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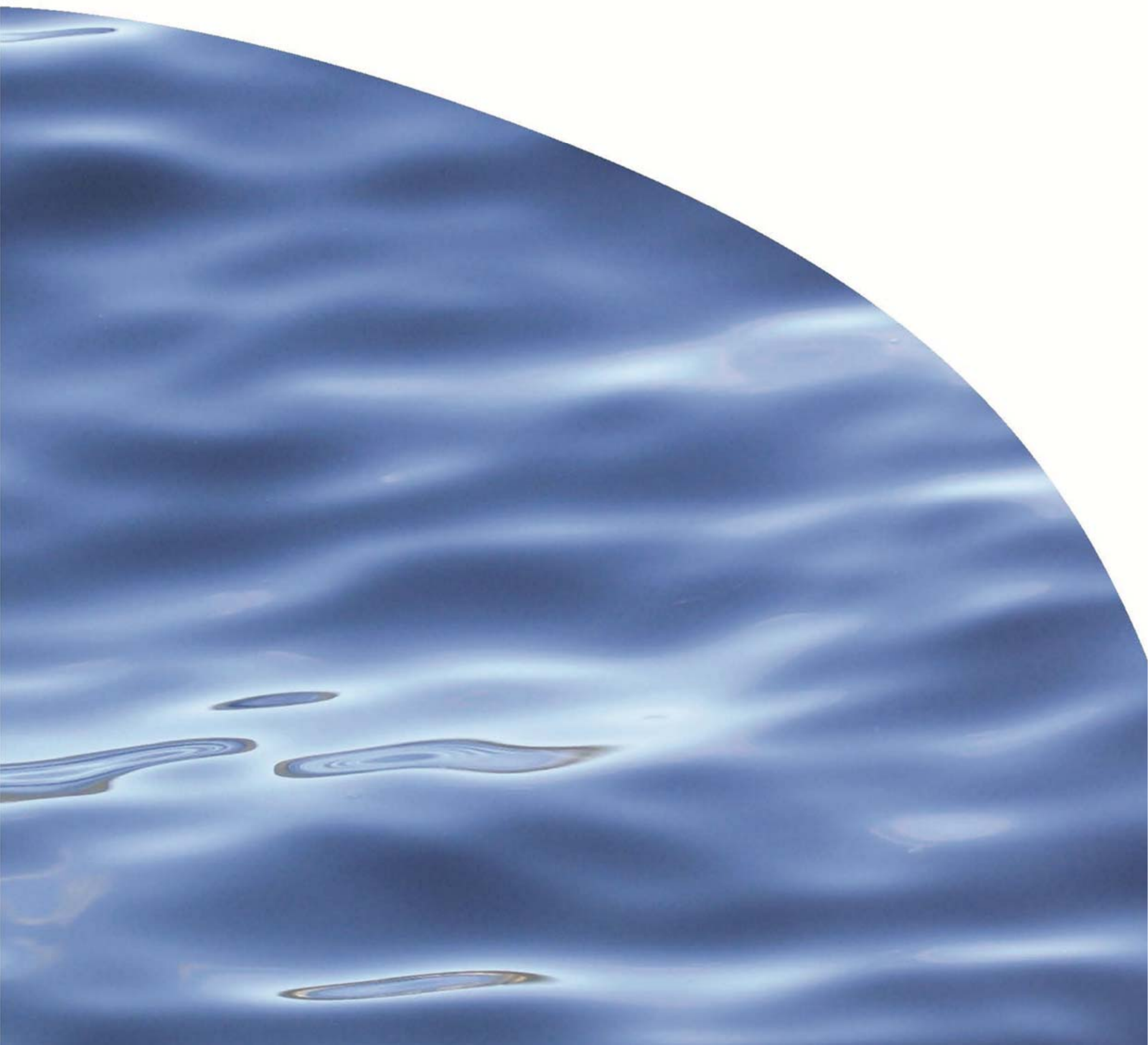
A CALIBRATED ECOLOGICAL HEALTH ASSESSMENT FOR SOUTHLAND LAKES



A CALIBRATED ECOLOGICAL HEALTH ASSESSMENT FOR SOUTHLAND LAKES

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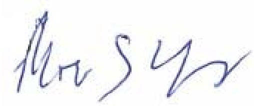

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EXECUTIVE SUMMARY

The National Policy Statement for Freshwater Management (Ministry for the Environment) requires regional regulators to report on and protect ecological values of lakes in their jurisdiction. Environment Southland is looking to implement a monitoring programme which allows them to report on the ecological condition of lakes in their region and to evaluate trends in these lakes. For successful assessment of the health of the lakes, a framework is required to guide the development of the monitoring programme and to provide context to data analysis and temporal trends in lake condition.

In order to develop such a framework, this study had three main aims:

1. To review existing frameworks for assessing ecological conditions in lakes and select a framework which may be developed to use for assessing lakes in the Southland region. This review consisted of the evaluation of recent work towards a New Zealand framework for ecological integrity (EI) in lake systems, as well as a review of frameworks in use internationally.
2. To develop the selected framework into a robust system which is calibrated nationally using lake typology and which spans the range of anthropogenic pressures.
3. To assess the ecological condition of Southland's lakes relative to the developed framework.

Several frameworks have been developed internationally, however, given the significant amount of work on New Zealand waterbodies and more specifically in Southland's lake systems, the Ecological Integrity framework (based on work by Schallenberg et al. (2011)), was selected for use in the context of this study. In this framework there are four key EI components: 'nativeness', pristineness, diversity and resilience.

Nationwide lake data on up to 36 shallow and 17 deep lakes, including the Southland lakes, were used for the derivation of EI value bands and their thresholds for the various lake metrics. These data were obtained from extensive ecological surveys which provided data on water quality, phytoplankton, zooplankton, macrophytes, macroinvertebrates and fish. In-lake and catchment metrics were calibrated against two independent measures of EI, consisting of an independent expert assessment and the measure of the percentage of the lake's catchment that is in native vegetation. A similar banding system for EI condition was used to the NPS-Freshwater Management National Objectives Framework bands to delineate quartiles of EI condition. Bands were calculated using both 95th and 80th percentile groupings to delineate the data range quartiles, with the 80th percentile ranges providing a more even spread of the data ranges.

For the shallow lake national data set, three nativeness, four pristineness and two resilience metrics were calibrated against the two independent measures of EI, providing a fairly good, but incomplete coverage of the four major EI components. None of the diversity metrics (fish, macrophytes, zooplankton, phytoplankton or benthic invertebrates) showed clear

relationships to the independent measures of EI. In the deep lakes national dataset, four pristineness and two diversity metrics were calibrated against the two independent measures of EI. The metrics of nativeness and resilience did not show relationships with the independent measures of EI and hence were not used for calibrating the deep lakes dataset. In general, relationships between modelled catchment nutrient loss metrics and the independent measures of lake EI were weak or non-existent, however some metrics (e.g., Vollenweider model predicted in-lake TN and TP) were able to be related to lake EI measures.

The banding and scoring exercises undertaken in this report yield scores for a number of lake and catchment metrics that are related to EI. The metric scores for a given lake/catchment can be aggregated in various ways to produce overall EI scores, which may be useful for lake and catchment management. We aggregated the scores for Southland's shallow and deep lakes and their catchments in two ways: (1) Average aggregation, where the overall score is an average of a lake's/catchment's metric scores, and (2) Minimum aggregation, which sets the overall score by the minimum score achieved among all of a lake's/catchment's metrics.

The Southland shallow lakes scores ranged from Excellent to Fair depending on the type of aggregation used and, as expected, the average aggregation method produced higher EI scores than the minimum aggregation method. Overall, an excellent value band (band A) was calculated for the Stewart Island/Rakiura lakes (Lakes Calder and Sheila). The aggregated EI scores were lower for the four mainland shallow lakes which have higher human pressures on their catchments. Lakes Vincent and George have aggregated EI scores which fall in the Excellent to Good (bands A-B) or Good value bands, The Reservoir and Lake Murihiku had aggregated EI scores that fall in the Good to Fair (bands B-C), and The Reservoir had aggregated EI scores that fall in the Fair to Unacceptable (bands C-D) depending on the aggregation method used.

The EI metric scores for the Southland deep lakes Te Anau and Manapouri were scored in the Excellent to Good range. The catchments of these lakes are also scored as Excellent to Good. Maximum macrophyte depths were affected by high native vegetation-derived coloured humic acid concentrations limiting light penetration in the lakes relative to other deep glacial and volcanic lakes, confounding the ability to use water clarity as a metric to score lake EI.

The method of assessing lake EI has been largely successful at identifying overall lake health and is broadly in line with previous assessments of Southland's lakes. It is recommended therefore that this system be adopted as a way of holistically measuring lake health. However the limitations of the approach indicate that currently the use of EI should not completely replace existing methods of assessing lake health, but rather further add to existing protocols for assessing lake condition (e.g., NOF ecosystem health metrics, LakeSPI). Some considerations will need to be made around the inclusion of EI metrics within ES's future lake monitoring. Ongoing monitoring of these metrics will allow temporal trends in overall EI to be identified for the Southland lakes.

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GLOSSARY

Ecological Integrity (EI)	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
EI Component	Ecological integrity is a composite concept; it encompasses many ecological components. EI components were considered in regards to Schallenberg et al (2011). This included four core components including (1) nativeness, (2) resilience, (3) diversity and (4) pristineness. Under each component a wide range of standard ecological metrics were evaluated in regard to their ability to holistically inform these core elements
EI Independent Measure	Independent measures of EI were considered that included an independent expert assessment of the condition of the lake, and the condition of the lake catchment defined by the proportional coverage of native vegetation.
EI Metric	Is a metric or indicator that is aligned with the EI components. For example chlorophyll-*a* concentration was a metric aligned with pristineness.
EI Value Band	Value bands were statistically determined groupings of lake metric scores that defined a metric ranges for ranking lakes relative to other lakes within the same lake class. Lake classes were defined in terms of whether the lake was deep (seasonally stratifying, > 30 m max depth) or shallow (polymictic, <10 m). Bandings were developed both for individual metrics and combined EI components.

1. INTRODUCTION

Environment Southland (ES) is interested in implementing a monitoring programme to enable reporting on the status and trend of ecological condition of lakes within their region. Before ES can implement a monitoring programme, they require a framework to work within, one that incorporates relevant sampling design and data analysis tools to address the particular concerns likely to occur in the Southland region's lakes. The framework would enable evaluation of the condition of Southland lakes for the purpose of comparison both within the Southland region as well as lakes from across New Zealand. This is particularly timely as other councils are also grappling with defining lake monitoring strategies to manage their lakes resource (e.g. Champion 2012).

1.1. Background

Southland contains a number of shallow coastal and deeper inland lakes. The shallow coastal lakes are generally sand dune lakes located in small catchments which have either mixed land use or mostly intensive agricultural land uses such as dairying. The deep, inland lakes include some iconic and relatively pristine lakes of glacial origin with predominantly wilderness catchments.

Schallenberg and Kelly (2012) studied the state and trends of ecological health (ecological integrity) and Schallenberg and Kelly (2013) predicted the historical reference conditions of most of Southland's shallow coastal lakes. Kelly et al. (2013a) related the ecological integrity of the lakes to catchment land use and nutrient loads. Previously Drake et al. (2009, 2010) analysed a large dataset of mainly shallow lowland lakes which included Lakes Vincent and George and the Reservoir. This work allowed these Southland lakes to be placed into a national context with regard to ecological integrity. Relatively little work has been done on the deep, inland lakes with regard to ecological state and trends. Water quality monitoring in these lakes has been sporadic, but can provide a basis for an assessment of lake health (e.g. Özkundakci et al. 2013).

Agricultural land use in Southland has rapidly intensified in the past two decades, mainly due to an increase in dairy farming in the region. As dairy farming tends to leach higher levels of nutrients into surface waters and groundwaters (Elliott & Sorrell 2002) than the traditional sheep and beef farms of the region, this change and intensification may have increased the nutrient loads to lakes in the Southland region. Kelly et al. (2013a) showed that nutrient losses from land correlate with in-lake nutrient concentrations.

In light of these developments and of a need to set limits and targets safeguarding lake health as specified in the National Policy Statement (NPS) for Freshwater Management (Ministry for the Environment 2014), there is a need to develop a robust system where the ecological state of Southland's lakes can be calibrated and described quantitatively and robustly. This will allow comparison of the state of the lakes in relation to each other and to the state of similar lakes across New Zealand. Such an assessment can potentially benefit lake management and restoration planning in Southland.

1.2. Aims

This report has a number of aims to help inform Environment Southland's limit setting process with regard to its lakes:

- Evaluate a range of frameworks for assessing ecological condition (integrity) in lakes
- Develop a robust, calibrated assessment procedure for determining the ecological condition of Southland's shallow and deep lakes. This procedure must be compatible with the NPS-FM and the NOF (National Objectives Framework) water quality guidelines but will expand the latter to assess other appropriate indicators of lake ecological integrity.
- Use the assessment procedure on a number of shallow, lowland and deep lakes to determine their states of ecological health
- Conduct pilot analyses of in-lake response variables across a range of pressures within a national and regional context
- Use the assessment procedure to also assess the condition of Southland lake catchments in terms of their impacts on lake ecological integrity.

2. EVALUATING FRAMEWORKS FOR ASSESSING ECOLOGICAL CONDITION

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 & Death 2004), macroinvertebrates (Collier 2008), and periphyton (Hill et al. 2000). As ecological indicators have become more widely applied there have been increasing numbers of studies measuring a combination of stream components to assess stream condition (e.g. Carlisle et al. 2008; Johnson & Hering 2009). Recent comparative studies of multiple indicators have shown how different groups of organisms provide complementary information on 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 much less often on average 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 projects (Cross-Departmental Research Pool Freshwater; Clapcott et al. 2010) and monitoring reform initiatives (National Environmental Monitoring and Reporting; Hudson et al. 2012) have considered such aspects.

2.1. Ecological Integrity framework for New Zealand freshwaters

The development of an EI framework to protect New Zealand's biodiversity has received some attention in recent years (e.g. Lee et al. 2005; Drake et al. 2010; Kelly et al. 2013b). Lee et al. (2005) suggested an EI framework (for mainly terrestrial systems) based on a set of indicators and metrics that together comprise a means of assessing the ecological integrity of a representative site network. They defined EI as the full potential of indigenous biotic and abiotic factors, and natural processes, functioning in sustainable communities, habitats, and landscapes. The term encompasses all levels and components of biodiversity, and can be assessed at multiple scales. At the simplest level, 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).

Schallenberg et al. (2011) developed a framework for the evaluation of the ecological integrity (EI) of New Zealand lakes and rivers. The term 'ecological integrity' is a complex normative concept[1] that in essence integrates a diverse range of ecological values to define the condition of an ecosystem. Since EI is a normative concept there are many different definitions and interpretations of EI (Schallenberg et al. 2011).

In New Zealand, considerable effort has been made to defining ecological integrity in the context of New Zealand freshwater systems by Schallenberg et al. (2011). Their eventual working definition of EI was:

> 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 reflecting negligible or minimal anthropogenic impacts.

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. A wide range of standard ecological metrics were evaluated in regard to their ability to holistically inform these core elements (Table 1).

2.1.1. Testing of EI indicators against human pressures

To further evaluate the EI framework for New Zealand freshwaters, a Cross-Departmental Research Pool (CDRP) research project was funded (by the Foundation for Research Science and Technology (FRST) to examine relationships between a range of EI indicators and gradients of human pressure (e.g. native forest removal, eutrophication, introduction of exotic species, urbanisation, and water abstraction). Relationships between EI metrics and human pressures were used to inform pressure response functions in the Freshwater Ecosystems of New Zealand (FENZ) model that predicts the overall condition of waterbodies based on pressure information. It was from this research that the Schallenberg et al. (2011) definition of EI for New Zealand freshwater systems was developed (see Section 1.2).

Environmental monitoring data from regional councils, Crown Research Institutes (CRIs), and other sources (e.g. universities) was used to evaluate national coverage of EI indicators (metrics). The data was also used to identify key areas to be pursued where there were gaps in existing knowledge for key indicators or under-represented habitats. The collection of functional process indicators for lakes (in particular, shallow lowland lakes) along with further consideration of wetland monitoring were seen as a key requirements to fill existing knowledge gaps.

Careful choice of structural and functional indicators (metrics) was identified as crucial to creating a practical scheme for assessing EI. A range of common measures used for lake monitoring are available that can be used to quantify the four core

[1] subjective relative to human values or prescribed norms

components of EI (i.e. nativeness, resilience, diversity and pristineness) (Table 1). Overall the indicators from the CDRP framework are relatively compatible with the Lee et al. (2005) framework (see Kelly et al. 2013b for review).

In developing the EI framework for aquatic systems, it is important to define the standards by which a change is measured as good or bad. Schallenberg et al. (2011) discuss this in some detail, suggesting a reference condition approach would be suitable (hence its inclusion in their definition of EI referred to in Section 2.1). Since the 2011 report an attempt has been made to establish appropriate reference conditions for NZ shallow freshwater lakes, deep lakes and brackish lakes and lagoons by Schallenberg (in press). A combination of two approaches was used to assign reference condition. The first approach involved a survey-calibration whereby contemporary data on lake status and condition and expert judgement was used to infer reference condition. The second approach involved analysing palaeo-limnological reconstruction data to provide information on historic pre-human in-lake condition.

Overall the EI framework can be considered a holistic framework for assessing the condition of lakes, including a wide range of metrics to evaluate the pristineness, diversity, nativeness, and resilience of freshwaters. The overall selection of metrics was also strongly considered in relation to a wide range of human pressures.

Table 1. Suggested list of metrics for the assessment of ecological integrity (EI) in lakes. Modified from Schallenberg et al. (2011).

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

2.1.2. 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 (2012); however, the reports are yet to be made publicly 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)

As with the other 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 metrics 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 metrics retained in the NEMaR framework were focused mainly around assessment of water quality (Table 2). However, for lake ecosystems, a greater number of biological community indicators such as for macrophytes and fish were endorsed (Table 2); the former related to the widespread use of the aquatic macrophyte (LakeSPI) monitoring being used by regional councils (Verburg et al. 2010). There were no functional process indicators adopted into the core set, but some were included as optional indicators.

Overall, the NEMaR framework identifies a wide range of indicators and metrics that represent the bulk of monitoring currently being conducted in New Zealand by regional councils and NIWA in lakes. Many of the indicators overlap with a number of metrics of those in Schallenberg et al. (2011), however, the scope of the indicators is narrower than the broad scope identified in the EI framework.

Table 2. 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. Also included are examples of main stressors that may be detected by the metrics.

Measure/EI component	Metric class	Metrics	Examples of main stressor that may be detected
Nativeness	Biota	Macrophytes[1] Pest fish Native fish	Exotic species
	Habitat	Macrophytes	Exotic species
	Hydrology	Lake level variation Residence time	Hydrological alteration
Pristineness	Biota	Macrophytes Pest fish Cyanobacteria	Eutrophication
	Habitat	Macrophytes	Eutrophication
	Water quality	Chlorophyll-*a* Total nitrogen Total phosphorus Secchi depth Dissolved oxygen profile Temperature profile DIN[2] CDOM[3]	Eutrophication
	Hydrology	Lake level variation Residence time	Connectedness, abstraction, irrigation, artificial human barriers
Diversity	Biota	LakeSPI Pest fish	Loss of biodiversity
	Habitat	Macrophytes	Loss of biodiversity
Resilience	Biota	Pest fish Macrophyte variability Cyanobacteria	Risk of cyanobacterial blooms
	Habitat	Macrophytes	Macrophyte collapse
	Water quality	Chlorophyll-*a* variability	Risk of cyanobacterial blooms
Optional	Biota	Rotifer TLI MCI for lakes Invasive zooplankton	Loss of biodiversity
	Habitat	Sedimentation/ sediment loading	Anoxia, eutrophication
	Water quality	pH TSS/VSS Diel dissolved oxygen GPP Developments to TLI	Eutrophication, toxicity, loss of productivity
	Hydrology	Connectedness	Artificial human barriers

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

2.2. Ecological Status of dune lakes—Northland

Northland Regional Council in conjunction with NIWA developed a framework for assessing the ecological condition for the region's dune lakes (Champion & de Winton 2012). Ecological values were assessed for each lake including the following:

1. habitat size (lake area)
2. catchment buffering (native vegetation)
3. water quality (largely nutrient status)
4. aquatic vegetation diversity and integrity (based on LakeSPI)
5. presence of endangered and key species (vegetation and fish)
6. connectivity (fringe wetlands).

Using available data on lake morphometry, water quality, aquatic plants, and catchment cover, NIWA evaluated the ecological condition of 76 lakes using this framework. The dune lakes were further classified according to a geomorphic classification that identified six major classes of lakes including perched dune lakes and coastal deflation hollows both typically with tea-stained water (e.g., Lake Mokena), window[2] lakes with clear spring-fed water (e.g., Lake Taharoa), lakes formed by mobile dunes damming valleys or basins (e.g., Lake Humuhumu), marine contact lakes (e.g., Waitahora Lagoon) and ephemeral pools in mobile sands (e.g., Te Arai Pond). Lakes were further classified based on soil age and geographical area, with a total of 27 lake classes.

Overall this framework is well suited to dune lakes, and is based on readily available monitoring data for these lakes. The classification system, while not applicable to Southland lakes, could be considered under a revised classification system. The ranges of scores applied to lakes could potentially be applicable to the shallow lakes in Southland, however these scores would need to be re-calibrated for deep glacial lakes. The overall framework is narrower in its focus than described for other frameworks such as the EI framework and NEMaR, and is more focused on aquatic vegetation aspects of these lakes which are a high priority for management in the region and are well suited to the quantification of shallow lake health.

2.3. European Union – Water Framework Directive

The European Union (EU) Water Framework Directive arose in response to increasing pressure by citizens and environmental organisations for cleaner rivers and lakes, groundwater and coastal beaches. As a result of extensive consultation there was a widespread consensus that, while considerable progress had been made in tackling individual issues, the current water policy was fragmented, in terms both of objectives and of means. A single piece of framework legislation was developed to

[2] Window lakes dune are lakes which directly connect to subsurface groundwater

move forward in resolving these problems—the Water Framework Directive (WFD). The aims of the WFD were:

- expanding the scope of water protection to all waters, surface waters and groundwater
- achieving 'good status' for all waters by a set deadline
- water management based on river basins (i.e. a single system of water management by river basin—identified as important because some of Europe's major rivers traverse several countries)
- 'combined approach' of emission limit values and quality standards
- getting the prices right (i.e. balancing the need to conserve adequate supplies of a resource for which demand is continuously increasing)
- getting citizens involved more closely
- streamlining legislation.

The WFD defines the ecological status of surface waters as 'an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters …' (European Union 2000). WFD uses primarily biological indicators to assign water bodies, including lakes, to one of five ecological classes ranging from high to low quality (European Union 2000). 'High quality' is defined as the biological, chemical and morphological conditions associated with no or very low human pressure. The 'high status' class was also referred to as the 'reference condition' as it is the best status achievable—the benchmark. These reference conditions are system-specific, so they are different for different types of rivers, lakes or coastal waters in order to take into account the broad diversity of ecological regions in Europe.

