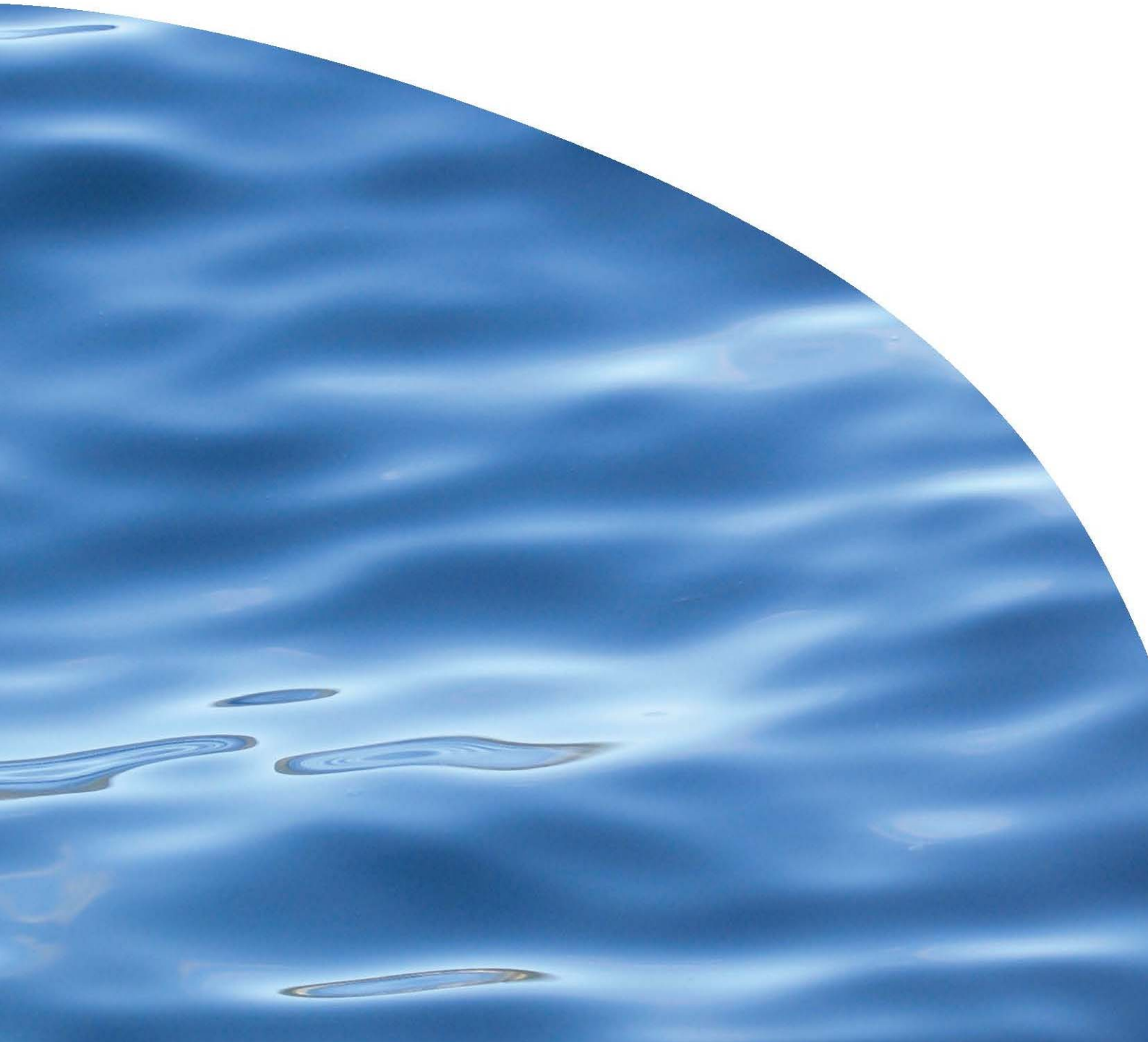
CAWTHRON INSTITUTE

REPORT NO. 2362

DEVELOPMENT OF A FRESHWATER TIER 1 BIODIVERSITY MONITORING PROGRAMME: SCOPING REPORT



DEVELOPMENT OF A FRESHWATER TIER 1 BIODIVERSITY MONITORING PROGRAMME: SCOPING REPORT

[1] DAVID KELLY, [2] DAVE WEST, [2] HUGH ROBERTSON, [1] KATI DOEHRING, [2] OLLIE GANSELL

[1] CAWTHRON INSTITUTE
[2] DEPARTMENT OF CONSERVATION, AQUATIC AND REPORTING UNIT

Prepared for the Department of Conservation

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Joanne Clapcott

APPROVED FOR RELEASE BY:
Rowan Strickland

ISSUE DATE: 3 October 2013

RECOMMENDED CITATION: Kelly D, West D, Robertson H, Doehring K, Gansell O. 2013. Development of a Freshwater Tier 1 Biodiversity Monitoring Programme: Scoping Report 2013. Prepared for Department of Conservation. Cawthron Report No. 2362. 59 p. plus appendices.

EXECUTIVE SUMMARY

The Department of Conservation (DOC) aims to implement a monitoring programme to enable reporting on the status and trend of freshwater biodiversity at a national scale. This necessitates the development of a monitoring and reporting framework and set of indicators that would holistically assess freshwater biodiversity values, and a network of sites to provide an unbiased representation of the status and trend of freshwater ecosystems nationally.

The purpose of the report is to scope the development of a freshwater biodiversity monitoring programme including; 1) providing the context for biodiversity monitoring within DOC, 2) describe existing monitoring frameworks used within and outside of DOC that may be suitable for developing a national freshwater biodiversity monitoring programme, 3) identify a range of indicators and measures that are appropriate for use in a proposed freshwater framework, and 4) provide a broad summary of existing freshwater monitoring by DOC and other management agencies that could be used to inform the framework.

1. Context for DOC biodiversity monitoring

The Department of Conservation has developed a biodiversity monitoring and reporting system as part of Natural Heritage Management System (NHMS). It consists of a hierarchical integrated monitoring system with broad scale Tier 1 monitoring to inform the status and trends of key indicators on public conservation land (PCL), Tier 2 monitoring associated with select high priority managed areas through DOC's ecosystem and species optimisation projects, and Tier 3 monitoring at a small number of sites designated for development of management practices (*e.g.* ecosystem or species restoration). Using a nested hierarchy DOC aims to collect information with different levels of scope and spatial coverage to report on gains and losses in biodiversity across all areas of its responsibility.

2. Existing monitoring frameworks

As part of the initial process around designing a biodiversity monitoring and reporting system, the Department engaged Landcare Research to develop a framework for monitoring and reporting on the status and trend of ecological integrity (Lee *et al.* 2005). Ecological integrity (EI) was defined as the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes (Lee *et al.* 2005). Although the focus of the framework was principally in relation to terrestrial ecosystems, it did consider aspects of freshwater ecosystems.

Several other freshwater monitoring frameworks were considered in relation to the goals of the Tier 1 monitoring and reporting programme, including the Cross Departmental Research Pool (CDRP) freshwater ecological integrity framework, the Ministry for the Environment (MfE) national environmental monitoring and reporting (NEMaR) framework, the wetland condition index, and the DOC Arawai Kākāriki wetland monitoring framework. The CDRP freshwater framework for assessing EI was the broadest framework and was based on a range of indicators that together quantify the core components of nativeness, pristineness,

diversity and resilience, with many being highly relevant to Tier 1 biodiversity monitoring and reporting. The NEMaR framework is similarly based on assessing EI, but at this stage the scope of the framework is narrower, being predominantly focused on water quality related indicators. Both the CDRP and NEMaR framework also lacked a wetland component. The DOC Arawai Kākāriki wetland monitoring framework is quite comprehensive (for palustrine wetlands) and closely tied with the original Lee *et al*. (2005) framework. The wetland condition framework is not as comprehensive, but represents a good working example of how indicators covering a wide array of EI components can be integrated in assessing ecosystem condition holistically.

3. Proposed Tier 1 framework and indicators

Information from the four frameworks were used in developing a revised biodiversity monitoring framework from Lee *et al.* (2005) including new measures for rivers, lakes and wetland environments (Table ES1). The framework consists of 32 freshwater measures covering 13 indicators related to the three targeted national outcomes. These cover a wide range of indicator types including productivity, water quality and yield, ecosystem disruption, contaminants, exotic weeds and pests, conservation status of species, occupancy range of species, environmental representation and protection status, and biological responses to climate change. The amended framework includes a more comprehensive range of freshwater measures, but is compatible with the monitoring and reporting indicators framework being used by DOC for terrestrial Tier 1 biodiversity monitoring and reporting.

4. Existing freshwater monitoring to inform the proposed framework

The Department of Conservation presently monitors approximately 2,000 sites for freshwater biodiversity and biosecurity purposes. Approximately 350 sites are threatened for species monitoring developed in association with species recovery plans. Freshwater biosecurity surveillance monitoring is conducted by DOC at approximately 1,500 sites mostly in regards to pest fish species, but more recently monitoring for the presence of the invasive algae *Didymosphenia geminata* at just under 500 sites. While some of the monitoring is at regular intervals using set protocols, much of it is not a part of routine monitoring programmes so would need to be revised significantly to fit a Tier 1 monitoring programme.

The National River Water Quality Network (NRWQN) operated by NIWA, and regional councils and unitary authorities conduct significant river monitoring. This includes over 1,000 sites for water quality, 300 sites for macroinvertebrates, 930 sites for periphyton, and 171 sites for fish. The combined NRWQN and council monitoring information would provide reasonably robust information for wadeable rivers in regards to the Lee *et al.* (2005) framework indicators on water quality and yield (1.3), some information related to river productivity (1.2) and community composition (5.1) could also be applied to reporting on Lee *et al.* (2005) indicators. However, monitoring is predominantly focused on water quality, and would require a greater number of biological measures (*e.g.* fish community, aquatic plants) to be more applicable for DOC's biodiversity reporting purposes. These networks are also limited in coverage of river environment types, and bias towards sites within agriculturally

dominated catchments with limited network coverage of public conservation lands, one of the primary objectives of the Tier 1 programme.

Approximately 112 lakes are monitored nationally by regional councils for water quality (between 2005–2009) and at present 200 lakes nationally have had aquatic macrophyte assessments using the LakeSPI methodology. This monitoring could enable reporting in regards to water quality and yield (1.3.), and some information related to lake productivity (1.2) (planktonic, macrophytes). Additionally, some data on macrophyte community composition could also be applied to assessment of ecosystem composition (5.1), and new weed species and weed dominance (2.1 and 2.2). Lake monitoring is biased towards medium and larger sized lakes, and similar to river monitoring, occurs mostly outside of public conservation land limiting the ability to report on status and trends within PCL.

DOC presently conducts routine monitoring of a small number of wetlands nationally, and number of regional councils have recently established, or are in the process of establishing, wetlands monitoring programmes. A revised terrestrial monitoring framework to be applied by councils was developed recently in a workshop process between councils, central government, and Landcare Research (Lee & Allen 2011). The adoption of such a framework by councils would have the potential to enhance wetland biodiversity reporting, but at this time only a limited number of councils are implementing specific wetland monitoring. The extent of wetland monitoring is therefore insufficient to underpin national reporting in a Tier 1 programme, and would need to be expanded significantly to achieve this objective.

Tier 1 implementation process

Taking account of other agency freshwater monitoring, especially biodiversity focused sampling; we recommend that the DOC Freshwater Tier 1 programme concentrates on freshwater ecosystem monitoring that enables a good estimate of EI while capturing key aquatic biodiversity metrics such as species abundance and diversity. Wetlands monitoring is viewed as a key priority, with DOC taking a national lead on mapping, assessing (WONI-FENZ) and now monitoring (Arawai Kākāriki). DOC has traditionally put significant effort into freshwater fish monitoring, and some of these datasets are the longest running sets in New Zealand. Therefore these are two areas that would meet primary management objectives of DOC, and fill gaps in current ecological monitoring, and provide good linkages with other monitoring agencies. Similarly, a targeted programme across lakes, rivers and wetlands could occur if only a limited set of measures were applied, and integration with monitoring networks overseen by other agencies (*e.g*. regional councils, NRWQN).

It is anticipated that a pilot, or several pilot studies, be investigated around the design and implementation of a Tier 1 network, considering various attributes for design of a statistically robust network of sites. This would include metrics used to inform indicators and measures, field survey and laboratory methodologies, sampling design, and statistical analyses to inform reporting on indicators. The type of pilot would very much depend on the focus area of the Tier 1 programme, as presently there are very different quantities of existing environmental data to inform EI indicators for rivers, lakes and wetlands. The scale and

location of the pilot, inclusion of partners in monitoring, and decisions on departmental expertise, are required to get accurate estimate of costs of a monitoring network, which will be a key aspect in its implementation. It is anticipated this pilot process will be in conjunction with a consultation process with key stakeholders within DOC and other central government agencies (*e.g.* MfE, MPI), and potential partner monitoring agencies (*e.g.* regional councils).

Table ES1. Suggested list of indicators and measures for the assessment of freshwater biodiversity for rivers, lakes and wetlands. Note that more detailed tables individually for rivers, lakes and wetlands are included in the appendices.

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
Indigenous dominance	1 Maintaining ecosystem processes	1.1 Soil status	1.1.1 Substrate modification and/or erosion	1.1.2 Sediment loading / accumulation / deposition and infill rates	1.1.3 Soil chemistry (*e.g*. pH, N/P levels, redox)	1
		1.2 Productivity	1.2.1 Ecosystem primary production (plankton, periphyton, macrophytes)	1.2.2 Ecosystem secondary production (macroinvertebrate, zooplankton)	1.2.3 Fisheries production (native fish community)	1
		1.3 Water quality and yield	1.3.1 Hydrological alteration- (water level, yield, flow regime)	1.3.2 Eutrophication	1.3.3 Toxicity (DO, NH4, NO3, pH)	1
			1.3.4 Flow habitat retention for key species	1.3.5 Visual clarity		
		1.4 Ecosystem disruption	1.4.1 Barriers to species migration (dams, bunds, culverts)	1.4.2 Modification of morphology and sediment transport (channelization, drainage)	1.4.3 Riparian processes (shading, nutrient uptake)	1
	2 Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species	2.1.1 Occurrence of self-maintaining populations of new environmental weeds and animal pests			1
		2.2 Exotic weeds and pest dominance	2.2.1 Distribution and abundance of exotic weeds and pests	2.2.2 Indigenous systems released from exotic pests		1

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
	3 Environmental pollutants	3.1 Contaminants	3.1.1 Persistent contaminants (metals, organochlorines)	3.1.2 Endocrine disrupting substances		3
Species occupancy	4 Preventing declines and extinctions	4.1 Extinct taxa	4.1.1. Number of taxa presumed extinct			1
		4.2 Conservation status of species	4.2.1 Abundance and distribution of species listed as 'threatened'	4.2.2 Abundance and distribution of species listed as 'at risk'		1
		4.3 Genetic change in reduced species	4.3.1 Changes in quantitative genetic characters in critically reduced species	4.3.2 Changes in quantitative genetic characters in range restricted species		2
	5 Ecosystem composition	5.1 Composition	5.1.1 Trends in abundance of widespread native taxa	5.1.2 Representation of plant functional types	5.1.3 Representation of animal guilds	2
		5.2 Occupancy of environmental range	5.2.1 Extent of potential range occupied by focal indigenous taxa			1
Environmental representation	6 Ecosystem representation	6.1 Environmental representation and protection status	6.1.1 Proportion of environmental unit under indigenous cover	6.1.2 Proportion of environmental unit under indigenous cover and protected (conservation orders)	6.1.3 National change in extent and integrity of naturally uncommon and significantly reduced habitats	1
	7 Climate change and variability	7.1 Biological responses to climate change	7.1.1 Status of habitats prone to adverse effects from climate change	7.1.2 Aquatic pest and weed occupancy range	7.1.3 Status of cold-water dependent species	2

Note: Targeted national outcomes, Outcome objectives and Indicators are based on Lee *et al.* (2005). Measures are based on Lee *et al.* (2005), Schallenberg *et al.* (2010), and Hudson *et al.* (2011), modified to encompass lake ecosystems.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

The Department of Conservation (DOC) aims to implement a monitoring programme to enable reporting on the status and trend of freshwater biodiversity at a national scale. This necessitates the development of a monitoring and reporting framework and set of indicators that would holistically assess freshwater biodiversity values, and a network of sites to provide an unbiased representation of the status and trend of freshwater ecosystems nationally. Monitoring will likely focus on widely distributed species and ecosystem indicators thus is unlikely to capture trends in rare ecosystems or species with highly limited distributions, covered by other core monitoring programmes of the Department. It is also a goal for DOC that the framework aligns, where practical, with existing DOC monitoring frameworks (*i.e.* Lee *et al.* 2005) and freshwater monitoring conducted by other agencies so as to maximise the sharing of information on the status and trends of freshwaters for the country.

When rationalised with other national marine and terrestrial environment monitoring programmes, the freshwater component intends to provide a New Zealand-wide framework for monitoring and reporting on the condition of, and trends in, biodiversity.

1.1. Purpose of this scoping report

The purpose of the report is to scope the development of a freshwater biodiversity monitoring programme. This includes the following key components:

- Background — providing the context for biodiversity monitoring within DOC and a summary of current biodiversity monitoring initiatives
- Relevant frameworks — describe existing freshwater and terrestrial monitoring frameworks used within and outside of DOC, that may be suitable for developing a national freshwater biodiversity monitoring programme
- Indicators — identify a range of indicators and measures that are appropriate for use in a proposed freshwater framework
- Current monitoring — provide a broad summary of existing freshwater monitoring by DOC and other management agencies that could be used to inform the DOC monitoring and reporting framework.

The project aims to ensure that all relevant technical information is gathered in order to develop a detailed scope of a programme which, when implemented, will allow DOC to report on the biodiversity of freshwaters in New Zealand. A secondary aim of the report was to provide advice on the scoping of a pilot programme, or a series of pilots to test the proposed freshwater framework before application in a full scale national programme.

This report achieves these aims by:

1. Presenting a high level framework that follows a hierarchy of "Outcome — Objective — Indicator — Measure" similar to Lee *et al.* (2005) utilising the same indicators if possible but adding measures, where appropriate, for freshwaters. These will be drawn from work undertaken through previous work such as the DOC-led Cross Departmental Research Pool (CDRP) programme on measuring ecological integrity in freshwaters, and the National Environmental Monitoring and Reporting (NEMaR) project led by the Ministry for the Environment (MfE).
2. Presenting an evaluation of possible indicators and measures that could be included in a freshwater biodiversity monitoring programme.
3. Proposing a framework to cover all freshwater ecosystem types, i.e. lakes, rivers and wetlands and freshwater indicator species.
4. Making recommendations on how a nationwide freshwater biodiversity monitoring programme can be developed across jurisdictional boundaries recognising and incorporating existing State of Environment (SOE) monitoring, and the particular niche that DOC can best fill.
5. Providing guidance on the various sampling design options and aspects to consider in the implementation of a pilot programme to test the proposed freshwater framework.

