What is biodiversity?

The term biodiversity is a popular contraction of two words: ‘biological diversity’, meaning the variety of living things in oceans and on land that occupy the earth with humans.

Biological diversity is complex. It is

- Multi-levelled, including genes (diversity within species), species, and ecosystems, with extraordinary variety at each level.
- Interdependent, with different components linked together through biological and ecological networks and feedbacks.

‘Biodiversity’ is now a universally used term in high level international agreements and national policy agendas. The statement on biodiversity issued in 2012 at the United Nations Rio+20 Conference in Article 197 affirms the intrinsic value of biological diversity including: ‘the ecological, genetic, social, economic, scientific, educational, cultural, recreational and aesthetic values of biological diversity and its critical role in maintaining ecosystems that provide essential services’. However, Article 197 also stresses that nations should include as a component of biodiversity a very wide range of direct and indirect human benefits including sustainable development. The Aichi targets of the Convention of Biological Diversity which New Zealand has endorsed, are also very broad as they include economic and cultural targets as well those concerning biodiversity loss.

New Zealand is recognised as one of the earth’s biodiversity hotspots, with high levels of endemism in its fungi, plants and animals. Endemic organisms are those that are unique to this country. Many make an important contribution to global biodiversity, especially groups such as wrens, kiwi, kauri, land snails, and red algae which contain ancient and distinctive members that have evolved for long periods in relative isolation. Other non-indigenous species that pre-date human arrival descend from more recent immigrants from southern continents and other islands.

Since Polynesian settlement in the 13th Century significant numbers of species (more per capita than any other country) have been introduced to sustain humans e.g. for food, forestry, and erosion control. Some, especially mammalian predators and ecosystem-transforming weeds, have become major pests, contributing to the extinction and population declines of many bird, lizard and large invertebrate species. Others, including trout, deer and pigs, for example, are widely accepted recreational food sources but have impacts in natural ecosystems. A few introductions (e.g. tahr, bushtail possum) thrive in New Zealand but are threatened in their native range.

Because of New Zealand’s unusual evolutionary history without terrestrial mammal carnivores and herbivores, rapidly-spreading, fire-adapted conifers, and many continental wildlife diseases, the protection of indigenous biodiversity invariably requires active management. Without this, much of New Zealand’s indigenous biodiversity would succumb to the current suite of introduced species and human activities.

The New Zealand Biodiversity Strategy (NZBS) goal is to ‘halt the decline in New Zealand’s indigenous biodiversity’ and Goal 3 is to:

> ‘Maintain and restore a full range of remaining natural habitats and ecosystems to a healthy functioning state, enhance critically scarce habitats, and sustain the more modified ecosystems in

> production and urban environments; and do what else is necessary to maintain and restore viable populations of all indigenous species and subspecies across their natural range and maintain their genetic diversity.'

This operational statement recognises the full variety of life across the spectrum of environments present in New Zealand, while acknowledging that irreversible ecosystem changes and missing biodiversity components make it impossible to return to the ecosystems and diversity of historical times.

The recent New Zealand 'Biodiversity Action Plan', a targeted update of the original Strategy (DOC 2016) simplifies this goal in the form of 'Goal C', namely to 'Improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity'. However, two further concepts (Ecological or Biological Integrity and Ecosystem Health) have also been developed in order to emphasise the importance of ecological processes in maintaining indigenous biodiversity.

In 2005, Landcare Research and the Department of Conservation developed a concept of Ecological Integrity (EI) as a practical framework for assessing achievement of Goal 3 of the NZBS. The three components of EI are:

1. indigenous dominance (the degree to which species composition, structure, biomass, and interactions and processes in an ecological community are dominated by indigenous plant and animal),
2. species occupancy (the extent to which the full range of plants and animals that can potentially occupy an ecosystem are present), and
3. environmental representation (the extent to which indigenous ecosystems and/or their protection covers the full range of New Zealand's physical environments).

EI has been used as a framework for inventory and monitoring measures by DOC and Regional Councils.