Assessment of quality is based on the extent of deviation from these reference conditions, following the definitions in the WFD. 'Good status' means 'slight' deviation, 'moderate status' means 'moderate' deviation, and so on. The definition of ecological status takes into account specific aspects of the biological quality elements, for example 'composition and abundance of aquatic flora' or 'composition, abundance and age structure of fish fauna'.

As part of the framework an intercalibration is performed—a complex task that takes into account current scientific knowledge about the structure and functioning of aquatic ecosystems, and how human activities influence them.

Overall the system of ranking indicators under the WFD is comparable to what has previously been developed for New Zealand (e.g., Schallenberg et al. 2011; Davies-Colley et al. 2012; Kelly et al. 2013b). The complexity of benchmarking indicators against a set of reference condition lakes, as is done for the WFD zones (i.e., usually countries or regions), makes the implementation of this framework more difficult, however reference conditions have been described for some indicators in Southland's shallow and brackish lakes (Schallenberg & Kelly 2013).

2.4. Biological Condition Gradient—United States of America

In the United States of America, legislation provides the long-term, national objective to 'restore and maintain the ... biological integrity of the Nation's waters' (United States Clean Water Act (1972), section 1251). However, the legislation does not define the ecological components, or metrics, that constitute biological integrity. Nor does it recommend scientific methods to measure the condition of aquatic biota (Davies & Jackson 2006).

Research undertaken in the United States has focused on using biological assessments to evaluate aquatic resource condition more uniformly and directly, and to set protection and restoration goals for aquatic life (Davies & Jackson 2006). To overcome the difficulty of different states using different methods to determine biological condition, Davies and Jackson (2006) developed a nationally applicable model that allowed biological condition (i.e. EI) to be interpreted independently of assessment methods with the aims of allowing for:

1. more uniform and direct assessment of aquatic resources, and
2. clearer communication pathway to the public both the current status of aquatic resources and their potential for restoration.

Davies and Jackson (2006) developed and tested the Biological Condition Gradient (BCG), a descriptive model of biological response to increasing levels of anthropogenic stress that is comprehensive and ecosystem based. The model evaluates environmental conditions and the status of ecosystem services in order to identify, communicate, and prioritise management action.

Future work suggested for the BCG included focus on developing a comparable model for tiering the generalised stressor gradient and quantifying the relationships between the BCG and both general and stressor-specific gradients. This work would aid in defining 'reference' conditions across different states and ecoregions, and to cover the fact that biotic response to stressors will vary due to biogeographical differences across the states.

In recent years, several states and the United States Environmental Protection Agency have developed a framework to support improved biological assessment. The framework, called Tiered Aquatic Life Use (TALU), supports development of a means of ranking biological criteria in a state's water quality standards that can protect the best quality waters (United States Environmental Protection Agency 2005). This was intended to be used as a tool to prevent or remediate cumulative, incremental degradation, and facilitate establishment of realistic management goals for impaired waters. The basis of the TALU framework is recognition that biological condition of water bodies responds to aggregate human-caused disturbance and stress, and that biological condition can be measured reliably. For TALU implementation, biological condition is measured on the Biological Condition Gradient (BCG), a universal measurement system or yardstick that is calibrated on a common scale for all states and regions.

Overall the methodologies employed in the United States to evaluate and report on the ecological condition of freshwaters is a useful approach that would be applicable to New Zealand. However considerable work would be required to allow for the implementation of such a system for New Zealand. While this process was initiated as part of the MfE NEMaR project, further work is required before it could be implemented. Therefore an equivalent framework for the Southland region is beyond the scope of this project and would most likely need to be considered at a national level.

2.5. Recommended Framework for Southland Lakes

Based on the range of frameworks available for assessing the condition of lakes in New Zealand and overseas, the Ecological Integrity framework (Schallenberg et al. (2011) was agreed amongst the project team (ES staff, Cawthron, Otago University) as the most applicable framework for Southland's lakes. This was based on the following criteria:

- breadth of metrics covering a range of EI components (i.e., nativeness, pristineness, diversity, resilience)
- previous work to test metrics against a range human pressures across New Zealand
- monitoring data available for Southland lakes covering a range of EI metrics
- previous work on EI metrics in Southland's shallow lakes (Schallenberg & Kelly 2013).

The following sections of the report outline the analyses undertaken to develop a calibrated assessment procedure for assessing the Ecological Integrity of Southland's lakes.

3. METHOD FOR THE DEVELOPMENT OF THE LAKE ASSESSMENT FRAMEWORK

The lake condition assessment methodology developed here is based on the lake ecological integrity framework described by Schallenberg et al. (2011) and utilised for shallow lakes by Schallenberg & Kelly (2012, 2013) and Kelly et al. (2013b) and for deep lakes by Özkundakci et al. (2013). This framework defines four key components of New Zealand freshwater ecological integrity (EI): 1. biotic nativeness, ecological pristineness, biological diversity and ecological resilience to pressures. Various indicators/metrics are linked to the different components and assessments of ecological integrity. If possible, these metrics should include all those covering the four EI components. Our assessment procedure involved 6 steps, illustrated in Figure 1, and was applied to shallow lakes, deep lakes and the lake catchments.

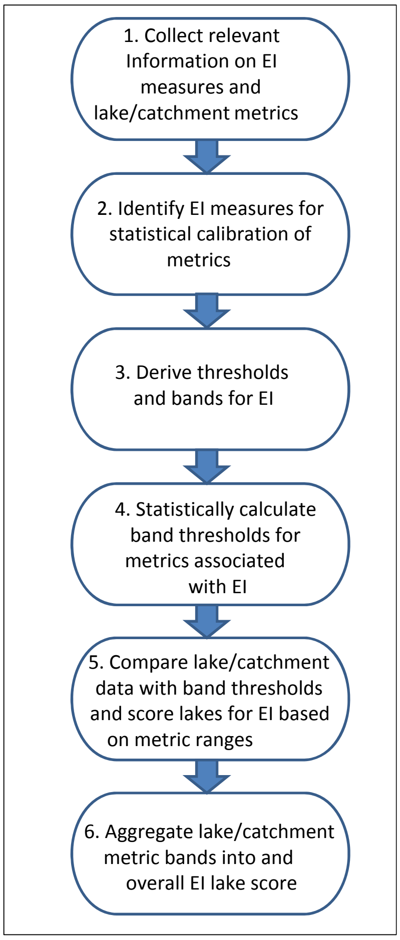

Figure 1. Procedure for developing the lake/catchment ecological integrity assessment.

3.1. Collecting the relevant data

3.1.1. Shallow lakes

Data on up to 36 shallow (< 10m maximum depth, sensu Scheffer (2004)) lowland lakes nationwide, including the Southland lakes, (Table 3) were used for the derivation of EI value bands and their thresholds for the various lake metrics (see Section 3.3). These data were obtained from extensive ecological surveys conducted in 2004 (Drake et al. 2009, 2011; Schallenberg & Kelly 2012) and 2013 (Schallenberg & Kelly 2013). These surveys typically included data on water quality, phytoplankton, zooplankton, macrophytes, macroinvertebrates and fish. The lakes span the range of ecological condition and anthropogenic pressures. Morphometric and water quality data for 36 of these lakes are presented in Table 3.

Data for the six shallow Southland lakes were then used to assess the condition of Lakes George, Vincent, Murihiku, Sheila, Calder and The Reservoir relative to the EI value bands. Supplementary data on water quality was obtained for lakes George and Vincent and The Reservoir from Environment Southland.

3.1.2. Deep lakes

Data on 17 nationwide, deep seasonally stratifying lakes (> 30 m maximum depth) including the two Southland lakes (Table 4) were used for the derivation of EI value bands and their thresholds for the various lake metrics (see Section 3.3). Comparable data on the deep glacial lakes Te Anau and Manapouri were obtained from the study of EI of deep lakes by Özkundakci et al. (2014). Information on water quality, phytoplankton, zooplankton, macrophytes, macroinvertebrates and fish were used as well as information on dissolved oxygen and nitrogen cycling. Data included in the analyses were based on a data set of 25 deep lakes compiled as part of an investigation on ecological indicator responses to human pressure gradients (CDRP project discussed in Section 2.2). Eight lakes were excluded from the data analyses based on their size and depth. The lakes spanned a wide range of ecological condition and anthropogenic pressures. Morphometric and water quality data for 17 of these lakes are presented in Table 4.

3.1.3. Catchments

Data from the shallow and deep lake catchments were utilised for the derivation of EI value bands and thresholds for the various lake catchment metrics. The metrics utilised for catchment assessment were associated with nutrient fluxes obtained from catchment land cover mapping, CLUES modelling of nutrient fluxes and Vollenweider calculations of in-lake nutrient concentrations (Kelly et al. 2013; 2014). The methods used for these modelling approaches are presented in Appendix 1.

Table 3. Lake morphometric data, native land cover, and total nutrient concentrations (2009–2014 median concentrations) for shallow New Zealand lakes including Southland lakes used in the nutrient loading study. N = nitrogen, P = phosphorus.

Lake	Region	Lake area (ha)	Max depth (m)	Residence Time (y)	Catchment area (ha)	Native land cover (%)	Median in-lake total-N (mg^3/m^3)	Median in-lake total-P (mg^3/m^3)	Median in-lake Chl-*a* (mg/L)
George	Southland	90.8	2.0	0.09	2912	46.1	858	27.9	2.7
Murihiku	Southland	5.7	1.3	0.11	314	17.1	2093	235.0	27.9
Vincent	Southland	17.2	5.0	0.07	573	6.2	842	29.0	8.3
Reservoir	Southland	35.5	5.0	0.16	60	32.3	613	39.4	24.3
Sheila	Southland	14.1	6.6	0.08	103	100.0	253	10.8	1.2
Calder	Southland	4.1	6.7	0.19	31	100.0	220	6.5	1.5
Mahinapua	West Coast	393.8	10.0	0.11	3595	76.9	323	10.3	1.9
Poerua	West Coast	212.7	7.8	0.07	1974	73.0	245	8.0	1.7
Ryan	West Coast	3.5	3.0	0.02	50	26.8	696	66.3	10.1
Ship	West Coast	10.2	3.0	0.02	203	97.8	260	6.3	0.7
Maori	West Coast	36.8	0.6	0.03	6464	100.0	228	3.7	0.9
Tuakitoto	Otago	131.7	3.0	0.85	14434	8.1	952	54.3	3.2
Waihola	Otago	607.6	2.2	0.44	7055	15.4	600	19.3	1.7
Waipori	Otago	183.7	1.0	0.00	56133	40.7	4	17.5	1.0
Wilkie	Otago	1.0	4.0	0.06	15	87.5	692	23.3	5.7
Coopers	Canterbury	43.2	3.0	4.08	105	0.9	1381	16.0	1.0
Rotorua	Canterbury	1.7	3.2	0.01	391	38.5	3672	270.0	17.0
Kaihoka	Tasman	6.8	10.2	0.47	84	66.4	151	6.6	1.6
Otuhie	Tasman	84.7	2.1	0.07	1720	96.3	235	7.4	0.7
Pounui	Wellington	46.0	6.5	0.19	718	91.2	277	11.7	3.2
Papaitonga	Manawatu	51.5	1.1	0.15	322	38.1	1784	72.5	12.5
Waitawa	Manawatu	15.8	6.3	0.32	243	11.1	1463	188.8	6.5

Table 3, cont.

Lake	Region	Lake area (ha)	Max depth (m)	Residence Time (y)	Catchment area (ha)	Native land cover (%)	Median in-lake total-N (mg^3/m^3)	Median in-lake total-P (mg^3/m^3)	Median in-lake Chl-*a* (mg/L)
Kaitoke	Whanganui	25.3	1.0	1.81	3265	2.3	1667	491.9	35.3
Marahau	Whanganui	9.8	5.3	0.29	772	2.7	674	31.5	3.1
Oingo	Hawkes Bay	85.1	1.8	0.57	981	13.3	798	10.0	1.5
Runanga	Hawkes Bay	110.5	0.9	0.24	769	19.4	2439	335.4	116.0
Pokorua	Waikato	25.9	1.2	0.13	486	23.0	852	39.6	19.2
Spectacle	Auckland	43.8	7.0	0.25	369	16.5	1338	89.2	42.2
Tomarata	Auckland	14.4	5.0	0.40	95	41.1	361	6.4	4.5
Whatihua	Auckland	3.9	3.2	0.11	106	2.6	416	8.1	1.8
Humuhumu	Northland	139.6	15.0	2.18	879	31.5	257	7.0	2.0
Kai-Iwi	Northland	26.8	16.0	0.60	486	58.6	318	5.0	1.7
Ngatu	Northland	51.7	6.5	1.66	172	40.0	530	4.6	1.4
Rotokawau	Northland	25.7	11.0	0.18	1490	25.6	314	6.8	1.6
Shag	Northland	17.4	6.2	0.71	53	35.1	582	11.8	7.2
Waiparera	Northland	108.6	6.0	1.02	704	27.6	621	13.0	3.2

Table 4. Lake morphometric data, native land cover, and total nutrient concentrations for deep New Zealand lakes including Southland lakes used in the nutrient loading study. N = nitrogen, P = phosphorus.

Lake	Region	Lake area (ha)	Max depth (m)	Residence Time (y)	Catchment area (ha)	Native land cover (%)	Annual median in-lake total-N (mg^3/m^3)	Annual median in-lake total-P (mg^3/m^3)	Annual median in-lake Chl-*a* (mg/L)
Manapouri	Southland	14177.7	444.0	2.03	448134	96	81	6.7	1.1
Te Anau	Southland	34296.6	417.0	17.78	308404	95	79	10.8	1.1
Wakatipu	Otago	29825.2	380.0	13.73	305892	87	67	5.5	1.2
Wanaka	Otago	20399.8	311.0	12.95	258015	86	63	4.3	1.2
Alexandrina	Canterbury	645.7	27.0	358.37	4624	21	217	8.2	1.7
Coleridge	Canterbury	3687.6	200.0	26.00	21845	59	47	3.2	0.5
Ohau	Canterbury	5926.8	129.0	1.73	113614	86	45	5.3	0.6
Pukaki	Canterbury	17273.6	70.0	2.30	135418	79	39	8.1	0.4
Tekapo	Canterbury	9659.4	120.0	3.91	143091	80	45	4.8	1.2
Okareka	Bay of Plenty	334.1	33.5	11.29	2389	66	200	8.9	3.9
Okataina	Bay of Plenty	1072.8	78.5	14.09	5957	87	118	10.1	2.1
Rotoiti	Bay of Plenty	3369.1	126.0	5.57	62713	52	232	22.0	7.3
Rotoma	Bay of Plenty	1111.6	83.0	23.84	2866	72	133	5.5	1.2
Rotomahana	Bay of Plenty	902.3	125.0	15.26	8362	48	209	39.8	4.4
Tarawera	Bay of Plenty	4115.4	87.5	7.26	33589	75	110	13.7	1.6
Taupo	Waikato	61264.5	162.8	11.81	343200	58	85	5.5	1.0
Tikitapu	Bay of Plenty	144.2	27.5	13.11	464	81	237	8.3	2.1

3.2. Establishing bands and thresholds for the EI components

3.2.1. Independent measures of EI

Two independent measures of EI have been used for calibrating lake and catchment metrics.

For shallow lakes, these are (1) an independent expert assessment based on site visits (Drake et al. 2011), and (2) the measure of the percentage of the lake's catchment that is in native vegetation. The expert assessments of the shallow lakes involved ranking the lakes for ecological integrity independently by three experts and then calculating the average rank. The rankings produced by the three assessors were highly correlated ($r^2 > 0.80$). The average rank was then standardised to a scale of 0 to 100, with a score of 100 representing the best condition of ecological integrity. The percent of the catchment in native vegetation is a measure which is already scaled from 0 to 100%. The catchment native vegetation measure was included because the removal of native vegetation in a catchment was considered to reflect the major anthropogenic pressures on lakes. It is recognised that neither measure will fully capture the essence of EI and, while the two independent measures of shallow lake EI are significantly positively correlated ($r^2 = 0.57$; $n = 33$; $p < 0.0001$), the correlation is not high enough to justify using only one of the measures of EI.

For the deep lakes, two independent measures of EI were also used. Again, the percentage of the lake's catchment that is in native vegetation was used, but instead of an expert ranking of EI based on site visits, EI scores for the deep lakes were developed from a ranking derived using a statistical model based on 25 deep lakes (Özkundakci et al. 2014).

3.2.2. Deriving thresholds and value bands for EI

The NOF water quality guidelines (Ministry for the Environment 2014) classify lakes into four value bands: Excellent, Good, Fair and Unacceptable. In extending our analysis beyond water quality to include other metrics of EI, we elected to adopt a similar banding system. The NPS-FM encourages the setting of ecological health thresholds based on expert scientific advice and on community values. In the absence of community values to guide the setting of value bands and their thresholds for EI, we have set the value band thresholds to delineate each quartile of the two independent EI measures. In other words, Excellence is an EI score greater than 76 out of 100 (for expert assessed EI and for percent catchment in native vegetation), Good is a score between 51 and 75%, Fair is a score between 26 and 50% and Unacceptable is a score less than 25%.

3.2.3. Statistical calculation of metric thresholds and bands (calibration)

The process of statistically calculating the thresholds between value bands for each metric, was undertaken by first assessing whether there were clear relationships between lake/catchment metrics and the two EI measures. These relationships could be linear, curvilinear or data envelopes with upper or lower limits related to the EI independent measures. Schallenberg (in press) identified metrics associated with the EI components, nativeness, pristineness, diversity and resilience, in the shallow and deep lakes datasets, that showed some form of relationship with EI independent measures.

The metrics identified were calibrated in this study against the two independent measures of EI. Two approaches were initially used to derive the statistical metric thresholds that delineated the four value bands (Figure 2). One method was to simply split the lake data sets up into Excellent, Good, Fair and Unacceptable EI bands and then to statistically calculate the 95th percentile of the data distributions within these classes of lakes. This approach did not assume any particular type of statistical model to describe the relationships. One disadvantage of this method was that sometimes the 95th percentiles did not follow a monotonic trend with EI, due to the small datasets we were working with and apparent small differences in lake metric values between some adjacent EI bands.

The second approach used was to perform quantile regression analysis on the relationships to statistically model the 95th and 80th percentiles of the data distributions along the EI gradients. For this approach, a model (linear or exponential) was attributed to the relationships and the models were derived using iterative least absolute value curve fitting (http://statpages.info/nonlin.html), where the model parameters were optimised by iteratively fitting the model to the data until model stability was achieved. One disadvantage of this method is that sometimes the models did not fit the data without some bias along the EI gradient (e.g., see Figure 2).

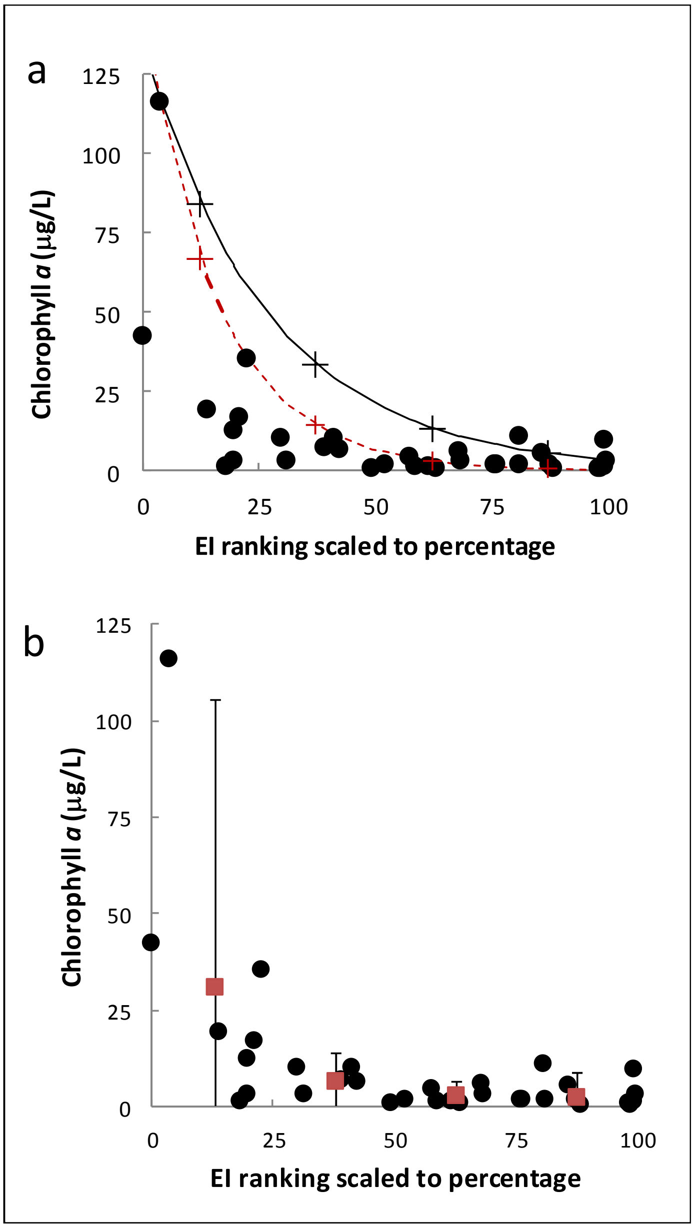

Figure 2. Calibration relationships between shallow lake chlorophyll-*a* and ecological integrity (EI) expert assessment rankings; (a) Calculated by assuming an exponential relationship, fitting non-linear 95% percentile (black) and 80th percentile (red) regression models using least-absolute-value curve fitting. Calculated 95th percentiles (black) and 80th percentiles (red) for the midpoint of the quartile ranges are indicated by the crosses. (b) Calculated by grouping lakes into EI quartiles and assessing 95% confidence intervals of the means of the lakes/data in each quartile. Circles represent the points from the shallow lake dataset.

The two calibration methods yielded similar results in the case of the relationship of shallow lake chlorophyll-*a* vs EI (Table 5). Note in Table 5 that the use of the grouping method resulted in band B (Good) having a lower 95th percentile for chlorophyll *a* than band A (Excellent). Note also that the model method tended to be biased toward lower chlorophyll *a* values for the lakes with the highest EI (Figure 2).

Table 5. Comparison of chlorophyll-*a* quartiles using the two methods.

Ecological integrity (EI) quartiles	Midpoint 95th Chl-*a* percentile (model method)	Midpoint 95th Chl-*a* percentile (grouping method)
76-100 (A)	1.6	6.1
51-75 (B)	5.8	3.9
26-50 (C)	20.7	7.5
0-25 (D)	74.0	74.4

After weighing up the limitations of the two methods, it was decided to use the model method and to calculate both 95th and 80th percentiles of the relationships. Using this method, it was observed that the 95th percentiles are more influenced by outliers in the data and by poor model fits than the 80th percentiles, which seem to provide more robust estimates of metric thresholds related to EI (Figure 3).

