LCDB3, LCDB4) have characterised the vegetation further and could provide important metrics for the NZSD, e.g. land area under indigenous vegetation. Strengths of the LCDB include national coverage, standard measures and repeated measures that can identify areas where indigenous species are the major or key components. However, accuracy within and between vegetation classes and the types of vegetation recognised by LCDB have been challenged and the tool was not designed to work well at the farm, orchard or vineyard scale.

Land Environments of New Zealand (LENZ)[240] and S-Map[241]

LENZ integrates climate, soil and topographical data layers to help predict land cover and production capacity. It can provide a useful *What-if* decision support tool for farmers and regional councils to create land use scenarios at farm and catchment levels. S-Map collates existing, somewhat patchy, soil information from throughout New Zealand and interpolates to fill gaps as best as possible. There is huge potential for incorporating S-Map information into the dashboards to provide crucial context indicators automatically for each participant's farm and to upscale soil indicators up to regional and national levels if required.

Use of national GIS databases for identifying conservation priority sites

IUCN criteria for ecosystems[195] have been applied to determine which rare ecosystems in New Zealand[242,243] are vulnerable. These ecosystems are currently being mapped in relation to land tenure information to determine where these ecosystems occur and if they are protected or not.[272] This tool allows farmers to do a quick check on whether they have a particularly sensitive site in their area that might require adjustment of their land use and farming methods.

Indicator schemes are scale dependent[230]

GIS was used to integrate standard maps and satellite imagery in two catchments of Otago to show that upstream land use is more influential in larger streams, while local land use and other factors may be more important in smaller streams in determining nutrient concentrations. The amount of pasture per subcatchment correlated well with total nitrogen and nitrate in one catchment and turbidity and total phosphorus in the other catchment. Stocking rates were only correlated with total phosphorus in one pasture catchment but showed stronger correlations with ammonium, total phosphorus and total nitrogen in the other pasture catchment. Winter and spring floods were significant sources of nutrients and faecal coliforms from one of the pasture catchments into a wetland complex. These temporal and spatial scale effects indicate that water-monitoring schemes and interpretation of the indicators need to be scale-sensitive. A similar study and technique demonstrated the importance of both underlying geology and nutrient additions (which act as synergistic 'multiple stressors') on the health of stream invertebrate communities.[244] Clearly land use and farming practices well beyond each participating farmer can influence water quality measured on their own farm and this would need to be understood and taken into account in any benchmarking or target setting around water quality indicators.

Using catchment-level metrics to check and interpret stream health indictors[245]

A cultural stream health indicator (akin to that illustrated for inshore marine ecosystems in Box 4) was shown to perform well alongside scientific indicators of stream health. Local scores were highly correlated with catchment-level measures of '% of developed land' upstream from sampling sites which were calculated using GIS and remotely-sensed land cover.

Box 9: Simplicity and elegance builds understanding and usefulness of models and management

The following quotes were assembled by Marjan Van den Belt[xxxi,247] to guide modelling for consensus environmental ecision making. They equally apply to the design of sustainability monitoring frameworks and selection of indicators.

'All models are wrong. Some models are useful'. (W. Edwards Deming)

*'The best explanation is as simple as possible, but no simpler.' (*Albert Einstein)

*'Perfection is attained not when there is no longer anything to add, but when there is no longer anything to take away'. (*Antoine de Saint-Exupéry)

'Seek simplicity . . . and then distrust it.' (Alfred North Whitehead)

'Models can easily become so complex that they are impenetrable, unexaminable, and virtually unalterable.' (Donella Meadows)

Box 10: Strategies for reducing the number of indicators to a minimal essential set

This review identified that the following strategies can limit the number of indicators and time required to score them, yet maintain a wide scope to the NZSD monitoring:

