Shallow coastal lakes in New Zealand: assessing indicators of ecological integrity and their relationships to broad-scale human pressures

NIWA Client Report: CHC2009-004
October 2009

NIWA Project: DOC07511

Shallow coastal lakes in New Zealand: assessing indicators of ecological integrity and their relationships to broad-scale human pressures

Deanne Drake
David Kelly
Marc Schallenberg
Agate Ponder-Sutton
Matt Enright

Prepared for

Department of Conservation

NIWA Client Report: CHC2009-005
October 2009
NIWA Project: DPC07511

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street, Riccarton, Christchurch 8011
P O Box 8602, Christchurch 8440, New Zealand
Phone +64-3-348 8987, Fax +64-3-348 5548
www.niwa.co.nz

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Reviewed by:

Piet Verburg

Approved for release by:

C. Howard-Williams

Clive Howard-Williams

Executive Summary

We collected baseline biological, chemical and physical data from 45 shallow coastal New Zealand lakes (<10 m depth and usually within 25 km of the coastline) for evaluation as potential indicators of lake ecological integrity (EI). The 45 lakes of this study are geographically representative of the ~900 shallow coastal lakes in New Zealand, and the large and complex data set assembled here provides unique, detailed information about of a group of lakes that have received very little attention in the past.

The original, stated goal of this project was to identify indicators of shallow coastal lake EI by comparing the measured variables to human pressure gradient values developed by the Department of Conservation's Waterbodies of National Importance (WONI) programme. We carried out an extensive and detailed analysis of the lakes by measuring ca. 40 variables relating to lake condition and found that: 1. they were were representative of the geographic spread of NZ lakes and 2. they are a discrete group of lakes. However, in the absence of a historical understanding of shallow coastal lake ecology the EI concept proved to be difficult to define. Shallow Lake EI remained subjectively defined as being a "desirable state" with no quantitative values (e.g. Chl *a* < 0.05 mg/l) for the purposes of this study and we recognise that there is currently no way to quantitatively relate EI to the measured variables or to the WONI pressure gradients.

To ameliorate this difficulty we identified correlates between the following WONI pressure gradients: N and P loading corrected for lake water residence time; catchment impervious area; native vegetation removal; the ~40 measured variables and we also compared both WONI pressure gradients and measured variables to EI determined subjectively by expert assessment. A fifth potential WONI gradient was invasive macrophyte pressure, but gradient data were available for only 18 of the 45 lakes, and this was ultimately dropped from the analysis due to lack of power. A more in-depth analysis of relationships between invasive macrophytes and potential drivers of degradation has been reported separately (Willis et al. 2009).

The WONI pressure gradient values were compared to measured variables using Pearson's correlation and Boosted Regression Tree (BRT) analyses. Correlation analysis was used to first identify potential relationships and redundancy between measured variables. BRTs were then used to identify multiple predictors including non-linear relationships. BRT analysis was identified by the project Technical Advisory Group (TAG) as the best approach for this type of exploratory multivariate analysis, and is valued for being both resistant to over-fitting and capable of incorporating non-linear relationships. We recognise that the interpretive power of quantitative analyses was limited by the relatively small sample size –150 or more lakes would be desirable rather than the 45 in this study.

We employed a second BRT approach in which the suite of WONI pressure gradients (native vegetation removal, catchment imperviousness, and N and P loading) were tested as predictors of each of 28 of the 40 measured variables (in contrast to our original approach where the WONI pressure

gradients were treated as response variables). The second BRT approach is comparable to related work on rivers in New Zealand. This approach yielded results similar to those obtained using the first BRT approach; only a few good cross-validated correlations were identified - % native fish, pH, and Ln Chl *a*. The WONI pressure gradients were strong predictors of EI subjectively determined by three experts.

Variables most consistently useful in the correlation and BRT analyses were: total macrophyte cover (exotics and natives), % native fish in the total fish assemblage, mean distance to centroid (a food web metric), pH, rotifer diversity, Chlorophyll *a* concentration, and the light attenuation coefficient (K_d). These may, by extension, provide indicators of shallow coastal lakes EI.

The WONI pressure gradients related to catchment disturbance (i.e. N loading, P loading, and native vegetation removal) are generally related to the measured variables in ways that we expect. Lakes in highly disturbed catchments tended to have higher Chlorophyll *a* concentrations, higher pH, reduced light penetration, a lower % cover by macrophytes, a larger proportion of exotic fish species, "smaller" food webs (seen in BRT analyses only), and lower rotifer diversity

Based on these analyses, a parsimonious, predictive model that is most cost-effective and useable for managers could potentially include total macrophyte cover (exotics and natives), pH, % native fish in the total assemblage, and mean late summer Chlorophyll *a* concentration, and/or mean late summer light attenuation coefficient (K_d). However, of these, only the relationship between pH and the WONI pressure gradients was very strong, and we would not advise the formulation of a predictive multimetric model at this time because it would have low predictive power. The inability to produce a good model may be a result of the limited sample size (45 lakes), and the highly "individualistic" nature of lake ecosystems.