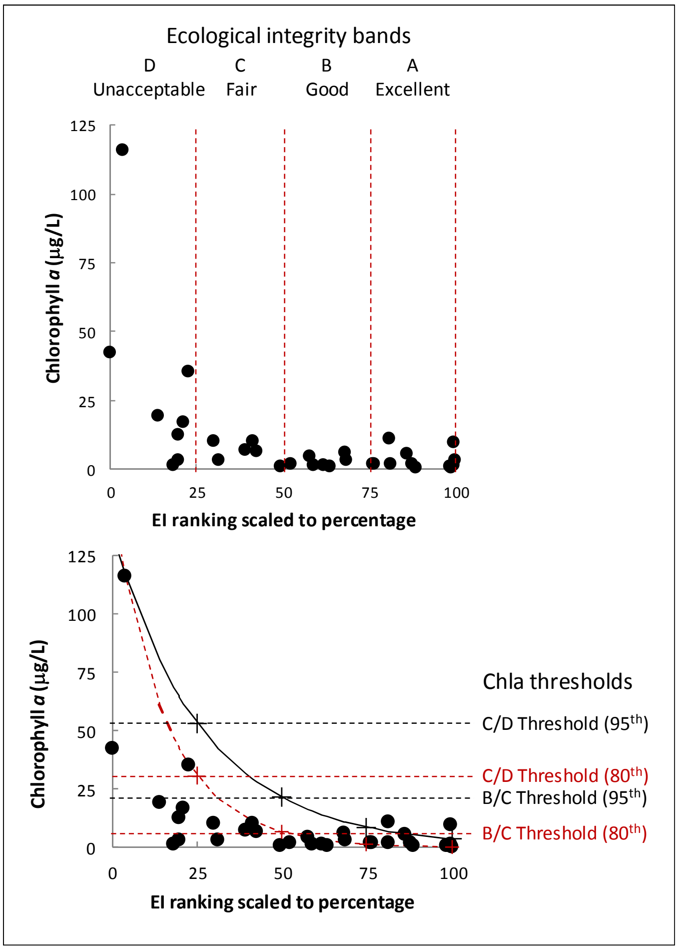

Figure 3. Illustration of the statistical calibration of metric (chlorophyll-*a*) thresholds to EI value bands using the model method (top) and fitting both 95th percentile and 80th percentile regressions to the data (bottom).

Ideally, to cover all aspects of freshwater EI, at least one metric representing each of the EI components (nativeness, pristineness, diversity and resilience) should be included for analysis. However, our analysis determined that for shallow lakes, no diversity metrics were related to EI measures. Similarly, for deep lakes no nativeness or resilience metrics were related to EI indicators. Therefore, no calibration could be undertaken with metrics from these EI components. To analyse catchment health as related to lake EI, three metrics of catchment health were examined: (1) the N and P yields from the catchments (kg/ha/y), (2) the areal N and P loads to the lakes (kg/ha/y) and 3) the modelled in-lake TN and TP concentrations (see Appendix 1). The catchment nutrient yields and the estimated in-lake nutrient concentrations showed some relationships to lake EI measures, whereas the lake areal N and P loads were generally not related to EI measures and were, therefore, dropped from further analysis of thresholds and bands.

In most cases, relationships between EI measures and lake/catchment metrics were negatively trending with diminishing variability among lakes with higher EI. In these cases, useful EI thresholds could be calculated from the 95th and 80th percentile models statistically fitted to the relationships. Conversely, where metrics, as well as the variation in the metrics among lakes increased with EI, the EI thresholds were calculated in the same way, but the utility of calculating such EI thresholds is limited because lakes/catchments with high EI also showed high variability in the metrics. In the case of nativeness metrics, the lower limit of relationships with EI showed a clear positive trend and in these cases EI thresholds were calculated based on the 5th and 20th percentile models which were statistically fitted to the relationships.

3.3. Scoring the Southland lakes into value bands

With the metric thresholds between value bands established, the recent data (Environment Southland lake monitoring data 2007–2013) from Southland lakes was used to place the lakes into bands for each metric. The calibrated value bands and metric thresholds are presented in Section 4 along with the scores of the Southland lakes relative to these bands. The value bands derived from both the expert EI assessment and the percent catchment in native vegetation are used for this purpose, i.e. two sets of bands are used. Where the bands differ for the same lake and metric, then some uncertainty exists due either to weak relationships between the lake metric and measures of EI or because the metric for the lake falls near a threshold.

3.4. Assessing lake catchment health

In the analysis of catchment health measures, modelled catchment N and P yields (per unit area of catchment) and the modelled in-lake TN and TP concentrations (Kelly et al. 2013a) were used as catchment health metrics. Modelling methods for calculating catchment metric scores are shown in Appendix 1.

3.5. Aggregating the scores for all of the metrics to derive an overall lake EI score

When the lakes/catchments have been given a score for each metric, the scores may be aggregated into an overall lake/catchment EI score. We aggregated the lake/catchment scores using two methods: (1) averaging the scores and (2) attributing the overall score as the minimum band obtained for that lake/catchment across all metrics (minimum aggregation). Averaging was accomplished by assigning a score of 1 for Unacceptable, 2 for Fair, 3 for Good and 4 for Excellent for each metric score and then by averaging the assigned numbers. The average number was then back transformed to yield an average EI score for each lake/catchment. The minimum aggregation method implies that all metrics must achieve a certain score for that score to be assigned to a lake/catchment. The averaging method allows some metrics to score lower if others score higher than the overall average.

4. CONDITION ASSESSMENT FOR SOUTHLAND'S LAKES

The conditions of Southland's shallow and deep lakes are calibrated against a national set of lakes for which comparable ecological integrity data sets were available. In this section of the report, the calibrations of the EI measures and value band assessments are first presented for the nationwide survey of shallow lakes and deep in-lake metrics. Then calibrations of shallow and deep lake catchment nutrient loads to lake EI are presented. Finally, Southland's lakes (shallow and deep) are scored in order to assess their EI condition for each of the in-lake and catchment components.

4.1 Shallow lake metrics (in-lake)

Three nativeness, four pristineness and two resilience metrics were calibrated against the two independent measures of EI (Table 6), providing a fairly good, but incomplete coverage of the four major EI components. No diversity metrics related to EI could be included in subsequent band calculations.

Table 6. The EI components assessed for shallow lakes and the metrics used to calibrate them to value bands based on the independent measures (EI expert opinion and percent of catchment in native vegetation). The pristineness metrics are measured in in-lake mid-to-late summer concentrations.

EI component	Metric
Nativeness	% of fish species that are native
	% of macrophyte species that are native
	% of native macrophyte cover
Pristineness	Chl-*a*
	In-lake Total N
	In-lake Total P
	Trophic Level Index[3]
Resilience	Nutrient Balance Index[4]
	Food chain length[5]

4.1.1. Nativeness

Figure 4 presents the value bands (coloured columns) calculated for the EI nativeness component, with the three metrics calibrated against both the expert assessment measure and the percent of native land cover measure, as well the average for these two independent measures. Also indicated is analysis of the relevant metric in the shallow Southland lakes (black columns).

[3] TLI3—including TN, TP and chlorophyll-*a* components according to Burns et al. (2000)
[4] Nutrient balance index was calculated as the ratio of LogDIN : LogTP and related to predicted nutrient limitation where DIN:TP ratios of > 4 indicate P limitation and DIN:TP 1-4 indicate co-limitation, and DIN:TP <1 indicate N limitation (Morris & Lewis 1988)
[5] Calculated as the number of trophic positions top predator was above baseline seston isotopic $\delta^{15}N$ values

Rather than showing linear, monotonic relationships, the plots of nativeness metrics versus EI measures revealed envelopes where the lower percentiles of nativeness showed linear relationships with measures of EI (see Appendix 2). This indicates that while lakes with high EI had high percent nativeness in species composition (fish and macrophytes), lakes with low EI showed a wide range of nativeness in species composition. Because the minimum percentiles were linear with EI, the quantile regression method worked well at identifying minimum thresholds for nativeness bands for fish and macrophyte communities (Figure 4, a-d). For percent native macrophyte cover, the relationship with expert-derived EI was subject to a less even distribution of data points and greater leverage (See Appendix 2, Figure A2.1), so the percentage catchment in native vegetation gave a more robust calibration (Figure 4, e-f).

The Southland lakes generally appeared in the Excellent and Good bands, reflecting high percentages of native fish and macrophyte species as well as macrophyte cover. The Reservoir had a lower percentage for native macrophyte species in the Fair band (Figure 4d) reflecting the dominance of the non-native, *Elodea canadensis*, which is also present in Lake Vincent, but is not dominant in that lake (Schallenberg & Kelly 2013). The Reservoir has also scored in the Fair band for the native macrophyte cover metric (Figure 4f).

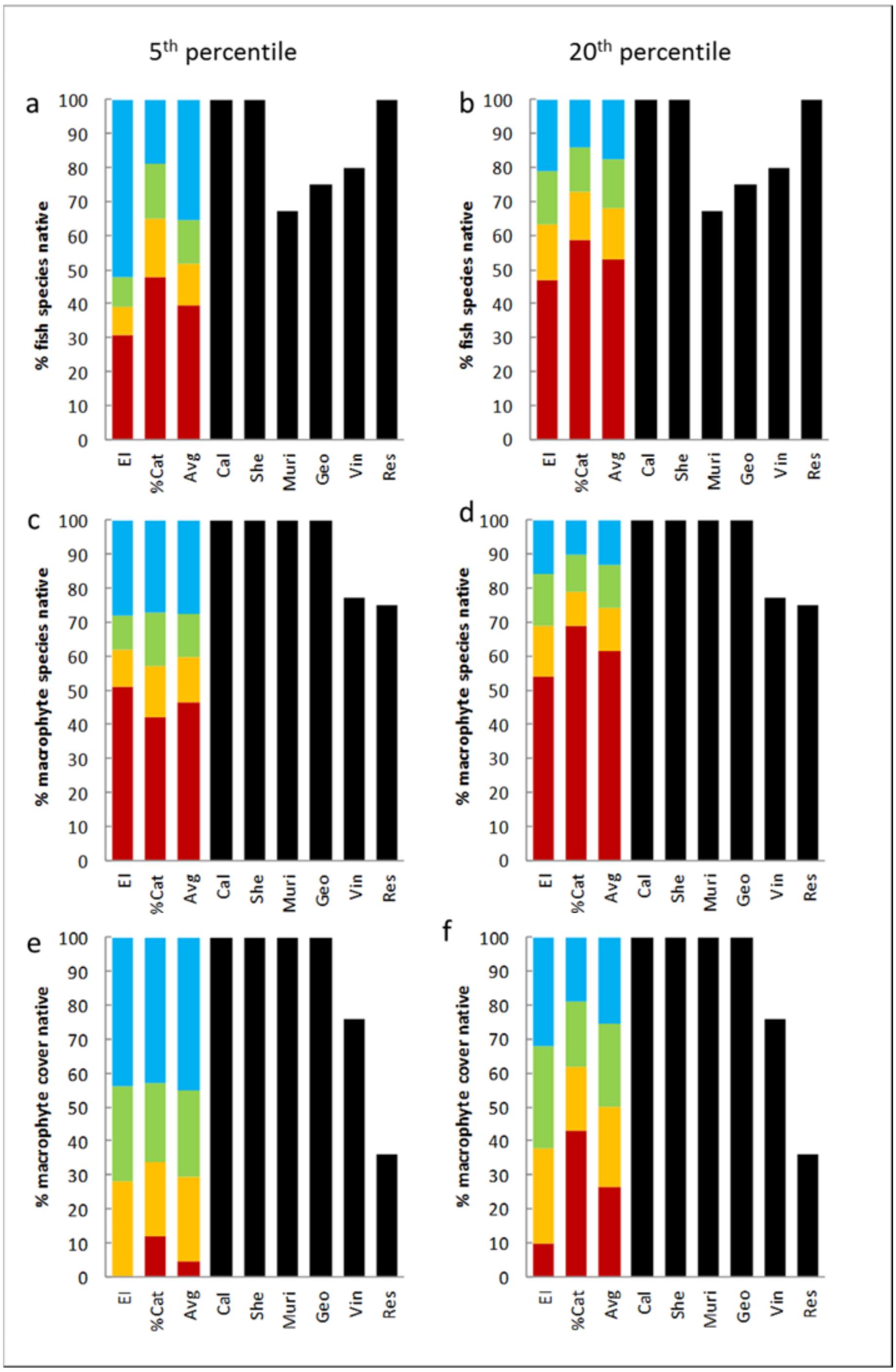

Figure 4. Ranges of shallow lake nativeness value bands for the three metrics calibrated against two measures of EI: EI expert assessment (EI) and percentage of catchment in native vegetation (%Cat). Average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 5th percentile and the 20th percentile of relationships between nativeness metrics and measures of EI are shown in the left and right hand panels, respectively. Black bars represent recent data from Southland lakes: Calder (Cal), Sheila (She), Murihiku (Mur), George (Geo), Vincent (Vin) and The Reservoir (Res), except fish species for George, Vincent and The Reservoir, which are from a 2004 survey (Drake et al. 2009).

4.1.2. Pristineness

Figure 5 presents the value bands (coloured columns) calculated for the EI pristineness component, with the four metrics calibrated against both the expert assessment measure and the % of native land cover measure, as well the average for these two independent measures. Also indicated is analysis of the relevant metric in the shallow Southland lakes (black columns).

The four pristineness metrics were all related to trophic status (Appendix 2, Figure A2.2). Southland's shallow lakes generally appear in the Excellent or Good value bands. These bands indicate that in a national context the lakes have low nutrient and Chl-*a* concentrations and hence have low Trophic Level Index scores. The exception to this is Lake Murihiku, which tended to fall in the Fair or Unacceptable value bands reflecting higher nutrient and Chl-*a* concentrations. These are reflected in the Unacceptable TLI score for this lake.

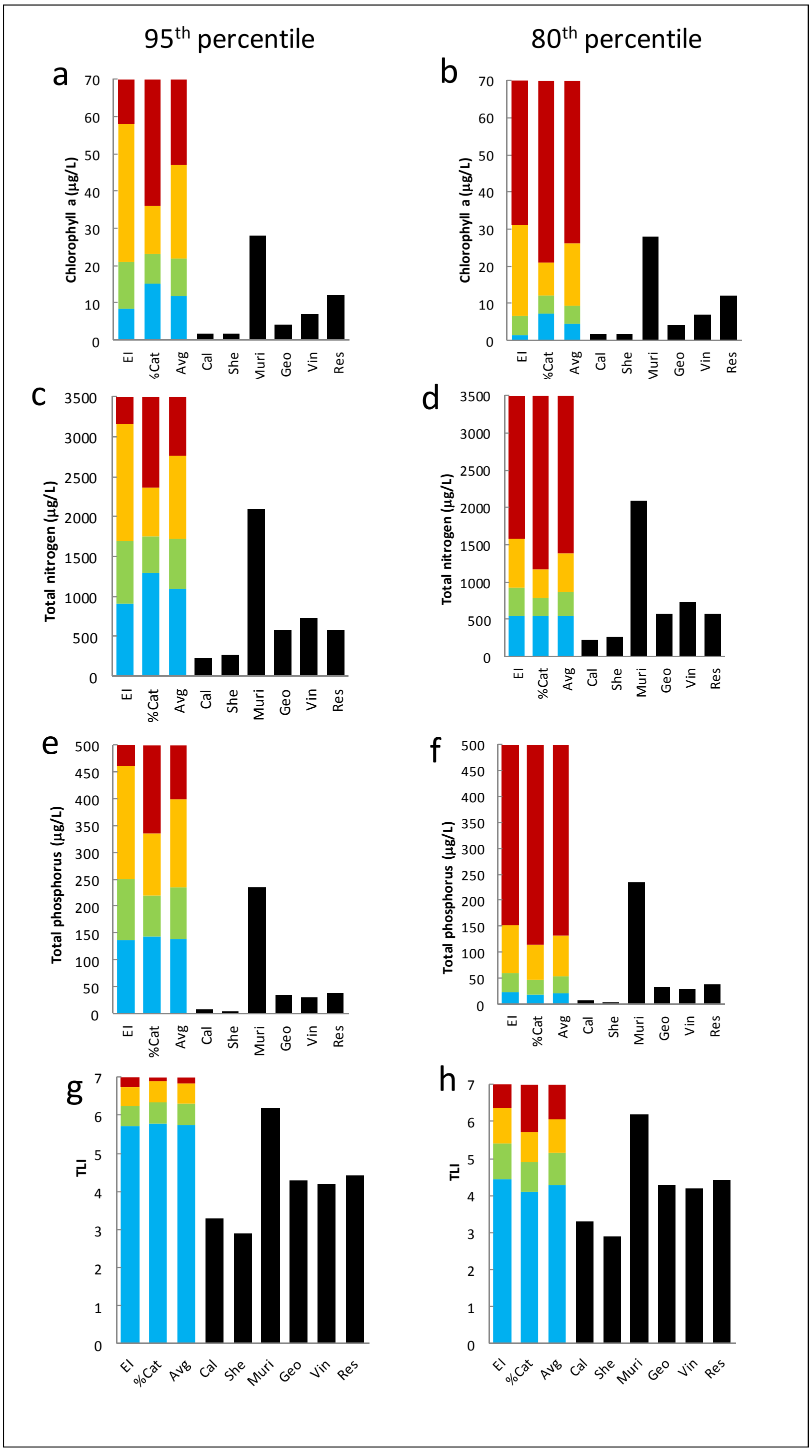

Figure 5. Ranges of shallow lake pristineness value bands for the four metrics calibrated against two measures of EI: EI expert assessment (EI) and percentage of catchment in native vegetation (%Cat). Average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 95th percentile and the 80th percentile of relationships between nativeness metrics and measures of EI are shown in the left and right hand panels, respectively. Black bars represent recent data (2007-2014 summer average) from Southland lakes: Calder (Cal), Sheila (She), Murihiku (Mur), George (Geo), Vincent (Vin) and The Reservoir (Res).

4.1.3. Diversity

None of the diversity metrics (fish, macrophytes, zooplankton, phytoplankton and benthic invertebrates) showed clear relationships to the independent measures of EI (Appendix 2, Figure A2.3). Therefore, the lakes could not be scored in relation to how their diversity contributes to EI.

4.1.4. Resilience

Figure 6 presents the value bands (coloured columns) calculated for the EI resilience component, with the two metrics calibrated against both the expert assessment measure and the percent of native land cover measure, as well the average for these two independent measures. Also indicated is analysis of the relevant metric in the shallow Southland lakes (black columns).

Two metrics of shallow lake resilience to anthropogenic pressures were weakly related to EI (Appendix 2, Figure A2.4). The nutrient balance index is a transformation of the absolute value of the ratio of dissolved inorganic nitrogen to total phosphorus in the water column. This metric indicates whether the ratio of available nitrogen to phosphorus in lakes is roughly in balance or is unbalanced (Morris & Lewis 1988). Unbalanced nutrient availability can indicate that either one nutrient is usually available in concentrations that saturate phytoplankton demand (meaning that this nutrient is in excess) and/or that the ratio of N:P could favour cyanobacterial blooms, potentially shifting the system into an undesirable, stable state. The food chain length indicates whether or not the system has higher-order predators, a characteristic which could confer instability to the system, due to variations in predator control of the food web, and hence phytoplankton biomass.

Unfortunately, the statistical relationships between these metrics and measures of EI were quite weak, resulting in a poor ability to differentiate bands of ecological integrity on this basis. Nevertheless, Southland's shallow lakes fall in the Excellent value band for both the Nutrient Balance Index and Food Chain Length (Figure 6). This indicates that the nutrients in the lakes are relatively balanced and that food chain lengths are relatively short, both suggesting that the lakes have some degree of resilience to anthropogenic pressures.

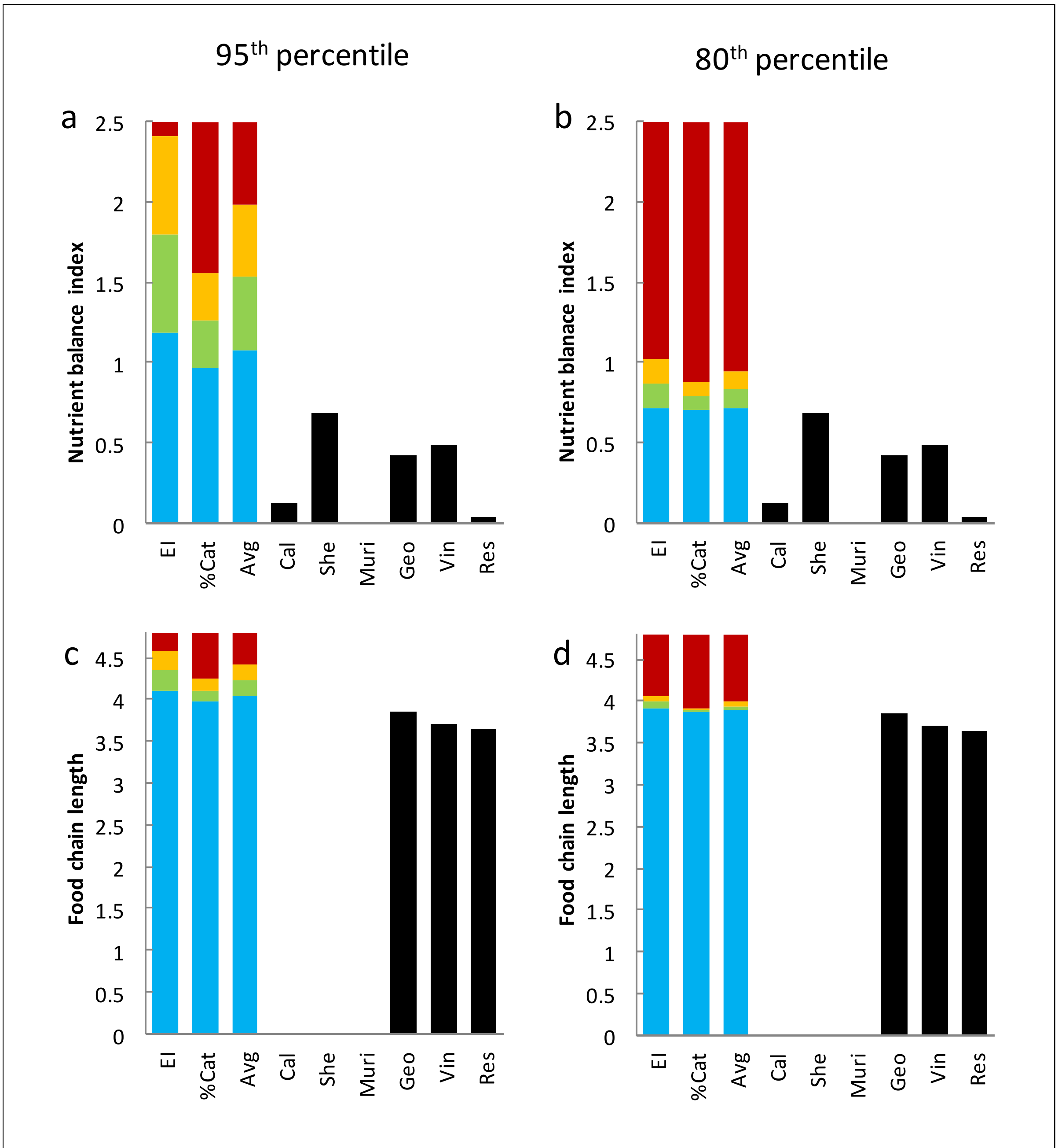

Figure 6. Ranges of shallow lake resilience value bands for the two metrics calibrated against two measures of EI: EI expert assessment (EI) and percentage of catchment in native vegetation (%Cat). Average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 95th percentile and the 80th percentile of relationships between nativeness metrics and measures of EI are shown in the left and right hand panels, respectively. Black bars represent recent data from Southland lakes: Calder (Cal), Sheila (She), Murihiku (Mur), George (Geo), Vincent (Vin) and The Reservoir (Res).