2. BACKGROUND

Freshwater biodiversity in New Zealand is subject to a range of pressures including habitat modification, environmental toxicants, water abstraction, exotic species incursions and spread, overfishing, and climate change. In many lowland areas these pressures continue to increase. Freshwater ecosystems in New Zealand, and internationally, are often considered of the most imperilled ecosystems (Parliamentary Commissioner for the Environment 2004; Vörösmarty *et al.* 2005). Information on the state and trend of freshwater biodiversity at a national scale is critical to developing effective conservation strategies. However, New Zealand at present lacks a coordinated national system for detecting changes in the ecological integrity of river, lake, wetland and other freshwater ecosystems.

This omission along with a lack of other national scale environmental monitoring has only recently been highlighted in an Environmental Reporting Bill tabled, "The proposed environmental reporting system will provide New Zealanders with comprehensive information on five key environmental domains — air, climate and atmosphere, freshwater, marine and land, with biodiversity as a theme across all the domains"[1]. This follows on from initiatives to address our environmental information needs led by Statistics New Zealand and partners, Ministry for the Environment and DOC (Statistics New Zealand *et al.* 2013). The freshwater 'enduring questions' of most relevance to this report are:

> *How is the quality, abundance, and use of New Zealand's freshwater changing, and what is the impact on ecosystems and humans?"*
> *"What impact does the change to quality, quantity, and use of freshwater have on ecosystems and humans?*
> *"What, where, and how is environmental protection effort being done to maintain and improve freshwater?*

In 2005, DOC began development of the Natural Heritage Management System (NHMS). A core aim of the NHMS programme was for the Department to prioritise investment so that two key biodiversity objectives were met, specifically:

- Objective 1.1: A full range of New Zealand's ecosystems is conserved to a healthy functioning state.
- Objective 1.2 Nationally threatened species are conserved to ensure persistence.

The Department's Statement of Intent (2013–2017) subsequently sets out how the Department will demonstrate success in terms of achieving these objectives, through monitoring of the status and trend of biodiversity at different scales, which includes freshwaters. A national biodiversity monitoring system for terrestrial biodiversity has

[1] Taken from beehive.govt.nz

been developed and implemented with summary information reported in the DOC Annual Report (MacLeod *et al.* 2012). At present there is no comparable system for freshwater biodiversity.

The need to "expand monitoring procedures (and establish new ones) for freshwater bodies (including lakes, rivers, underground systems, wetlands and geothermal systems) important for indigenous biodiversity" was recognised in the NZ Biodiversity Strategy (under Objective 2.1). This has initially been pursued by DOC through development of standardised monitoring methodologies as part of the NHMS monitoring toolbox for assessing some biodiversity components such as periphyton, macroinvertebrates and native fish communities in rivers. However, the application of a formalised national monitoring programme and site network for freshwaters has not yet been developed.

In contrast to terrestrial ecosystems, regional councils have been actively monitoring rivers and lakes for SOE reporting for 20 years or more. The SOE monitoring sites provide the basis for a national network to assess changes in water quality in particular, but which also captures aspects of biodiversity. This presents an opportunity to align the proposed DOC freshwater biodiversity monitoring programme with regional councils, to deliver a programme that is mutually beneficial.

Prior to implementation of a DOC freshwater programme, the monitoring and reporting framework, approach to data collection, data management and reporting need to be developed and then tested. As such the potential design of a pilot programme is included as part of the scoping process.

2.1. Overview of current Department of Conservation Biodiversity monitoring programme

The Department of Conservation developed a Biodiversity Monitoring and Reporting System as part of NHMS that consists of three integrated components (Tier 1, Tier 2 and Tier 3), all of which are required to report on biodiversity outcomes. Using a nested hierarchy (Figure 1), DOC aims to collect information with different levels of scope and spatial coverage to report on gains and losses in biodiversity across its areas of responsibility.

Each tier includes a suite of indicators, measures, and monitoring and reporting tools that are intended to operate at a range of scales, and collectively contribute to reporting on ecological integrity.

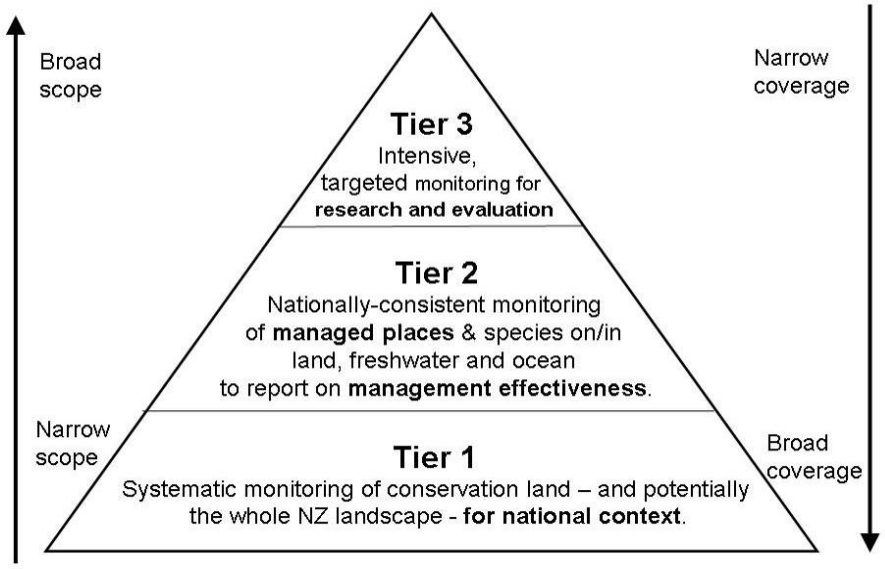


Figure 1. Department of Conservation's three tier approach to monitoring changes in the ecological integrity of New Zealand's ecosystems and species.

Tier 1 monitoring is intended to provide broadscale biodiversity information to inform the status and trends of key indicators on public conservation land (PCL), and where possible, all New Zealand. It is anticipated that these indicators could be tied to existing SOE monitoring networks run by regional councils, with gaps in parameters and sites (*e.g.* reference sites on PCL) added to the SOE networks by the Department where appropriate.

Tier 2 monitoring would occur in areas identified as a high priority for management through DOC's ecosystem and species optimisation projects, where there are more intensive management actions to maintain or enhance the integrity of species and ecosystems. Monitoring is designed to report on the difference made from management interventions in these areas.

Tier 3 monitoring would occur at a small number of sites that were designated for development of management practices (*e.g.* ecosystem or species restoration) or where information on reference condition and natural variation was intended. An example of Tier 3 monitoring are the large freshwater sites in the Arawai Kākāriki Wetland Restoration Programme; Whangamarino wetland, Ō Tū Wharekai (Ashburton Lakes and Upper Rangitata River), and Awarua-Waituna (Robertson & Suggate 2011).

3. FRAMEWORKS FOR TIER 1 BIODIVERSITY MONITORING

3.1. Ecological Integrity Framework (Lee *et al.* 2005)

As part of the initial process around designing the DOC Monitoring and Reporting System, the Department engaged Landcare Research to develop a framework for monitoring and reporting on the status and trend of biodiversity (Lee *et al.* 2005). Although the focus of the framework was principally in relation to terrestrial ecosystems, it did consider aspects of freshwater ecosystems. The Lee *et al.* (2005) framework is based on a set of indicators and measures that together comprise a means of assessing the 'ecological integrity' of a representative site network. Ecological integrity (EI) was defined as the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes (Lee *et al.* 2005). 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 EI when all the indigenous plants and animals typical of a region are present, together with the key ecosystem processes that sustain functional relationships between all these components. At larger scales, EI is achieved when ecosystems occupy their full environmental range (Lee *et al.* 2005).

From a biodiversity conservation perspective, EI was considered to comprise a mix of three distinct elements: **long-term indigenous dominance**; **potential occupancy by all appropriate biota**; and **full environmental representation of ecosystems**, which can be measured at a range of hierarchical scales within a monitoring network (*e.g.* populations, species, and ecosystems; Table 1).

Within this framework, nine outcome objectives were recognised and designed to measure and report on progress towards DOC's targeted national outcomes. These national objectives (Table 1) are:

- maintaining ecosystem processes
- reducing the spread and impact of exotic/invasive species
- reducing environmental pollutants
- preventing declines and extinctions
- improving ecosystem composition
- improving ecosystem representation
- responding to the impact of climate change and variability
- maintaining the sustainable use of indigenous ecosystems
- fulfilling community aspirations.

The hierarchical framework then presents a range of indicators for each outcome objective, each with specific measures for potential use for monitoring and reporting. Development of measures and metrics was initially more in depth for terrestrial ecosystems and species, simply related to the scientific expertise involved in the project.

It was determined in a workshop held in May 2013 that the main aim of the freshwater scoping project would be to assess the Lee *et al.* (2005) framework's coverage of key freshwater indicators and develop a suite of measures for freshwater ecosystems.

Table 1. Outcome framework for monitoring and reporting on the status and trend of terrestrial* biodiversity (compiled from Lee *et al.* 2005).

National outcome	Targeted national outcome	Outcome objectives	Indicator
Ecological integrity	**Indigenous dominance**	**1) Maintaining ecosystem processes**	1.1 Soil status 1.2 Productivity 1.3 Water quality and yield 1.4 Ecosystem disruption 1.5 Land cover
		2) Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species 2.2 Exotic weed and pest dominance
		3) Limiting environmental pollutants	3.1 Ecosystem levels of persistent toxins
	Species occupancy	**4) Preventing declines and extinctions**	4.1 Extinct taxa 4.2 Status of acutely threatened taxa 4.3 Status of chronically threatened taxa 4.4 Genetic change in critically reduced species
		5) Ecosystem composition	5.1 Composition 5.2 Occupancy of environmental range 5.3 Patch size/fragmentation of wooded ecosystems
	Environmental representation	**6) Ecosystem representation**	6.1 Environmental representation and protected status
		7) Climate change and variability	7.1 Basic climate series 7.2 Biological responses to climate change
	All three combined	**8) Sustainable use**	8.1 Recreational use of DOC land and its impacts 8.2 Economic use of DOC land and its impacts
		9) Community participation in conservation	9.1 Community involvement 9.2 Iwi partnerships 9.3 Eco-vandalism 9.4 Conservation profile

* Although freshwater ecosystems were considered in Lee *et al.* (2005) the development of aquatic indicators and measures was not comprehensive.

3.2. Other freshwater monitoring frameworks

3.2.1. Cross Departmental Research Pool Project — measuring and quantifying ecological integrity in rivers and lakes

From 2006–2010 a CDRP project funded by the Foundation for Research Science and Technology was directed towards quantifying relationships between human pressures and EI in lakes and rivers. The research also aimed to develop the concept of EI in freshwaters, exploring ways in which it could be measured, and quantitatively assessing a range of EI metrics against known human pressure gradients such as native forest removal, eutrophication, and exotic species. The project consisted of four main parts:

1. Defining and developing a measure of ecological integrity for freshwaters
2. Collating and expanding field monitoring of appropriate ecological integrity indicator variables in freshwaters
3. Quantifying relationships between ecological integrity indicators and river and lake catchment pressure indices
4. Developing a multi-metric index of ecological integrity.

From this programme of work, a definition of EI in a freshwater context was developed by Schallenberg *et al.* (2011), described as "the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and maintained close to a reference condition in which anthropogenic impacts on these are negligible or minimal". Four core components of EI were recognised under this definition according to Schallenberg *et al.* (2011) including 1) nativeness, 2) resilience, 3) diversity and 4) pristineness, with a list of recommended measures and metrics for these core components described for river and lakes (Tables 2 and 3).

While the nomenclature differs between the Lee *et al.* (2005) and the Schallenberg *et al.* (2011) frameworks, it is likely that the specific indicators and measures selected to report on freshwater biodiversity are relatively consistent. At higher levels of the frameworks, for instance, the concept of nativeness in Schallenberg *et al.* (2011) is directly related to the outcome objective of indigenous dominance of the Lee *et al.* (2005) framework. Similarly species occupancy (*i.e.* ecosystems containing the species meant to inhabit them) is closely tied to pristineness measures that evaluate the structural (and functional) components of ecosystems in relation to their reference condition. The idea of minimally impacted reference condition was adopted for the Schallenberg *et al.* (2011) definition to address the aspect of quantifying of EI metrics in terms of their departure from expected 'non-impacted' condition.

Existing sources for environmental monitoring data from Regional Councils, Crown Research Institutes (CRIs), and other sources (*e.g.* universities) were used to

evaluate national coverage of EI indicators, and three key areas that would be pursued to fill gaps in existing knowledge for key indicators or under-represented habitats. This included the collection of functional process indicators for rivers and lakes, and a range of indicator collection for large non-wadeable rivers, and shallow lowland lakes. National rivers and lakes analyses were conducted to examine relationships between a range of EI indicators and gradients of human pressure from the FENZ (Freshwater Ecosystems of New Zealand) model.

Careful choice of structural and functional indicators was identified as crucial to creating a practical scheme for assessing EI. A range of common measures (and in some cases metrics) that can be used to quantify the four core components of EI were identified for rivers and streams (Table 2) and lakes (Table 3). These tables have been modified to show the alignment of the proposed freshwater Tier 1 monitoring programme 'measures' with the CDRP 'indicators'.

Overall we would view the measures and metrics from the CDRP framework to be compatible with the Lee *et al.* (2005) framework. The research undertaken to identify relevant metrics for lakes and rivers by the CDRP programme will directly inform the selection of measures under the broader Lee *et al.* (2005) framework that is presently being used in DOC monitoring and reporting. However, the CDRP project did not consider wetland monitoring which creates a potential gap in reference to DOCs design of a comprehensive Tier 1 biodiversity framework for rivers, lakes and wetlands.

Table 2. Suggested list of metrics for the assessment of ecological integrity (EI) in rivers and streams. Modified from Schallenberg *et al.* 2011.

EI core component	**EI measure (metrics)** ***In CDRP termed: 'Indicator'***	**Examples of main stressors that may be detected**	**Freshwater equivalent Lee *et al.* (2005) framework measures from Table 1**
Nativeness	Native fish (% native, no. of introduced species, O/E)	Invasion and introduction	5.1
	Presence of invasive macrophytes/ algae	Invasion and introduction	2.1 & 2.2
Pristineness			
Structural	Macroinvertebrate community composition (MCI, %EPT)	Multiple disturbances	5.1
	Fish IBI	Invasion and introduction	5.1
Functional	Ecosystem metabolism	Eutrophication, habitat degradation, flow abstraction	1.4 & 1.3 & 1.6
	Wood decomposition rates	Eutrophication, change in land use,	1.2 & 1.6
	BOD	Organic enrichment	1.4
	$\delta^{15}N$ of primary consumers	Specific N and P enrichment	1.2 & 1.4
Physico-chemical	Water clarity, turbidity	Eutrophication, sedimentation	1.6
	Nutrient concentrations	Eutrophication, sedimentation	1.4
	Water temperature, dissolved oxygen	Riparian and catchment clearance, abstraction	1.6 & 1.3
Diversity	Macroinvertebrate taxonomic richness, diversity, O/E richness	Multiple disturbances	5.1
	Abiotic structure (Habitat template)	Change in physical template, abstraction, irrigation	5.3
Resilience	Presence/absence of key indicator taxa	Multiple disturbances	2.1 & 5.1
	Ecosystem function	Change in physical template	

Note: Metrics are thought to be universally applicable, robust, and relatively inexpensive, require minimal taxonomic skill and are likely to be the most responsive to anthropogenic stressors. Examples of main stressors that may be detected by the metrics and measures equivalent to the Lee *et al.* (2005) framework are also reported.

Table 3. Suggested list of metrics for the assessment of ecological integrity (EI) in lakes. Modified from Schallenberg *et al.* (2011).

EI core component	**Measures (metrics)** ***In CDRP termed: "Indicator"***	**Examples of main stressors that may be detected**	**Freshwater equivalent Lee *et al.* (2005) framework measures from Table 1**
Nativeness	Catch per unit effort (CPUE) of native fish	exotic species	1.2
	% native species (macrophytes, fish)	exotic species	5.1 & 5.2
	Absence of invasive fish and macrophytes	exotic species	2.1 & 2.2
Pristineness *Structural*	Depth of lower limit of macrophyte distribution	Eutrophication	1.4
	Phytoplankton community composition	Eutrophication	1.2
Functional	Intactness of hydrological regime	Connectedness, abstraction, barriers	1.3 & 1.5
	Continuity of passage to sea for migrating fish (diadromous fish composition	Connectedness, artificial human barriers	1.5 & 1.5
	Water column DO fluctuation	Eutrophication	1.4
	Sediment Anoxia (rate of redox potential change in sediments)	Anoxia, eutrophication	1.1 & 1.4
Physico-chemical	TLI and components	Eutrophication	1.4 & 3.1
	Non-nutrient contaminants	Depends on pressures	3.1
Diversity	Macrophyte, fish, invertebrate diversity indices	Loss of biodiversity	5.1 & 4.2
Resilience	Number of trophic levels	Loss of top predators	5.1
	Euphotic depth compared to macrophyte depth limit	Macrophyte collapse	1.2, 5.1
	Instance/frequency of macrophyte collapse or recorded regime shifts between clear water and turbid states	Macrophyte collapse	1.2
	Compensation depth compared to mean depth	Potential for light or nutrient limitation of phytoplankton growth	1.2
	DIN:TP ratio	Risk of cyanobacterial blooms	1.4
	Bloom-forming cyanobacteria presence/absence)	Risk of cyanobacterial blooms	1.4

3.2.2. Ministry for the Environment — National Environmental Monitoring and Reporting Framework

The Ministry for the Environment (MfE) started the National Environmental Monitoring and Reporting (NEMaR) programme in 2011 when they commissioned NIWA (National Institute of Water and Atmospheric Research) and GNS Science to write a report detailing a consistent monitoring framework for reporting on the status and trend of freshwaters nationally (*i.e.* Dependable Monitoring of Freshwaters for National-scale Environmental Reporting, Davies-Colley *et al.* 2011). Monitoring requirements for both wetlands and estuaries were not included in the scope of this early work, or in the more detailed NEMaR reports that followed. Development of the science to underpin the NEMaR work was undertaken in three work streams: variables or analytes (Davies-Colley *et al.* 2012), indicators (Hudson *et al.* 2012), and the spatial coverage of monitoring networks (Larned *et al.* 2012). The work streams are summarised in Schmidt *et al.* (2012), however the reports are yet to be made publically available and implementation mechanisms are being considered in light of:

- freshwater reforms, *i.e.* the proposed National Objectives Framework
- the Environment domain plan (Statistics New Zealand *et al.* 2013)
- changes to MfE's internal operating model, *i.e.* formation of a monitoring unit
- the development of National Environmental Monitoring Standards (NEMS)
- the proposed Environmental Reporting Bill.