Ecosystem health and ecological integrity

Ecosystem health and ecological integrity are widely (often interchangeably) used to articulate the desired qualities of biodiversity beyond mere existence of a range of species and ecosystems. For instance, the last audit of biodiversity management in DOC (Auditor-General 2012) used both in describing the desired state for biodiversity. It is important to maintain a distinction between these terms.

Ecosystem health (EH)

Ecosystem health is a high level goal motivating much environmental legislation and is described as follows:

'a biological system…can be considered healthy when its inherent potential is realised, its condition is stable, its capacity for self-repair when perturbed is preserved, and minimal external support for management is needed' (Karr, 1991).

Ecosystem health thus extends from individual organisms through landscape level processes to economic and societal impacts (Rapport et al., 1998). It describes the fundamental physical and biological state of an ecosystem in relation to its ability to support services. An ecosystem in good health is functionally appropriate for a given environment, generates biomass, exchanges gases, recycles nutrients, protects the land and water from erosion and pollutants and, unless deliberately managed for production, is self-sustaining. It is resilient to external threats and supports adequate functional diversity. All expected trophic levels are present and well interconnected (Tett et al., 2013). A healthy ecosystem may potentially take many different forms in identical environments: for instance, in a warm, well-watered region it could be productive grassland, a forestry plantation or an unmanaged indigenous forest. Even in a built-up area, if the biological components are thriving, and pollutants minimized, the term 'healthy' still seems appropriate. Much of the New Zealand landscape, rural and wild alike, is under this definition in an ecologically healthy state: plants, fish, mammals, birds and invertebrates are abundant in self-sustaining communities; ecosystem services are maintained; citizens derive wealth and enjoyment.

Ecological Integrity (EI)

The Water Pollution Control Act (1972) in the United States and its requirement to 'restore and maintain' biotic integrity, spurred development of an operational definition of the concept (Karr 1991). In a much cited paper Karr and Dudley (1981) defined *biological integrity* as:

> 'the ability to support and maintain 'a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organisation comparable to that of the natural habitat of the region'.

Ecological integrity is a broader term for this fundamental concept. The Canada National Parks Act (2000) states that ecological integrity means, with respect to a park:

"…a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes."

The original ecological integrity concept thus centred on the concept of 'naturalness'. Later elaborations argued for more factors (Andreasen et al., 2001):

'Ecological integrity encompasses ecosystem health, biodiversity, stability, sustainability, naturalness, wildness, and beauty. As more narrowly defined, but more easily measureable, it encompasses chemical, physical and biological integrity. By most definitions, integrity suggests wholeness, completeness, and intactness…'.

The definition in the New Zealand Environmental Reporting Act 2015, which establishes the mandate for regular national environmental reporting, is:

'..the full potential of indigenous biotic and abiotic features and natural processes, functioning in sustainable communities, habitats, and landscapes'.

This is the same definition as in Lee et al. (2005), who go on to say that the term:

'…encompasses all levels and components of biodiversity, and can be assessed at multiple scales, up to and including the whole of New Zealand. At its simplest, ecosystems have ecological integrity when all the indigenous plants and animals typical of a region are present, together with the key major ecosystem processes that sustain functional relationships between all these components. At larger scales, ecological integrity is achieved when ecosystems occupy their full environmental range.'

Implications of EI and EH for monitoring

EH is most important as a concept for locations and ecosystems where human use is high: water ways and coastal locations and natural landscapes near cities or intensively developed regions are examples. Many exotic organisms are tolerated in such settings or can be used as an indicator of EH: introduced passerines and trout in streams are an example. Likewise, aspects of environmental change that in a less human-affected setting would be regarded as part of a renewal cycle – vegetation die-back in drought, slope or beach erosion for example – may be seen as negatives requiring remedial action. However, pathogens of humans, stock and cultigens, pollution, eutrophication, siltation, and wild-fire, are regarded as absolute negatives.

Under EI, fluctuations, disturbances and disruption are seen as essential parts of the natural regenerative cycle and it is only when these affect the persistence of species or genetic variation that they are seen as important. Chief among these EI-degrading processes are invasion by ecosystem-altering exotic organisms, pollution of waterways with toxins or nutrients, and clearance and fragmentation of natural ecosystem cover. However, all exotic organisms are seen as 'undesirable' (with certain exceptions such as trout in National Parks) mainly because they either currently, or may in the future, threaten EI.