4.2. EI value bands and scores for shallow lakes

The analyses presented in Figures 4 through 6 yields thresholds and ranges of the metrics used to measure EI components for the different value bands. These are presented in Tables 7 (Nativeness and Pristineness) and 8 (Diversity and

Resilience). The tables also show some suggested bands based on other criteria, including the bands for pristineness metrics from the national objectives framework (Ministry for the Environment 2014). Where some metrics are generally accepted to confer EI (such as nativeness and diversity) and where no relationships with EI were observed in the data (e.g., diversity metrics), normative bands were arbitrarily allocated based on the quartiles of the ranges of these metrics observed in the New Zealand shallow lakes dataset.

Table 7. Ranges of shallow lake nativeness and pristineness metrics representing different lake ecological integrity (EI) value bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to expert EI assessment, and as calibrated to the percentage of native vegetation in the lake's catchment, derived from 80th (and 20th for nativeness) percentiles of the relationships between the metrics and ecological integrity (EI). The bands at the bottom of the table are derived from other sources such as a normative approach by which the ranges observed for the shallow lakes assessed in this report were evenly split into quartiles (Normative), as well as the NOF shallow lake guidelines (Ministry for the Environment 2014), and the Burns trophic level index (Burns et al. 2000).

	Nativeness	**Pristineness**					
	% native fish species	**% native macrophyte species**	**% native macrophyte cover**	**TN (µg/L)**	**TP (µg/L)**	**Chl-*a* (µg/L)**	**TLI**
Metric thresholds for EI Value bands as calibrated to the Independent Measures in this report							
Value Bands	**Calculated from expert EI assessments**						
A	>79%	>84%	>68%	≤542	≤22	<1.4	≤4.4
B	63-79%	69-84%	38-68%	542-926	22-58	1.4-6.4	4.4-5.3
C	47-62%	54-68%	10-37%	927-1587	59-151	6.5-30	5.4-6.4
D	<47%	<54%	<10%	>1586	>151	>31	>6.4
	Calculated from % catchment in native vegetation						
A	>86%	>90%	>81%	≤539	≤19	<7.3	≤4.1
B	73-85%	79-90%	62-81%	539-793	19-46	7.4-11	4.2-4.8
C	59-72%	69-78%	43-61%	794-1171	47-115	12-21	4.9-5.7
D	<59%	<69%	<43%	>1171	>115	>21	>5.7
Metric thresholds for EI Value bands from other sources							
Value Bands	**Normative***	**Normative***	**Normative***	**NOF (annual median)**	**NOF (annual median)**	**NOF (annual median/maximum)**	**Burns et al. (2000)**
A	>82%	>82%	>75%	≤300	≤10	<2 / <10	2-3 (oligotrophic)
B	64-81%	64-81%	51-75%	301-500	11-20	2-5 / 10-25	3-4 (mesotrophic)
C	46-63%	46-63%	26-50%	501-800	21-50	5-12 / 25-60	4-5 (eutrophic)
D	<46%	<46%	<25%	>800	>50	>12 / >60	5-6 (hypertrophic)

* bands were determined based on calculated quartiles of the range of native species richness observed in surveyed shallow lakes

Table 8. Ranges of shallow lake diversity and resilience metrics representing different lake ecological integrity (EI) bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to expert EI assessment, and as calibrated to the percentage of native vegetation in the lake's catchment, derived from 80th percentiles of the relationships between the metrics and ecological integrity (EI). NA = not applied due to lack of statistical relationship. The bands at the bottom of the table were derived from other sources such as a normative approach by which the ranges observed for the shallow lakes assessed in this report were evenly split into quartiles (Normative), as well as the NOF polymictic lake guidelines (Ministry for the Environment 2014),

	Diversity			**Resilience**		
	Native fish taxonomic richness	**Native macrophyte taxonomic richness**	**Benthic invertebrate taxonomic richness**	**Cyanobacteria (cell counts per mL)**	**Food chain length ($\delta^{15}N$ units)**	**Absolute value of log(DIN:TP)**
Metric thresholds for EI Value bands as calibrated to the Independent Measures in this report						
Value Band	**Calculated from expert EI assessments**					
A	N/A	N/A	N/A		≤3.9	≤0.72
B	N/A	N/A	N/A		3.9-4.0	0.72-0.86
C	N/A	N/A	N/A		4.0-4.1	0.87-1.02
D	N/A	N/A	N/A		>4.1	>1.02
	Calculated from catchment native vegetation					
A	N/A	N/A	N/A			≤0.70
B	N/A	N/A	N/A			0.70-0.78
C	N/A	N/A	N/A			0.79-0.88
D	N/A	N/A	N/A			>0.88
Metric thresholds for EI Value bands from other sources						
Value Band	**Normative***	**Normative***	**Normative***	**NOF (80th percentile)**		
A	>4	>8	>25	≤500	N/A	N/A
B	3	5-7	17-24	N/A	N/A	N/A
C	2	3-5	9-16	N/A	N/A	N/A
D	<2	<3	<9	N/A		

* bands were determined based on calculated quartiles of the range of native species richness observed in surveyed shallow lakes. EI was assumed to increase with increasing diversity.

4.2.1. Trends over time

For a number of the EI metrics, data exist for multiple years although the data is patchy and incomplete. The data for Lake George (Table 9), Lake Vincent (Table 10) and The Reservoir (Table 11) are presented, allowing a comparison of the lakes' EI performance over time.

Lake George generally retained scores in the Excellent or Good value bands (bands A-B) for the nativeness metrics indicating the percentage of native species (fish and macrophytes) and native macrophyte cover have been consistently high relative to shallow lakes nationally (Table 9). Pristineness metrics over the timeframe presented in Table 9 score in lower value bands with total phosphorus, generally scoring in the Fair value band (band C), indicating relatively high total phosphorus concentrations, while both total nitrogen and chlorophyll-*a*, were highly variable between the years 2000 and 2013.

Table 9. Ecological metric values and metric EI bands (in brackets) for Lake George based on data collected over time. Bands were determined using the 80th or 20th percentiles from calibrations using the two Independent Measures of ecological integrity (EI): 1. Expert assessment, and 2. the percentage catchment in native vegetation, as described in Section 3.3. The pristineness metrics are measured late summer concentrations.

Component/Metric	Year				
	2000	2004	2012	2013	Average*
Nativeness					
% macrophyte species native			100 (A)	100 (A)	
% macrophyte cover native			100 (A)	100 (A)	
% fish species native		67 (B/C)			
Pristineness					
Total nitrogen (µg/L)	1100 (C)	434 (A)	1395 (C)	434 (A)	577 (B)
Total phosphorus (µg/L)	74 (C)	27 (B)	111 (C)	32.5 (C)	34.5 (C)
Chl-*a* (µg/L)		6 (B)	17 (C)	2.2 (A)	4.1 (B)
TLI		4.8 (B)	4.9 (B)	3.3 (A)	
Resilience					
Nutrient Balance Index		0.4 (A)	0.18 (A)	1.48 (D)	0.32 (A)

* average summer values from Environment Southland data from 2007-2013.

Lake Vincent generally retained scores in the Excellent and Good value bands (A-B) (Table 10). The exception to this was for the percent of macrophyte species which are native, which declined between 2012 and 2013 to score in the Fair to Unacceptable bands (bands C-D) related to the encroachment of exotic weeds (predominantly *Elodea canadensis*). Scores for the chlorophyll-*a* metric have improved post-2000 from the Fair value band (band C) to Excellent to Good bands (bands A-B). The nutrient balance index has scored in the Unacceptable band (band D) in 2004 and 2012 indicating an imbalance in nutrient concentrations, however this has improved to score in the Good/Fair band in 2013.

Table 10. Ecological metric values and metric EI bands for Lake Vincent based on data collected over time. Bands were determined using the 80th or 20th percentiles from calibrations using two measures of ecological integrity (EI): (1) Expert assessment and (2) the percentage catchment in native vegetation, as described in Section 3.3.

Component/Metric	Year				
	2000	2004	2012	2013	Average*
Nativeness					
% macrophyte species native			86 (B)	67 (C)	
% macrophyte cover native			77 (A)	75 (B)	
% fish species native		80 (B)			
Pristineness					
Total nitrogen (µg/L)	662 (B)	563 (B)	670 (B)	515 (A)	718 (B)
Total phosphorus (µg/L)	26 (B)	15 (A)	19 (B)	22.5 (B)	28.5 (B)
Chl a (µg/L)	13 (C)	1 (A)	1.5 (A)	0.4 (A)	7.06 (B)
TLI		3.8 (A)	3.9 (A)	3.3 (A)	
Resilience					
Nutrient Balance Index		3 (D)	3.29 (D)	0.84 (B)	0.69 (A)

* average summer values from Environment Southland 2007-2013

The Reservoir EI metric scores were generally in the Good to Fair value bands (bands B-C) over the time period for which data are available, reflecting moderate EI relative to shallow lakes nationally (Table 11). The change between 2012 and 2013 were mixed for the nativeness metrics, with the percentage of native macrophyte species declining from Excellent-Good (bands A-B) to Fair-Unacceptable (bands C-D), but their cover increasing from Fair-Unacceptable (bands C-D) to Good-Fair (bands B-C. The pristineness metrics appeared relatively steady between 2000 and 2012 with improvements between 2012 and 2013. The Resilience metric (Nutrient Balance Index) improved between 2004 and 2013

Table 11. Ecological indicator values and bands for The Reservoir based on data collected over time. Bands were determined using the 80th percentile from calibrations using two measures of ecological integrity (EI): (1) Expert assessment and (2) the percentage catchment in native vegetation, as described in Section 3.3.

Component/Metric	Year				
	2000	**2004**	**2012**	**2013**	**Average***
Nativeness					
% macrophyte species native			83 (B)	67 (C)	
% macrophyte cover native			19 (D)	53 (B)	
% fish species native		100 (A)			
Pristineness					
Total nitrogen (µg/L)	925 (C)	615 (B)	630 (B)	535 (A)	578 (B)
Total phosphorus (µg/L 3)	46 (B)	21 (B)	36 (B)	38.8 (B)	39.1 (B)
Chl a (µg/L)	5 (B)	10 (C)	20 (C)	2.5 (A)	12.9 (C)
TLI		4.7 (B)	5.1 (C)	4.3 (B)	
Resilience					
Nutrient Balance Index		0.9 (C)	0.39 (A)	0.14 (A)	0.2 (A)

* average summer values from Environment Southland data from 2007-2013

4.3. Deep lakes

In the deep lakes national dataset, four pristineness and two diversity metrics (Table 12) were calibrated against the two independent measures of EI: (1) EI score from Özkundakci et al. (2014), and (2) percent of catchment in native vegetation). The metrics of nativeness and resilience did not show relationships with the independent measures of EI and hence were not used for calibrating the deep lakes dataset.

Table 12. The EI components assessed for deep lakes and the metrics used to calibrate them to the value bands based on the independent measures (EI score from Özkundakci et al. (2014), and percent of catchment in native vegetation). The pristineness metrics are measured in-lake mean concentrations from the period 2004-2006.

EI component	Metric
Pristineness	In-lake Total N
	In-lake Total P
	Chl-*a*
	Maximum macrophyte depth limit
Diversity	Rotifer species richness
	Phytoplankton species richness

4.3.1. Pristineness

The four pristineness metrics related to the two measures of EI are presented in Table 14. These are all related to aspects of lake trophic state (Burns et al. 2000), except the maximum macrophyte depth limit which may still reflect trophic state but is not used in the calculation of a Trophic Level Index. In general, the independent measure of the score of EI from Özkundakci et al. (2014), related much more closely to pristineness metrics than did the percentage of the catchment in native vegetation. This resulted in consistent discrepancies in the band thresholds calibrated against the two measures of EI and indicated that the bands derived from the EI score from Özkundakci et al. (2014) are more robust.

Figure 7 presents the value bands (coloured columns) calculated for the EI pristineness component, with the four metrics calibrated against both independent measures; the EI score from Özkundakci et al (2014), and the percent of native land cover. The average for these two independent measures is also presented, as is analysis of the relevant metric in the two deep Southland lakes (black columns).

In general, the scores for Lakes Te Anau and Manapouri fall within the Excellent and Good bands, reflecting low nutrient and Chl-*a* concentrations and consequent low trophic status, relative to deep lakes nationwide. An exception to this is the maximum macrophyte depth limit, which is scored as Unacceptable for both lakes (Figure 7). The relationship between this metric of water clarity and EI, while positive in trend, showed the widest range of variation among lakes with high EI. This is partly due to natural humic acids (coloured dissolved organic matter—CDOM) which contributed to light attenuation in waters and is derived from runoff from extensive beech forest vegetation in the catchments (Vant & Davies-Colley 1984), as compared to most other deep lakes in the dataset. The humic acids absorb light and limit light penetration, restricting macrophytes to shallower waters in these lakes. Thus, the Unacceptable scoring is related to a natural factor in the lake water and highlights a limitation of our analysis caused by the small number and low diversity of big, deep lakes in our dataset. The nature of the relationship between maximum macrophyte depth limit and EI indicates that this metric can be useful for distinguishing degraded lakes (which tended to have shallow depth limits), but is not useful for distinguishing lakes with high EI, which showed a wide range of depth limits.

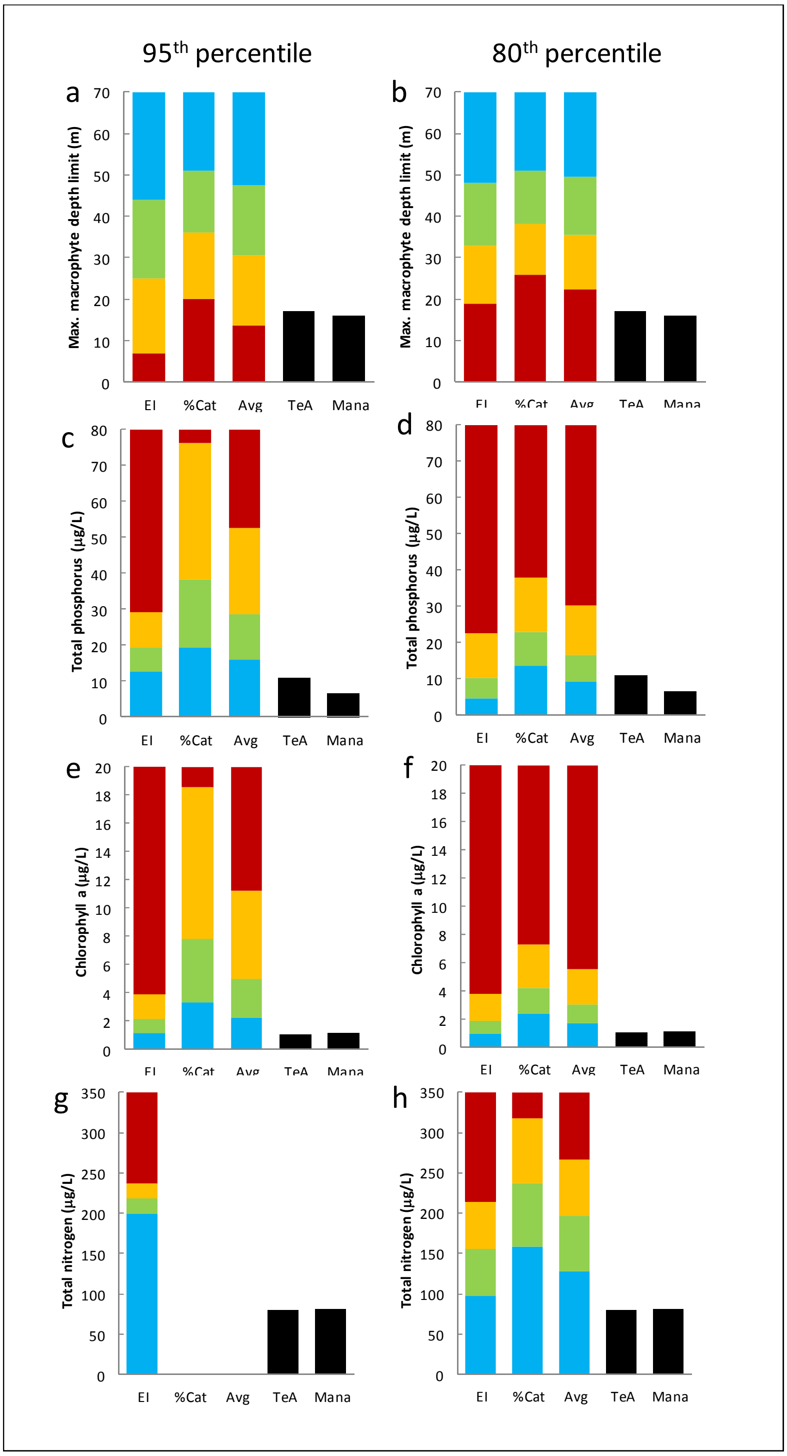

Figure 7. Ranges of deep lake pristineness value bands for the four metrics calibrated against two independent measures of EI: EI score from Özkundakci et al. 2014 (EI) and percentage of catchment in native vegetation (%Cat). Average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 95th percentile and the 80th percentile of relationships between pristineness metrics and measures of EI are shown in the left and right hand panels, respectively. The maximum macrophyte depth limit, while positively related to measures of EI, is of limited utility for setting thresholds because variation in depth limits increased with EI in the dataset (see text). Black bars represent recent data from Southland lakes: Te Anau (TeA) and Manapouri (Mana). In panel g, total nitrogen only showed a clear relationship with EI.

4.3.2. Diversity

Figure 8 presents the value bands (coloured columns) calculated for the EI diversity component, with the two metrics calibrated against the independent measure of the EI score from Özkundakci et al. (2014). No clear relationships between diversity metrics and percent of the catchment in native vegetation were found.

Two diversity metrics were related to the measure of EI: rotifer species richness and phytoplankton species richness. In both cases, higher richness was indicative of reduced EI in the deep lakes. Data for the deep Southland lakes was only available for the rotifer species richness metric (black columns in Figure 13).

In general the two deep Southland lakes scored in the Excellent value band for rotifer species richness reflecting relatively low species diversity.

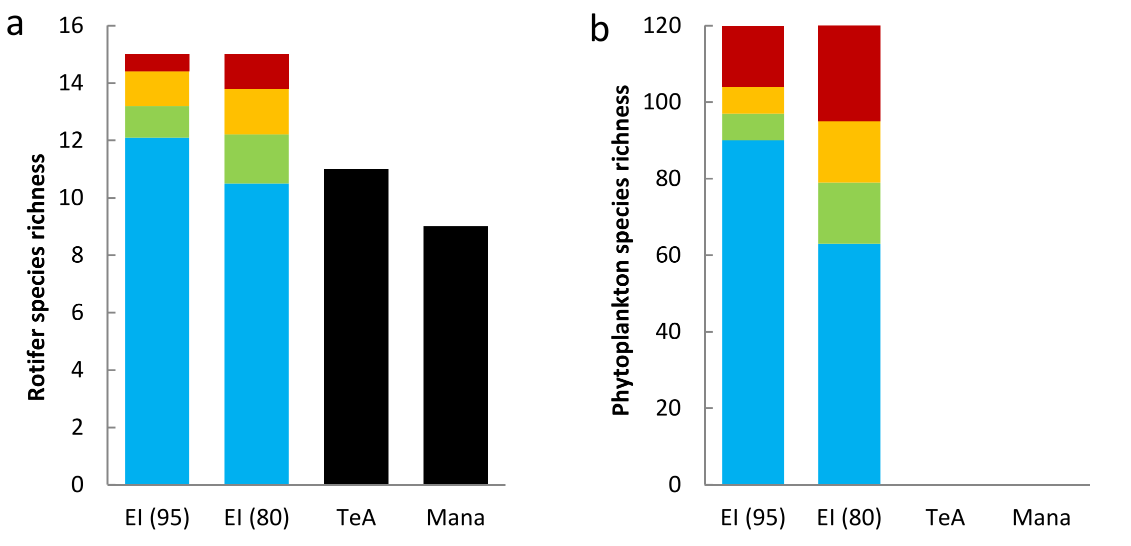

Figure 8. Ranges of deep lake diversity value bands for the two metrics calibrated against EI score from Özkundakci et al. 2013. Bands calculated based on the 95th percentile and the 80th percentile of relationships between diversity metrics and EI are shown. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Black bars represent recent data from Southland lakes: Te Anau (TeA) and Manapouri (Mana).

4.3.3. Nativeness

None of the nativeness metrics tested (the ratio of native to non-native fish species, the number of native fish species, the number of native macrophyte species, a native macrophyte diversity score and a native macrophyte condition index) were related to measures of EI in the deep lake dataset (Schallenberg in press) and hence these were not used in the EI assessment of the deep lakes.

4.3.4. Resilience

The nutrient balance index (related to the ratio of dissolved inorganic nitrogen to total phosphorus) was the only resilience metric tested, and it was not related to either of the two measures of deep lake EI.

4.4. EI value bands for deep lakes

The analyses presented in Figures 7 and 8 produced thresholds and ranges of the metrics used to measure EI components for the different value bands. These are presented in Tables 13 (Pristineness) and 14 (Diversity). The tables also show some suggested bands for all four EI components based on other criteria, including the bands for pristineness metrics from the National Objectives Framework (Ministry for the Environment 2014). Nativeness and diversity are generally accepted to confer EI. Although no relationships with EI were observed in the data, normative bands can be arbitrarily allocated based on the quartiles of the ranges of these metrics observed in the New Zealand deep lakes dataset.

Table 13 Ranges of deep lake nativeness and pristineness metrics representing different lake ecological integrity (EI) bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to EI scores from Özkundakci et al. (2014), and as calibrated to the percentage of native vegetation in the lake's catchment, derived from 80th (and 20th for nativeness) percentiles of the relationships between the metrics and ecological integrity (EI). NA = not applied due to lack of statistical relationship. The bands at the bottom of the table are derived from other sources such as the NOF guidelines for stratifying lakes (Ministry for the Environment 2014) and a normative approach by which the ranges observed for the 17 deep lakes were evenly split into quartiles (Normative).