As with the two previous frameworks, a holistic approach for assessing freshwaters was adopted by the NEMaR process. With the recent development of the Schallenberg *et al.* (2011) framework for assessing EI, this approach was thought most suitable, and subsequently adopted as the underpinning framework. However, many of the original recommended measures under the Schallenberg *et al.* (2011) framework were considered to be 'under development' and not ready for application to a national monitoring and reporting system (Davies-Colley *et al.* 2012). Thus a subset of core variables was adopted by the NEMaR monitoring programme (Hudson *et al.* 2011). As many of the indicators removed from the original Schallenberg *et al.* (2011) list were either biological or functional process oriented, this meant that the main set of indicators retained in the NEMaR framework were focused mainly around assessment of water quality (Table 4). This was reflected in the parameters used in the current MfE River Condition indicator although Macroinvertebrtae Community Index (MCI) is also used [2]. The lack of any suitable guidance for freshwater fish monitoring was acknowledged at later stages of the NEMaR project and fisheries experts were given the opportunity to meet to consider what would be required, and resulted in an exotic fish metric to be included in the framework. For lake ecosystems, a greater number of biological community indicators for macrophytes and fish were

[2] http://www.mfe.govt.nz/environmental-reporting/fresh-water/river-condition-indicator/summary-key-findings.html

endorsed (Table 5), the former related to the widespread use of the aquatic macrophyte (LakeSPI) monitoring being used by regional councils. There were no functional process indicators adopted into the core set, but were included as optional indicators.

The indicators and measures identified in the NEMaR tables represent the bulk of freshwater monitoring currently being conducted in New Zealand by regional councils and in the National River Water Quality Network by NIWA and cover a number of indictors detailed in the Lee *et al.* (2005) framework (Tables 4 and 5). However, the scope of the indicators is narrower than the broad scope identified by Lee *et al.* (2005) in reference to assessing EI, and as with the CDRP programme the framework lacks a wetland biodiversity component. Thus there will be a need to consider the applicability of other indicators for wetland ecosystems, and likely a greater number of biological and process based indicators for rivers and lakes to achieve DOC's biodiversity monitoring goals.

Table 4. Suggested list of metric classes and metrics endorsed by the National Environmental Monitoring and Reporting (NEMaR) expert panel for assessing and reporting ecological integrity (EI) in rivers and streams. Examples of main stressors that may be detected by the metrics and measures equivalent to the Lee *et al.* (2005) framework are also reported.

Measure/EI component	**Metric class**	**Metrics**	**Examples of main stressor that may be detected**	**Freshwater equivalent Lee *et al.* (2005) framework measures from Table 1**
Nativeness	Biota	Percent alien species (fish) Observed *vs.* expected for native species (fish)	Invasion and introduction	5.1& 2.1 & 2.2
Pristineness	Biota	QMCI EPT richness taxon richness	Multiple disturbances	5.1 & 5.2
	Habitat	Per cent sediment cover Stream Ecological Valuation (reconstructed)	Sedimentation, Eutrophication	1.1 & 1.4
	Water quality	*E. coli* Visual clarity Nutrients [A] Electrical conductivity Dissolved copper, zinc, cadmium	Eutrophication, Sedimentation, Specific N and P enrichment, toxicity	1.4 & 3.1
	Hydrology	Abstraction index Flow Connectivity	Riparian and catchment clearance, flow abstraction	1.6 & 1.3
Diversity	Biota	Taxon richness (macro invertebrates)	Multiple disturbances	5.1 & 5.2
Resilience	Biota	Taxon richness (Macro invertebrates)	Multiple disturbances,	5.1 & 5.2
Optional	Biota	Gross primary productivity Respiration Per cent periphyton cover	Eutrophication, habitat degradation, flow abstraction, change in physical template	1.4 & 1.3 & 1.6
	Water Quality	Temperature, dissolved oxygen concentration (continuous measurement) [B]	Riparian and catchment clearance, abstraction	1.6 & 1.3

A Total and dissolved reactive phosphorus, ammoniacal-, dissolved inorganic- and total nitrogen
B Retained as secondary variables to enable calculation of GPP and respiration

Table 5. Suggested list of metric classes and metrics endorsed by the National Environmental Monitoring and Reporting (NEMaR) expert panel for assessing and reporting ecological integrity (EI) in lakes. Examples of main stressors that may be detected by the metrics and measures equivalent to the Lee *et al.* (2005) framework are also reported.

Measure/EI component	Metric class	Metrics	Examples of main stressor that may be detected	Freshwater equivalent Lee *et al*. (2005)
Nativeness	Biota	Macrophytes[1] Pest fish Native fish	Exotic species	1.2 & 5.1
	Habitat	Macrophytes	Exotic species	5.1 & 5.2
	Hydrology	Lake level variation Residence time	Exotic species	1.3
Pristineness	Biota	Macrophytes Pest fish Cyanobacteria	Eutrophication	2.1 & 2.2
	Habitat	Macrophytes	Eutrophication	5.1 & 2.2 & 1.2
	Water quality	Chlorophyll-*a* Total nitrogen Total phosphorus Secchi depth Dissolved oxygen profile Temperature profile DIN[2] CDOM[3]	Eutrophication Toxicity	1.3 & 1.2
	Hydrology	Lake level variation Residence time	Connectedness, abstraction, irrigation, artificial human barriers	1.3 & 1.5
Diversity	Biota	LakeSPI Pest fish	Loss of biodiversity	5.1 & 4.2
	Habitat	Macrophytes	Loss of biodiversity	5.1 & 4.2
Resilience	Biota	Pest fish Macrophyte variability Cyanobacteria	Risk of cyanobacterial blooms	1.4 & 2.2 & 2.1
	Habitat	Macrophytes	Macrophyte collapse	1.2, 1.3
	Water quality	Chlorophyll-*a* variability	Risk of cyanobacterial blooms	1.3
Optional	Biota	Rotifer TLI MCI for lakes Invasive zooplankton	Loss of biodiversity	5.1 & 4.2
	Habitat	Sedimentation/ sediment loading	Anoxia, eutrophication	1.1 & 1.3 & 1.4
	Water quality	pH TSS/VSS Diel dissolved oxygen GPP Developments to TLI	Eutrophication, Toxicity, Loss of productivity	1.2 & 1.4 & 3.1
	Hydrology	Connectedness	Artificial human barriers	1.3 & 1.5

[1] Lake Submerged Plant Index, [2] Dissolved inorganic nitrogen, [3] Coloured dissolved organic matter

3.2.3. Handbook for monitoring wetland condition (Clarkson et al. 2004)

The development of standard approaches to wetland monitoring in New Zealand received increased attention during the early 2000s with the publication of the Handbook for Monitoring Wetland Condition (Clarkson *et al.* 2004). A framework for assessing wetland condition was developed that included five core wetland indicators (Table 6). Specific measures (indicator components) and metrics (plot indicators) were also defined, many of which would fit within the Lee *et al.* (2005) framework.

The Clarkson *et al.* (2004) wetland condition approach is now generally regarded as the benchmark for undertaking assessment of wetland biodiversity and function elements such as soil chemistry and plant composition.

Table 6. Wetland indicators identified on the 'Co-ordinated Monitoring of New Zealand Wetlands' project (Source: Clarkson *et al*. 2004)

Indicator	Indicator components	Examples of metrics	Freshwater equivalent Lee *et al*. (2005)
Hydrological integrity	Impact of manmade structures	Water table depth Von post index Conductivity pH Vegetation cover & composition	1.3 & 1.4
	Water table		1.3
	Dryland plant invasion		1.3 & 5.1
Physicochemical parameters	Fire damage	Soil bulk density TN, TP, TC pH Soil water content Von post index	1.4
	Sedimentation / erosion		1.4
	Nutrient levels		1.1 & 1.3
	Peat decompostion		1.1
Ecosystem intactness	Loss of wetland extent	Wetland area	1.5 & 5.3
	Connectivity barriers		1.4 & 5.3
Browsing, predation & harvesting regimes	Domestic/feral animal damage	Vegetation cover & composition	2.2
	Exotic predator impacts		2.2
	Harvesting levels		1.3 & 1.4
Dominance of native plants	Exotic canopy dominance	Vegetation cover & composition	2.1, 2.2 & 5.1
	Exotic understorey dominance		2.1, 2.2 & 5.1

There have been new developments and applications of the Clarkson *et al.* (2004) indicators such as in the DOC Arawai Kākāriki programme (see Section 3.2.4), in regional council monitoring of wetlands (*e.g.* Clarkson *et al.* 2013) and in scientific panel discussions to inform the MfE National Objectives Framework (NOF).

The framework developed by Clarkson *et al.* (2004) is being used by regional councils in combination with other wetland measures developed by DOC for monitoring and reporting on the SOE of wetlands. For example, Landcare Research, DOC and Environment Southland recently produced a report describing an approach to SOE wetland monitoring in Southland with refined components on soil chemistry, wetland plant composition and abundance, wetland extent and wetland hydrology (Clarkson *et al.* 2013). These indicator components are considered directly applicable to reporting on wetland biodiversity at a national level.

3.2.4. Department of Conservation-led wetland frameworks — Arawai Kākāriki

The Arawai Kākāriki ('Green Waterway') Wetland Restoration Programme began in July 2007 at three of New Zealand's foremost wetland sites (Robertson & Suggate 2011). It is a DOC flagship programme aimed at protecting, restoring and understanding these ecosystems with the assistance of community. The three Arawai Kākāriki sites are; the Whangamarino wetland in Waikato, Ō Tū Wharekai (Ashburton Basin and upper Rangitata River) in Canterbury, and Awarua/Waituna in Southland.

The programme involves a broad range of wetland restoration and monitoring initiatives that are undertaken in collaboration with local community, iwi and other agencies. Restoration and monitoring actions are based on the best available science and from gathering new information on wetland values and threats.

There are 10 defined national objectives for the Arawai Kākāriki Wetland Restoration Programme under the themes of Biodiversity, Community and Learning. The four biodiversity objectives; *wetland extent, water quality and quantity, habitat condition, and species*, collectively align with the concept of maintaining and enhancing EI.

A framework for monitoring and reporting has been developed for the Arawai Kākāriki programme, with indicators developed to report on the programmes national objectives. For the biodiversity objectives, indicators and measures consist of a wide range of biophysical and policy based outcomes for monitoring and reporting (Table 7), very much in line with the Lee *et al.* (2005) framework in terms of its biodiversity components. There is also a reasonable alignment of the framework's biodiversity measures with the core components identified in the CDRP framework, suggesting reasonable compatibility between all the frameworks discussed in this section.

While the Arawai Kākāriki programme is an example of managed ecosystems (Tier 2) with targeted research (Tier 3), many of the indicators and monitoring methods are considered suitable for national assessment of wetland EI (Tier 1). The Arawai Kākāriki indicators and measures are also often derived from the Handbook for Wetland Monitoring (Clarkson *et al.* 2004) which ensures transferability across different agencies and councils.

Table 7. List of monitoring and reporting objectives, outcome, indicators and measures for wetlands as for the Department of Conservation (DOC) Arawai Kākāriki Wetland Restoration Programme. Also shown are linkages to the core components of the CDRP ecological integrity (EI) indicators.

Arawai Kākāriki national objective	**Arawai Kākāriki indicator**	**Arawai Kākāriki measure**	**Freshwater equivalent Lee *et al*. (2005)**
1. Maintain or enhance the extent of wetland habitat	Wetland extent & protection	[AK1.i] Extent of wetland habitats on PCL in management area	6.1
		[AK1.ii] Extent of wetland habitats outside of PCL in management area and protected private land	6.1
2. Maintain and enhance water regime and water quality to support aquatic values	Hydrological regime	[AK2.i] Frequency, duration, extent and timing of inundation for different wetlands, lakes and lagoons	1.3 & 1.4
	Sedimentation	[AK2.ii] Sediment deposition rates at key sites	1.4
	Water chemistry	[AK2.iii] Sediment load of tributary drains/creeks	1.3
		[AK2.iv] Water properties at key sites - select from nutrients, light, DO, pH, salinity, pollutants	1.3
	Soil status	[AK2.v] Soil N/P levels	1.1
		[AK2.vi] Soil pH	1.1
	Biological water quality metrics	[AK2.vii] Biotic indices of water quality at key sites - select from TLI, MCI, Periphyton (rivers)	1.3 & 5.1
3. Protect and restore habitat	Indigenous habitat extent	[AK3.i] Extent of indigenous habitats on PCL in management area	6.1
		[AK3.ii] Extent of indigenous habitats outside of PCL in management area	6.1
	Ecosystem composition & occupancy	[AK3.iii] Biotic indices - select from LakeSPI, Fish IBI	5.1
		[AK3.iv] Abundance of indicator species/plant functional types across height classes	5.1
		[AK3.v] Proportion of sites with expected plant functional types	5.1
	Indigenous dominance	[AK3.vi] Ratio of indigenous to exotic plant species (richness) in each habitat type	2.2

Arawai Kākāriki national objective	Arawai Kākāriki indicator	Arawai Kākāriki measure	Freshwater equivalent Lee *et al*. (2005)
		[AK3.vii] Ratio of indigenous to exotic plant species (abundance) in each habitat type	2.2
	Soil decomposition	[AK3.viii] Peat formation	1.4
	Fire impact	[AK3.ix] Number and extent of wild fires	1.4
	Environmental weed /pest dominance	[AK3.x] Distribution and abundance of weed species considered a threat	2.2
		[AK3.xi] Distribution and abundance of pest species considered a threat (grazers)	2.2
	New weed incursions	[AK3.xii] Number of new incursions of environmental weeds	2.1
4. Maintain and enhance indigenous species diversity, including threatened species	Ecosystem composition & occupancy	[AK4.i] Species diversity in target local indicator guilds	5.1
		[AK4.ii] Proportion of sites with expected indicator guilds	5.1
		[AK4.iv] Counts or indices of abundance of individuals of target indicator species	5.1
	Indigenous dominance	[AK4.iii] Ratio of indigenous to exotic species within representative indicator guilds	2.2
	Threatened species status	[AK4.v] Number of nationally threatened species that rely on this site for long term recovery (>1% pop.)	4.2 & 4.3
		[AK4.vi] Population dynamics of selected threatened species both under management and not under management.	4.2 & 4.3
	Environmental weed /pest dominance	[AK4.vii] Distribution and abundance of predators considered a threat	2.2

4. DESIGNING A FRESHWATER BIODIVERSITY MONITORING FRAMEWORK

4.1. Goals and objectives of this Tier 1 Monitoring Framework

The primary goal of a freshwater Tier 1 monitoring programme is to be able to report nationally on the status and trend of biodiversity in freshwater systems in New Zealand. As with the other freshwater monitoring frameworks (*e.g.* NEMaR, CDRP), it is recommended the Tier 1 freshwater framework be oriented around holistically assessing biodiversity values in the context of measuring ecological integrity. Since the Lee *et al.* (2005) framework has been applied for the DOC Tier 1 terrestrial programme it would seem the most sensible approach for the freshwater framework to adopt the same hierarchical structure, but with further effort to develop freshwater measures and metrics. This would provide the most consistent integrated (freshwater, terrestrial and possibly marine) monitoring system for the Department.

Because freshwater ecosystems are also the focus of other central and regional government monitoring agencies (*e.g.* Ministry for the Environment, regional councils and unitary authorities) it is important that any framework is designed to take account of existing monitoring and reporting, and build on these initiatives.

A workshop was convened including representatives from DOC, Cawthron Institute, MfE and Waikato Regional Council (May 2013) to discuss some of the key objectives of the Tier 1 freshwater programme and discuss the scope of proposed monitoring. Some of the guiding principles identified from the workshop were as follows:

- Test alignment with DOC Tier 1 monitoring and reporting frameworks for terrestrial ecosystems — Lee *et al.* (2005)
- Complement and potentially utilise monitoring networks overseen by other agencies
- Collect data to allow reporting on the status of ‘at risk’ freshwater species, particularly in regards to assessing distributional range (*i.e.* expansion/contraction)
- Build on existing DOC freshwater monitoring initiatives (*e.g.* Otago non-migratory galaxiids)
- Collect national level data to support analysis of the condition of freshwater ecosystems in areas subjected to different land uses
- Collect national level data to support the quantification of freshwater ecosystem services provided by public conservation land (PCL).

Further, from the workshop it was concluded that the scope of the freshwater programme would be based on the following aspects:

- Monitoring extent to focus initially on public conservation land, but with options for future linkages to wider national reporting (MfE, regional councils)
- Reporting on the status of freshwater biodiversity primarily
- Ecosystem approach through assessment of ecological integrity
- Designed to assess long-term trends (akin to SOE reporting)
- Consider the possible use of indicator species
- Ecosystem coverage to include rivers, lakes (excluding coastal intermittently closed and open lagoons (ICOLLs) and wetlands (palustrine only in alignment with Freshwater Ecosystems of New Zealand; FENZ)
- Acutely threatened species will not specifically be covered as this aligns to Tier 2 monitoring but allow for some reporting on range expansion/collapse
- Declining/data deficient species can be considered in regards to the inclusion of an indicator species approach.

4.2. Development of Tier 1 freshwater indicators and measures

An exercise was undertaken to evaluate the Lee *et al.* (2005) framework for its use in monitoring and reporting on freshwater biodiversity.

At a higher level, the Lee *et al.* (2005) framework was considered to be a useful base for freshwater biodiversity reporting. Targeted national outcomes and outcome objectives used for the terrestrial Tier 1 monitoring were considered suitable for freshwater ecosystems, and subsequently adopted. At the indicator and measure level, it was felt that adjustments in the framework were needed to more comprehensively address measures for freshwater ecosystems and align with freshwater monitoring initiatives currently underway by DOC and other agencies.

Where there were perceived gaps, an expert panel approach was taken towards filling these gaps, some of which were informed by the aforementioned workshop with participation by DOC, Cawthron Institute, MfE and Waikato Regional Council.

4.2.1. Proposed framework design

The proposed freshwater biodiversity monitoring and reporting framework includes measures for rivers, lakes and wetlands (Table 8).

The freshwater framework at this scoping stage is intended to be comprehensive, with recommended measures to cover the entire range of indicators cited in the Lee *et al.*

(2005) framework. However, it is expected due to costs associated with monitoring at a national scale the Department will be required to rationalise a set of indicators within a monitoring programme to a limited number of key measures. This approach was followed for the terrestrial Tier 1 biodiversity monitoring, which currently reports on seven measures for three indicators at a national scale (MacLeod *et al.* 2013). It is expected that a consultation process and a pilot monitoring investigation would inform the selection of key indicators and measures. To assist rationalisation we have provided an expert driven ranking of the indicators in terms of their alignment with DOCs strategic vision, and core business areas. Further discussion on next steps towards implementing a freshwater biodiversity monitoring and reporting programme are included in Section 6.

It should be noted that the measures cited are defined at a high level, and further work will be needed to develop specific metrics under these measures. For example, in Table 8 the Ecosystem Productivity indicator (1.2) includes primary production and secondary production measures, but this will need to be further developed into metrics such as periphyton biomass, or macroinvertebrate community abundance. Some of the work conducted in the NEMaR and CDRP programmes have evaluated the use of these metrics (*e.g.* Hudson *et al.* 2012), and developed specific further details around methodologies for their field measurement, sampling frequency, and metric calculations (Davies-Colley *et al.* 2012). These could provide an effective means of evaluating what metrics might be applicable to national scale monitoring and align with indicators (and measures) identified through scientific evaluation and input from other management agencies (*e.g.* MfE and regional councils).