1. Ensure that the indicators and measures can be calculated or scored rapidly. Use proxy measures and relative indices if they are reliable and sensitive, or if the absolute measures are too expensive or technically difficult to monitor.
2. Prioritise indicator and measures selection in collaboration with key stakeholders, using a transparent process.
3. Generate indicators from several components that span and report a wide range of issues at once – the growers themselves will have integrated many of these so that splitting them into component parts may not always be necessary.
4. Establish a rota of different indicators to be scored in successive years or blocks of years. Some core indicators may need to be repeated every year, but slow-moving ones or ones with high precision can be rested from time to time.
5. Trigger scoring of more indicators (or the same indicators scored more frequently) only when flags or thresholds come up to signal vulnerability or opportunity on a participant's own vineyard, orchard, farm or forest[xxxii].
6. Present questions, or the sequence of individual components of an aggregated indicator, one by one from 'hidden' online lists. Being confronted by pages of questions at once may be dispiriting, and many of the questions may not be relevant to that participant, so the software should bring them to the screen only where and when relevant. A smart user-friendly design of the online scoring portal would be enormously helpful.
7. Configure some of the scores in a hierarchical manner so that most respondents don't need to cascade through the whole sequence (e.g. only a minority of respondents will need to persist through all of the steps in the indicator depicted in Figure 9).
8. Rotate what is reported to emphasise only part of the bigger picture at once. Feedback should highlight just some of the indicators and measures at regular intervals, but make the complete set easily accessible by those that wish to delve further.
9. Configure reporting in a hierarchical manner so that those with a particular interest in part of the sustainability assessment framework delve deeper to get 'customised reports'.
10. Do much of the work behind the scenes by programming the software to automatically link to other data or score generic indicators from more specific measures.
11. Ensure that a given indicator only appears once at the data entry stage. It can then be reused in several parts of the NZSD by incorporating it into composite indicators or shifting it between domains[xxxiii].

[xxxi] Box 4.1 on p. 90 of Van den Belt (2004).[104]

[xxxii] This 'adaptive sampling' will concentrate effort to where and when it is most needed and help reinforce the need to manage the risk or capture an opportunity. Help from the industry facilitators can be targeted to each grower once these flags are raised.

[xxxiii] e.g. expenditure planting trees is a potentially valuable indicator for environmental sustainability monitoring, but practically should be gathered by the economic resilience monitoring modules so that famers are just asked for it once

feedback and contribute their practical knowledge to hone the tool (Figure 4 and Figure 5). If farmers see their own suggestions and needs being listened to and reflected in subsequent iterations of their NZSD, they are much more likely to perceive the tool as theirs and to use it.

The transition from existing fragmentary and isolated monitoring systems to an integrated NZSD package should be:

- seamless
- gradual
- demonstrate some immediate benefits by removing duplication in reporting
- reference against past data to add value to sunk costs of past monitoring
- cross-link the latest monitoring results to completing new information, and
- provide immediate feedback to growers as soon as they have entered their own monitoring results for the year[249]

We expect a synergy between instantaneous feedback and improved data recording, especially if higher order synthesis and strategy-building based on NZSD data are reported back regularly.

Keep expectations realistic: monitoring alone cannot achieve sustainability

Monitoring looks back to determine what is likely to be coming up ahead. Past trends in indicators of the health of an agro-ecosystem may not continue at the same rate (or remain stable) even if farming or management has remained about the same. This dilemma arises because other system-level tipping points or feedbacks that affect indicators are now altered by disturbance unrelated to local farming. A circular logic may be operating that confounds use of past trends and reliable indications of future ones: if more severe or new shocks are degrading agro-ecosystem health, past trends in key indicators reflect an agro-ecosystem that was not disturbed by conditions that will prevail from now on. How then can we assume that past trends will apply in the future?

The alternative to monitoring for learning whether farming is sustainable is the ecological modelling approach. Here the interactions and associations between drivers or shocks and their ecological consequences are measured and modelled,[94] and then the future outcomes are projected according to plausible scenarios of changes in those same drivers and shocks.[228] Management intervention scenarios can then be modelled to guide investments to ensure sustainability[xxxiv]. The ecological modelling approach at first sight seems safer – it is attempting to look forwards and predict the responses of a system subject to new conditions that have not yet been observed, e.g. climate change. However, there is huge uncertainty in complex adaptive systems and the strengths of the interactions between elements are known imprecisely.[xxxv]

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and in the context that will seem most logical to them (grouping finance indicators together under economic resilience may seem more logical than asking for this under environmental integrity queries).