	Nativeness		Pristineness			
	% native fish species	% native macrophyte species	TN (µg/L)	TP (µg/L)	Chl-*a*	Maximum macrophyte depth (m)[1]
Metric thresholds for EI Value bands as calibrated to the Independent measures in this report						
Value Bands	**Calculated from EI score from Özkundakci et al. (2014)**					
A	N/A	N/A	≤97	≤4.6	<1.0	>51
B	N/A	N/A	98-156	4.7-10	1.1-1.9	37-51
C	N/A	N/A	157-214	11-22.5	2-3.80	22-37
D	N/A	N/A	>214	>23	>3.8	<22
	Calculated from percentage of catchment in native vegetation					
A	N/A	N/A	≤158	≤14	<2.4	>44
B	N/A	N/A	159-238	15-23	2.5-4.2	32-44
C	N/A	N/A	239-318	24-38	4.3-7.3	19-32
D	N/A	N/A	>318	>38	>7.3	<19

Metric thresholds for EI Value bands from other sources						
Value Bands	**Normative[2]**	**Normative[2]**	**NOF (annual median)**	**NOF (annual median)**	**NOF (annual median/maximum)**	**N/A**
A	>84	>88	≤160	≤10	<2 / <10	N/A
B	66-83	76-88	161-350	11-20	2-5 / 10-25	N/A
C	50-65	63-75	351-750	21-50	5-12 / 25-60	N/A
D	<50	<62	>750	>50	>12 / >60	N/A

[1] bands are of limited utility (see text).

[2] bands were determined based on calculated quartiles of the range of native species richness observed in 17 deep lakes surveyed.

Table 14. Ranges of deep lake diversity indicators representing different lake ecological integrity (EI) bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to EI scores from Özkundakci et al. (2014), and as calibrated to the percentage of native vegetation in the lake's catchment, derived from 80th percentiles of the relationships between the metrics and ecological integrity (EI). NA = not applied due to lack of statistical relationship. The bands at the bottom of the table are derived from a normative approach by which the ranges observed for the 17 deep lakes were evenly split into quartiles (Normative). No relationships between resilience metrics and EI measures were observed.

	Diversity					Resilience
	Rotifer taxonomic richness	Phytoplankton taxonomic richness	Benthic invertebrate taxonomic richness	Macrophyte taxonomic richness	Fish taxonomic richness	N/A
Metric thresholds for EI Value bands as calibrated to the Independent measures in this report						
Value Bands	**Calculated from EI score from Özkundakci et al. (2014)**					
A	<10	<63	N/A	N/A	N/A	N/A
B	11-12	64-79	N/A	N/A	N/A	N/A
C	13-14	80-95	N/A	N/A	N/A	N/A
D	>14	>95	N/A	N/A	N/A	N/A
	Calculated from percentage of catchment in native vegetation					
A	N/A	N/A	N/A	N/A	N/A	N/A
B	N/A	N/A	N/A	N/A	N/A	N/A
C	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A

Metric thresholds for EI Value bands from other sources						
Value Bands	**Normative***	**Normative***	**Normative***	**Normative***	**Normative***	N/A
A	>14	>86	>62	>22	>7	N/A
B	10-14	60-86	43-62	16-22	5-6	N/A
C	6-9	33-59	22-42	10-15	3-4	N/A
D	<6	<33	<21	<10	<2	N/A

* bands were determined based on calculated quartiles of the range of native species richness observed in 17 deep lakes surveyed.

4.5. Catchments

In general, relationships between modelled catchment nutrient loss metrics and the Independent Measures of lake EI were weak or non-existent (See Appendix 3, Figures A3.1, A3.3). However some metrics were able to be related to lake EI measures and these are discussed below for the shallow and deep lakes.

4.5.1. Shallow lakes

The only two shallow lake catchment metrics that were related to measures of EI were the modelled in-lake TN and TP concentrations (Appendix 3, Figure A3.1, A3.2). These were derived from catchment nutrient loads estimated from the CLUES model as described in Section 3.1.3. The calculation of modelled in-lake concentrations allowed a comparison with measured in-lake concentrations, and the modelled concentrations were found to be similar on average, but ranged from 96% lower to 186% higher than the measured concentrations for TN and from 98% lower to 658% higher for TP concentrations (Appendix 3, Figure A3.5). In regards to the TP

Vollenweider model predictions, there was an obvious trend for lakes with very high nutrient status to be under-predicted by catchment loads, particularly for TP. It is probable that internal loading sources could account for significant amounts of this additional in-lake P, and to a lesser extent TN. The only Southland lake with such under-prediction was Lake Murihiku, but other lakes included Lakes Papaitonga, Tuakitoto, and Runanga, all of which are likely to experience significant internal loads. For the other Southland lakes Vollenweider predictions were closer to the 1:1 line of predicted versus measured, with 77% of the variance of in-lake TP and 53% of in-lake TN explained by the predicted Vollenweider functions from CLUES. Overall the CLUES-based Vollenweider model made reasonable predictions of in-lake nutrient status, but was clearly less accurate for lakes with very high TP status lakes.

Keeping these limitations in mind, Figure 9 presents the value bands (coloured columns) calculated for the two metrics calibrated against both the expert assessment measure and the percent of native land cover measure, as well the average for these two independent measures. Also indicated, is the metric found to be relevant for the shallow Southland lakes (black columns).

The catchments of Southland's shallow lakes generally score in the Excellent or Good value bands, indicating low in-lake nutrient concentrations as calculated by CLUES modelling and Vollenweider calculations. The catchments of Lake George and to a lesser degree The Reservoir approached the Fair value band for the modelled lake TP metric based on the 80th percentile data (Figure. 9) indicating higher in-lake total phosphorus concentrations.

The analyses presented in Figure 9 produced thresholds and ranges of the two metrics used to measure EI components for the different value bands. These are presented in Table 15.

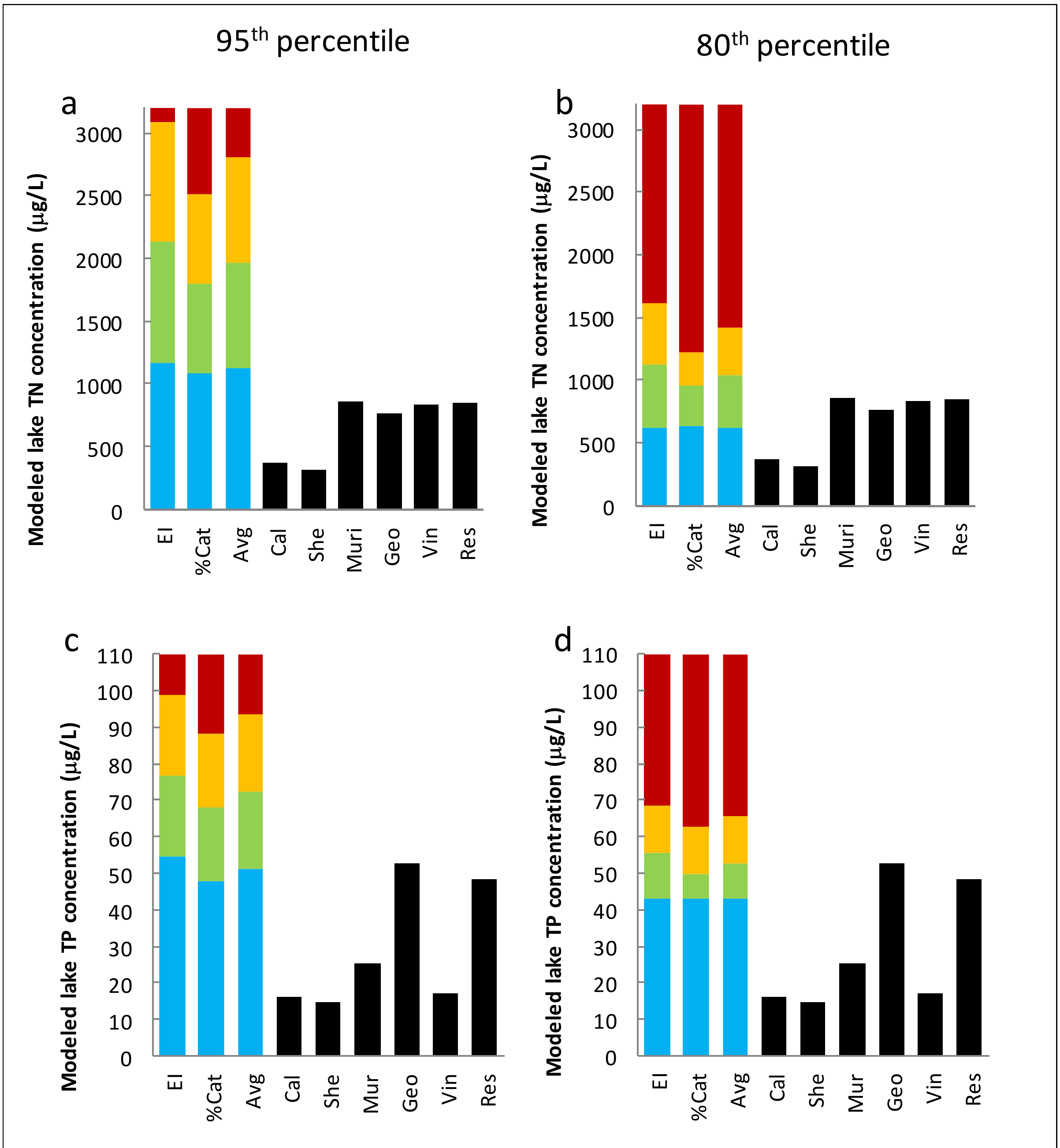

Figure 9. Ranges of catchment value bands for metrics calibrated against two measures of EI: EI expert assessment (EI) and percentage of catchment in native vegetation (%Cat). Average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 95th percentile and the 80th percentile of relationships between nativeness metrics and measures of EI are shown in the left and right hand panels, respectively. Black bars represent recent data from Southland lakes: Calder (Cal), Sheila (She), Murihiku (Mur), George (Geo), Vincent (Vin) and The Reservoir (Res).

Table 15. Ranges of catchment metrics related to different shallow lake ecological integrity (EI) value bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to expert EI assessment, and as calibrated to the percentage of native vegetation in the lake's catchment. Thresholds and bands are based on analysis of the 80th percentiles of the metric vs EI Independent Measure relationships.

	Metric thresholds for the EI value bands	
	Modelled in-lake TN concentration (mg/L)	**Modelled in-lake TP concentration (mg/L)**
Value Bands	**Calculated from expert EI assessments**	
A	<624	<43
B	624-1121	43-56
C	1122-1618	57-68
D	> 1618	> 68
	Calculated from percentage of catchment in native vegetation	
A	<630	<43
B	630-954	43-50
C	955-1217	51-63
D	> 1217	> 63

4.5.2. Deep lakes

Three deep lake catchment metrics were related to measures of EI: catchment nitrogen yield, catchment phosphorus yield and the modelled in-lake total nitrogen concentrations (Appendix 3, Figure A3.3). For the deep lakes, the modelled in-lake concentrations overestimated measured lake nutrient concentrations by around 50% on average, with individual lakes ranging from 63% lower to 269% higher for TN and 79% lower to 661% higher for TP. This indicates that the CLUES model may not be accurately estimating catchment loads for these deep lakes and/or that the Vollenweider transformation, based also on water residence time, is not resulting in an accurate estimate of in-lake concentrations. It is also noteworthy that the relationship between CLUES catchment P yield and EI is positive for these lakes and that variation in P yield increases with EI, limiting the utility of this metric for scoring catchment in relation to EI.

While noting these limitations, Figure 10 presents the value bands (coloured columns) calculated for the three metrics calibrated against both the expert assessment measure and the percent of native land cover measure, as well the average for these two independent measures. Also indicated is analysis of the relevant metric in the shallow Southland lakes (black columns).

The catchments of Southland's deep lakes, Te Anau and Manapouri, score in the Excellent to Good value bands for the catchment N yield and modelled in-lake total nitrogen concentration metrics. This likely reflects low nutrient exports relative to deep lakes nationwide. However there was an unexpected positive relationship between EI and catchment P yield for the deep lakes data set, which raises questions in regards to the accuracy of CLUES model in predicting P yield for these lake catchments and the usefulness of this metric. For this P yield metric, the Southland deep lakes fell into the Unacceptable to Fair value bands (Figure 10).

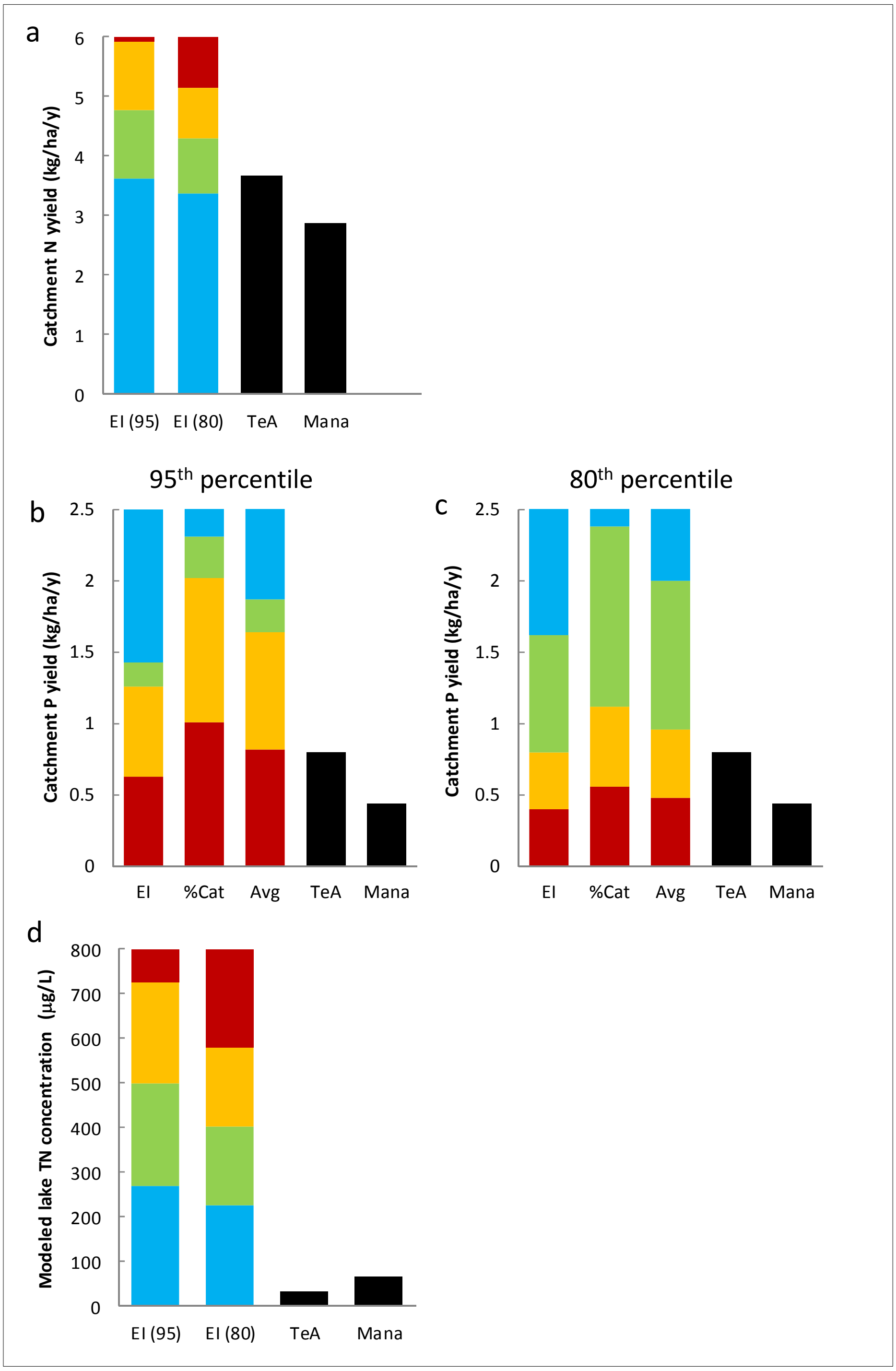

Figure 10. Ranges of deep lake catchment value bands for metrics calibrated against two measures of EI (panels b and c) and against only expert assessment of EI (panels a and d). In panels b and c, average (Avg) indicates the average of the two sets of bands. The ranges of four lake value bands are shown: Excellent (blue), Good (green), Fair (yellow) and Unacceptable (red). Bands calculated based on the 95th percentile and the 80th percentile of relationships between nativeness metrics and measures of EI are shown in b and c, respectively. In panels a and d, bands calculated based on the 95th and 80th percentiles are shown on the same graph. The catchment P yield was positively related to measures of EI and is therefore of limited utility for setting thresholds because variation in P yield increased with EI in the dataset (see text and Figure A3.3). Black bars represent recent data from Southland lakes: Te Anau (TeA) and Manapouri (Mana). The metrics only showed clear relationships with EI in panels a and d.

The analyses presented in Figure 10 produced the band ranges of the three metrics used to measure EI components for the different value bands. These are presented in Table 16.

Table 16. Ranges of catchment metrics related to different deep lake ecological integrity (EI) value bands. A = Excellent EI, B = Good EI, C= Fair EI, D= Unacceptable EI. Ranges are determined extrinsically, as calibrated to expert EI assessment, and as calibrated to the percentage of native vegetation in the lake's catchment. Thresholds and bands are based on analysis of the 80th percentiles of the metric vs EI relationships.

Metric thresholds for the EI value bands			
	Catchment N yield (kg/ha/y)	**Catchment P yield (kg/ha/y)***	**Modelled in-lake TN concentration (µg/L)**
Value Bands	**Calculated from expert EI assessments**		
A	<3.4	>1.7	<227
B	3.5-4.3	1.3-1.7	227-402
C	4.4-5.2	0.9-1.2	403-578
D	>5.2	<0.9	>578
	Calculated from percentage of catchment in native vegetation		
A	N/A	>1.2	N/A
B	N/A	0.7-1.2	N/A
C	N/A	0.1-0.6	N/A
D	N/A	<0.01	N/A

* bands are of limited utility (see text).

5. DISCUSSION AND RECOMMENDATIONS

5.1. Overall EI assessments for Southland lakes; aggregating lake/catchment scores

In our analysis, key metrics were selected to account for four different components of freshwater ecological integrity. The banding and scoring exercise undertaken in this investigation yielded EI scores for a number of in-lake and catchment metrics. The EI scores for a given lake/catchment can be aggregated in various ways to produce overall EI scores which may be useful for lake and catchment management. We aggregated the scores for Southland's shallow and deep lakes and their catchments in two ways: (1) average aggregation, where the overall score is an average of a lake's/catchment's metric scores and (2) minimum aggregation which sets the overall score by the minimum score achieved among all of a lake's or catchment's metrics.

Consideration by ES is also needed around the level of statistical precision for band calculations for each of the EI metrics, as the two levels of precision explored resulted in quite varied EI bands. The 95th percentiles are conservatively used to test hypotheses (for example, to set a probability for rejecting a hypothesis). Applying statistically modelled 95th percentile relationships in our datasets yielded results that could be strongly influenced by individual data points (e.g., apparent outliers). In contrast, 80th percentile relationships appeared to fit the overall trend of the data better and for this reason they may provide a more effective management tool as they resulted in a more even spread in the metric score ranges between the four bands. Thus, we chose to utilise the 80th percentile band ranges for evaluating the EI of the Southland lakes.

5.1.1. Shallow lakes and their catchments

A summary of the metric scores and aggregated EI value bands for Southland's shallow lakes is presented in Table 17. The Southland shallow lakes scored from Excellent to Fair depending on the type of aggregation used and, as expected, the average aggregation method produced higher EI scores than the minimum aggregation method, although only for one lake (The Reservoir) was this difference greater than half a value band.

The aggregated EI scores both fell within the Excellent band (band A) for the Stewart Island/Rakiura lakes (Lakes Calder and Sheila). Similarly the catchments of these lakes have aggregated EI scores in the Excellent value band. This reflects high scores for all EI components and metrics, relative to shallow lakes nationwide which span a range of human pressures. Native species, trophic level and resilience metrics are all high in these relatively undisturbed lake catchments.

The aggregated EI scores were lower for the four mainland shallow lakes which have higher human pressures on the catchments. Lakes Vincent and George had aggregated EI scores that fell in the Excellent to Good (bands A-B) or Good value band depending on the aggregation method used. These two lakes scored highly in terms of resilience but slightly lower in their nativeness and pristineness metrics. Hence these lakes seem to have good ecological integrity despite, in the case of Lake Vincent having the lowest proportion of the catchment in native vegetation and the highest proportion in pastoral cover (Table 3). Despite this the Lake Vincent catchment scored in the Excellent to Good value band in the relationship between catchment metrics and lake EI (Table 18). Lake Vincent may also be showing slight improvements in EI metrics (Section 4.2.1) although declines in the proportion of native macrophytes in 2013 warrants close attention.

The Reservoir has aggregated EI scores that fall in the Fair to Unacceptable (bands C-D) or Good value band depending on the aggregation method used. This illustrates the impact a single metric can have on the EI score when using the minimum aggregation method, in this case the dominance of an introduced macrophyte (*Elodea canadensis*) in the lake lowered the proportion of native macrophyte cover in the nativeness component. The aggregated EI score for The Reservoir was also lowered by a Fair score for Chl-*a* concentration. Hence The Reservoir appears to have moderate to poor ecological health relative to other shallow lakes nationwide. The lake's catchment scored in the Good value band in the relationship between catchment metrics and lake EI (Table 18).

Lake Murihiku has aggregated EI scores that fall in the Good to Fair (bands B-C) or Fair value band depending on the aggregation method used. The species-related (nativeness) metrics generally scored Excellent to Good, but the aggregated score was reduced by poor trophic level indicator metrics, particularly high modelled in-lake nutrient concentrations. Lake Murihiku's catchment is highly modified with low native vegetation cover and high pasture cover. However, the lake catchment scored in the Fair value band in the relationship between catchment metrics and lake EI (Table 18).

Table 17. Aggregation of the metric scores for Southland's shallow lakes to produce an overall EI score. Both average aggregation and minimum aggregation methods are presented.