Table 8. Suggested list of indicators and measures for the assessment of freshwater biodiversity for rivers, lakes and wetlands. Note that more detailed tables for rivers, lakes and wetlands individually are included in Appendix 1.

Targeted national outcomes	**Outcome objectives**	**Indicator**	**Measure 1**	**Measure 2**	**Measure 3**	**Priority (1=high, 3=low)**
Indigenous dominance	1 Maintaining ecosystem processes	1.1 Soil status	1.1.1 Substrate modification and/or erosion	1.1.2 Sediment loading / accumulation / deposition and infill rates	1.1.3 Soil chemistry (*e.g.* pH, N/P levels, redox)	1
		1.2 Productivity	1.2.1 Ecosystem primary production (plankton, periphyton, macrophytes)	1.2.2 Ecosystem secondary production (macroinvertebrate, zooplankton)	1.2.3 Fisheries production (native fish community)	1
		1.3 Water quality and yield	1.3.1 Hydrological alteration- (water level, yield, flow regime)	1.3.2 Eutrophication	1.3.3 Toxicity (DO, NH4, NO3, pH)	1
			1.3.4 Flow habitat retention for key species	1.3.5 Visual clarity		
		1.4 Ecosystem disruption	1.4.1 Barriers to species migration (dams, bunds, culverts)	1.4.2 Modification of morphology and sediment transport (channelization, drainage)	1.4.3 Riparian processes (shading, nutrient uptake)	1
	2 Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species	2.1.1 Occurrence of self-maintaining populations of new environmental weeds and animal pests			1
		2.2 Exotic weeds and pest dominance	2.2.1 Distribution and abundance of exotic weeds and pests	2.2.2 Indigenous systems released from exotic pests		1

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
	3 Environmental pollutants	3.1 Contaminants	3.1.1 Persistent contaminants (metals, organochlorines)	3.1.2 Endocrine disrupting substances		3
Species occupancy	4 Preventing declines and extinctions	4.1 Extinct taxa	4.1.1. Number of taxa presumed extinct			1
		4.2 Conservation status of species	4.2.1 Abundance and distribution of species listed as 'threatened'	4.2.2 Abundance and distribution of species listed as 'at risk'		1
		4.3 Genetic change in reduced species	4.3.1 Changes in quantitative genetic characters in critically reduced species	4.3.2 Changes in quantitative genetic characters in range restricted species		2
	5 Ecosystem composition	5.1 Composition	5.1.1 Trends in abundance of widespread native taxa	5.1.2 Representation of plant functional types	5.1.3 Representation of animal guilds	2
		5.2 Occupancy of environmental range	5.2.1 Extent of potential range occupied by focal indigenous taxa			1
Environmental representation	6 Ecosystem representation	6.1 Environmental representation and protection status	6.1.1 Proportion of environmental unit under indigenous cover	6.1.2 Proportion of environmental unit under indigenous cover and protected (conservation orders)	6.1.3 National change in extent and integrity of naturally uncommon and significantly reduced habitats	1
	7 Climate change and variability	7.1 Biological responses to climate change	7.1.1 Status of habitats prone to adverse effects from climate change	7.1.2 Aquatic pest and weed occupancy range	7.1.3 Status of cold-water dependent species	2

Note: Targeted national outcomes, Outcome objectives and Indicators are based on Lee *et al.* (2005). Measures are based on Lee *et al.* (2005), Schallenberg *et al.* (2010), and Hudson *et al.* (2011), modified to encompass lake ecosystems.

4.3. Integrating ecological integrity measures within a holistic framework

Karr (1981) was the first to suggest the combination of fish metrics to create an index of biological integrity (IBI). This has formed the cornerstone of multi-metric index development and has been widely adopted in river assessment. Multi-metric indexes have been developed using fish data (Joy and Death 2004), macroinvertebrates (Collier 2008), and periphyton (Hill *et al*. 2000). As biological indicators have become more widely applied there have been an increasing number of studies measuring a combination of stream components to assess stream condition (*e.g.* Carlisle *et al*. 2008, Johnson and Hering 2009). Recent comparative studies of multiple indicators have shown how different groups of organisms provide complementary information of ecological condition. For example, in a parallel investigation of fish, macroinvertebrates and diatom assemblages, Carlisle *et al*. (2008) showed how a single group evaluation indicated impaired conditions on average much less often than when several groups were used. Similarly, a recent New Zealand study illustrated how different indicators varied in their responses to varying land-use stressors (Clapcott *et al*. 2012). Such studies suggest that the assessment of multiple groups of organisms has the potential to provide a more robust evaluation of ecological integrity than the assessment of a single group.

There are few New Zealand examples of existing monitoring programmes that integrate a range of measures into a holistic index, although several research (CDRP Freshwater) and monitoring reform (NEMaR) projects have considered such aspects (Clapcott *et al.* 2009, Hudson *et al.* 2012). One of the best existing examples is the wetland condition framework (Clarkson *et al*. 2004) in which a range of hydrological, chemistry and biological community indicators are integrated into a single wetland condition index (Figure 2). There have been approximately 315 wetlands assessed nationally using the framework, although these represent only one-off assessments.

The integration of measures, as is proposed within the Tier 1 freshwater framework, is an appealing concept as it allows a wide range of indicator components to be considered in an assessment of EI for a particular site or environmental class. A multi-metric index, as is done for the wetland condition index, could be a model for consideration in implementing the Tier 1 framework. A pilot analysis of EI measures from sites covering a range of stressor types and magnitudes would be needed to evaluate the usefulness of such an approach.

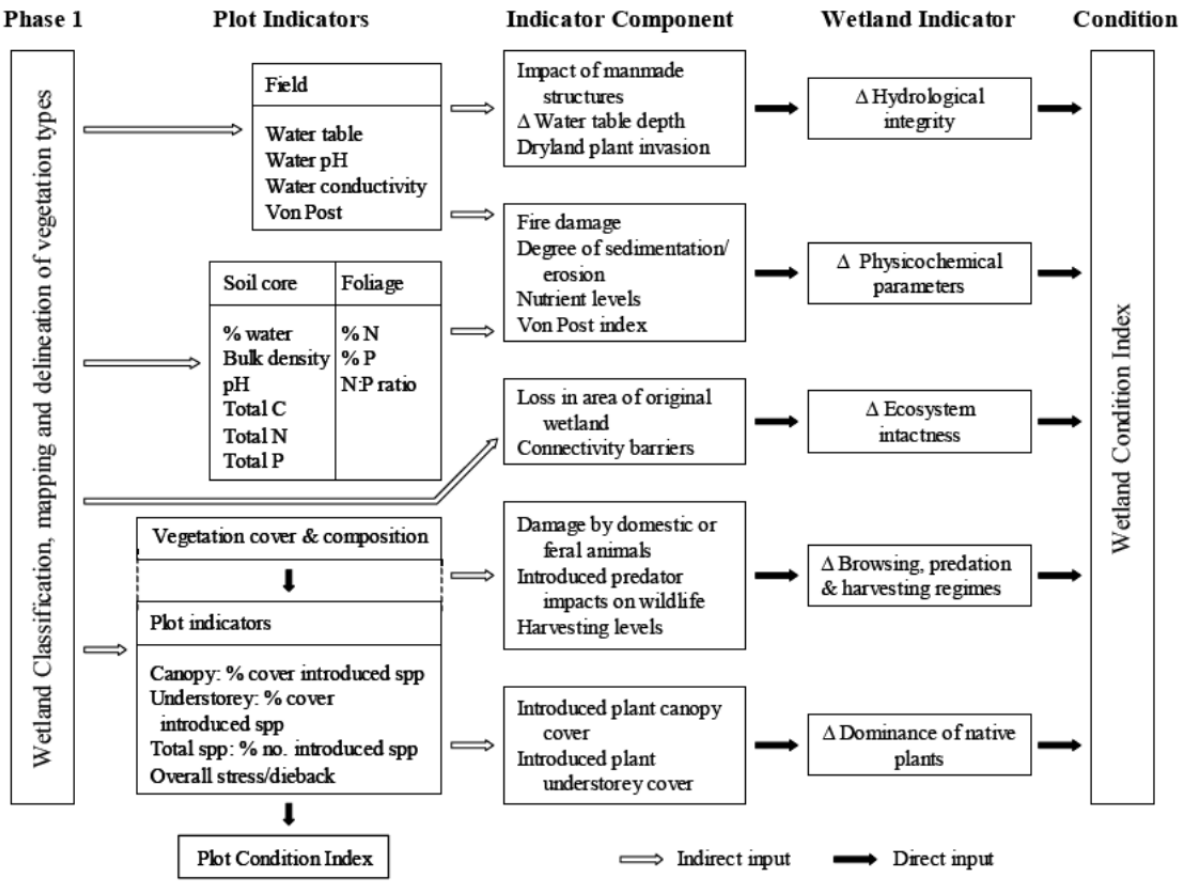


Figure 2 Links between wetland and plot indicators and Phase 1 of the Co-ordinated Monitoring of New Zealand Wetlands project (Source: Clarkson *et al.* 2004).

5. INTEGRATION OF THE PROPOSED FRAMEWORK WITH EXISTING MONITORING

A range of freshwater monitoring initiatives are presently being conducted by DOC and regional councils as part of their national State of Environment (SOE) monitoring, and NIWA as part of their river and lake monitoring networks. For rivers, measures include flow, water quality, benthic macroinvertebrate, and periphyton monitoring, and for lakes, water quality, macrophyte, and water level monitoring. Thus water quality and some biological community (macroinvertebrate and aquatic plants) measures are extensively monitored and reported on for rivers and lakes. However, there is in general limited scope in terms of the range of indicators that can be reported on in relation to biodiversity indicators within the Lee *et al.* (2005) framework. Wetland monitoring is less extensive, and although some councils are pursuing some wetland monitoring, there is no national monitoring. Tangata whenua will have a range of Mātauranga Māori that will contribute to monitoring information especially around mahinga kai sites.

A brief description of existing monitoring networks associated with different agencies is discussed in the following sections, starting with a summary of freshwater monitoring being conducted by DOC.

5.1. Current Department of Conservation biodiversity monitoring

The Department of Conservation has initiated a number of monitoring components for terrestrial systems and for some freshwater environments and includes:

- Tier 1 terrestrial biodiversity monitoring
- threatened species monitoring
- widespread and threatened indicator species monitoring.

5.1.1. Tier 1 terrestrial biodiversity monitoring

Tier 1 terrestrial monitoring was initiated in 2011 in combination with monitoring of carbon sequestration in the LUCAS site network as part of New Zealand's Kyoto commitments. Monitoring occurs at over 1,300 sites spaced in an 8 km grid system over the country, but with Tier 1 sites being predominantly located on public conservation land. The monitoring and reporting has predominantly focused on forest sites, but will in future years include some grassland and wetland habitats (MacLeod *et al.* 2013). The sampling intensity and methodologies applied to wetlands are currently however based on terrestrial systems, and in general considered inadequate for reporting on wetlands at a national scale.

Indicators and measures include those associated with vegetation, birds, soil and some introduced mammalian predators, and is reported in the context of the Lee *et al.* (2005) indicator framework. The three indicators and seven measures reported in 2012 are shown in Table 9. The reporting systems demonstrated in MacLeod *et al.* (2013) provide an example of the potential manner in which Tier 1 data network incorporates randomised and systematic sampling designs for unbiased reporting on indicators, and will be discussed in greater detail in Section 6.3 of this report.

Table 9. Summary of indicators and measures for the Department of Conservation (DOC) Tier 1 terrestrial biodiversity monitoring in 2012 (Source: MacLeod *et al.* 2013).

Ecological integrity			**Information source**
Component	**Indicator**	**Measure**	
Indigenous dominance	Indicator 2.2 Exotic weed and pest dominance	Measure 2.2.1 Distribution and abundance of exotic weeds and animal pests considered a threat – Weeds	An unbiased sample of *locations* (n = 155), within non-forested ecosystems (n = 79) and forested ecosystems (n = 76) on public conservation land
		Measure 2.2.1 Distribution and abundance of exotic weeds and animal pests considered a threat – Pests	An unbiased sample of *locations* (n = 155), within non-forested ecosystems (n = 79) and forested ecosystems (n = 76) on public conservation land
Species occupancy	Indicator 5.1 Composition	Measure 5.1.1 Size-class structure of canopy dominants	An unbiased sample of *locations* (n = 155), within non-forested ecosystems (n = 79) and forested ecosystems (n = 76) on public conservation land
		Measure 5.1.2 Demography of widespread animal species – Birds	An unbiased sample of *locations* (n = 155), within non-forested ecosystems (n = 79) and forested ecosystems (n = 76) on public conservation land
		Measure 5.1.3 Representation of plant functional types	An unbiased sample of *locations* (n = 155), within non-forested ecosystems (n = 79) and forested ecosystems (n = 76) on public conservation land

5.1.2. Threatened freshwater species and pest species monitoring

The Department of Conservation presently monitors approximately 2,000 sites for freshwater biodiversity and biosecurity purposes. Threatened species monitoring occurs at approximately 350 sites in association with species recovery plans. Most of the threat-listed fish, amphibian and bird species have monitoring programmes in one or more locations. However, only one-third of threatened aquatic plants and no aquatic invertebrate species (of 17 threat-listed species) are presently monitored, mainly due to limited resources (Table 10).

Biosecurity surveillance monitoring is conducted by DOC at approximately 1,500 sites that are viewed as high risk locations for invasive species. The bulk of this monitoring

is for pest fish species, but more recently (since 2007) monitoring for the presence of the invasive algae *Didymosphenia geminata* has occurred at just under 500 sites.

For both threatened species and pests the absence of a national monitoring and reporting system against which to align local programmes has led to a lack of consistency across the country in the way DOC monitors biodiversity. Because of this there are information gaps for some of the important issues and limited long-term datasets to detect and report on changes in unmanaged ecosystems and species populations.

Table 10. Freshwater biodiversity monitoring conducted by the Department of Conservation (DOC) for threatened species and aquatic invasive species (Source: MfE 2010).

Group	Species monitored (threat listed)	Number of sites monitored	Types of monitoring
Threatened species			
Fish	22 (28)	102	Status and population trend, establish new populations
Aquatic birds	20 (32)	288	Status and population trends predominantly
Aquatic invertebrates	0 (17)	0	No monitoring occurring
Aquatic amphibians	1 (1)	3	Status and population trend
Aquatic plants	56 (165)	119	Population trend, establish new populations
Invasive species			
Pest fish	na	972	Pest fish surveillance
Submerged aquatic weeds	na	13	Aquatic weed surveillance
Didymosphenia geminata	na	474	Didymo surveillance

The largest amount of threatened freshwater species monitoring DOC currently conducts originates from threatened fish species recovery plans and regional threatened fish population monitoring (*e.g.* Coastal Otago non-migratory galaxiid monitoring). This monitoring data is of variable duration and geographical coverage because the species of focus often have highly limited distributions. Monitoring covers a wide range of species (Table 11) and some species have insufficient numbers of sites and duration of monitoring to enable trends in populations to be analysed statistically. In terms of monitoring of threatened species to report on the effectiveness of the DOC species prescriptions (DOC Species Optimisation Tier 2), there have not been any threatened freshwater monitoring implemented to date.

For the purposes of developing a Tier 1 freshwater programme, the requirements for monitoring threatened freshwater fish, plants, and invertebrates are likely to be site specific, and may not suitable for a national programme. This is, as previously

mentioned, due to the highly range restricted nature of many of the acutely threatened species. For more widespread species that are currently cited as “in decline” including longfin eel, giant kokopu, and koaro (Allibone *et al.* 2010), it is possible that community level monitoring could provide information of their distributional range as well as trends in range expansion or collapse. Monitoring of widespread and ‘in decline’ species would be of significant value to the threat ranking process.

Pest fish monitoring (474 sites historically) could go a reasonable way to informing trends on exotic pest distributions (indicator 2.2). However this monitoring at present is conducted in an *ad hoc* manner, and thus a more consistent approach to monitoring would need to be considered by DOC to inform trends in this indicator. Didymo surveillance monitoring could partially inform indicator 2.2 in rivers as it is conducted at a reasonable number of sites, and was (until recently) done routinely by DOC or regional council operational offices. Other aquatic weeds (*e.g.* lake aquatic weeds) are monitored at a very small number of sites, but could be integrated with council monitoring to be applicable to national reporting. It is unknown how many wetland sites are presently monitored by DOC for weeds, but it is unlikely this would be of a sufficient intensity to report on at a national scale.

Table 11. Summary of current freshwater fish monitoring being undertaken by the Department of Conservation (DOC). Source: DOC unpublished data, August 2013.

Status	Species	Number of sites
Threatened species	Bignose galaxias (*Galaxias macronasus*)	5
	Canterbury mudfish (*Neochanna burriwsius*)	8
	Central Otago roundhead galaxias (*Galaxias anomalus*)	11
	Clutha flathead galaxias (Galaxias "species D")	14
	Dusky galaxias (*Galaxias pullas*)	10
	Eldon's galaxias (*Galaxias Eldoni*)	14
	Giant kokopu (*Galaxias argenteus*)	2
	Koaro (*Galaxias brevipinnis*)	1
	Longfin and shortfin glass eels (*Anguilla dieffenbachia, Anguilla australis*)	1
	Lowland longjaw galaxias (*Galaxias prognathus*)	17
	Nevis galaxias Smeagol galaxias (Galaxias "Nevis")	8
	Shortjaw kokopu (*Galaxias postvectis*)	2
	Taieri flathead galaxias (*Galaxias depressiceps*)	3
	Teviot flathead galaxias (*Galaxias "Teviot"*)	2
	Upland longjaw galaxias (*Galaxias prognathous)*	4
Exotic species	Brown trout removal (barrier survey)	1
	Rudd removal	2
	Total	**105**

5.1.3. Widespread indicator species monitoring

Common, widespread species are critical to the structure, biomass and function of most ecosystems (Elliott *et al.* 2010). As such, establishing trends in widespread native taxa is an important component of the suite of biodiversity indicators identified in the biodiversity monitoring framework. Three of the four elements within indicator 5.1 of the Lee *et al.* (2005) framework can be thought of as an indicator of trends in widespread native taxa, these are: 'Composition', 'Demography of widespread animal species', 'Representation of plant functional types' and 'Representation of animal guilds'. Monitoring species occupancy, for instance, relates to the Lee *et al.* (2005) objectives pertaining to (1) preventing declines and extinction and (2) maintaining ecosystem composition.

Monks *et al.* (in press) undertook a review of native species considered suitable for selection as indicator species, which included freshwater biota. Freshwater species that ranked the highest in this process are identified in Table 12. Several of the species identified as indicator taxa would be highly applicable to Tier 1 monitoring because they are widespread and sensitive to various human pressures or habitat modifications. Thus these could be viewed as possible indicators for consideration of reporting on indicator 5.1 of the Lee *et al.* (2005) framework. The freshwater mussel (*Hydridella menziesii*) was shortlisted as one of the 28 widespread indicator species that are scheduled for development of monitoring plans.