[xxxiv] Critics of the monitoring approach highlight that it is akin to trying to drive a car safely by looking in the rear vision mirror. Modelling attempts to predict behaviour of the agro-ecosystem as it enters new circumstances, or in the preceding metaphor, to look through the car's windscreen to navigate through new territory. The dilemma is that New Zealand's agroecosystems are so poorly understood that very few models are available and tested to make the modelling approach workable.

[xxxv] Many of the input parameters for such models, like vital rates of threatened species or pest animals for instance, are also measured under past conditions that may not apply anymore. The strength of the

Most wildlife managers combine the monitoring and predictive modelling approaches when assessing sustainability.[94,95,228] Each checks the other. Also, the monitoring results may be used to calibrate and parameterise the model. For example, the rate of decline in bird abundance observed by monitoring can be used to calculate the fecundity or survival rates that are consistent with that rate of decline.[85,93] Fecundity and survival rates might then be reused for predicting population trajectories if, say, predators are controlled.[250] Monitoring is the first and main priority for the dashboards and trends in indicators will give the first indication of sustainability. Analysis of the way the indicators co-vary between farms or between years will give first clues about the way the agro-ecosystem works, what causes the changes underway, and what to do about it.[xxxvi] However, intensive ecological process research will probably eventually be needed to perfect and build predictive models to guide farm management later.

We recommend that the NZSD programme seeks direct links to separately funded upcoming process-oriented research projects that focus on key parts of agro-ecosystems. The dashboards provide ideal vehicles for uptake of this more fundamental and process-oriented research. Deployment of a sustainability monitoring framework and indicators suggested in this report will soon test priorities and challenge current expectations of the way agro-ecosystems behave and are responding to drivers. The most appropriate time for nominating priorities for future process research is in 2014 once the prototype dashboards are in action.

Leveraging off SAFA to ensure global relevance of NZSD

We recommend dovetailing with the Sustainability Assessment of Food & Agriculture Systems (SAFA) framework to drive and demonstrate global best practice among New Zealand growers. SAFA is the most cost effective and complementary of many international monitoring systems available (Table 1) and closest to the participatory approach sought by New Zealand stakeholders (Figure 4 and Figure 5), i.e.

- SAFA is a current and far-reaching initiative to harmonise a plethora of approaches.
- SAFA is designed and promoted by the United Nations' Food and Agricultural Organisation, a credible, scrupulously neutral and influential advocate for intergovernmental policy and action. Trust and buy-in by stakeholders is more likely.
- A thorough and prolonged process of development of SAFA was undertaken by FAO. This is likely to make the tool applicable and practicable for a wide range of food and fibre enterprises in New Zealand and throughout the world.
- SAFA covers a more complete range of the drivers and spatial scales than covered by other frameworks (Table 1).
- SAFA indicators are designed to be inclusive of a wide span of values and contexts (Figure 15). It is therefore more universal than most indicator frameworks designed by experts or professional monitoring agencies.
- The designation of SAFA indicators is very flexible so that locally-tuned NZSD indicators can easily nest underneath the SAFA components.
- SAFA is particularly innovative in including several dimensions of governance that are usually not included in sustainability assessments in New Zealand because they are embedded in wider society and our way of doing things (e.g. rule of law, equity, transparency, lack of corruption). Social–ecological resilience thinking emphasises the importance of appropriate

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interactions between elements of the agro-ecosystem may change because of multiple stressor effects so that feedbacks and responses to a given perturbation may now be very different.

[xxxvi] Our analysis of the way indicators co-vary between orchards, vineyards or farms, or from one year to the next, will form the basis of the first 'What-if' decision making tools; ❾ in Figure 1.

governance for sustainable production. SAFA offers a chance to demonstrate explicitly these advantages that are usually taken for granted in New Zealand.