	Calder	Sheila	Murihiku	George	Vincent	The Reservoir
Shallow lakes - nativeness						
Metric						
% fish species native	A (100)	A (100)	B (67)	B (75)	A/B (80)	A (100)
% macrophyte species native	A (100)	A (100)	A (100)	A (100)	A/B (89)	A/B (86)
% of macrophyte cover native	A (100)	A (100)	A (100)	A (100)	A/B (77)	C/D (19)
Nativeness average	**A**	**A**	**A**	**A**	**A/B**	**B/C**
Nativeness minimum	**A**	**A**	**B**	**B**	**A/B**	**C/D**
Shallow lakes – Pristineness						
Metric						
Chlorophyll-*a* (µg/L)	A (1.5)	A (1.5)	C/D (28)	A/B (4)	A/B (7)	C (12)
Total nitrogen (µg/L)	A (220)	A (265)	D (2093)	B (577)	B (718)	B (578)
Total phosphorus (µg/L)	A (6.5)	A (2)	D (235)	B (35)	B (29)	B (39)
TLI	A (3.3)	A (2.9)	C/D (6.2)	A/B (4.3)	A/B (4.2)	B (4.4)
Pristineness average	**A**	**A**	**D**	**B**	**B**	**B**
Pristineness minimum	**A**	**A**	**D**	**B**	**B**	**C**
Shallow lakes – Resilience						
Metrics						
Nutrient balance index	A (1.2)	A (0.7)	N/A	A (0.4)	A (0.5)	A (0.04)
Food chain length (µ^{15}N units)	N/A	N/A	N/A	A (3.9)	A (3.7)	A (3.7)
Resilience average	**A**	**A**	**N/A**	**A**	**A**	**A**
Resilience minimum	**A**	**A**	**N/A**	**A**	**A**	**A**
EI average	**A**	**A**	**B/C**	**A/B**	**A/B**	**B**
EI minimum	**A**	**A**	**C**	**B**	**B**	**C/D**

Table 18. Aggregation of the metric scores for Southland's shallow lakes catchments to produce an overall EI score. Both average aggregation and minimum aggregation methods are presented.

	Calder	Sheila	Murihiku	George	Vincent	The Reservoir
Metrics						
Modelled lake total nitrogen concentration (µg/L)	A (365)	A (318)	B (861)	B (757)	B (826)	B (850)
Modelled lake total phosphorus concentration (µg/L)	A (15.9)	A (14.7)	A (25.2)	B/C (52.8)	A (17.2)	B (48.2)
Catchment average	**A**	**A**	**A/B**	**B**	**A/B**	**B**
Catchment minimum	**A**	**A**	**B**	**B/C**	**B**	**B**

5.1.2. Deep lakes and their catchments

The EI metric scores for Lakes Te Anau and Manapouri scored in the Excellent to Good range (Table 11) and the catchments of these lakes also scored as Excellent to Good.

A summary of the metric scores and aggregated EI value bands for Southland's deep lakes is presented in Table 19 showing that the two aggregation methods for scoring the lakes placed the lakes in the Excellent to Good range (Table 19). The catchments of these lakes are also scored as Excellent to Good (Table 20). The average aggregation method indicates that both lakes scored in the Good value band, while for the minimum aggregation method both lakes scored in the Fair value band. This discrepancy is due to low metric scores for the maximum macrophyte depths. As discussed in Section 4.3.1 these low scores are due to a natural phenomenon of high native vegetation-derived CDOM concentrations limiting light penetration in the lakes. Hence the average aggregating method is to be preferred and even this will be decreased by the low macrophyte depth metric score. Apart from the maximum macrophyte depth limit, the lakes would be scored in the Excellent to Good range (Table 19). The catchments of these lakes are also scored as Excellent to Good (Table 20).

Table 19. Aggregation of the metric scores for Southland's deep lakes to produce an overall EI score. Both average aggregation and minimum aggregation methods are presented.

	Te Anau	Manapouri
Deep lakes - pristineness		
Metrics		
Chlorophyll-*a* (µg/L)	A (1.1)	A (1.1)
Total nitrogen (µg/L)	A (79)	A (81)
Total phosphorus (µg/L)	A (10.8)	B (6.7)
Maximum macrophyte depth (m)	N/A	N/A
Pristineness average	**A**	**A**
Pristineness minimum	**A**	**B**
Deep lakes - diversity		
Metrics		
Rotifer species richness	B (11)	A (9)
Phytoplankton species richness	N/A	N/A
Diversity score	**B**	**A**
EI average	**A**	**A**
EI minimum	**B**	**B**

Table 20. Aggregation of the metric scores for Southland's deep lake catchments to produce an overall EI score. Both average aggregation and minimum aggregation methods are presented

	Te Anau	Manapouri
Metrics		
Catchment nitrogen yield	B (3.66)	A (2.87)
Catchment phosphorus yield	N/A	N/A
Modelled lake total nitrogen concentration (µg/L)	A (32.6)	A (63.8)
Catchment average	**A/B**	**A**
Catchment minimum	**B**	**A**

5.2 Limitations

The process of assessing EI in Southland's lakes relative to a nationally calibrated framework of metric value bands has highlighted some limitations with both the approach and the available data.

Statistically significant relationships were not always apparent between some of the metrics and the EI independent measures. Because of this, some metrics were not included in the calculation of bands and this resulted in some of the EI components not being represented in the analysis (e.g. the diversity component was not represented in the shallow lake analysis while the nativeness and resilience components were not represented in the deep lake analysis). Given the potential impact of individual EI component scores on the final aggregated EI scores, these 'missing' components and metrics may limit the potential for comparing lake EI bands in future monitoring should they include some of the metrics/components not included in this study.

The EI framework used in this study was developed by the Department of Conservation and, therefore, reflected the department's priorities. The EI framework could easily be adapted by regional councils after careful consideration of the applicability and relevance of the different EI components and metrics focused on in the current EI framework to regional council policies and plans. Ideally the existing framework could be refined to better address regional values by soliciting community/iwi involvement in the process.

The bulk of the data set used in this study was collected from mid-to-late summer so as to provide a consistent snapshot of ecological state during the summer and to ensure that the timing of data collection was consistent between lakes. So comparisons with other data sets should also focus on data collected from mid-to-late summer. For example, it is possible that the pristineness metrics, largely consisting on the TLI components, could vary throughout the year, whereas other biological metrics (such as nativeness and diversity) could be relatively more stable over an annual cycle and also over longer time frames (e.g. Talbot and Ward 1987; Kelly & Hawes 2005).

The deep lake analysis highlighted a potential issue related to water clarity, where natural factors affecting some lakes may mask water clarity responses due to human pressures or catchment modifications. Thus, where natural variability is high, those metrics may not be useful for scoring lakes with respect to EI, despite the fact that relationships may exist between measures of EI and the metric. This was particularly prevalent for the deep lakes we examined which varied in their lake optical properties due to the prevalence of CDOM or glacial suspensoids. In such cases, other metrics may be helpful in resolving issues. For example the use of optical data such as turbidity may help resolve the effects of natural humic acids from particulate material reflecting soil erosion from the catchment. This issue suggests that further classification of lake types within deep and shallow lake classes could be useful for refining EI calibration.

There is also some uncertainty if the indicators utilised for deep lakes would have been particularly sensitive to effects of water level regime changes from hydroelectric operations, which affect several of the deep lakes in the study (including the Southland lakes). Although macrophytes have been shown to be a useful indicator of water level regime (Riis & Hawes 2002; James et al. 2002), our use of macrophyte metrics was confounded by differences in lake optical properties amongst our lake set. Marginal turf communities could be a more useful indicator associated with water level regime (Wells 2001; Riis & Hawes 2002), however these plant community data were not available for our lake set. Future consideration of other suitable indicators relevant to hydroelectric operations in Manapouri and Te Anau could be considered.

Relationships between EI and catchment variables were generally quite weak, both in the deep and shallow lakes, suggesting that either in-lake nutrient processing (e.g., sequestration, internal loading, denitrification, etc.) could be very important in these lakes or that the CLUES model does not calculate catchment nutrient losses accurately enough to be helpful to the purposes of our study. The resulting large discrepancies between the modelled in-lake N and P concentrations and measured N and P concentrations indicate that more work needs to be done to understand the relationships between catchment land use and lake water quality. Time lags related to legacy loads in lake sediments or to groundwater flows through catchments may also confound attempts to relate lake condition to catchment condition at a particular point in time. Presently there is a high degree of reliance on modelled hydrometric (e.g., morphometry, hydraulic residence time) and catchment nutrient loss rates under varying land use and climate conditions. Further monitoring to assist in the calibration of these model predictions (e.g., lake bathymetry and flow-through rates) would assist in improving these model predictions.

5.3 Recommendations

The method of assessing lake EI has been largely successful at identifying overall lake health and is broadly in line with previous assessments of Southland's lakes (e.g. Schallenberg & Kelly 2012, 2013; Kelly et al. 2013a). It is recommended therefore that the EI framework be adopted as a way of holistically measuring lake health, although some modification to components and metrics may be desirable.

However the limitations of the approach (Section 5.2) indicate that currently the use of EI should not completely replace existing methods of assessing lake health. The EI framework incorporates and expands on the current suite of monitoring tools for assessing lake health (e.g., TLI parameters, Lake SPI). This data could also easily be brought into the EI framework to inform some metrics. Further work could seek to refine the approach and identify further lake metrics not able to be included as part of this investigation, especially those which could improve the cover of the core EI components (e.g., dissolved oxygen and pH fluctuations related to redox induced internal recycling of nutrients). Further investigation of alternative independent measures against which to calibrate the lake metrics could be useful.

Some considerations will need to be made around the inclusion of EI metrics within ES's future lake monitoring programme (e.g., food web variables). The metrics identified as relating to EI could be added to lake monitoring programs, with an expectation that monitoring of some biological metrics could be conducted over longer return cycles of 3–5 years. This approach has been identified as part of other frameworks as a means of enabling more cost effective monitoring (Hudson et al. 2012; Kelly et al. 2013b). Ongoing monitoring of these metrics will allow temporal trends in overall EI to be identified for the Southland lakes.

6. ACKNOWLEDGEMENTS

We thank James Dare and Nick Ward for helpful discussions on Southland's lakes and providing guidance on most appropriate methods for ranking Southland lakes. Significant data was made available by the Department of Conservation (Cross Departmental Research Project- Lake ecological integrity project) to allow analyses of ecological condition of lakes across New Zealand. Helpful review comments on the draft report were provided by James Dare, Nick Ward and Michelle Hayward from Environment Southland.

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8. APPENDICES

Appendix 1. CLUES catchment modelling for lake catchment metrics

Lake catchment land cover mapping was conducted in order to derive catchment nutrient export by CLUES modelling. Lake catchment localities and land cover maps are shown in Figures A1.1 to A1.5, (Lakes Calder and Sheila not shown due to 100% native land cover) and a table of the proportional coverage using the Land Cover Database (LCDB v4.0) land cover categories is provided in Table A1.1. Lake catchment areas were derived from the Freshwater Ecosystems of New Zealand (FENZ; Leathwick et al. 2010) and for Southland Lakes only overlaid with land cover information from Land Cover Database version 4.0 (Landcare Research 2014).

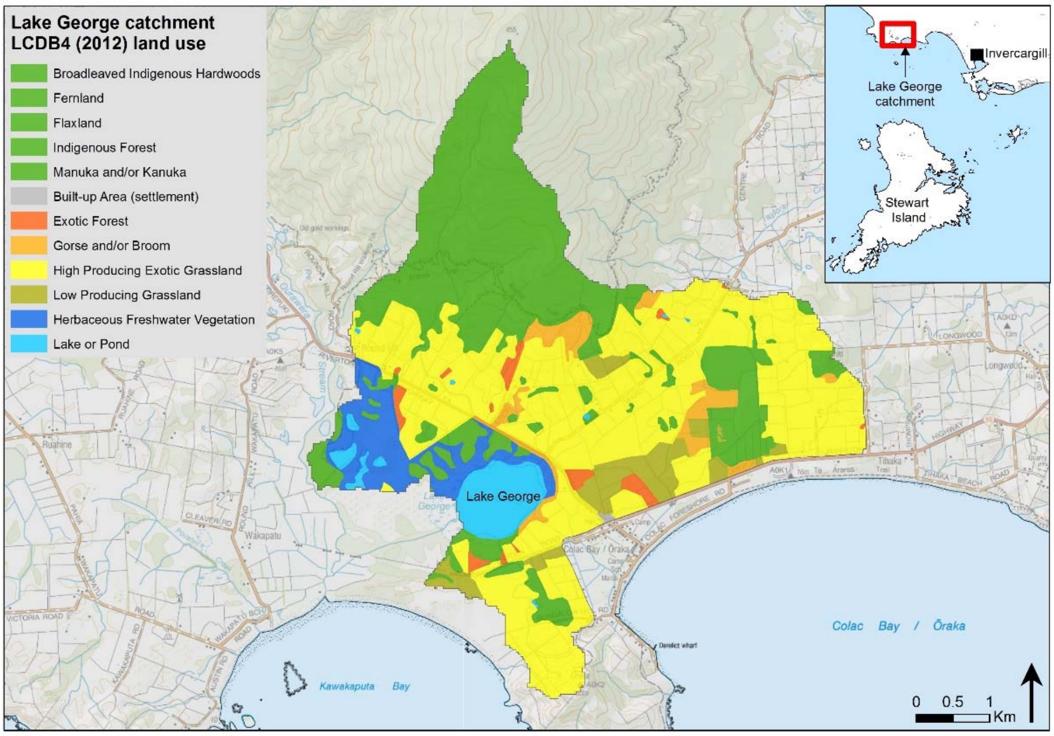

Figure A1.1 Lake catchment land use (Land Cover Database version 4.0) for Lake George, Southland.

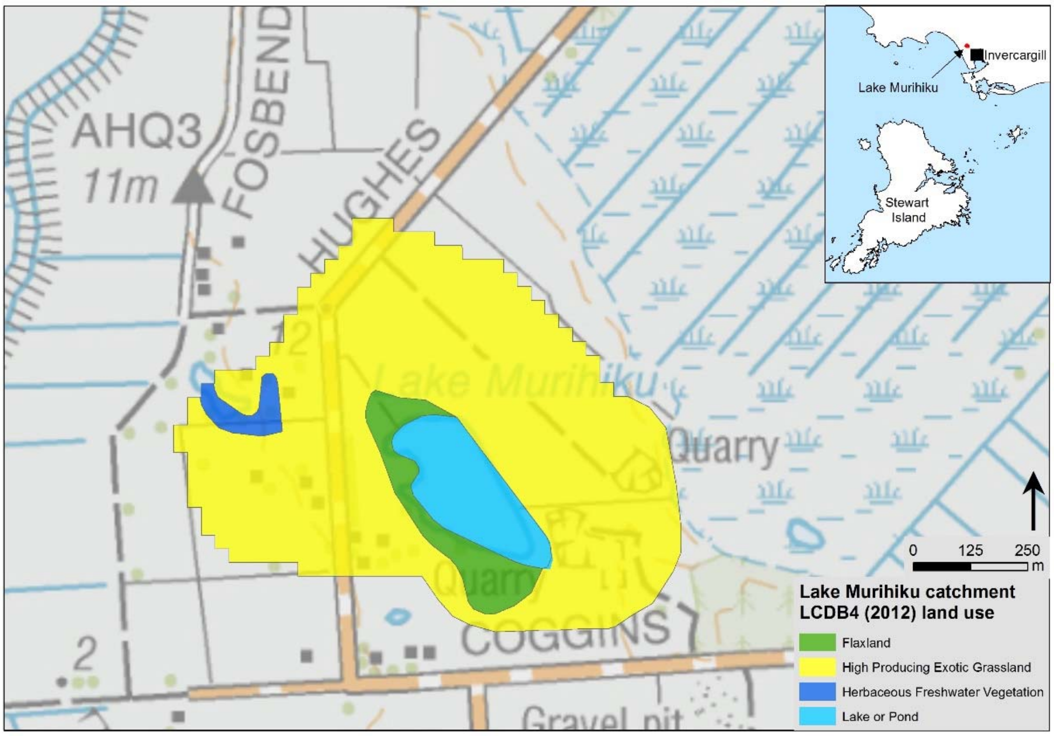

Figure A1.2 Lake catchment land use (Land Cover Database version 4.0) for Lake Murihiku, Southland.

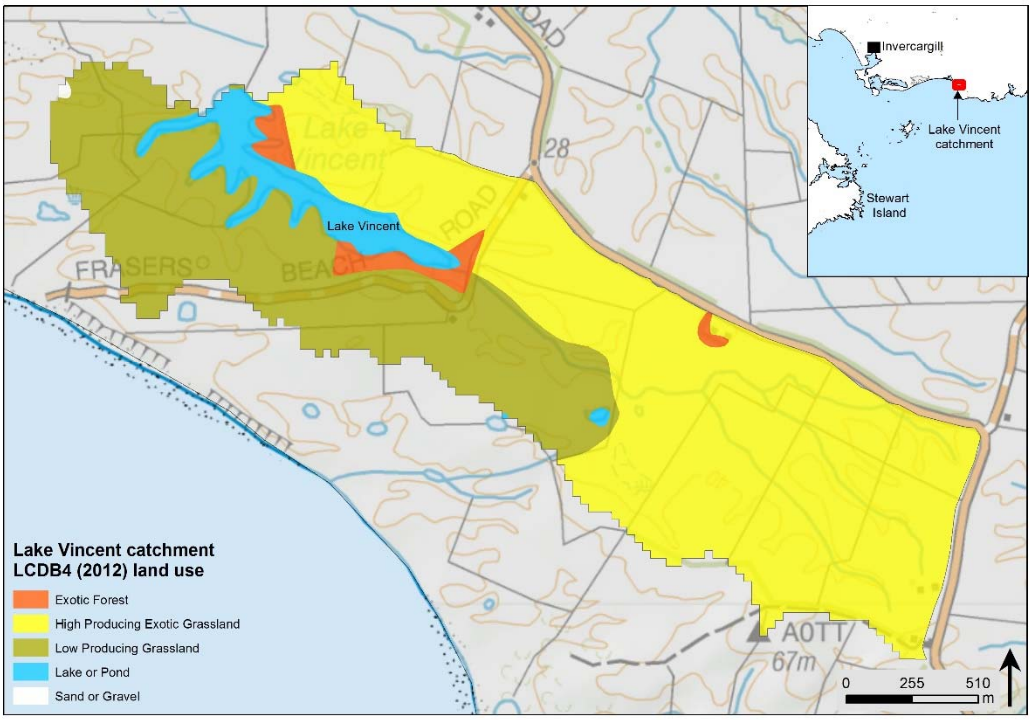

Figure A1.3. Lake catchment land use (Land Cover Database version 4.0) for Lake Vincent, Southland.

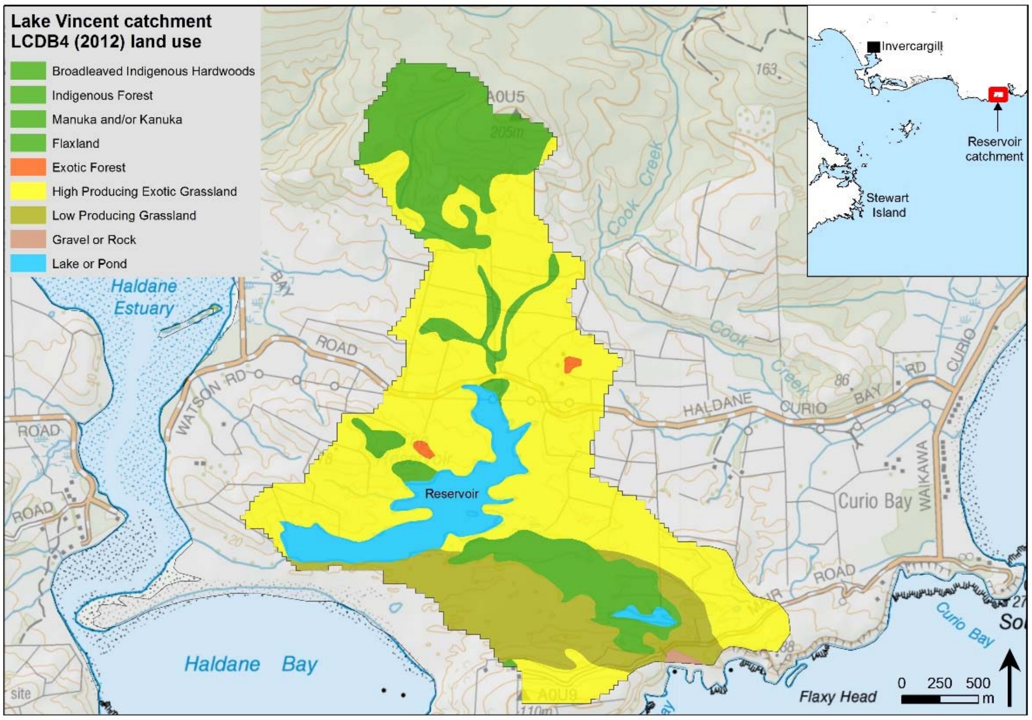

Figure A1.4. Lake catchment land use (Land Cover Database version 4.0) for The Reservoir, Southland.

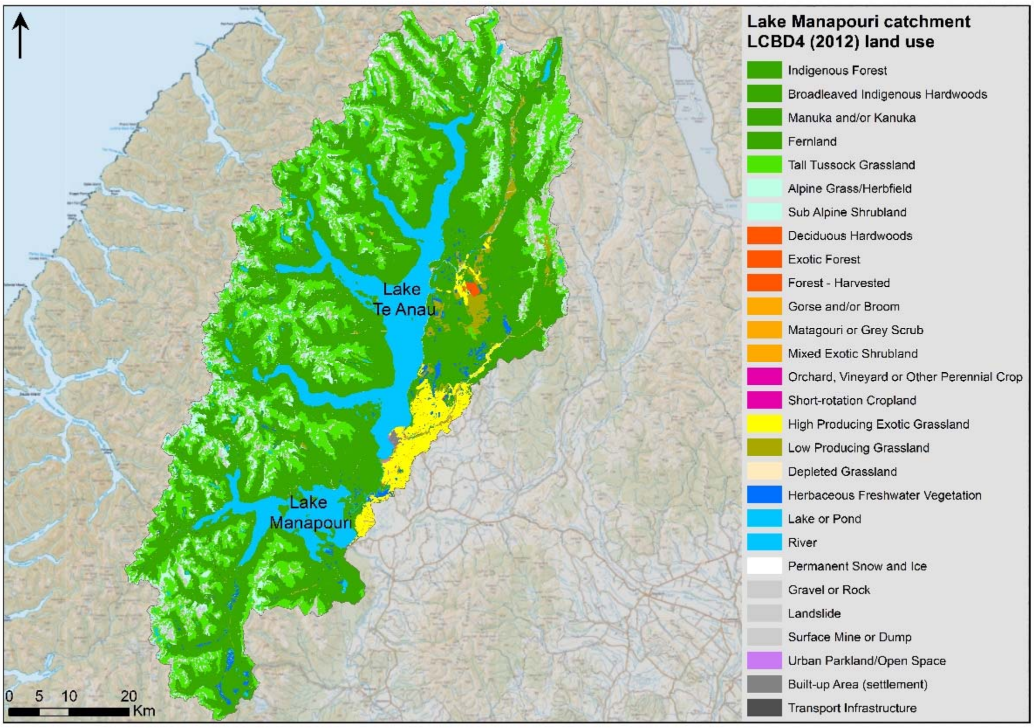

Figure A1.5. Lake catchment land use (Land Cover Database version 4.0) for Lakes Te Anau and Manapouri, Southland

Table A1.1 Land cover for selected shallow and deep Southland lakes.