Table 12. Indicator taxa and groups that would form a comprehensive suite of widespread indicators as part of the New Zealand Inventory and Monitoring Framework (modified from Monks *et al.* in press)

Taxonomic group	Habitat type	Pressure	Species	Common name
Birds	Freshwater	Habitat modification	*Anas rhynchotis*	New Zealand shoveler
			Aythya novaeseelandiae	Scaup
		Human impact	*Egretta alba*	White heron (kotuku)
	Rivers / gravels	Human impact	*Larus bulleri*	Black-billed gull
		Predation	*Anarhynchus frontalis*	Wrybill
			Charadrius bicinctus bicinctus	Banded dotterel
			Larus bulleri	Black-billed gull
Freshwater fish	Freshwater	Habitat modification	*Galaxias argenteus*	Giant kokopu
		Human impact	*Anguilla dieffenbachii*	Longfin eel
			Galaxias maculatus	Inanga
		Predation	*Galaxias brevipinnis*	Koaro
Freshwater invertebrates	Freshwater	Habitat modification	*Hydridella menziesii*	Freshwater mussel
Herpetofauna	Freshwater	Habitat modification	*Oligosoma chloronoton*	Green skink
			Oligosoma polychroma	Common skink
Plants	Freshwater	Human impact	*Ruppia* spp.	Horsehair weed
		Competition	*Carex tenuiculmis*	Sedge
			Epilobium pallidiflorum	Willowherbs

Taxonomic group	Habitat type	Pressure	Species	Common name
			Nitella and *Chara* spp.	Charophytes
		Habitat modification	*Carex secta*, *Carex virgata*	Wetland carex
			Lycopodiella serpentina	Club moss
			Trithuria inconspicua	Hydatella
		Herbivory	*Aciphylla traversii*	Chatham Island speargrass
	Rivers / gravels	Competition	*Muehlenbeckia axillaris*	Pohuehue
			Muehlenbeckia ephedroides	Pohuehue
			Raoulia spp.	Scabweeds

5.1.4. Department of Conservation wetland monitoring — Arawai Kākāriki

The Department of Conservation commits resources to a range of wetland management projects, however, except for the Arawai Kākāriki programme, monitoring of the status and trend of wetlands is not coordinated at a national level.

Monitoring and reporting for the Arawai Kākāriki is nationally organised, which results in standard approaches to field measurement, and evaluating wetland EI. Table 13 below summarises the biodiversity monitoring implemented by DOC across the three Arawai Kākāriki sites.

Table 13. Wetland biodiversity monitoring conducted by the Department of Conservation (DOC) within the Arawai Kākāriki (AK) programme (Source: Robertson & Suggate 2011).

Parameter	Number of AK sites (max 3)	Lee *et al.* indicator
Wetland extent and protection status	3	6.1
Soil status / chemistry	3	1.1
Hydrological regime	3	1.3 & 1.4
Plant composition / abundance	3	5.1 & 2.2
New weed incursions	3	2.1
Weed distribution / abundance	3	2.2
Pest distribution /abundance	3	2.2
Threatened species — vascular plants	3	4.2 & 4.3
Threatened species — cryptic wetland birds	3	4.2 & 4.3
Threatened species — giant kokopu	1	4.2 & 4.3
Threatened species — mudfish	1	4.2 & 4.3

5.2. National River Water Quality Network

The National River Water Quality Network (NRWQN) is operated by NIWA, which includes 77 sites located on 35 rivers throughout New Zealand (Figure 3). Sites are

classified by their land-use status as either ‘baseline’ stations, which account for natural or near-natural state and trends, and ‘impact’ stations which are downstream of present, and possible future, areas of agriculture, exotic forestry, industry and urbanisation. As such, the design of the NWRQN does provide to some degree a gradient of possible ecological integrity over the country.

These sites have been sampled monthly since 1989 for a range of water quality variables, such as:

- temperature and dissolved oxygen
- pH and conductivity
- nutrients
- visual clarity
- periphyton
- macroinvertebrates (carried out annually at 66 of the 77 national sites)
- continuous river flow (all 77 sites).

The NRWQN provides a consistent set of sites and variables on which long term trends and current water quality status can be observed. National and international reporting by MfE relies heavily on the network but its limited number of sites often makes the observing of trends difficult in areas of particular land use, especially urban. In addition, the sites chosen were those perceived to be of national or regional importance of larger sized rivers, ideally with a mean flow exceeding 15–20 m/s, and therefore the network does not represent smaller rivers and streams.

Monitoring information from the national networks sites (along with regional council monitoring discussed in Section 5.3) would provide reasonably robust information for larger wadeable rivers in regards to the Lee *et al.* (2005) framework indicators on water quality and yield (1.3), and some information related to river productivity (1.2) (periphyton, macroinvertebrates). Additionally, some ecological data on macroinvertebrate and periphyton community composition could also be applied to assessment and reporting on ecosystem composition (5.1).

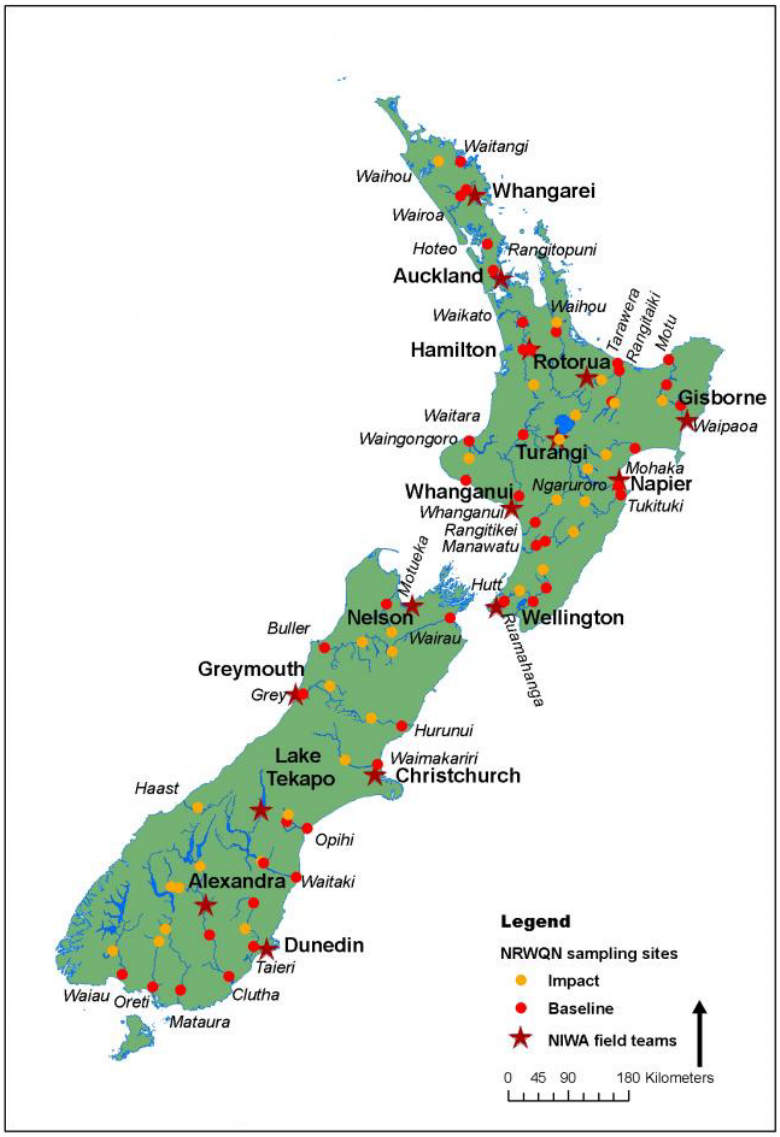


Figure 3. Locations of freshwater monitoring sites in the National River Water Quality Network (NRWQN) overseen by NIWA (Source: http://www.niwa.co.nz/freshwater/water-quality-monitoring-and-advice/national-river-water-quality-network-nrwqn).

The NRWQN is, however, predominantly focused on water quality, and would not meet other objectives for reporting on biodiversity and EI indicators. A greater number of biological measures (*e.g.* fish community, aquatic plants) within the NWQRN would be required to be more applicable for DOC's biodiversity reporting purposes. The network is also limited in terms of its coverage of the river and stream environments network, and thus would provide a biased subsample of larger wadeable rivers to report on, and includes no smaller rivers or non-wadeable large rivers. This shortfall could be remedied to some extent by the inclusion of some additional sites from regional council monitoring networks.

5.3. Linkages to regional council and unitary authority monitoring

Regional councils (and unitary authorities) conduct significant freshwater monitoring as part of their SOE monitoring and in some cases, consent auditing processes. A short synopsis of monitoring is provided below, in respect to informing indicators for the proposed freshwater Tier 1 biodiversity framework.

5.3.1. Rivers

Monitoring of river water quality comprises the largest proportion of monitoring effort expended by councils. This includes over 1,000 sites for water quality monitoring and over 300 sites for macroinvertebrates. Based on rationalisation of sites to meet the sampling frequency (WQ monthly, macroinvertebrates annually) and duration of record (minimum three years data) required for national analysis, there were 789 river water quality monitoring sites, 289 river benthic macroinvertebrate monitoring sites, and 930 river periphyton monitoring sites (Larned *et al.* 2013) (Table 14). Coverage of the monitoring network by regional council monitoring is biased towards sites within agricultural dominated streams, with only a small number of sites considered reference sites (Larned *et al.* 2012). There is also very limited network coverage of rivers within public conservation lands (Figure 4), which is one of the primary objectives of the Tier 1 programme. However recent discussion in the NEMaR programme of work has identified a need for greater information on state and trend of reference sites for informing target water quality conditions. The NEMaR programme has recommended 80 potential water quality sites for this purpose (Larned *et al.* 2013), most of which are either located in or just immediately downstream of PCL so as to provide reference status (Figure 4). The possible inclusion of these proposed sites in NEMaR or council monitoring networks would provide greater information on water quality status of rivers in PCL.

As with the NWQRN, the range of measures collected within the regional council monitoring network are oriented towards water quality. As a result, similar limitations apply in regards to the extent to which this monitoring data can be used to report on biodiversity indicators. However, there has been growing interest in fish community monitoring since the development of standardised fish sampling protocols for wadeable streams (Joy *et al.* 2013), with approximately 171 sites presently being monitored by regional councils nationally. This data could contribute to a greater ability to report on several of the proposed framework indicators, including on acute and chronically threatened fish species (4.2 and 4.3), and ecosystem composition and occupancy of range (5.1 and 5.2). For this to happen however, the number of sites would need to be expanded significantly to allow for this type of national-scale reporting.

Table 14. Numbers of monitoring sites within each authority's region based on the National Environmental Monitoring and Reporting (NEMaR) sampling criteria for water quality, macroinvertebrates, periphyton (Source: NIWA unpublished data) and sites sampled using Joy *et al.* or comparable fish monitoring protocols.

Region	Water quality	Macroinvertebrate	Periphyton	Fish
Auckland	21	11	0	0
Bay of Plenty	18	6	0	0
Canterbury	135	20	183	10*
Southland	71	29	85	20
Waikato	109	11	317	66
Gisborne	20	0	0	TBC
Wellington	54	46	49	2
Hawke's Bay	54	39	43	10
Horizons	61	14	59	10
Marlborough	20	2	0	TBC
Northland	20	10	36	0
Otago	36	0	30	27
Tasman/Nelson	74	24	63	16
Taranaki	10	10	27	10
West Coast	32	20	37	0

TBC - To be confirmed * - Abandoned after one year due to poor fit with braided rivers.

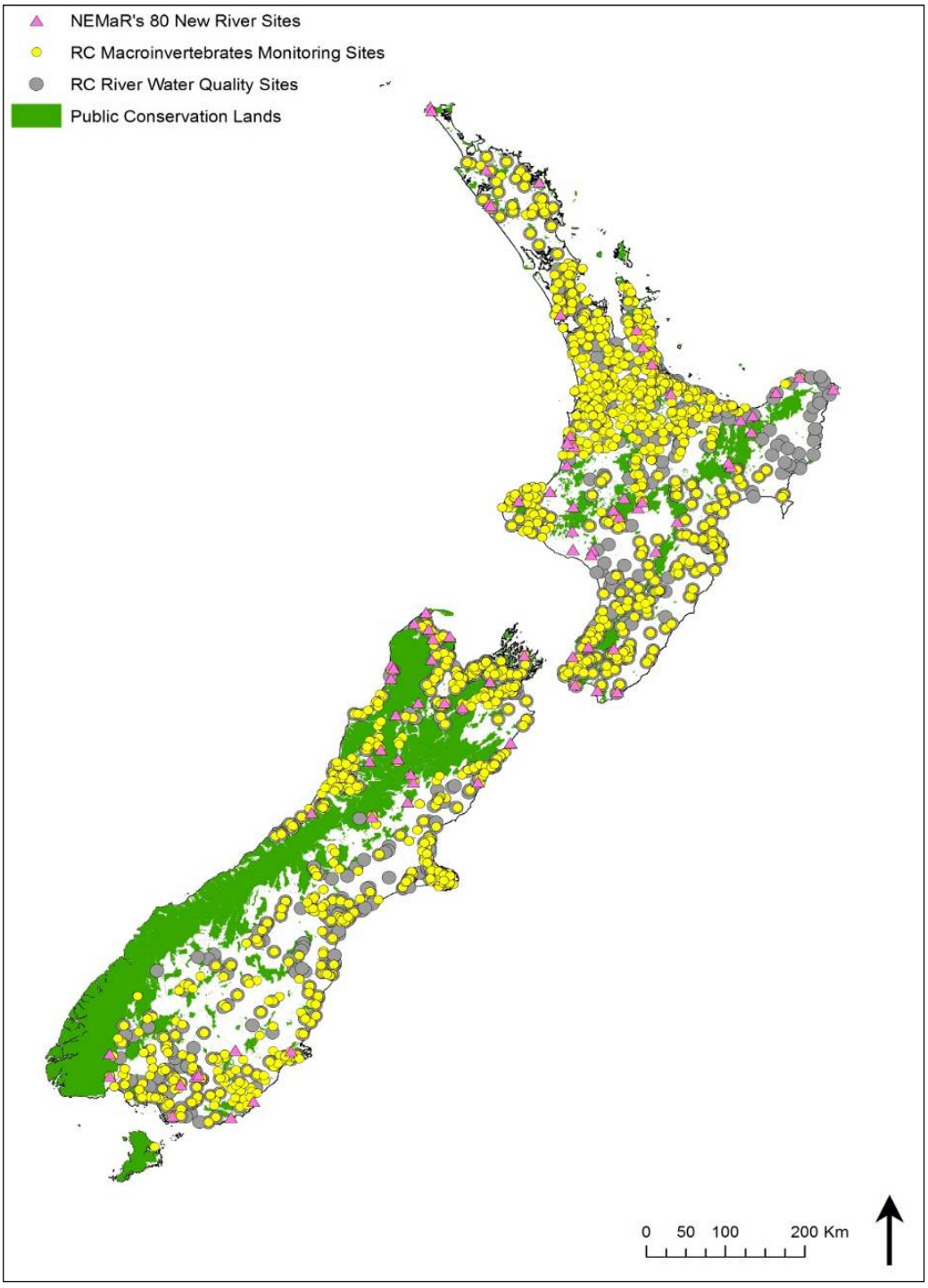


Figure 4. Location of regional council river water quality / macroinvertebrate monitoring sites and of NEMaR's (the National Environmental Monitoring and Reporting programme) proposed new river monitoring sites compared to Department of Conservation (DOC) public conservation lands.

5.3.2. Lakes

Approximately 112 lakes were monitored nationally by regional councils for water quality between 2005–2009 (Figure 5). Lake monitoring predominantly focused on nutrient status using trophic level index (TLI), a composite index comprised of measurements of total nitrogen, total phosphorus, chlorophyll-*a*, and Secchi disk depth (Burns *et al.* 2000). These lakes are typically monitored at least five times annually (usually during summer) to provide an annual average. Approximately 200 lakes nationally have recently had aquatic macrophyte assessments to allow reporting on aquatic plant community status (Figure 5), with assessments usually following the protocols of the LakeSPI methodology (Clayton & Edwards 2006).

Monitoring data obtained from regional council monitoring of lakes would enable reporting in regards to water quality and yield (1.3), and some information related to lake productivity (1.2) (planktonic, macrophytes). Additionally, some data on macrophyte community composition could also be applied to assessment of ecosystem composition (5.1), and new weed species and weed dominance (2.1 and 2.2).

There are approximately 3,650 lakes in New Zealand (Leathwick *et al.* 2010), so this reporting would represent between 3–4% of the target population sampled. Monitoring at present is biased towards medium and larger sized lakes that are of greater recreational interest to councils. Few small, shallow lakes are monitored even though they make up approximately 93% of lakes in New Zealand (Table 15). It is unknown how this would impact overall reporting statistics on the status and trend in biodiversity and ecological integrity condition of lakes. Similar to monitoring of rivers, most lakes monitored by regional councils are outside of public conservation land, so this would also detract from the ability of the DOC to report on status and trends within PCL, a primary objective of the monitoring programme.

Table 15. Numbers of lakes in Freshwater Ecosystems of New Zealand (FENZ) lake classes and the dominant land-cover categories in their catchments. (Source: Ministry for the Environment, 2007).

Class	Alpine	Exotic forest	Native	Pasture	Urban	Total
Small warm		178	251	1,086	39	1,554
Small central	14	42	396	468	3	923
Small cool	290	2	773	9		1,074
Medium cool	12		63			75
Medium warm		5	58	31		94
Large shallow				4		4
Large deep	2		26	4		32
Total	**318**	**227**	**1,567**	**1,602**	**42**	**3,756**

Note: Some of the 3,820 lakes for which catchments cannot be clearly defined (mainly small warm lakes) are excluded.