Biodiversity monitoring

Monitoring requires resources but is essential for the protection of biodiversity

Monitoring is an accepted part of 21st Century life. For the most part, we monitor things we regard as important. Virtually every important aspect of human life has reliable statistics: birth, death, marriage, education, health, income, tax, resource supply and consumption are well-documented. Infrastructure and its condition are assessed regularly. All businesses and publicly-funded activities are required by law to be financially monitored. Topography, weather and climate have dedicated databases. We do not usually place the responsibility for this data collection on 'citizens': nearly all these datasets are collected and analysed by professionals – such as accountants, statisticians, planners etc, and the databases and their analysis are entrusted to long-lived institutions.

Biodiversity is an exception. Data on biodiversity is collected widely, but mostly in an unsystematic manner. Long-term data sets are rare. Until recently, the nation has had no over-arching view of what sort of effort and what sort of data needed to be collected, and by whom. Systematic collection of data was carried out by some science organisations from the late 1940s on, but the science restructuring of the 1990s put an end to most of this. Recently, the Department of Conservation has developed a systematic monitoring scheme, but it would be fair to say that its long term prospects – which are essential to its success – remain unclear.

The Environmental Reporting Act (2015) has given some structure and impetus to national monitoring, but it appears to rely for the most part on aggregation of already existing data. Emblematic of this biodiversity monitoring problem is the failure to use provisions under the Resource Management Act (1991). Under Section 333 *Power of entry for survey*, local authority officers are permitted access to any land for survey and under Section 35 *Duty to gather information, monitor, and keep records* are obliged to do so. Nevertheless, local authorities – while willing to enter land to assess many aspects of the environment, are not inclined to do so for biodiversity purposes.

This is part of a wider problem. As a general rule, conservation practitioners feel acutely aware of the need to balance conservation resources between management of biodiversity threatening processes and the measurement of both background biodiversity change plus outcomes to identify that the correct management actions are being taken. Because of this tension, biodiversity monitoring can become *ad hoc*, and organised at a low level designed to measure progress against very localised concerns. This brings with it problems such as monitoring budgets which can be traded-off against other activities, lack of clear reporting mechanisms, variable protocols and poor archiving.

Types of monitoring

Biodiversity monitoring can be done for several reasons. The first and most basic is *Inventory*: the task being to understand what is where and how it is changing. Second, *Surveillance*: usually where threats are well-understood, and monitoring is necessary to give early warning. And finally, *Outcome monitoring*: to document changes in biodiversity condition after intervention.

As the threat to biodiversity is the main reason for heightened global and national concern, most monitoring schemes either explicitly or implicitly follow the Driver-Pressures-State-Impacts-Responses (DPSIR) framework (Svarstad et al., 2008) and thus favour surveillance/outcome monitoring. DPSIR monitoring is convenient for national agencies because it puts at its centre the stressors which are the immediate cause of both scientific and public concern. It focuses on a few major drivers and the reporting of a limited set of data from a limited set of places. Such a focus can lead to a de-emphasizing of the broad scale monitoring aspect in favour management-relevant issues. This view of biodiversity monitoring makes a number of highly debatable assumptions about pre-existing knowledge and policy development.

The first assumption is that the status of the biota is well enough understood that it does not require broad-scale monitoring. The second is that the pressures are well understood. The third assumption is that what management action to take is well understood and that the consequences of management have a high degree of predictability. These assumptions are demonstrably false. New observations have a tendency to change priorities and when what were thought to be well established cause-effect relationships fall apart, a narrowly based observational system has trouble coping. As well, much is happening to biodiversity which is not threatened but which we need to know about as essential background. A 'DPSIR alone' approach is far too limited and should be augmented by a broader suite of observations.

Commonly monitored aspects of biodiversity

Lee et al. (2005) summarised the broad categories of biodiversity data collected and monitored by OECD countries. In general this sort of monitoring is focused on legal status, broad scale indicators such as land cover, and legacy data sets from freshwater fisheries, forestry etc. Systematic, comprehensive schemes are rare: more common are monitoring networks devoted to a single issue, such as birds in farmland, butterfly abundances or waterway pollution.