Lake	Land Cover type				
	Native Cover (%)	Pastoral Cover (%)	Urban Cover (%)	Cropping (%)	Exotic Forest (%)
Shallow					
George	46.1	48.8	0.1	0.0	5.1
Murihiku	17.1	82.9	0.0	0.0	0.0
Vincent	6.2	91.2	0.0	0.0	2.5
The Reservoir	32.3	67.1	0.0	0.0	0.0
Sheila	100.0	0.0	0.0	0.0	0.0
Calder	100.0	0.0	0.0	0.0	0.0
Deep					
Manapouri	95.5	4.2	0.12	0.0	0.2
Te Anau	95.7	4.7	0.1	0.0	03

CLUES modelling of nutrient fluxes

Annual loads (tonnes / annum) of total nitrogen (TN) and total phosphorus (TP) to the lakes were estimated using a nutrient transport model combined with the regionally-based hydrological regression model, CLUES version 10.2.2 (Woods et al. 2006). TN and TP loadings generated by this model reflect the effects of various land uses such as production forestry, low-intensity grazing, high-intensity grazing, dairy farming, horticulture and urban development and take into account upstream retention by lakes and wetlands.

Catchment land-use in the shallow and deep lakes was compared between the Land Cover Database version 3 (LCDB v3.0—Ministry for the Environment 2012) on which the present CLUES version 10.2.2 is based, and the latest land cover information in Land Cover Database version 4 (LCDB v4.0—Landcare Research 2014). This comparison was used to determine which lakes required updated CLUES land-use scenarios based on more recent land cover information. The following simple rule was applied: lake catchments that had land cover of agriculture or forestry classes differing between LCDB v3.0 and LCDB v4.0 by greater than 2% of the total catchment area were updated by running LCDB v4.0 land-use scenarios. This was done in ARCMap 10.1 using the CLUES polygon tool to trace the updated LCDB v4.0 land cover. In some cases alternative scenarios needed to be run when the digital elevation stream model was a poor fit the lake drainage area. As a result of updating land-use cover or stream networks, alternative LCDB v4.0 land-use scenarios were run for the following lakes; Lakes George, Vincent, the Reservoir, as well as Southland's deep lakes, Manapouri and Te Anau.

The CLUES model produced an overall estimate of TN and TP load in tonnes per annum, by summing the TN and TP loads for the inflows of each lake. Mean annual inflow TN and TP concentrations were calculated by dividing tributary inflows by the mean annual flow obtained from the CLUES model hydro-edge function. Mean annual areal loads of TN and TP were calculated by dividing the total annual load (kg/y) by the area of the lake (ha). Catchment yields were calculated by dividing the total annual load (kg/y) by the area of the lake catchment (ha). Nutrient loads and yields are presented in Table A1.2 for the Southland lakes.

Direct deposition of N and P to the lake surface in rainfall was also incorporated into estimates of annual nutrient loads. Annual estimates of rainfall (in mm/y) were obtained from contour maps of the Southland region of mean annual precipitation during 2004–2014 (NIWA climate database). Mean concentrations of TN and TP in rainfall were not readily available for Southland sites, and overall there has been very little monitoring conducted on N and P content of rainwater in New Zealand. Therefore, average nutrient concentrations had to be obtained from data for other regions, with the most extensive data source being from three sites in the Lake Taupo catchment during 2004–2005 (Vant & Gibbs 2006). Methods for that study included daily collection of rainwater samples on days having significant rainfall events. Rainwater analyses were conducted for various forms of soluble and total N and P, but only TN and TP concentrations were used in the calculation of loads for Southland. Rain samplers were specifically designed to exclude particulate deposition. Mean rainfall concentrations over the two-year study were calculated as follows: for TN, 440 mg N/m^3, and for TP, 35.4 mg P/m^3 (Vant & Gibbs 2006). These concentrations were multiplied by annual rainfall over the entire lakes surface to determine annual TN and TP atmospheric loads.

Vollenweider modelling of mean annual in-lake nutrient concentrations

Vollenweider models were used to transform the predicted inflow nutrient loading rates (from CLUES) into in-lake TN and TP concentrations (see Table 6). Vollenweider (1982) found that annual average TP and TN concentrations in lakes (TP_{Lake} and TN_{Lake} in mg m^{-3}) could be estimated from lake flushing rates and inflow concentrations according to equations 1 to 4. Two sets of Vollenweider equations derived for South Island shallow lakes (Kelly et al. 2013a) and deep lakes (Özkundakci et al. 2014) were tested:

Shallow lakes (from Kelly et al. 2013):

$$\mathrm{TP}_{\mathrm{Lake}} = 3.018\left[\mathrm{TP}_{\mathrm{Inflow}}/\left(1+\sqrt{\tau}\right)\right]^{0.723} \quad (1)$$

$$\mathrm{TN}_{\mathrm{Lake}} = 158\left[\mathrm{TN}_{\mathrm{Inflow}}/\left(1+\sqrt{\tau}\right)\right]^{0.2} \quad (2)$$

Deep lakes (from Özkundakci et al. 2014):

$$\mathrm{TP}_{\mathrm{Lake}} = 1.55\left[\mathrm{TP}_{\mathrm{Inflow}}/\left(1+\sqrt{\tau}\right)\right]^{0.82} \quad (3)$$

$$\mathrm{TN_{Lake}} = 5.34\left[\mathrm{TN_{Inflow}}/\left(1+\sqrt{\tau}\right)\right]^{0.78} \qquad (4)$$

Where TP_{Inflow} and TN_{Inflow} are the annual average inflow concentrations of P and N, respectively (mg m^{-3}), and τ is the residence time of the lake (y).
TP_{inflow} and TN_{inflow} were derived from the flow-weighted average nutrient concentrations from the CLUES catchment model output (see above) and used to calculate an annual mean discharge to the lake. The multiplier (a) and exponent (b) terms for the functions were optimised for the Southland lakes using a non-linear regression model in the statistical program 'R'. The regression model uses the measured values of TN_{Lake} and TP_{Lake} from monitoring data (median of the annual averages for the years 2009 to 2014). For TP, an additional Vollenweider-type model was also considered (Brett & Benjamin 2008) that included a term for lake mean depth, as below:

$TP_{Lake} = TP_{inflow} / [1+ (v \mid / Z_{mean})]$

Where v is a constant optimised to fit the TP_{lake} data for the shallow and deep lakes.

Parameters used in calibrating Vollenweider models, including lake volume, hydraulic residence time (|), mean depth (Z_{mean}), and fetch were obtained from bathymetric data reported in the FENZ lakes geo-database were used (Leathwick *et al.* 2010).

The modelled nutrient yields, loads and In-lake concentrations are presented in Table 6 for the Southland lakes. In general the yields, loads and concentrations of TN were lower in those catchments with higher percent of native vegetation land cover. TP was less correlated with native land cover, although in-lake concentrations in the relatively unmodified catchments (Sheila, Calder, Manapouri and Te Anau) were substantially lower.

Table A1.2. Nutrient catchment yields, lake areal loads and mean annual in-lake concentrations for Southland lakes derived from modelling using CLUES. The in-lake concentrations were derived from Vollenweider transformations. These estimates used LCDB3, except for the deep lakes where yields and loads were calculated using LCDB4.

Lake	CLUES N-yield (kg/ha/y)	CLUES P-yield (kg/ha/y)	CLUES N-load (kg/ha/y)	CLUES P-load (kg/ha/y)	Predicted in-lake total-N (ug/l/)	Predicted in-lake total-P (ug/l)
Shallow						
George	2.01	0.22	64.4	7.0	757.2	52.8
Murihiku	7.54	0.26	79.1	2.71	861	25.2
Vincent	11.2	0.25	205	4.26	826	17.2
Reservoir	6.47	0.58	104.3	9.42	850	48.2
Sheila	5.0	0.22	36.5	1.62	318	14.7
Calder	5.0	0.22	38.2	1.70	365	15.9
Deep						
Manapouri	2.87	0.44	90.8	14.0	82.6	2.54
Te Anau	3.66	0.80	32.9	7.2	70.2	2.31

Appendix 2. Shallow lake metric bands

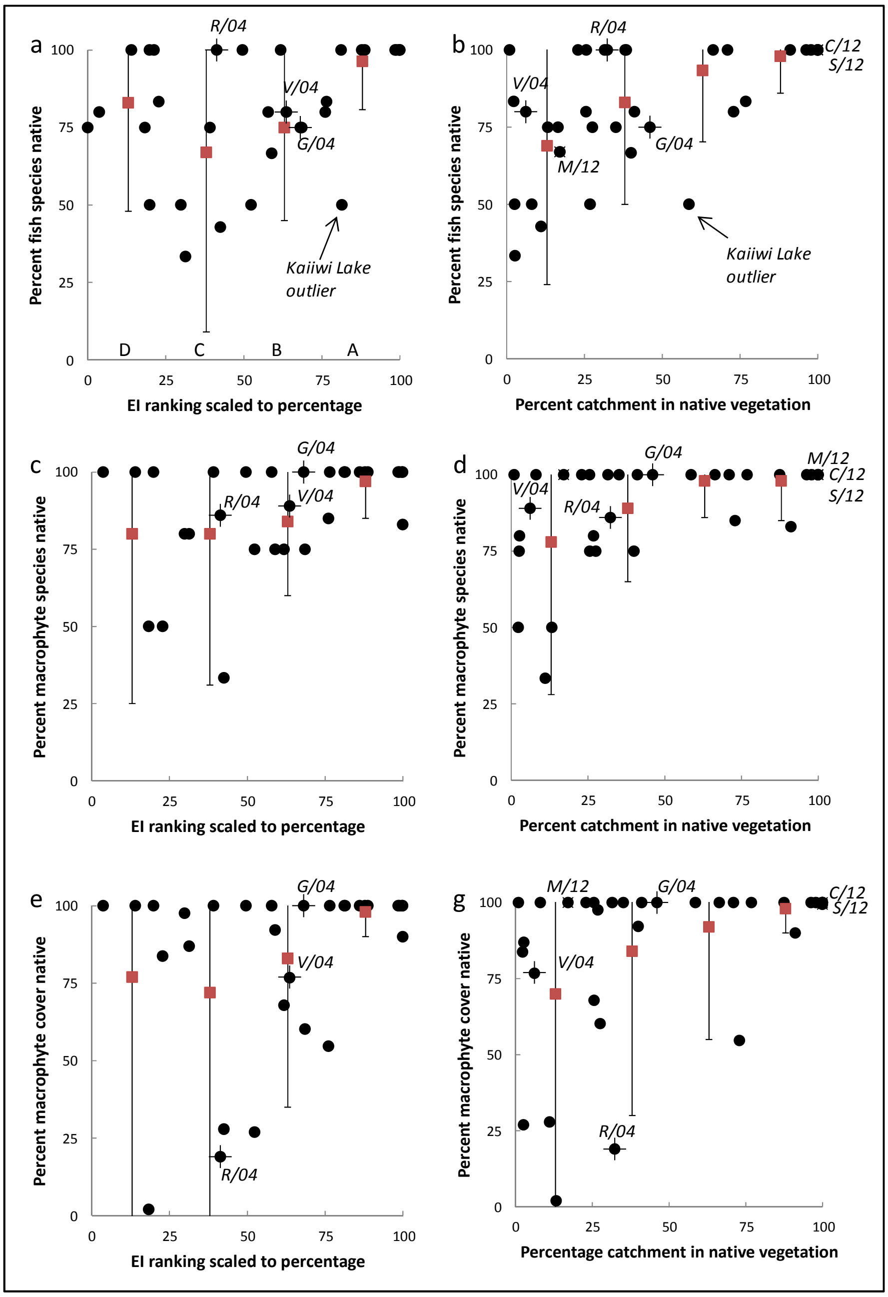

Figure A2.1 Calibration relationships between shallow lake nativeness indicators and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes. A cross through the circle indicates Southland lakes sampled in 2004 (G= Lake George, R= the Reservoir, V= Lake Vincent). X indicates Southland lakes sampled in 2012 (M= Lake Murihiku, S= Lake Sheila, C= Lake Calder). Red squares represent the means of the indicator values (with 5% confidence intervals of the data distributions) for lakes in each EI quartile. Quartiles: A = excellent (75-100), B = good (50-74), C = fair (25-49), and D = unacceptable (0-24). Outliers not included in the calculations are indicated on the graphs.

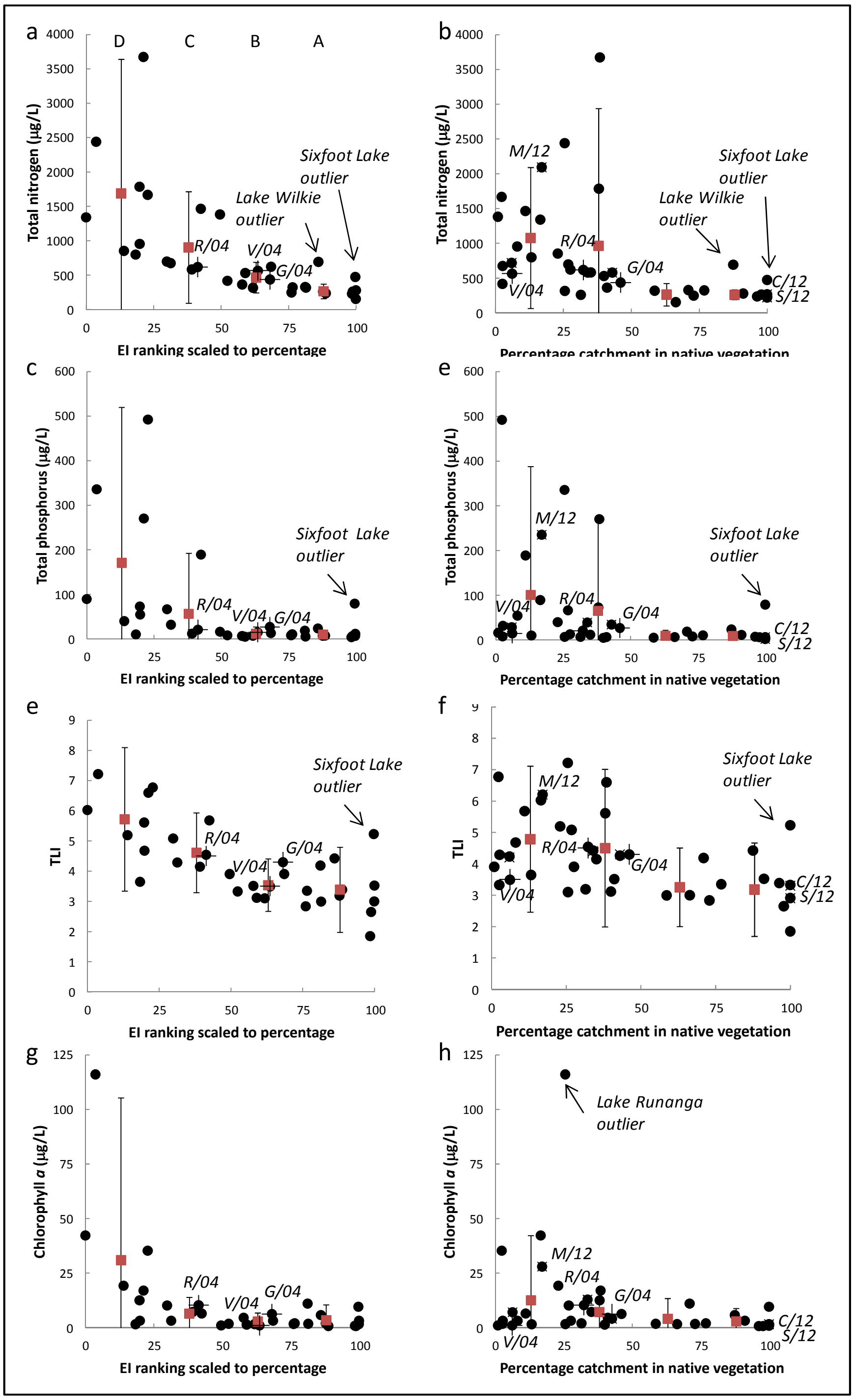

Figure A2.2. Calibration relationships between shallow lake pristineness indicators and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes. A cross through the circle indicates Southland lakes sampled in 2004 (G= Lake George, R= the Reservoir, V= Lake Vincent). X indicates Southland lakes sampled in 2012 (M= Lake Murihiku, S= Lake Sheila, C= Lake Calder). Red squares represent the means of the indicator values (with 95% confidence intervals of the data distributions) for lakes in each EI quartile. Quartiles: A = excellent (75-100), B = good (50-74), C = fair (25-49), and D = unacceptable (0-24). Outliers not included in the calculations are indicated on the graphs.

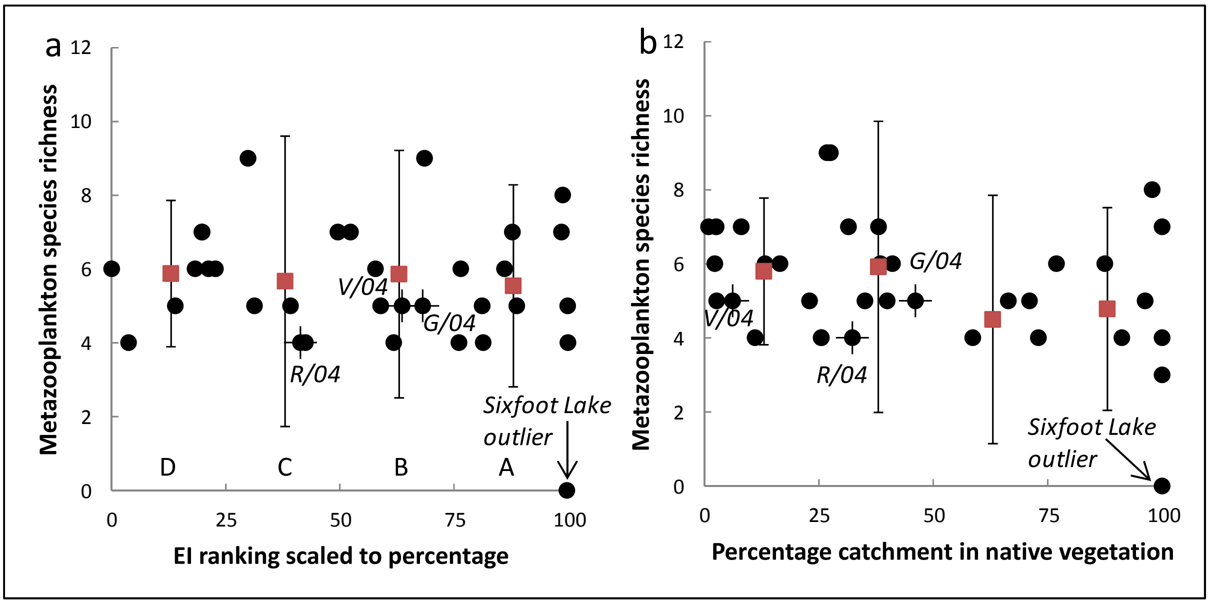

Figure A2.3. Calibration relationships between shallow lake metazooplankton diversity and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes. A cross through the circle indicates Southland lakes sampled in 2004 (G= Lake George, R= the Reservoir, V= Lake Vincent). Red squares represent the means of the indicator values (with 95% confidence intervals of the data distributions) for lakes in each EI quartile. Outliers not included in the calculations are indicated on the graphs. Metazooplankton diversity (and diversities of other biotic communities) showed no relationships with either EI expert rank assessments or percentage of catchment in native vegetation. Therefore, calibration to EI bands was unsuccessful.

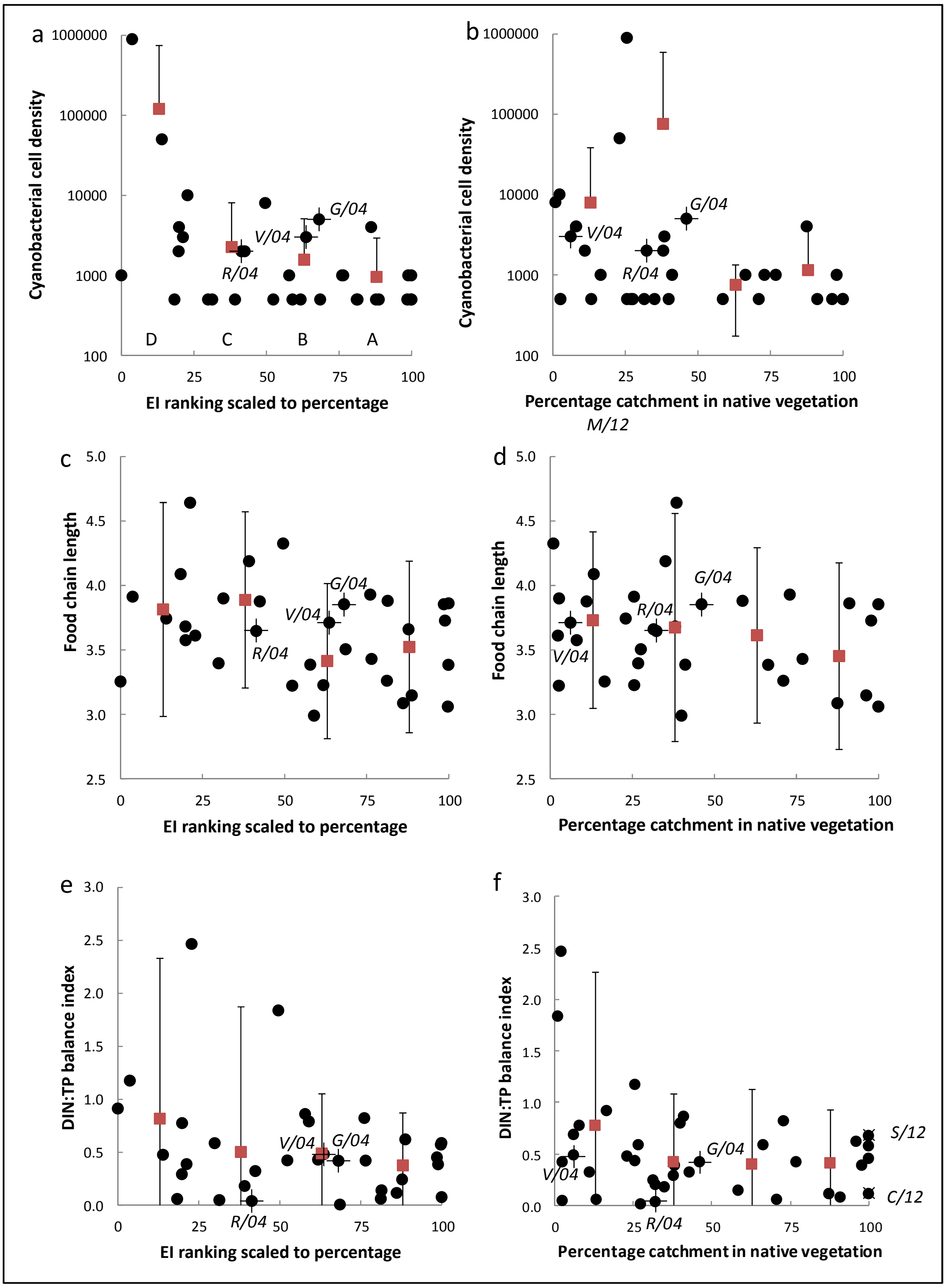

Figure A2.4. Calibration relationships between shallow lake resilience indicators and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes. A cross through the circle indicates Southland lakes sampled in 2004 (G= Lake George, R= the Reservoir, V= Lake Vincent). X indicates those lakes plus additional Southland lakes sampled in 2012 (S= Lake Sheila, C= Lake Calder). Red squares represent the means of the indicator values (with 95% confidence intervals of the data distributions) for lakes in each EI quartile. Quartiles: A = excellent (75-100), B = good (50-74), C = fair (25-49), and D = unacceptable (0-24).