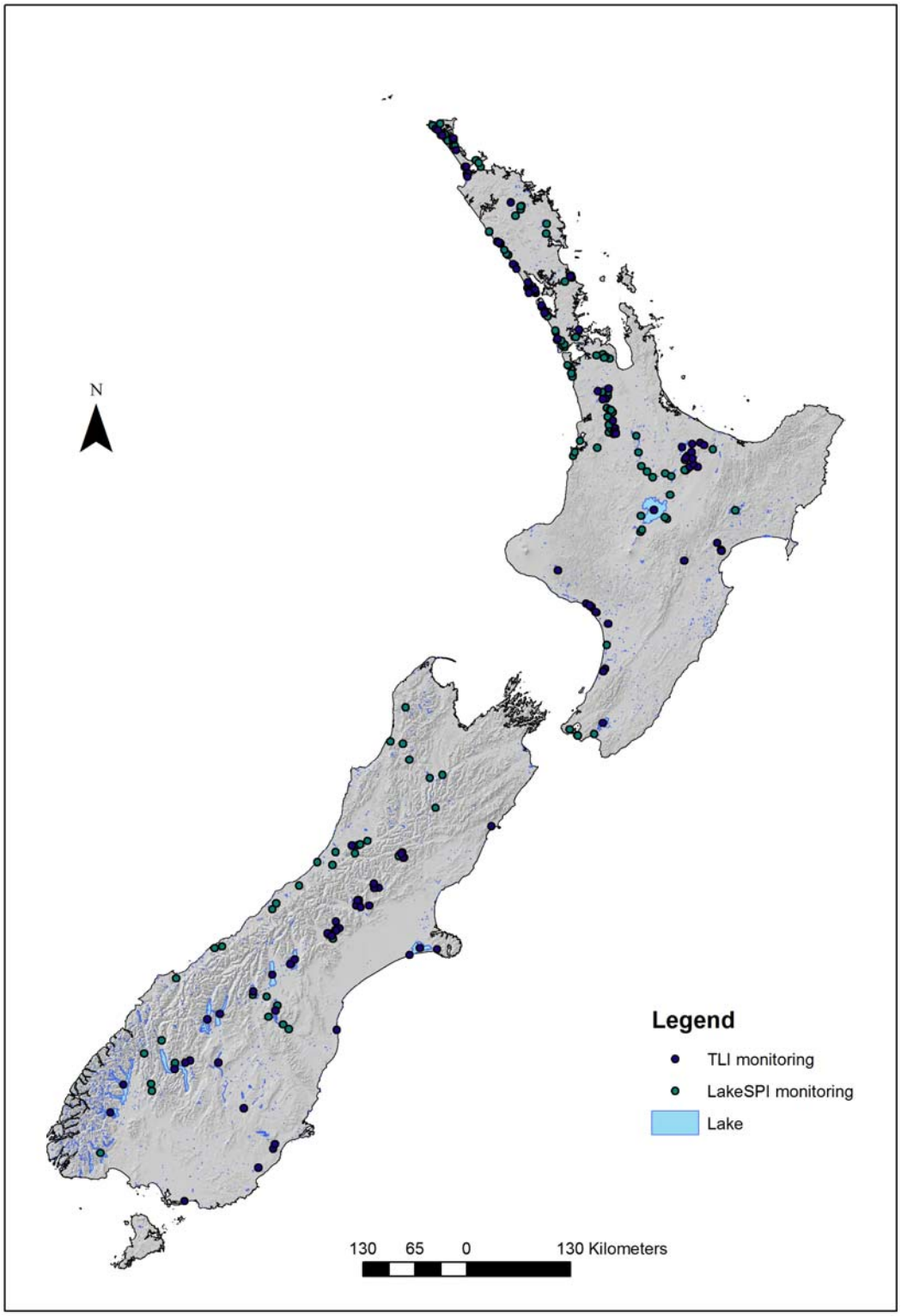


Figure 5. Lakes monitored for LakeSPI aquatic plant community indicators (green dots) and lake trophic level index (TLI) water quality indicators (purple dots) up to 2012. Source: Verburg *et al.* (2010) and M. de Winton unpublished data.

5.3.3. Wetlands

A number of regional councils have recently established, or are in the process of establishing terrestrial monitoring for SOE reporting, which may include wetlands (Figure 6). A revised terrestrial monitoring framework to be applied by councils was developed recently in a workshop process between councils, central government, and Landcare Research (Lee & Allen 2011). The adoption of such a framework by councils would have the potential to enhance wetland biodiversity reporting, but at this time only a limited number of councils are implementing specific wetland monitoring. The Department of Conservation also has a limited number of Tier 1 terrestrial monitoring sites (n = 20) that occur in wetlands for which terrestrial indicators are collected (seen in Table 9).

Auckland Council is the most advanced authority, having implemented a systematic SOE programme for wetlands over the past 2–3 years, with a focus on assessing vegetation status and soil status. Environment Southland is also preparing to initiate SOE wetland monitoring, as described in the Clarkson *et al.* (2013) report," A monitoring approach for Southland's wetlands: Stage 1". While a number of other councils such as Bay of Plenty, Greater Wellington, Waikato and Taranaki have wetland programmes in development. Given wetland monitoring by regional councils is in the initial stages of development across New Zealand, this presents an opportune time for DOC to develop Tier 1 wetland monitoring in partnership with council SOE monitoring.

A recent project overseen by DOC has compiled all available hydrological data for wetlands, obtained from councils, research organisations (CRIs and universities) and DOC (Allen *et al* 2013). The project identified approximately 96 wetlands for which data on hydrology is available. Some of this data could inform reporting for water quality and yield (1.3) for the various wetland classes monitored (predominantly bogs, swamps and kettleholes), but some classes such as marshes, gumlands, fens, and interdunal wetlands are poorly or not represented in the database. Some of the databases are of considerable age, and thus may not be appropriate for reporting on current status of ecological integrity.

The focus of both DOC and regional council monitoring would be in terms of wetland extent/protection (6.1), soil status (1.1), water quality/yield (1.3), ecosystem composition (5.1) and weeds/pests (2.1 and 2.2). However, the present extent of wetland monitoring is insufficient to underpin national reporting in a Tier 1 programme, and would need to be expanded significantly to achieve this objective.

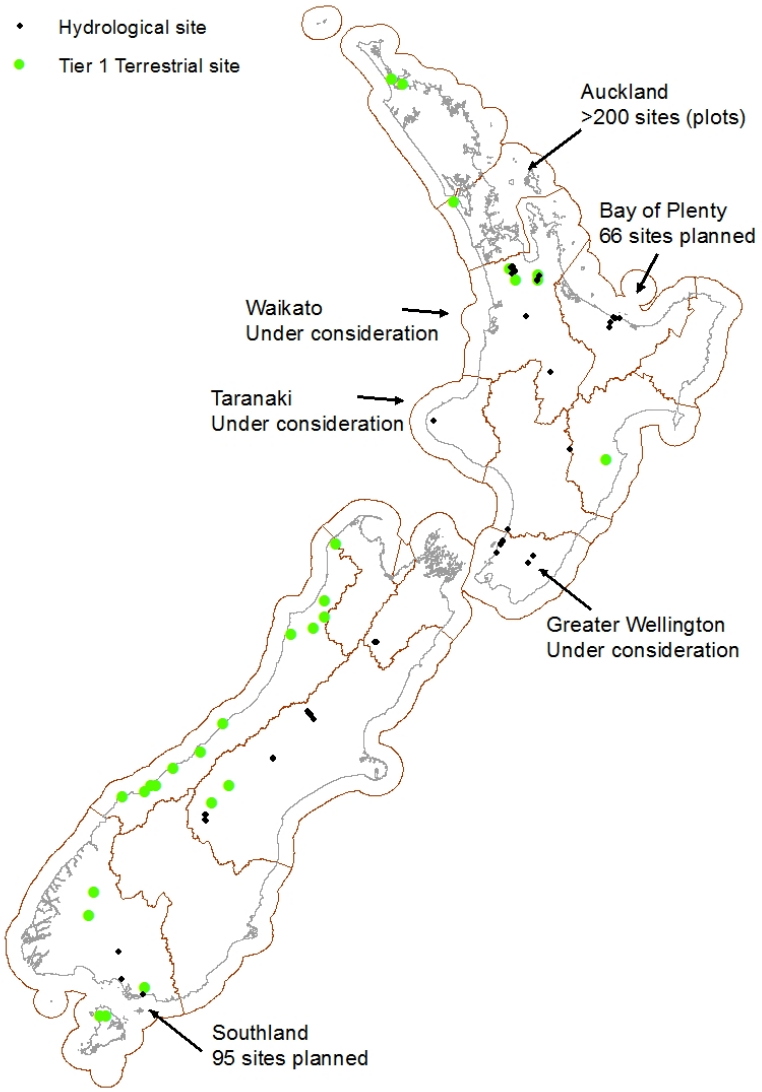


Figure 6. Regional councils with current or proposed wetland monitoring for State of the Environment (SOE) reporting, Tier 1 terrestrial monitoring, and location of known wetland hydrological monitoring sites.

5.4. Other agencies collecting freshwater biodiversity data

There are various small monitoring programmes at sites associated with major river infrastructure works (diversions and dams) and compliance monitoring related to consents. This monitoring could further inform some aspects of biodiversity reporting, mainly in rivers. Monitoring is conducted by consent holders and overseen by regional council compliance monitoring sections. A non-comprehensive list of examples include:

- Hydro-electric industry: upstream/downstream periphyton and benthic macroinvertebrate monitoring

- Municipal and district councils: water quality and macroinvertebrate monitoring associated with major point source discharges (*e.g.* sewage treatment)
- Other industry: predominantly river water quality related to point source discharges.

5.4.1. Ministry of Primary Industries

The Ministry of Primary Industries (MPI) compiles catch statistics for some freshwater species, including longfin and shortfin eels, and flounder species (in some brackish lakes). Eel fisheries are managed under a quota management system, with quotas determined and reported upon on a regional basis. Recently (since 2011) commercial eel fishers have voluntarily reported catches for some areas, making it possible to report catch statistics from specific river catchments (pers. comms. Marc Griffiths, MPI). This included annual reporting of catch statistics for 35 sub-areas on the South Island and 43 sub-areas on the North Island. Flounder fisheries are mainly associated with river estuaries and coastal lakes, and thus are not relevant to Tier 1 freshwater biodiversity which is focused on freshwater (not brackish) habitats. The Ministry of Primary Industries also collates data from hydro-electric dams around recruitment of elvers (trap and transfer) over dams annually.

5.5. Gaps or shortfalls in existing monitoring related to national biodiversity reporting

Significant investment is made in freshwater monitoring nationally, and thus it is critical to evaluate the extent to which this monitoring effort can be used to report of biodiversity within an ecological integrity framework. Most obvious, is the large investment by regional councils in river, lake, and to a lesser extent wetland, monitoring (*e.g.* MCI, fish, water quality, wetland condition, lake macrophytes, *etc.*). Environmental information is available for a significant network of sites, and monitored at frequencies sufficient to report on both state and trends in condition. However monitoring is mainly in relation to water quality and yield (Indicator 1.2), productivity (Indicator 1.3), ecosystem composition and occupancy (Indicators 5.1 and 5.2), and could be used to a limited extent to report on exotic weed and pest dominance (Indicator 2.2). This would allow reporting on these indicators nationally for the existing monitoring networks (Table 16). A significant shortfall is lack of monitoring on PCL, which greatly diminishes the extent to which DOC could report on the status of freshwater biodiversity for PCL, and therefore, across New Zealand in general.

A number of indicators in the proposed freshwater frameworks can be evaluated with existing information available in GIS databases such as those on catchment land cover (LCDB3) and land protection status (NATIS). These data sources are updated by various central government agencies in regards to changes in PCL or private land covenants (*e.g.* acquisition of lands by DOC, QEII land covenants), or change in land

cover (*e.g.* MfE LCDB3). These databases could inform indicators on land cover in freshwater catchments (1.5), and environmental representation and protection status (6.1). Similarly GIS databases from councils and other sources (*e.g.* FENZ database) could be used as the basis for future reporting on ecosystem disruption (1.4) (*e.g.* FENZ dams database, council fish passage databases). Reporting on these indicators could be conducted nationally for both PCL lands and areas outside of PCL.

The lack of monitoring data in PCL for some indicators (*e.g.* water quality and yield, composition) could be addressed through predictive modelling. The ability to use spatial databases on climate, geology and land cover in combination with existing water quality datasets for predicting water quality and some stream biotic metrics in unmonitored sites is becoming increasingly sophisticated and accurate (Leathwick *et al.* 2005). In particular this has recently been used to allow quantitative predictions of freshwater indicator values for reference river sites that are largely representative of PCL (McDowell *et al.* 2013, Clapcott *et al.* 2013). However the use of these models would be greatly enhanced by collection of additional validation data in these freshwater habitats, and could provide a niche for DOC's freshwater monitoring efforts.

A great deal of focus of monitoring has been in relation to rivers and secondarily lakes, and there has been very limited focus on wetland monitoring until recently despite their rarity and degraded status. There is growing recognition of this, and interest by management authorities such as regional councils to increase monitoring in these habitats. Given DOC has a primary management role in wetland management, it is anticipated that this could comprise a significant focus of Tier 1 monitoring. Existing Tier 1 terrestrial monitoring will include some monitoring of wetlands, but a significantly larger number indicators and broader network coverage would be required to meaningfully report on wetland ecological integrity at a national scale.

Finally, a significant component of the DOCs present freshwater focus is the management of habitats for native freshwater fish populations, including updating of the threat status classification (Allibone *et al.* 2010) and oversight of the whitebait fishery. The present monitoring networks managed by councils and other authorities (*e.g.* NWRQN) do not cover monitoring of fish communities to any significant degree. Limited freshwater monitoring is conducted by DOC around acutely threatened species, but species known to be in-decline or data deficient, which together comprise nearly 80% of native freshwater fish species, are largely unmonitored. Thus this would be a significant gap in the existing monitoring effort nationally, and would likely be considered a high priority for filling monitoring gaps.

Table 16. Monitoring coverage of ecological integrity indicators (EI) for rivers, lakes, wetlands inside and outside of public conservation lands (PCL) by existing freshwater monitoring programmes.

	Indicator	Rivers		Lakes		Wetlands	
		PCL	Non-PCL	PCL	non-PCL	PCL	non-PCL
1) Maintaining ecosystem processes	1.1 Soil status	–	+	-	+	+	+
	1.2 Productivity	–	+++	+	++	+	+
	1.3 Water quality and yield	–	+++	+	++	+	+
	1.4 Ecosystem disruption	+	+	+	+	+	+
	1.5 Land cover	++	++	++	++	++	++
2) Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species	–	+	+	+	+	+
	2.2 Exotic weed and pest dominance	+	+	+	+	+	+
3) Limiting environmental pollutants	3.1 Ecosystem levels of persistent toxins	–	++	–	–	–	–
4) Preventing declines and extinctions	4.1 Extinct taxa	–	–	–	–	–	–
	4.2 Status of acutely threatened taxa	+	+	–	–	+	+
	4.3 Status of chronically threatened taxa	–	+	–	-	+	+
	4.4 Genetic change in critically reduced species	–	–	–	–	–	–
5) Ecosystem composition	5.1 Composition	+	+	+	+	+	+
	5.2 Occupancy of environmental range	+	+	+	+	+	+
	5.3 Patch size / fragmentation of wooded ecosystems	–	–	–	–	–	–
6) Ecosystem representation	6.1 Environmental representation and protected status	+	+	+	+	+	+
7) Climate change and variability	7.1 Basic climate series	+	+	+	+	+	+
	7.2 Biological responses to climate change	–	–	–	–	–	–

Note:
+++ = significant monitoring
++ = some monitoring
+ = little monitoring or insignificant monitoring
– = not presently monitored.

6. NEXT STEPS TOWARDS DEVELOPING A TIER 1 FRESHWATER BIODIVERSITY NETWORK

6.1. Options for a Tier 1 Freshwater Monitoring Programme

There are a number of options for the design and implementation of a freshwater Tier 1 monitoring and reporting network. The approach adopted will most likely depend on resources available within DOC, and the success of partnerships with other monitoring agencies. It is probable that a Tier 1 freshwater network will mirror that of the Tier 1 terrestrial programme, focusing on a select smaller number of indicators and measures, with possible growth over time.

A number of scenarios are identified below with a brief discussion on their merits and limitations. Four key points are considered 1) gap in current monitoring and reporting by other agencies, 2) priority for DOC's management focus 3) current Departmental expertise in the monitoring area, and 4) achievability of the monitoring within DOC resources. It should be noted that the options focusing on single ecosystems or genera have a reduced suite of indicators.

1. **Comprehensive: 'All indicators, all ecosystem types'**

   This scenario would see monitoring and reporting on all indicators and measures within the proposed frameworks. There would need to be consideration as to the organisational responsibility for the network, and whether DOC would monitor only sites within the PCL, with reliance on other partner agencies to include some biodiversity measures to fill gaps in the existing monitoring.

   The current capacity and skills of DOC operational offices would need to be increased significantly in the area of freshwater monitoring to implement such a programme. This would provide a significant financial obligation on DOC, now and into the future. It would also rely on commitments from other partner agencies to broaden their freshwater monitoring scope to include a wider set of biodiversity indicators, and may require additional sites. Wetland monitoring programmes by regional councils would need to be expanded both in terms of the number of sites and indicators.

   Overall we would view this option as unfeasible.

2. **Focused: 'Wetlands only' Tier 1 network**

   Wetlands presently receive the least monitoring resources of the three freshwater types considered, and are considered high priority ecosystems by DOC due to their rarity (only 10% remaining) and overall degraded condition. The Department is also viewed as having the primary freshwater management oversight for wetlands nationally, with further international reporting obligations (*e.g.* Ramsar Convention). If there are only limited resources available, it could be targeted at Tier 1 wetland

monitoring to comprehensively report on wetland status and trends. This would still likely entail partnerships in a monitoring network with other agencies, potentially with DOC focusing on PCL, and working in conjunction with regional councils, land-owners, and the community on monitoring wetlands contained on private lands. Department of Conservation operations and technical support presently have a significant proportion of wetland expertise nationally, thus skill capacity could potentially be accommodated without significant further investment or acquiring new expertise. Freshwater Tier 1 monitoring could also complement the existing DOC Tier 1 terrestrial monitoring programme, which presently includes a few wetland sites.

However, a narrower focus of the Tier 1 programme would come at the expense of being able to report more effectively on biodiversity in river and lake ecosystems than is presently occurring, with obvious gaps in monitoring previously identified.

Overall we would view this more focused option favourably in terms of pragmatic use of resources and meeting DOCs primary management objectives.

3. **Focused: 'Lakes only' Tier 1 network**

Monitoring of lakes is presently conducted by regional councils, and is limited to a relatively biased network of larger lakes considered important for recreation. Council monitoring is limited mainly to water quality, with intermittent aquatic plant monitoring. A focused lake Tier 1 programme would enable a more representative network to be monitored with a greater inclusion of lakes in PCL, which at present is not monitored to any significant extent. The Tier 1 programme would also likely be able to broaden the scope biodiversity indicators monitored (*e.g.* native and pest fish), enabling more comprehensive reporting on the ecological integrity of lakes. The ecological functioning of lakes are very prone to invasive weed and pest species, and increased monitoring effort would allow early detection of management issues. The programme would require DOC to work in conjunction with councils to promote a wider scope of lake indicators and measures.

At present the expertise and capacity of DOC operations and technical support in lakes biodiversity is limited and new expertise would need to be acquired to implement such a programme. As with the focused wetland option, the focused lake option would limit the ability to report on wetlands and rivers, which historically have been seen as greater priority areas by DOC. The limited number of threatened freshwater fish species that occur in lakes (compared with rivers and wetlands), is likely to lessen the priority for DOC's biodiversity monitoring and reporting in lakes.

Overall we do not view this as a potential focus area for the Tier 1 biodiversity network due to its lower priority for species and ecosystem management.

4. Focused: 'Rivers only' Tier 1 network

There is significant investment currently by DOC and other monitoring agencies in monitoring river ecological integrity, with a high probability of further development in this area by the NEMaR programme led by MfE. Focus by DOC on a Tier 1 biodiversity network in rivers could enhance the ability to nationally report on freshwater biodiversity by broadening the scope of existing monitoring to include additional measures, and by expanding the site network within PCL. A clear gap has been identified by NEMaR in terms of requiring information on the reference condition of rivers, and NIWA has proposed the inclusion of 80 reference sites that are mostly contained within PCL (Figure 7). Reference sites could be viewed as a monitoring niche for DOC nationally, with further possibilities of engaging the NWRQN or regional council partners to include a wider range of biodiversity indicators outside of PCL. This would most likely be in the form of greater native freshwater fish and indicator species, which are the traditional monitoring focus of DOC, and thus it already has staff capacity and expertise in this area.