Table 1. Summary of biodiversity and environmental indicator groups used in national level programmes (after (Lee et al., 2005))

Indicator group	Rational	Comment
Protection status	Minimum guarantee of protection against exploitation.	Often used as a key indicator of progress. Of limited use in New Zealand
Extent of landcover types	Essential because most other indicators rely on this data layer to some extent	Very cost effective to collect with advances in remote sensing
Remote sensing of biodiversity related indices	Metrics around fragmentation and connectivity may be important; overall ecosystem health or change in parameters such as canopy height, greenness, broad composition etc can be analysed	Often used simply because they are easy to collect rather than vital, but increasing power of remotely sensed imagery analysis will change this.
Abiotic factors (climate, air pollution, nutrient status, runoff, soils.)	Essential background data	Not often collected by primary conservation agencies
Status of freshwater systems	Widely regarded as being at extreme risk, mainly through development and nutrient run-off.	One of the most regularly featured items in national reports
Forest status	Major land cover category considered of high importance	Developed countries are beneficiaries of extensive forest plot systems which can be repurposed for more comprehensive biotic reported.
Abundance and range of animal populations	Critical and often rapidly changing biodiversity element	Long data series available for large animals. Arthropods severely under-represented aside from butterflies/dragonflies.
Diversity indices	Species richness indices and other diversity measures are often proposed as part of a national system to overcome the limitations of a species-based approach.	Controversial as quite sensitive to approach and data selection.
Exotic species	Major concern for conservation agencies	Very regularly reported on.
Threatened biota status	Major concern and responsibility at agency and national level.	The Red List approach is almost universally employed

DOC biodiversity monitoring framework

The current Department of Conservation high level biodiversity monitoring scheme aims to provide a comprehensive framework centred on National Assessment Outcomes.

Environmental quality

Description: The extent to which the abiotic environment is capable of supporting healthy ecosystems, free of environmental pollutants.

Quality here is encapsulated in the corresponding Outcome objectives as the 'maintenance of ecosystem processes' and 'limiting environmental contaminants'.

Commentary: This national outcome deals mainly with ecosystem health. The identity of species is not the issue, but whether ecosystems are functioning well in the sense of processing nutrients and energy, providing quality habitat and ecosystem services, and are free of anthropogenic toxins, heavy metals, other ecosystem-disrupting chemicals and excessive nutrients. A wide range of observations and processes are potentially included. Some can be captured by remote sensing and are already monitored (e.g., indigenous vegetation cover, net ecosystem primary productivity). Others are the focus of existing monitoring networks (e.g., water quality and quantity; seeding of key indigenous trees; fire) but others still are not systematically monitored (e.g. substrate alteration; disease outbreaks). This national outcome is a key component for aquatic ecosystems.

Indigenous Dominance

Description: The degree to which an ecosystem – including its composition, structure, biomass, trophic interactions, mutualisms etc - is shaped by indigenous plants and animals.

The ideal is that native ecosystems can perpetuate themselves in the absence of human intervention. The Outcome objective is 'reducing the spread and dominance of exotic species'.

Commentary: In New Zealand, few ecosystems are free of exotic organisms, but these are not regarded as degrading indigenous dominance *per se* unless they are abundant or play a critically negative role. However, taking steps to prevent further enrichment of the biota with exotics is a sensible precautionary activity (Owen 1998) and the presence and abundance of exotics in the biota should be monitored and the indicators and measures reflect this.

Species representation (or occupancy)

Description: The degree to which indigenous species that occupied a given ecosystem before human interference began are now present.

This concept includes global-scale extinction as an irreversible degradation of ecological integrity. The Outcome objectives are 'preventing declines and extinctions' and 'maintaining ecosystem composition'.

Commentary: Some have debated the need to refer to the historic past, suggesting such information is irrelevant when we consider the changed environments of the present, and the multiple states ecosystems have adopted in the past. Hilderbrand et al. (2005) refer to this use of historic or ideal states as the 'myth of the carbon copy'. However, some reference to an historic state is inevitable. That is, shrinking of species ranges or decline in their abundance can only be assessed versus historic range states. We may not regard some of these declines as being of significance, but nevertheless we should know that they are occurring.