- Other countries that are exporting into the same markets targeted by New Zealand are likely to use SAFA, so New Zealand growers can future-proof market advantages by participating in the same assessment.
- The NZSD researchers have had an influence on the SAFA design and succeeded in making it more relevant to New Zealand agriculture.[xxxvii]
- Four pilot runs using the preliminary SAFA framework and indicator guidelines showed that New Zealand scores very favourably against the international benchmarks.[251] This is unlikely to change even though a revised SAFA framework and indicators are about to be released.[252]
- Those pilot tests showed that a knowledgeable expert can perform a SAFA assessment rapidly and with little expense. The criteria are scored at such a generic level that international compliance and strong sustainability performance can be reported either (i) automatically by the NZSD software for each individual orchard, vineyard, forest or farm, or (ii) occasionally by an industry expert or parent body. Little direct engagement by the individual grower in understanding a lengthy framework description and instruction manual will be needed.
- The coincidental timing of the SAFA refinements and NZSD prototype designs will allow harmonising of the two systems from the outset.
- Participation in SAFA is voluntary and free, so there is no requirement for an expensive accreditation process to claim compliance. Any New Zealand industry audit processes that are currently used for their market accreditation protocols can simultaneously serve the SAFA needs.

SAFA is very strong at the overarching level (steps ❶ and ❷ in Figure 1), but comparatively weak at the specific and local context (❸) from where dashboards will drive highly quantified monitoring (❺ and ❽) for learning and niche market assurance. As the NZSD indicators can be nested within the flexible SAFA framework, we believe that the two frameworks and protocols can be complementary.

Nevertheless, there is one international concern that is not well covered by SAFA: the agricultural products themselves and their flow through global food systems. SAFA is an assessment tool for enterprises and supply chains but it does not cover products in detail. By contrast, Life Cycle Assessment (LCA) tracks products through an entire supply chain, i.e. assembly of all materials and infrastructure used to farm, inputs on the farm to grow food or fibre, processing and distribution, consumption, waste and eventually even reintegration of the materials back into biophysical systems.[253-259] There are many overlaps between LCA and enterprise sustainability assessment. However, LCA is weaker on issues of governance, social/economic equity and ecosystem services; and SAFA does not provide the comprehensive tracking of the fate of specific products that are increasingly being incorporated into regulatory frameworks such as the EC Envifood programme.[260] We expect that LCA outcomes and associated indicators will eventually be incorporated into the NZSD frameworks, but in the meantime the SAFA focus on enterprises is a better fit for our whole-farm learning agenda, which the ARGOS programme identified as a key 'site of action' for sustainability.[30,103]

[xxxvii] Five team members performed four test SAFAs and three of us attended a workshop in Rome in March 2013 to share lessons with 26 other project teams. Jon Manhire then helped revamp and edit the guidelines in the light of the pilot tests.