However undertaking a comprehensive river network covering PCL that meets the sampling protocols defined under NEMaR is likely to require increased DOC resources, due to monthly monitoring of water quality variables and the remote location of some sites. The Department's core interest centred around species and community level indicators are presently being monitored at only very few sites, and it's questionable the number of additional sites partner agencies (Councils, NWRQN) could pick up (outside PCL) in their existing monitoring programme resources. Thus it could be up to DOC to fund these sites in addition to PCL site network. The focus of the Tier 1 monitoring on rivers would also detract from any possible monitoring effort on wetlands or lakes, which are already receiving less monitoring resources.

Overall the rivers only scenario is viewed as a desirable Tier 1 monitoring network design, but it is unlikely to be able to be implemented without significant investment by DOC.

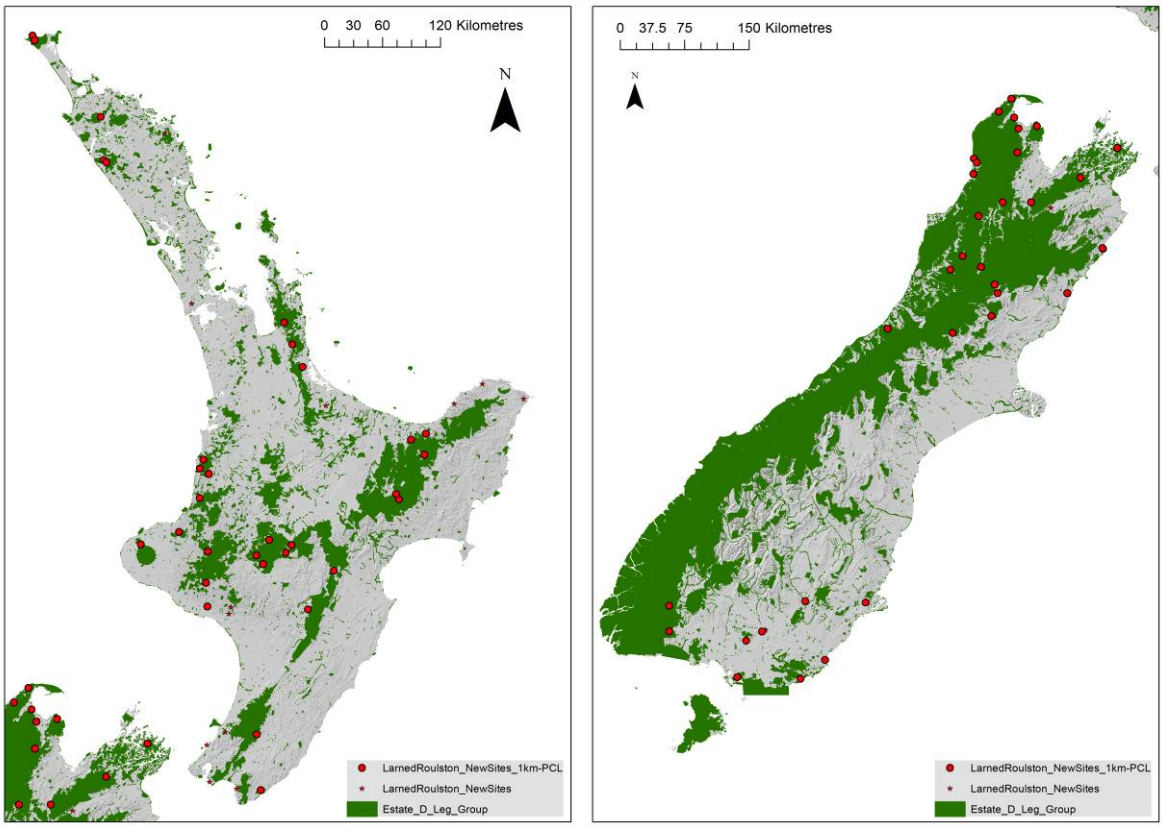


Figure 7. National Environmental Monitoring and Reporting (NEMaR) recommended new river monitoring sites that are in or adjacent to public conservation lands (Larned & Roulston 2013).

5. Focused: 'Rivers Freshwater Fish only' Tier 1 network

As with the previous scenario this freshwater fish Tier 1 option aims to build on the already significant investment in monitoring river ecological integrity, exclusively focusing on native freshwater fish due to it being a priority management area for DOC. The narrower focus would still enhance the ability to nationally report on biodiversity in rivers by adding new sites and new biodiversity measures, which is an obvious present gap. This gap has also been identified by NEMaR reports that cite a longer term vision of acquiring greater monitoring capacity (Hudson *et al.* 2012). The focus on freshwater fish would allow a larger number of sites to be accommodated, and would not require monthly monitoring of water quality. DOC presently has good operational and technical support skills in this area to oversee a national Tier 1 monitoring network.

It is important to recognise the narrower focus of monitoring would limit the number of indicators and measures that could be reported on for PCL sites. The use of widespread freshwater species as indicators, while identified as an option by DOC species experts, poses several challenges given biogeography of the fish species suggested and diadromous life histories. Some species are also commercially

harvested which would have to be accounted for in monitoring site selection or analysis. There is also a major challenge to increase sampling coverage to larger non-wadeable rivers, and no protocols have been developed to date. The focus of the Tier 1 monitoring exclusively on rivers would also detract from any possible monitoring effort on wetlands or lakes, which are already receiving limited amounts of monitoring resources.

Overall this is an attractive option if there are limited monitoring resources, as it focuses on key areas of interest for DOC. Long-term interactions and partnerships with other monitoring agencies (Councils, NWRQN) could benefit DOC and the wider freshwater management by expanding monitoring effort in a high priority area.

6. Focused: 'Rivers Freshwater Macroinvertebrates only' Tier 1 network

This Tier 1 option aims to build on the already significant investment in monitoring river ecological integrity, exclusively focusing on macroinvertebrates due to their widespread use in ecological monitoring. The narrower focus would still enhance the ability to nationally report on biodiversity in rivers by broadening monitoring to a larger number of sites in PCL and including reference sites, which is an obvious present gap (Hudson *et al.* 2012). The macroinvertebrate focus would potentially allow a larger number of sites to be accommodated in PCL with annual monitoring required (by NEMaR methodology), and without a requirement for monthly monitoring of water quality. Monitoring is not technically demanding requiring basic field skills and DOC presently has good operational support for implementing this Tier 1 monitoring network.

The much narrower focus of the monitoring would limit the number of indicators and measures that could be reported on for PCL sites and macroinvertebrates would be viewed as a lower biodiversity priority than freshwater fish within DOC and other agencies. The focus of the Tier 1 monitoring exclusively on rivers would also detract from any possible monitoring effort on wetlands or lakes, which are already receiving limited amounts of monitoring resources.

Overall this could be viewed as a very cost effective manner of initiating a Tier 1 monitoring network, but would have limited management impact for freshwater biodiversity. Thus it would not be prioritised highly amongst the scenarios considered.

7. Focused: Across all ecosystems — limited indicators

This option could leverage the significant current investment by DOC and other monitoring agencies and report on a limited set of key biodiversity indicators for all ecosystem types. This would also allow potential further investment in key gap areas, such as monitoring in the PCL to provide a more complete national picture, but for a limited number of biodiversity indicators viewed as a priority by the DOC and other end users or monitoring partners. It is probable that DOC would have skills in monitoring for some of the key indicators that could be identified (*e.g.* wetlands and freshwater fish), but would most likely need to invest in expertise for some areas (*e.g.*

water quality, lakes). This would be viewed favourably because it would allow DOC to report on biodiversity for all three target ecosystems.

However a wider focus on rivers, wetlands and lakes could dilute monitoring effort, by the Department and limit the extent to which a comprehensive picture of ecological integrity could be reported on. Thus there could be risk that the limited number of chosen indicators would not reflect the wider picture of ecological integrity of the network. Careful consideration of indicators would be needed to avoid such issues.

Overall this could be an effective manner of reporting on biodiversity across all of freshwater ecosystems in a cost-effective manner, would align well with the current approach taken in terrestrial Tier 1 monitoring.

6.2. Interim recommendations for a pilot of Tier 1 programme

Taking account of other agency freshwater monitoring, especially biodiversity focused sampling; we recommend that the DOC Freshwater Tier 1 programme concentrates on freshwater ecosystem monitoring that enables a good estimate of EI while capturing key aquatic biodiversity metrics such as species abundance and diversity. Freshwater fish are an example of this whereby suitable monitoring will not only document what fish are present but provide indications of previous year's recruitment and river connectivity from mountains to the sea. Lake macrophytes, wetland plants and wetland soil status are other suitable measures for assessing freshwater EI.

Consideration of the advantages and disadvantages around each scenario would indicate several 'more likely' options for Tier 1 monitoring, given that resourcing of monitoring is likely to be a significant factor. Wetlands (Option 2) are an ecosystem that DOC has taken the lead on mapping, assessing (WONI-FENZ) and now monitoring (Arawai Kākāriki). The leadership and skill base within DOC would make a significant contribution to getting other stakeholders to apply consistent methods in the right places to generate a good set of national data. As described in this report, DOC has traditionally focussed its freshwater monitoring efforts on freshwater fish in rivers (Option 5). Collected data contains some of the longest records of continuous fish data in New Zealand and while initially absent, this monitoring is also starting to collect useful habitat and water quality data. Therefore the two options that would meet primary management objectives of DOC, fill gaps in current ecological monitoring, and provide good linkages within DOCs monitoring and with other monitoring agencies would be the wetlands option, or the river freshwater fish freshwater option. Similarly, the last option (Option 7) presents an opportunity for a targeted programme across lakes, rivers and wetlands, if only a limited set of measures (and hence monitoring methods) are applied. The best option would also allow DOC to start collecting data as soon as possible and increase the likelihood that regional councils and other partners would join in partnership monitoring.

6.3. Considerations for a pilot Tier 1 monitoring network design

A successful Tier 1 network monitoring design should take into consideration the following aspects:

- Metrics used to inform indicators and measures
- Field survey and laboratory methodologies
- Sampling design
- Statistical analysis.

A discussion of each of these considerations is provided below. It is important to note that the degree of analysis of the network design is dependent on the area of focus of monitoring and whether an existing network occurs for which a set of biodiversity indicators are applied (*e.g.* rivers), or if the network design is largely a new network design with limited existing monitoring (*e.g.* wetlands).

1. **Metrics used to inform indicators and measures**

   Metrics used for reporting on indicators and measures are very important considerations for the network, and could require considerable quantitative pilot analyses to be confident the metrics are reflecting the particular conditions and stressor gradients considered most important in the Tier 1 network. Considerable work has been conducted for commonly used river and lake ecological metrics as part of the CDRP programme (Clapcott *et al.* 2010, 2012; Drake *et al.* 2009, 2011). However it has been noted that for freshwater fish communities, that the limited range of metrics (*e.g.* Fish IBI) correlated poorly with stressor gradients, and was complicated by distributional covariates such as distance to the coast (Clapcott *et al.* 2012). As such fish metrics are still considered "under development" in the NEMaR programme of work (Hudson *et al.* 2012). There is relatively lesser work conducted on for wetlands, with the wetland condition index (Clarkson *et al.* 2004) being the most commonly used metric for reporting on condition. Thus it is expected that significant work would be required to develop a set of metrics for wetlands.

2. **Field survey and laboratory methods**

   Field and laboratory protocols: Protocols used in the field measures and laboratory are likely to affect the calculation of metrics from field monitoring. It is difficult at this preliminary stage to make specific comments on the appropriateness of field or laboratory methodologies until a set of indicators, measures and metrics are decided upon for the network. Possibly the most important consideration at this stage is that methods are aligned with other partner agencies that would be collecting similar data for national reporting purposes. It is recommended standardised protocol be developed for the indicators/measures to ensure national consistency amongst all operational areas overseeing collection of field data. This process in DOC is presently

being overseen by the NHMS toolbox team, and thus would provide this guidance in conjunction with any monitoring partners (*e.g.* regional councils, MfE).

Ancillary data: Inference around trends in data are important when interpreting environmental monitoring datasets. While population data can be very powerful information for understanding species trends and managing populations, supporting environmental data is equally important, providing explanatory variables which help in interpreting the causal agents behind any trends in the data. Therefore, in addition to specific data for calculating metrics, some consideration of supporting environmental data to interpret trends will need to be considered. This is one of the weaknesses of focusing on a single (or a few) specific indicators within the broader Lee *et al.* (2005) framework, which sets out to provide information on a wide array of ecological processes in the network. If a more focused approach is taken, some consideration of supporting environmental data should be considered. For this reason, alignment of the Tier 1 network sites with existing freshwater monitoring sites (*e.g.* river water quality) would provide significant support data for interpreting biodiversity trends.

3. Sampling design

Allocation of effort in time and space and use of stratification or randomisation are aspects to be considered in designing and monitoring a Tier 1 network. Several key points including network representativeness, bias, sampling frequency, and interpreting state in relation to reference condition are discussed below.

Representativeness: Consideration that existing and new monitoring sites (DOC, NRWQN, regional councils) in a network are representative of the range and abundance of physical environments in New Zealand. Physical environments could be defined either defined by FWENZ or the REC river classifications, or the FENZ wetland classification. It is anticipated that for fish communities that the FENZ classification would provide a better correlate with patterns of native fish distribution due to its sensitivity to distance inland and elevation, two proximal drivers of fish distribution (Leathwick *et al.* 2005). The present lack of representativeness of sites within the PCL land of all existing monitoring networks would need to be given significant consideration in considering the Tier 1 network design, and the objective of reporting (*i.e.* if PCL or nationally focused).

Replication: The suitability of the network for reporting biodiversity metrics on a particular class with a given level of precision. There are a number of manners in which his can be considered, in NEMaR the number of sites required in each class to achieve a standard deviation of the data that was equal to or less than the standard deviation of the data across all classes (Larned *et al.* 2013). However, variation in space (and over time) in environmental data differs amongst variables (*e.g.* wetland pH versus wetland plant community composition). Therefore, the number of replicate sites required to report with a given level of precision and to detect differences

between environmental classes depends on the metric being considered, as well as the minimum difference to be detected, and the required confidence level.

Bias: This is an important consideration for the network particular in regards to reporting on national status of a particular environment class. Consideration that the sampling population is comprised of a spatially balanced sampling design and not subject to bias in condition will be an important element of design for national reporting on state. This can be achieved a number of ways, through probabilistic network sampling designs in which sites within a network (or population) are randomly sampled over time (*e.g.* Collier and Hamer 2010), or spatially balanced randomised design (GRTS) in which sites are repeatedly sampled over time (Stevens & Olsen 2004). This would be dependent upon indicators and measures being reported upon and would likely differ depending on the scenario of Tier 1 monitoring pursued.

Temporal frequency: The frequency of sampling events required to detect change in a metric over a given time period to a given level of precision. This is largely a management decision, but for NEMaR and NRWQN this is cited as being able to detect a 10% change over a 10 year period (Davies-Colley *et al.* 2012; Macleod *et al.* 2013). As discussed previously, differences in variability between metrics is likely to contribute to different requirements for the frequency of sampling in order to detect temporal trends. As such highly dynamic variables such as water chemistry are sampled monthly, whereas community data is more often collected at annual (or longer) frequencies. There has been considerable work in this area for river water quality data analyses, and this could likely be applicable to wetland water quality or soil status sampling. However population variability is more likely to be species-specific and thus exploration of population data (where it exists) will provide information on appropriate sampling frequencies for specific indicators. For freshwater fish species, because of their diadromous life cycles, timing of sampling is likely to be as critical a factor, and would need to be standardised across the network.

Reference condition: The use of interpreting EI measures in relation to their expected reference condition is an important consideration for design of the Tier 1 network. This has been discussed to some extent in the document, but it was anticipated sites within PCL could provide a reference site context for many freshwater EI metrics. The use of the concept of ‘deviation from reference’ is a common theme that runs through the NEMaR project reports (Larned *et al.* 2012, Hudson *et al.* 2012), although few regional councils or the NRWQN have yet to direct scientific or sampling effort towards them. Thus the inclusion of reference site monitoring by DOC within PCL land could help in informing reference conditions for environmental classes contained within and outside PCL. Sampling of these sites would also contribute good data on abundances and trends of widespread taxa that should be present elsewhere in the freshwater network (*e.g.* outside PCL). The best reference sites within PCL would have the same physical (*i.e.* REC class) and ideally biological characteristics (*i.e.* FWENZ class) as the sites they would be compared with

outside of PCL. As the majority of PCL is upland environments and lowland environments are where the greatest change in freshwater environments is taking place, it's anticipated that lowland PCL sites would provide the most value as reference sites.

4. Statistical analyses

Depending on the sampling design chosen a range of statistical comparisons can be made. The power of inference will be determined by temporal and spatial replication.

Detecting differences between classes: The suitability of a network design for detecting differences between selected environmental classes would need to be statistically assessed, including the number of sites in each class (*e.g.* FENZ class, within and outside PCL). As discussed previously, the variability of metrics are likely to differ (*e.g.* between water quality and community data based metrics), thus it's possible that different numbers of sites would be required depending on the particular metric. However if appropriate consideration of the number of sites is considered in network design related to replication (discussed previously) this should be an appropriate intensity of sampling to detect any "real" differences between classes.

Detecting trends over time: As previously discussed, the frequency of sampling events that would be needed to detect a given level of precision change (*e.g.* 5% or 50%) in a metric over a given time period. This is largely a management decision, but for NEMaR and NRWQN this is cited as being able to detect a 10% change over a 10 year period.

6.3.1. Implementing a pilot – gap analysis

Implementation of a pilot is proposed by DOC to occur early 2014. There are various options for the pilot programme, which will require consultation with key end users and data providers (a workshop is proposed). Evaluation of whether existing datasets could inform some of the points raised (*e.g.* replication to detect trends, representativeness) could potentially be pursued using existing datasets. A gap analysis of existing datasets would also be needed to inform where further environmental data would be required to quantitatively evaluate the Tier 1 network design. This could possibly be followed by a field monitoring study to fill critical gaps.

The type of pilot would very much depend on the area of focus of the Tier 1 programme, as presently there are very different quantities of existing environmental data collection to inform EI indicators for rivers, lakes and wetlands. For a focused wetlands (Option 2), due to the paucity of available data (except for LCR national wetland data), it's likely that considerable monitoring would have to be conducted before a network design could be critically evaluated in a pilot. For river Tier 1 network, there is already significant work conducted to inform these criteria, and a site network through PCL proposed as part of the NEMaR programme that could be

implemented by DOC. Consideration of these aspects by DOC and end users is important for making decisions on the area of the Tier 1 focus. The scale and location of the pilot, inclusion of partners in monitoring, decisions on personal, need to get accurate cost estimates of site and measure sampling would also determine pilot design.