Appendix 3. Catchment metrics plotted against measures of EI for shallow and deep lakes

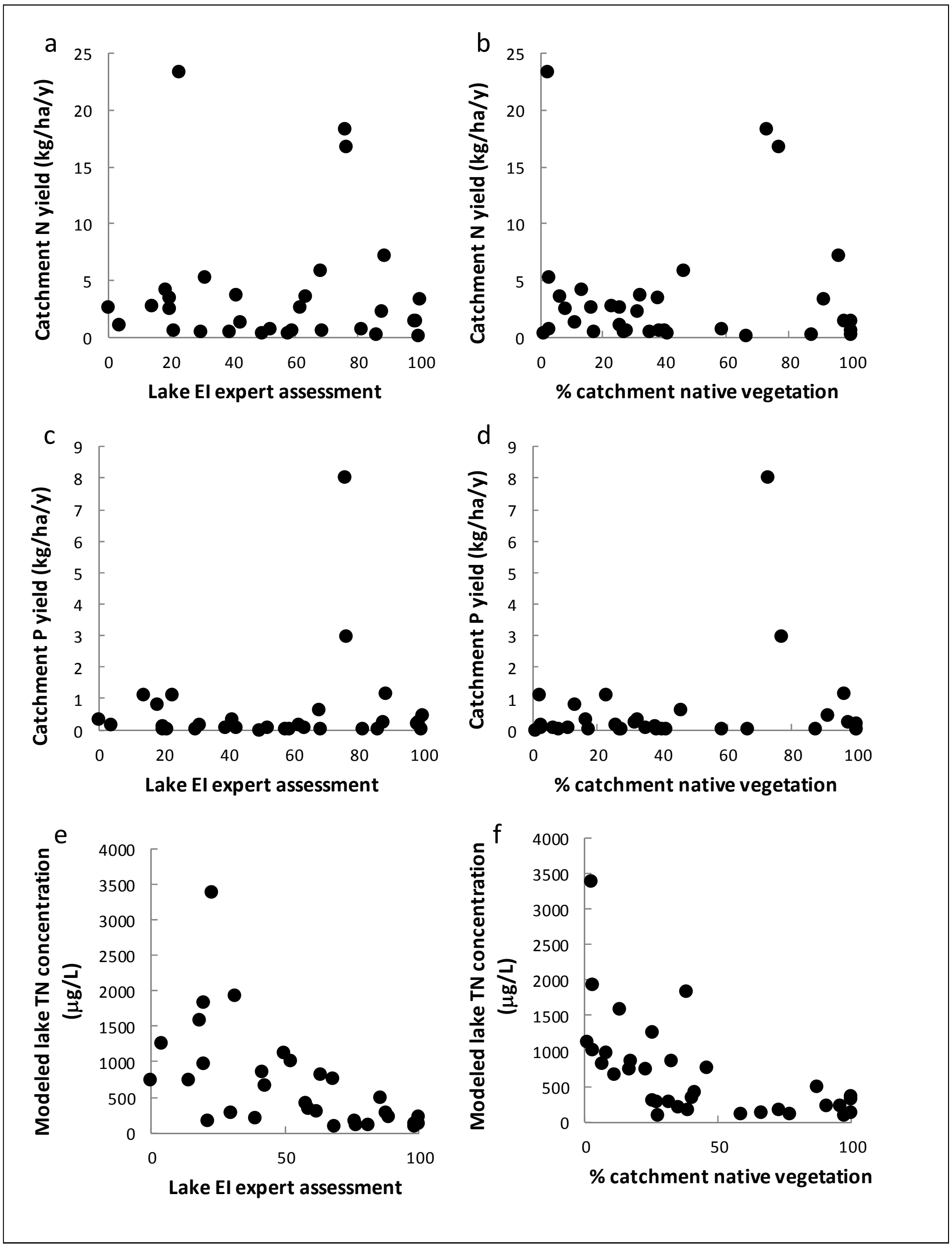

Figure A3.1. Relationships between shallow lake catchment metrics and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes.

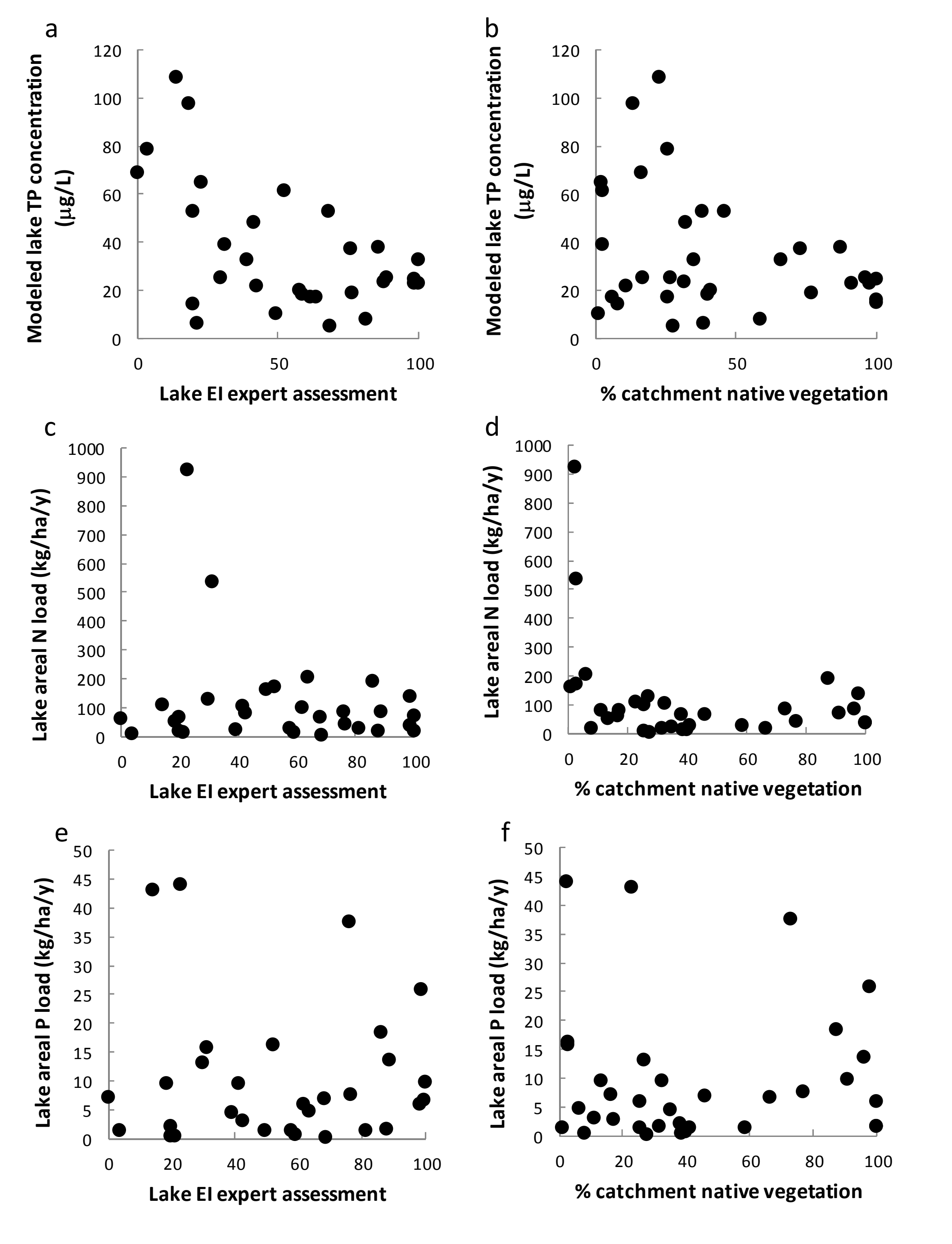

Figure A3.2. Relationships between shallow lake catchment metrics and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of shallow lakes.

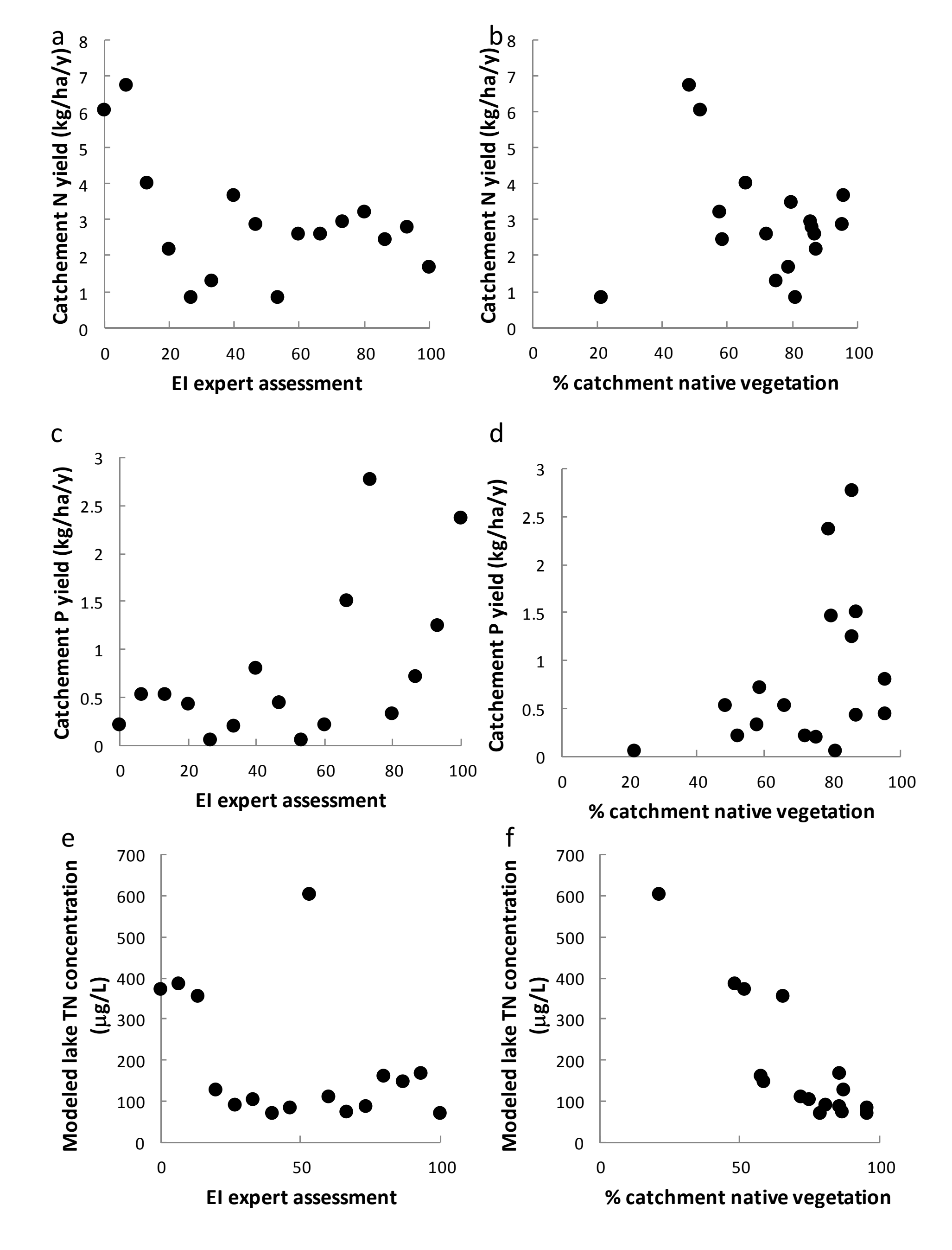

Figure A3.3. Relationships between deep lake catchment metrics and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of deep lakes.

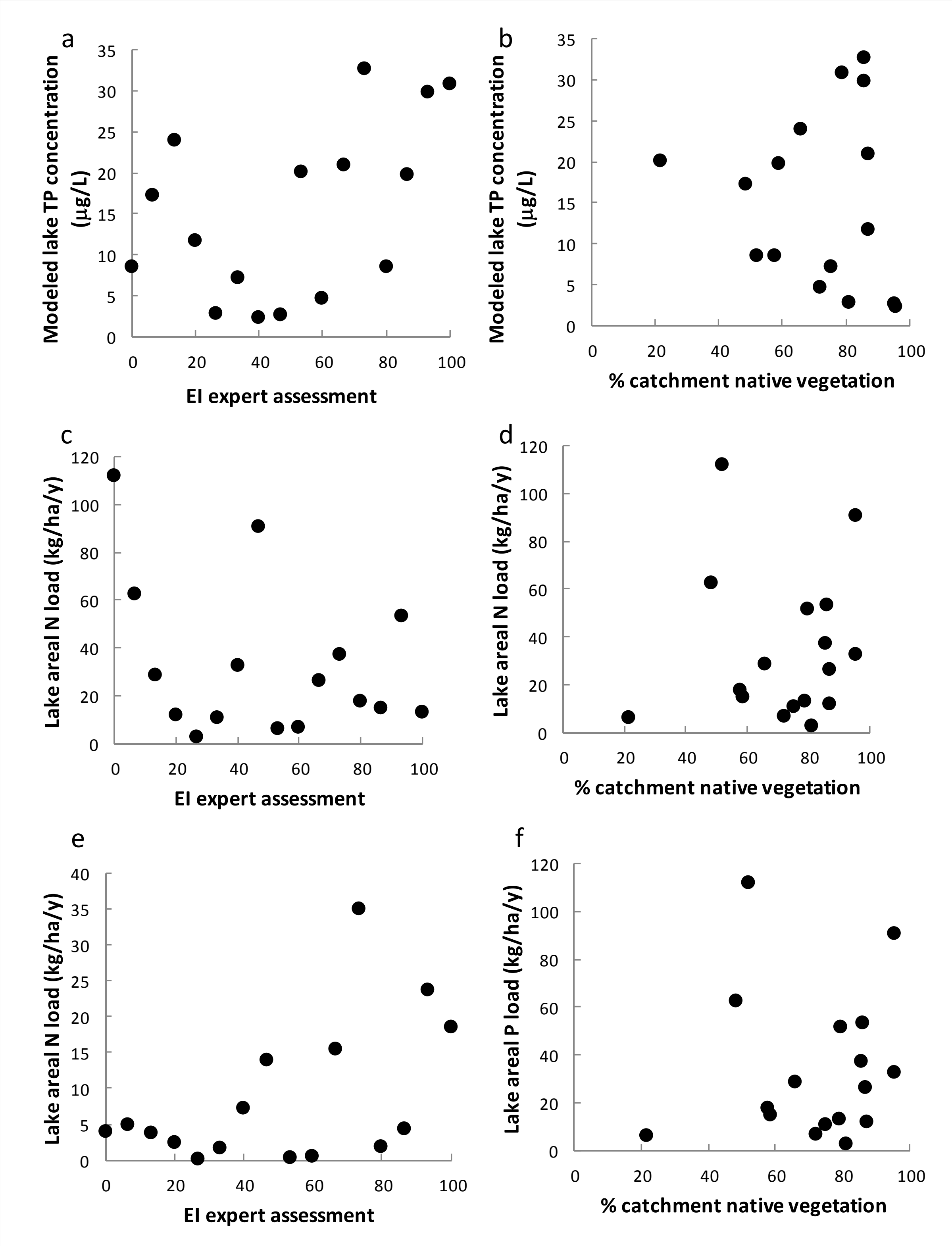

Figure A3.4. Relationships between deep lake catchment metrics and ecological integrity (EI) expert assessment rankings of the lakes (left panels) and percentage of the lake catchment in native vegetation (right panels). Circles represent lakes from the survey of deep lakes.

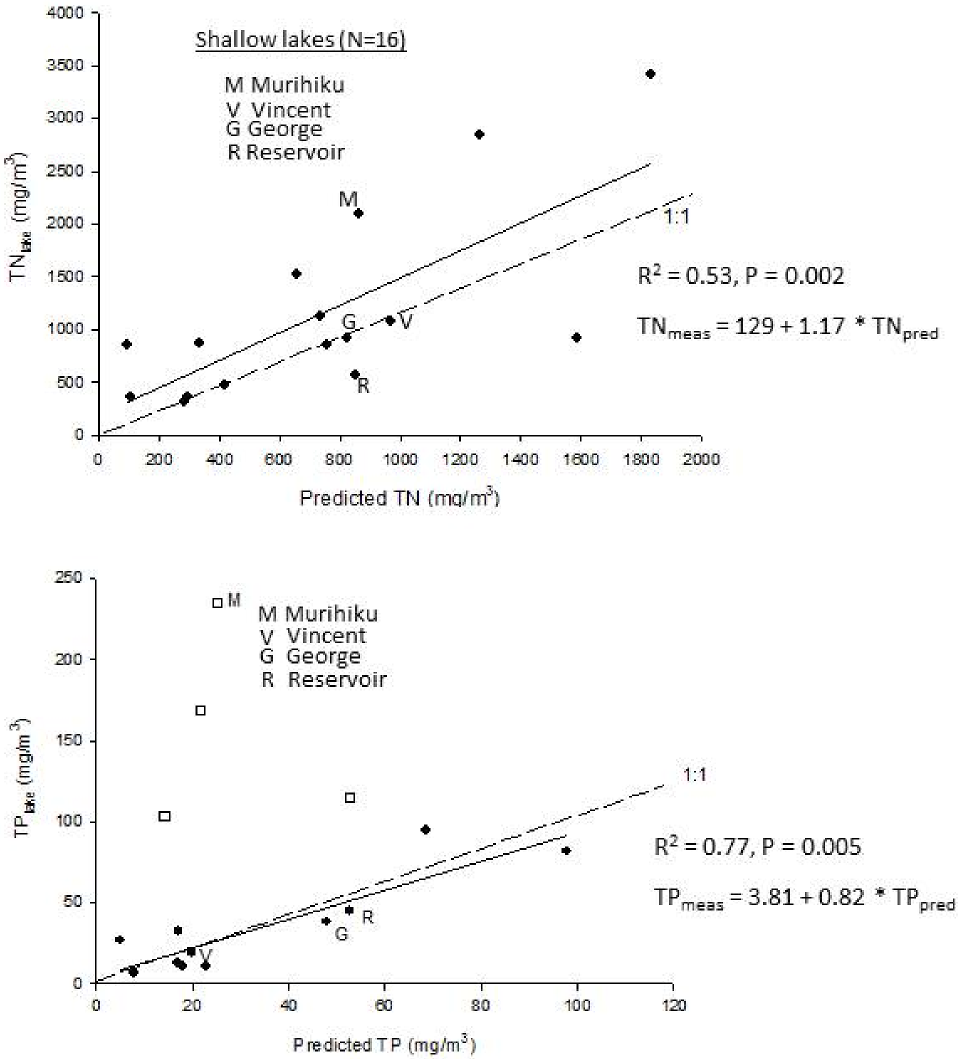

Figure A3.5. Validation of nutrient mass balance model predictions using Vollenweider models to predict mean annual total nitrogen and total phosphorus concentrations plotted against measured mean annual TN and TP concentrations (2009-2013 annual averages) for shallow lakes (Kelly et al. 2013) lakes (Özkundakci et al. 2014). Catchment nutrient loads to lakes were modelled using the CLUES model V10.2.2.

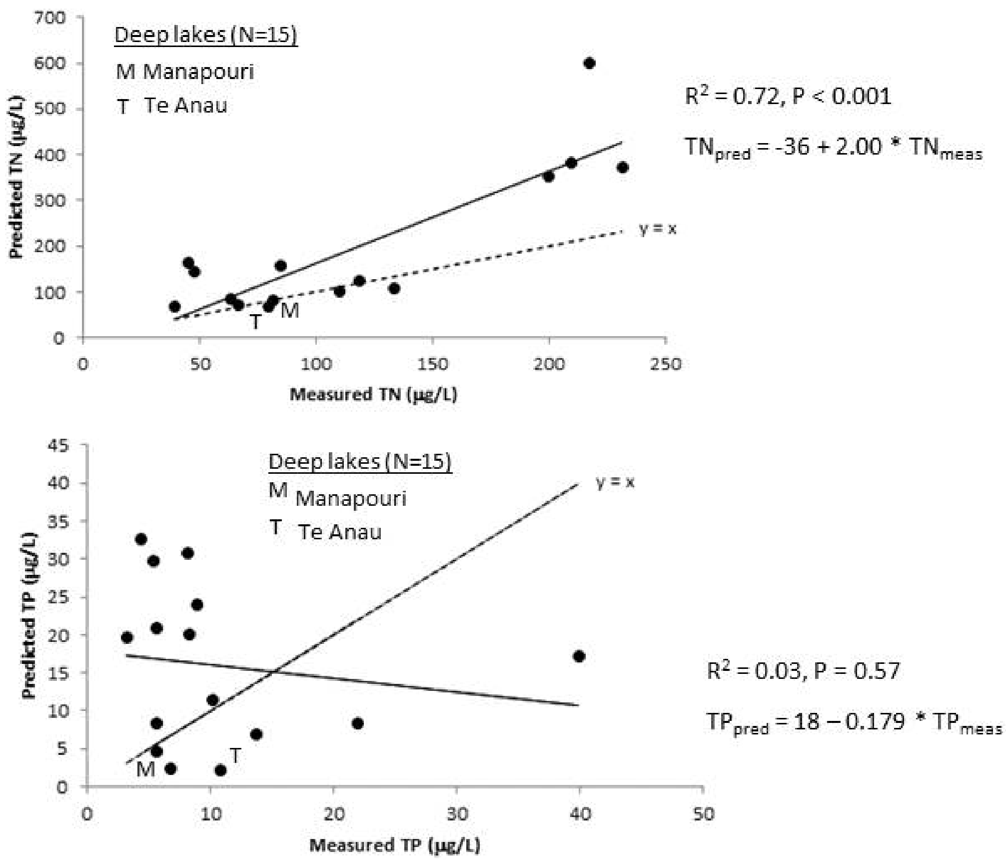

Figure A3.6. Validation of nutrient mass balance model predictions using Vollenweider models to predict mean annual total nitrogen and total phosphorus concentrations plotted against measured mean annual TN and TP concentrations (2009-2013 annual averages) for deep lakes (Özkundakci et al. 2014). Catchment nutrient loads to lakes were modelled using the CLUES model V10.2.2.