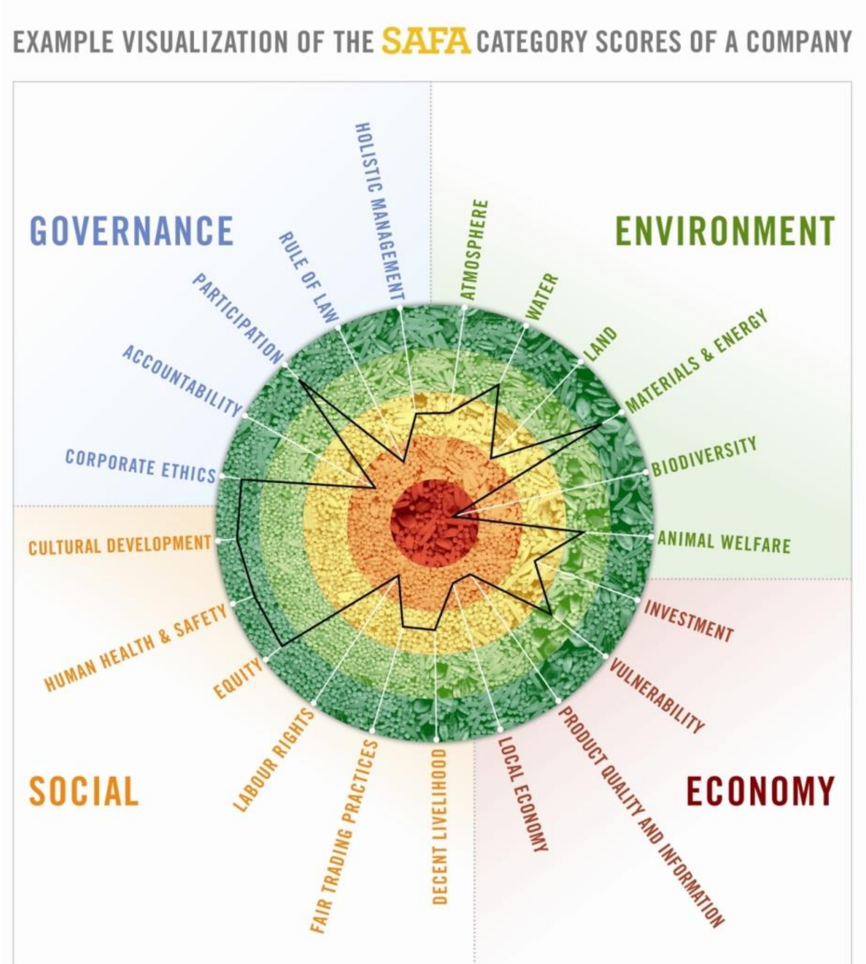

Figure 15: SAFA sustainability polygon.

Agricultural enterprises are scored according to prescribed indicator types within 21 themes spread between four dimensions (Governance, Environment, Economy and Social). In this hypothetical example, the score for an enterprise within each theme (black line) is marked between successive performance zones (outer deep green is best possible practice, red inner zone indicated unacceptable practice). (Source: FAO, in press.[252])

A need to integrate the NZSD with local monitoring frameworks

The dashboards will mainly monitor performance on local farms, while nesting it within the SAFA framework to demonstrate performance on universally derived and globally recognised criteria. It remains to fill in the 'meso-scale' in between: the ecological landscapes, catchments, regions and New Zealand as a whole. Many of the special features of New Zealand ecology and agro-ecosystems demand that environmental monitoring systems have particular emphases – for example threatened indigenous biota[3,122] forest remnants,[261-263] invasive weeds[264-268] introduced mammalian pests,[250] erosion and effects of agricultural intensification[50,216] have high priority, whereas there is comparative disinterest in flourishing introduced biodiversity,[269,270] especially within production landscapes.[49,69]

Fortunately and fortuitously New Zealand's Department of Conservation (DOC) and regional councils are currently developing their own monitoring frameworks and indicators to assess biodiversity[271-273] and pest control[274-276] outcomes, so a considerable opportunity has arisen to match the NZSD, DOC and regional council proposed frameworks. Farmers and their industry bodies cannot do all environmental monitoring and care by themselves, nor should they be expected to.[39] The question arises about how to achieve integration without compromising the efficiency and coverage of monitoring at a local orchard, vineyard, forest or farm level.

Although many of the forces acting on the biodiversity, land and environment of an individual farm are determined at ecological landscape levels, individual farm managers and particular agricultural sectors will design, operate and pay for their dashboard. We cannot expect wine growers to take time out of their farming activities, nor invest in monitoring birds in surrounding public spaces or on neighbouring farms that produce milk rather than wine. Similarly DOC cannot use their public funds to monitor biodiversity on local farms. Collaboration is therefore required and frameworks and indicators must mesh if data are to be pooled and aggregated in sensible ways for help each other. Investments and strategies for environmental care in New Zealand have been poorly coordinated, and divided along ownership and governance lines rather than social–ecological systems approaches.[248] Land use allocation has been *ad hoc* and a product of historical and technological accident rather than coordinated planning to maximise benefits and resilience for New Zealand, its economy, people and its plants and animals. Integrating sustainability monitoring frameworks across land tenures will help maximise well-being for New Zealand, foster collaboration, share costs and hasten learning.