Aspects to be included in the pilot could include a test of monitoring and reporting framework for a limited set of indicators using existing data sets and networks, as well as small scale regional monitoring field trials to develop and assess monitoring protocols and network design.

6.4. Next steps

There are a number of key steps prior to implementing a Tier 1 freshwater monitoring programme. Most importantly this process will need to include consultation with key end users both within DOC (Services, Freshwater, Monitoring and Reporting) and outside of the Department with other freshwater management agencies.

The key next steps in this process are as follows:

- Wider DOC discussion on best approach
- Pilot study evaluating data requirements for biodiversity reporting
- Refinement of framework post-pilot and peer review and integration of proposed framework
- Consultation with potential external partners (workshop)
- Scoping partnerships — *e.g.* other government agencies (MfE), regional authorities, universities (*e.g.* students to support field programme)
- Refinement of selected focus indicators, measures and metrics and design of a Tier 1 network
- Presenting a fully-cost considered business case for implementing a Tier 1 monitoring and reporting programme.

7. REFERENCES

Allen C, Kelly D, Robertson H 2013. Development of a National Wetland Hydrology Database . Prepared for Department of Conservation. Cawthron Report No. 2361. 18 p plus appendices.

Allibone R, David B, Hitchmough R, Jellyman D, Ling N, Ravenscroft P, Waters J 2010: Conservation status of New Zealand freshwater fish, 2009. New Zealand Journal of Marine and Freshwater Research 44: 271-287.

Burns N, Bryers G, Bowman E 2000. *Protocol for monitoring trophic levels of New Zealand lakes and reservoirs*. Prepared for Ministry of the Environment by Lakes Consulting, March 2000.

Carlisle DM, Hawkins CP, Meador MR, Potapova M, Falcone J 2008. Biological assessments of Appalachian streams based on predictive models for fish, macroinvertebrates, and diatom assemblages. Journal of the North American Benthological Society 27:16-37.

Clapcott J, Goodwin E, Snelder T 2013. Predictive Models of Benthic Macroinvertebrate Metrics. Prepared for Ministry for the Environment. Cawthron Report No. 2301. 35 p. plus appendices.

Clapcott JE, Collier KJ, Death RG, Goodwin EO, Harding JS, Kelly D, Leathwick JR, Young RG 2012. Quantifying relationships between land-use gradients and structural and functional indicators of stream ecological integrity. Freshwater Biology 57 (1): 74-90.

Clapcott JE, Young RG, Goodwin EO, Leathwick JR 2010. Exploring the response of functional indicators of stream health to land-use gradients. Freshwater Biology 55 (10): 2181-2199.

Clapcott J, Young R, Goodwin E, Leathwick J 2009. Exploring the relationship between land-use pressure gradients and the ecological integrity of rivers: Contribution to the development of a multi-metric index – In Review at DOC Research and Development Series. Prepared for Department of Conservation. 115 p.

Clarkson BR, Sorrell BK, Reeves PE, Champion PD, Partridge TR, Clarkson BD 2004. Handbook for monitoring wetland condition. Landcare Research, Palmerston North, 72 p.

Clarkson B, Hicks A, Robertson H, Rance B, Leggard S. 2013. A monitoring approach for Southland's wetlands: Stage 1. Landcare Research, Hamilton, 42p.

Clayton J, Edwards T 2006. *LakeSPI : A method for monitoring ecological condition in New Zealand lakes*. NIWA Technical Report Version 2.

Collier K, Hamer M 2010. Spatial and Temporal Patterns in the Condition of Waikato Streams Based on the Regional Ecological Monitoring of Streams (REMS) Programme. Environment Waikato Technical Report 2010/04.

Collier KJ 2008. Average score per metric: an alternative metric aggregation method for assessing wadeable stream health. New Zealand Journal of Marine and Freshwater Research 42:367-378.

Davies-Colley R, Larned S, Unwin M, Verburg P, Hughes A, McBride G, Ballantine D, Hudson N, Daughney C, Hamill K 2011. Dependable monitoring of freshwaters for national-scale environmental reporting. NIWA Client report HAM2011-055. Hamilton, NIWA.

Davies-Colley R, Verburg P, Hughes A, Storey R 2012. National Environmental Monitoring and Reporting (NEMaR). Variables for National Freshwater Monitoring.NIWA Client report HAM2012-006 for the Ministry for the Environment.

Department of Conservation 2010. Biodiversity Monitoring and Reporting System Factsheet.

Drake DC, Kelly D, Schallenberg M 2011. Shallow coastal lakes in New Zealand: current conditions, catchment-scale human disturbance, and determination of ecological integrity. Hydrobiologia 658 (1): 87-101.

Drake D, Kelly D, Schallenberg M, Ponder-Sutton A, Enright M 2009. Shallow coastal lakes in New Zealand: assessing indicators of ecological integrity and their relationships to broad-scale human pressures. NIWA Client Report CHC2009-005: 67p.

Elliott GP, Wilson PR, Taylor RH, Beggs JR 2010: Declines in common, widespread native birds in a mature temperate forest. Biological Conservation *143*: 2119-2126.

Hill BH, Herlihy AT, Kaufman PR, Stevenson RJ, McCormick FJ, and Johnson CB 2000. Use of periphyton assemblage data as an index of biotic integrity. Journal of the North American Benthological Society 19:50-67.

Hudson N, Ballantine D, Storey R, Schmidt J, Davies-Colley R 2012. National Environmental Monitoring and Reporting (NEMaR). Indicators for National Freshwater Reporting. NIWA Client report HAM2012-025 for the Ministry for the Environment.

Johnson RK Hering D 2009. Response of taxonomic groups in streams to gradients in resource and habitat characteristics. Journal of Applied Ecology 46:175-186.

Joy M, David B, Lake M 2013. New Zealand freshwater fish sampling protocols: Part 1 Wadeable rivers and streams. Massey University, Palmerston North. 64p.

Joy MK, Death RG 2004. Application of the index of biotic integrity methodology to New Zealand freshwater fish communities. Environmental Management **34**:415-428.

Karr JR 1981. Assessment of biotic integrity using fish communities. Fisheries **6**:21-27.

Larned S, Roulston H 2013. Recommendations for new sites in the New Zealand river environmental monitoring network. Christchurch, New Zealand, National

Institute of Water & Atmospheric Research Ltd. NIWA Client Report No: CHC2013-029.

Larned S, Snelder T, Schmidt J 2012. National Environmental Monitoring and Reporting (NEMaR). Network design principles for National Freshwater Monitoring. NIWA Client report CHC2012-027 for the Ministry for the Environment.

Leathwick JR, West D, Gerbeaux P, Kelly D, Robertson H, Brown D, Chadderton WL, Ausseil A-G 2010. Freshwater Ecosystems of New Zealand (FENZ) Geo-database User Guide. Department of Conservation.

Leathwick JR, Rowe D, Richardson J, Elith J, Hastie T 2005. Using multivariate adaptive regression splines to predict the distributions of New Zealand's freshwater diadromous fish. Freshwater Biology 50 (12): 2034-2052.

Lee WA, Allen RG 2011. Recommended monitoring framework for regional councils assessing biodiversity outcomes in terrestrial ecosystems. Landcare Research, Dunedin, New Zealand. 37p.

Lee W, McGlone M, Wright E 2005: Biodiversity Inventory and Monitoring: A Review of National and International Systems and a Proposed Framework for Future Biodiversity Monitoring by the Department of Conservation. Landcare Research, Wellington. 213 p.

MacLeod CJ, Affeld K, Allen RB, Bellingham PJ, Forsyth DM, Gormley AM, Holdaway RJ, Richardson SJ, Wiser SK 2013. Department of Conservation biodiversity indicators: 2012 assessment. Landcare Research, Dunedin. 64p.

McDowell R, Snelder T, Cox N, Booker D, Wilcock R 2013. Establishment of reference or baseline conditions of chemical indicators in New Zealand streams and rivers relative to present conditions. Marine & Freshwater Research 64: 387-400.

Ministry for the Environment 2010. New Start for Fresh Water Project 8: Dependable Monitoring and Reporting. Ministry for the Environment, Wellington, 72p.

Ministry for the Environment 2007. Lake Water Quality in New Zealand: Status in 2006 and recent trends 1990–2006. Ministry for the Environment, Wellington, 74p.

Monks JM, O'Donnell CJF, Wright, EF in press. Selection of potential indicator species for measuring and reporting on trends in widespread native taxa in New Zealand. Ecological Indicators.

Parlimentary Commissioner for the Environment 2004. Growing for good: Intesnive farming, sustainability and New Zealand's environment. Parlimentary Commissioner for the Environment, Wellington. 236 p.

Robertson HA, Suggate R 2011. Arawai Kākāriki Wetland Restoration Programme 2007–2010: Implementation Report. Department of Conservation, Wellington. 77p.

Schallenberg M, Kelly D, Clapcott J, Death R, MacNeil C, Young R, Sorrell B, Scarsbrook M 2011. Approaches to assessing ecological integrity of New Zealand freshwaters. Science for Conservation 307: 84p.

Schmidt J 2012. National Environmental Monitoring and Reporting (NEMaR): Summary of Recommendations for National Freshwater Monitoring and Reporting. National Institute of Water & Atmospheric Research Ltd. NIWA Client Report No: CHC2012-029. Christchurch, New Zealand.

Statistics New Zealand, Ministry for the Environment and Department of Conservation 2013. Environment domain plan 2013: Initiatives to address our environmental information needs. Wellington, New Zealand.

Stevens DL, Olsen RA 2004. Spatially-balanced sampling of natural resources. Journal of American Statistical Association 99(465): 262-278.

Verburg P, Hamill K, Unwin M, Abell J 2010. Lake water quality in New Zealand 2010: Status and trends. Report prepared by NIWA for the Ministry for the Environment.

Vörösmarty C, Leveque CR, Bos R, Caudill C, Chilton J, Douglas EM, Meybeck M, Prager D, Balvanera P, Barker S, Maas M, Nilsson C, Oki T, Reidy CA 2005. Ecosystems and Human Well-being: Current State and Trends: Chapter 7-Freshwater. In: Frank Rijsberman RC, Pedro Jacobi ed. Milenium Ecosystem Assessment. UNEP, Geneva. pp 166-206.

8. APPENDICES

Appendix 1. Suggested list of indicators and measures for the assessment of freshwater biodiversity for rivers.

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority ranking (1=high, 3=low)
Indigenous dominance	1 Maintaining ecosystem processes	1.1 Soil status	1.1.1 River substrate modification and/or removal			2
		1.2 Productivity	1.2.1 Ecosystem primary production (periphyton/ macrophytes)	1.2.2 Ecosystem secondary production (macroinvertebrate)	1.2.3 Fisheries (native fish community)	1
		1.3 Water quality and yield	1.3.1 Hydrological alteration/ Water yield	1.3.2 Habitat retention for key species	1.3.3 Eutrophication	2
			1.3.4 Toxicity (DO, NH4, NO3, pH)	1.3.5 Visual clarity		2
		1.4 Ecosystem disruption	1.4.1 Barriers to species migration	1.4.2 Modification of river channel form and sediment transport	1.4.3 Riparian processes (shading, nutrient uptake)	1
	2 Reducing Exotic spread and dominance	2.1 Naturalisation of new weed and pest species	2.1.2 Occurrence of self-maintaining populations of new \environmental weeds and animal pests			1
		2.2 Exotic weeds and pest dominance	2.2.1 Distribution and abundance of exotic weeds and pests	2.2.2 Indigenous systems released from exotic pests		1

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority ranking (1=high, 3=low)
Indigenous dominance	3 Environmental pollutants	3.1 Contaminants	3.1.1 Persistent contaminants (metals, organochlorines)	3.1.2 Endocrine disrupting substances		3
Species occupancy	4 Preventing declines and extinctions	4.1 Status of species at risk of extinction	4.1.1 Abundance and distribution of species listed as "threatened "	4.1.2 Abundance and distribution of species listed as "At risk"		1
		4.2 Genetic change in reduced species	4.2.1 Changes in quantitative genetic characters in critically reduced species	4.2.2 Changes in quantitative genetic characters in range restricted species		2
	5 Ecosystem	5.1 Composition	5.1.1 Demography of widespread animal species	5.1.2 Representation of plant functional types	5.1.3 Representation of animal guilds	2
		5.2 Occupancy of environmental range	5.2.1 Extent of potential range occupied by focal indigenous taxa			1
Environmental representation	6 Ecosystem representation	6.1 Environmental representation and protection status	6.1.1 Proportional composition of river types within PCE lands	6.1.2 Proportional composition of river types within Water Conservation Orders		1
	7 Climate change and variability	7.1 Biological responses to climate change	7.1.1 Status of habitats prone to adverse effects from climate change	7.1.2 Aquatic pest and weed occupancy range	7.1.3 Status of cold-water dependent species	2

Note: Targeted national outcomes, Outcome objectives are the same as suggested in Lee *et al.* (2005), Indicators are based on Lee *et al.* (2005), Schallenberg *et al.* (2010) and Robertson (unpublished), modified to encompass river ecosystems.

Appendix 2. Suggested list of indicators and measures for the assessment of freshwater biodiversity for lakes.

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
Indigenous dominance	1 Maintaining ecosystem processes	1.1 Soil status	1.1.1 Sediment accumulation-	1.1.2 Shoreline erosion		2
		1.2 Productivity	1.2.1 Ecosystem primary production- (phytoplankton, macrophytes)	1.2.2 Ecosystem secondary production- (macroinvertebrate)	1.2.3 Fisheries (native fish)	1
		1.3 Water yield	1.3.1 Hydrological alteration/ Water level	1.3.2 Water residence/ flushing rate		2
		1.3 Water quality	1.3.3 Eutrophication (TLI)	1.3.4 Toxicity (DO, NH4, NO3, pH)	1.3.5 Visual clarity	2
		1.4 Ecosystem disruption	1.4.1 Barriers to species migration (dams, bunds)	1.4.2 Riparian processes (nutrient uptake)	1.4.3 Modification of basin form	1
Indigenous dominance	2 Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species	2.1.1 Occurrence of self-maintaining populations of new potential environmental weeds and animal pests			1
		2.2 Exotic weeds and pest dominance	2.2.1 Distribution and abundance of exotic weeds and pests (exotic macrophytes)	2.2.2 Indigenous systems released from exotic pests (exotic fish CPUE)		1
	3 Environmental pollutants	3.1 Contaminants	3.1.1 Persistent contaminants (metals, organochlorines)	3.1.2 Endocrine disrupting substances		3

Targeted national outcomes	Outcome objectives	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
Species occupancy	4 Preventing declines and extinctions	4.1 Conservation status of species	4.1.1 Abundance and distribution of species listed as 'threatened'	4.1.2 Abundance and distribution of species listed as 'at risk'		1
		4.2 Genetic change in reduced species	4.2.1 Changes in quantitative genetic characters in critically reduced species	4.2.2 Changes in quantitative genetic characters in range restricted species		2
	5 Ecosystem composition	5.1 Composition	5.1.1 Demography of widespread animal species	5.1.2 Representation of plant functional types	5.1.3 Representation of animal guilds	2
		5.2 Occupancy of environmental range	5.2.1 Extent of potential range occupied by focal indigenous taxa			1
Environmental representation	6 Ecosystem representation	6.1 Environmental representation and protection status	6.1.1 Proportional composition of lake types within PCE lands	6.1.2 Proportion of lakes types within Water Conservation Orders		1
	7 Climate change and variability	7.1 Biological responses to climate change	7.1.1 Status of habitats prone to adverse effects from climate change	7.1.2 Aquatic pest and weed occupancy range	7.1.3 Status of cold-water dependent species	2

Note: Targeted national outcomes, Outcome objectives and Indicators are based on Lee *et al.* (2005). Measures are based on Lee *et al.* (2005), Schallenberg *et al.* (2010), and Hudson *et al.* (2011) modified to encompass lake ecosystems.

Appendix 3. Suggested list of indicators and measures for the assessment of freshwater biodiversity for wetlands.

Targeted national outcomes	**Outcome objectives (Lee *et al.***	**Indicator**	**Measure 1**	**Measure 2**	**Measure 3**	**Priority (1=high, 3=low)**
Indigenous dominance	1 Maintaining ecosystem processes	1.1 Soil status	1.1.1 Peat formation	1.1.2 Sediment loading / accumulation / deposition and infill rates	1.1.3 Soil chemistry (*e.g*. pH, N/P levels)	1
		1.2 Productivity	1.2.1 Primary production- plant cover/biomass	1.2.2 Secondary production — invertebrate biomass		2
		1.3 Water yield	1.3.1 Hydrological alteration / water level / yield			1
		1.3 Water quality	1.3.2 Eutrophication	1.3.3 Toxicity (DO, NH4, NO3, pH)	1.3.4 Salinity	2
		1.4 Ecosystem disruption	1.4.1 Barriers to species migration	1.4.2 Degree of drainage	1.4.3. Riparian / floodplain connectivity maintained	1
	2 Reducing exotic spread and dominance	2.1 Naturalisation of new weed and pest species	2.1.1 Occurrence of self-maintaining populations of new potential environmental weeds and animal pests			1
		2.2 Exotic weeds and pest dominance	2.2.1 Distribution and abundance of exotic weeds and pests	2.2.2 Indigenous systems released from exotic pests		1
	3 Environmental pollutants	3.1 Contaminants	3.1.1 Persistent contaminants metals organochlorines	3.1.2 Pollutant contaminants nutrients		3

Targeted national outcomes	Outcome objectives (Lee *et al.*	Indicator	Measure 1	Measure 2	Measure 3	Priority (1=high, 3=low)
Species occupancy	4 Preventing declines and extinctions	4.1 Conservation status of species	4.1.1 Abundance and distribution of species listed as 'threatened'	4.1.2 Abundance and distribution of species listed as 'at risk'		1
		4.2 Genetic change in critically reduced species'	4.2.1 Changes in quantitative genetic characters in species listed as 'threatened'	4.2.2 Changes in quantitative genetic characters in species listed as 'at risk'		2
	5 Ecosystem composition	5.1 Composition	5.1.1 Demography of widespread animal species	5.1.2 Representation of plant functional types	5.1.3 Representation of animal guilds	2
		5.2 Occupancy of environmental range	5.2.1 Extent of potential range occupied by focal indigenous taxa			1
Environmental representation	6 Ecosystem representation	6.1 Environmental representation and protected status	6.1.1 Proportional composition of wetland types legally protected within PCE lands	6.1.2 Proportional composition of wetland types legally protected outside of PCL (covenants)	6.1.3 Management effort across waterbody types	1
	7 Climate change and variability	7.1 Biological responses to climate change	7.1.1 Status of habitats prone to adverse effects from climate change	7.1.2 Aquatic pest and weed occupancy range	7.1.3 Status of cold-water dependent species	2

Note: Targeted national outcomes and Outcome objectives are the same as suggested in Lee *et al.* (2005), Indicators are based on Lee *et al.* (2005), Schallenberg *et al.* (2010) and Robertson (unpublished), modified to encompass wetland ecosystems.