A wide view of ‘species representation’ is taken here as abundance and genetic make-up are included. Therefore a wide range of indicators and measures are included under this Assessment Outcome. Some document the International Union for the Conservation of Nature threat status categories and range shrinkage (Mace et al., 2008), and others the demographic and genetic diversity issues that affect small, reduced populations of threatened organisms. Under ‘maintaining ecosystem composition’ the abundance of widespread and common taxa are also dealt with. Monitoring common species can be controversial, but the well-being of abundant taxa is vital to the provision of ecosystem processes (Gaston, 2008, 2010). For example, 50% of the basal area of New Zealand forests is made up by just five tree species (kamahi *Weinmannia racemosa*, southern rata *Metrosideros umbellata*, silver beech *Lophozonia menziesii*, red beech *Fuscospora fusca* and mountain beech *Fuscospora cliffortioides*) (unpublished inventory data, National Vegetation Survey). Moreover, that a given species is abundant now is no guarantee that that it will not come under threat as has happened repeatedly in the past. For instance, red-fronted parakeets (*Cyanoramphus novae-zelandiae*) were once numerous enough to be crop pests (Oliver 1955) and the once dominant and still common iconic kauri (*Agathis australis*) is now under threat from fungal infection.

Ecosystem representation

Description: The extent to which New Zealand environments have representative indigenous ecosystems.

The abiotic component of the New Zealand environment (climate, geology, oceanography, topography and soils) can be envisaged as forming discrete environmental units determined by unique climates, geology, soils or combinations thereof, and there are various ways of partitioning the landscape to reflect this: the best known and most widely used schemes being Ecological Districts (McEwen, 1987), the Land Environments of New Zealand (Leathwick et al. 2002), and Marine Environment Classification (Ministry of Fisheries and Department of Conservation 2008). Some of these units can be well defined both compositionally and spatially (lakes, waterways, screes, beaches) but many others far less so and resemble gradients. The Outcome objective is to ensure ecosystem representation and its indicators and measures focus on changes in protection status and extent particularly for critically reduced ecosystems.

Commentary: International agreements and national strategies argue that species, genetic variation and ecosystems should be maintained, but it is simply not feasible to monitor all aspects of biodiversity. The importance to ecological integrity of the environmental inclusiveness inherent in ecosystem representation is that species, genotypic variation and ecosystem composition tend to be sorted along environmental gradients and the presence of healthy ecosystems at all points on these gradients can be used as a surrogate for their maintenance.

Resilience to climate change

Description: The extent to which New Zealand ecosystems and organisms are, or are likely to be, stressed by climate changes including indirect influences such as sea level rise and human responses.

The objective under this outcome concerns adaptation to climate change.

Commentary: Climate change is a defining environmental issue of the 21st century (Oreskes, 2004). New Zealand is in the somewhat anomalous position relative to many places of having had little discernible environmental effects from climate change on land so far, despite a warming of nearly 1°C since the turn of the 20th century (McGlone and Walker, 2011). Biodiversity changes in the oceans surrounding New Zealand as a result of recent climate change are also not clearly detectable, although highly significant negative effects are predicted by the end of this century (Willis et al., 2007). Two reasons for this can be suggested: first, New Zealand at the beginning of the 20th century experienced a relatively short anomalously cold period and therefore, in part, the warming can be seen as a recovery to more normal conditions; and second, variability of mean annual and seasonal temperatures, and oceanic conditions is naturally high and thus the secular trends in climate and oceanic states have yet to register a step change. Nevertheless, there is every indication that this state of affairs will not last long and that by the end of this century mean annual temperature , in particular winter temperatures, will be significantly higher and rainfall patterns will have shifted markedly (McGlone and Walker, 2011). For this reason, a system for monitoring climate-related effects is needed as a watching brief to inform potential mitigation actions.

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Contact: Drs Matt McGlone and Bill Lee

Landcare Research | PO Box 69040 | Lincoln, 7640 | New Zealand

Ph: +64 3 321 9733| F: +64 3 321 9998 | E: mcglonem@landcareresearch.co.nz