Congruence between the upcoming NZSD, DOC and regional council monitoring can be most successful at generic levels (❷ in Figure 1). It is unrealistic to expect that one set of indicators can serve all stakeholders and agendas, just as there will have to be several dashboards, each tuned to individual sector needs to make them locally grounded, relevant and effective (❸ in Figure 1). However, using similar overarching concepts and parallel terminology will enable famers and agricultural industry facilitators to contribute more fully to future national-level land management policy, state of the environment reporting and active intervention to reach shared sustainability goals. Harmonisation of NZSD frameworks and indicators will also help future-proof a 'licence to farm' within New Zealand's wider society (Figure 1).

Appendix 1: Agreements and initiatives[xxxviii]

International and multilateral agreements

- Convention on Biological Diversity (CBD)
- International Convention on Trade in Endangered Species (CITES)
- Convention on Wetlands of International Importance Especially as Waterfowl Habitat (the RAMSAR Convention)
- UNESCO National Protection and International Protection of Cultural and Natural Heritage
- Convention on the Conservation of Nature in the South Pacific (Apia Convention)
- International Plant Protection Convention 1979 (directed at preventing spread of economic plant pests and diseases, but has clear implications for biodiversity protection)

Four additional non-binding but widely supported agreements are:

- Rio Declaration on Environment and Development (guidelines for sustainable development)
- Agenda 21 (a framework for use by governments, local authorities and the community in implementing the principles of sustainable development)
- Forest principles
- The Global Strategy for Plant Conservation ratified by 187 nations under the CBD

Other international initiatives

- IUCN (International Union for Conservation of Nature and Natural Resources) threatened species and ecosystems: Red list
- The **Montréal Process:**[277] New Zealand is one of 12 countries in the Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. The process endorses the following seven criteria:
    - Conservation of biological diversity
    - Maintenance of productive capacity of forest ecosystems
    - Maintenance of forest ecosystem health and viability
    - Conservation and maintenance of soil and water resources
    - Maintenance of forest contribution to global carbon cycles
    - Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies
    - Legal, institutional and economic framework for forest conservation and sustainable management.

Relevant national legislation and policy instruments include:

- Conservation Act 1987 – while DOC is 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.
- Reserves Act 1977 – administered by DOC, which includes protecting areas with special cultural, historical and ecological features.
- Wildlife Act 1953 – administered by DOC, protects indigenous birds and some other wildlife listed in schedules in the Act, and enables the establishment of wildlife sanctuaries and wildlife reserves.
- Wild Animal Control Act 1977 – DOC has oversight of management and control of feral populations of exotic species and deer farming.

[xxxviii] The material in this appendix is primarily sourced from Lee et al. (2005)[122], who mostly focus on implications for biodiversity.

- Resource Management Act 1991 administered by MfE. How people are going to use, develop or protect national and physical resources. For biodiversity this requires regard for the following:
    - Kaitiakitanga – the ethic of stewardship
    - Efficient use and development of natural and physical resources
    - Maintenance and enhancement of amenity values
    - Intrinsic values of ecosystems
    - Maintenance and enhancement of the quality of the environment
    - Any finite character of natural and physical resources
    - Protection of habitat of trout and salmon
- Biosecurity Act 1993 (MfE): prevention of potentially harmful exotic organisms arriving in the country, and their eradication or management if they do establish
- Hazardous Substances and New Organisms act 1996 (MPI): deals with deliberate introduction of new organisms that pose an environmental risk
- Forests Act 1949 and 1993: deals with management of the logging and export of indigenous trees
- Environment Act 1986 (MfE): Established the Ministry for Environment, which sets policy and conducts state of the environment reporting.[278] This also established (S.16) the Parliamentary Commissioner of Environment who acts as an environmental ombudsman and policy analyst. The commission has been concerned about agricultural sustainability as well as wider environmental health issues and monitoring.[279]

Key New Zealand policy documents include:

- The New Zealand Biodiversity Strategy (2000)[280]
- Environmental Performance Indicators: Signposts for sustainability (1997)[281]
- National Policy Statement for Biodiversity on Private Lands[282]
- New Zealand Coastal Policy Statement (1994)[283]
- Ministry for Environment: Green & Clarkson (2005);[284] MfE (1998[285], 2007[286])
- Statistics New Zealand[287]

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