Despite problems associated with calculating Ecological Integrity, this data set has great value for other applications and as a national-scale snapshot of the condition of shallow coastal lakes in New Zealand in 2004-2008.

The WONI programme is committed to the quantification of "Ecological Integrity" of aquatic ecosystems in New Zealand. But EI is all-inclusive, user-defined concept that, in the absence of clearly quantified end points (i.e. quantification of absolute integrity or zero integrity) is difficult to defend when scientific rigour is required. In the case of shallow lakes we therefore recommend that either:

(1) The "integrity" concept is dropped in favour of simply relating lake condition measurements and metrics to the WONI pressure gradients. This allows a more objective focus on better-defined measurements of lake condition. For example, ecological status as used by the European Water Framework Directive (e.g. Cabecinha 2009) may better reflect known mechanisms of degradation captured by the WONI pressure gradients, or

(2) For those (relatively few) lakes where EI is integral to policy development and/or operational management decision-making, and for those lakes that are recognised to be of high value and are under clearly defined threat, an expert panel may be appropriate to define EI. The expert assessments (ranking) of the study lakes examined here were strongly correlated with the indigenous vegetation pressure gradient, and weakly correlated with the other WONI pressure gradients. Expert assessment of EI was also correlated with 13 of the measured lake variables (some of which are co-linear).

"Integrity" is inherently a human value rather than a measurable attribute, so subjective quantification of EI is warranted in some cases. According to the NIWA legal team, expert assessment is legally defensible in a court setting if it is an established and standardized "best practice" (as in the European Water Framework Directive).

1. Introduction

1.1. Background

Over the last four years a Cross Departmental Research Pool (CDRP) funded project has been investigating relationships between human pressures and measured indicators of lake condition in an effort to quantify the Ecological Integrity (EI) of shallow coastal lakes in New Zealand. Because EI is not a measurable descriptor of ecosystems, a significant portion of this project was dedicated to developing an operational definition of EI for shallow coastal lakes and a suite of potential EI indicators. The freshwater CDRP technical advisory group conceptually described lake EI as:

"the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and maintained close to a minimally impacted reference condition" (Schallenberg et al. in review).

Pre-disturbance conditions are frequently a central theme of EI definitions and management goals (Seastedt et al. 2008), and the idea that minimally impacted ecosystems have the highest EI is explicit in the CDRP high-level definition. The high-level definition of EI was considered not practicable for coastal lakes as information on reference conditions is dependent on palaeo-limnological studies or pre-human pressure studies which are usually lacking. Thus the definition of lake EI was modified to reference a desirable, rather than pristine, condition.

The shallow lakes CDRP research team included freshwater scientists from Crown Research Institutes, Cawthron Institute, New Zealand universities, and the Department of Conservation (DOC). This research falls within the Waters of National Importance (WONI) portion of the government's Water Programme of Action wherein water bodies supporting a range of values including natural heritage, historic heritage, irrigation, recreation, energy, industry, and tourism were identified. This study pertains specifically to DOC-lead identification of lakes with high natural heritage and biodiversity values. The research described here may be used to support systematic conservation efforts and management of shallow lakes throughout New Zealand by quantifying relationships between their physical and chemical characteristics and human pressure indicators. Such management will require agency agreement on a set of clear operational objectives.

The lakes research within this project specifically targeted shallow, polymictic (multi-stratifying or non-stratifying) lakes for several reasons:

1) Most of New Zealand's shallow coastal lakes are in lowland regions, and are therefore at relatively high risk from land-use development.

2) Shallow coastal lakes, particularly dune lakes, have been historically neglected and poorly managed in New Zealand.

3) Currently, most lake ecological monitoring (e.g. conducted by regional councils) takes place in relatively large, deep lakes due to greater public interest (Hamill 2006). Thus, this project provides unique, initial biodiversity survey data for these poorly understood ecosystems.

4) The lakes CDRP group initially expected that the determination of ecological integrity (EI) might be simpler in shallow coastal lakes because they are not usually stratified.

This report contains the results of field surveys and quantitative analyses exploring relationships between human pressure gradients (disturbance) of lakes and their catchments and approximately 40 measured lake ecological characteristics (e.g. water chemistry, light penetration, fish and macrophyte diversity) which were selected to reflect EI qualitatively. Many of these characteristics, however, are not independent and there was no a priori definition of a "*minimally impacted reference condition*".

1.2. Study goals and rationale

The general lack of existing data for shallow coastal lakes in New Zealand meant that there were few expectations of what high "ecological integrity" or a lack of "integrity" might actually comprise. For example, it might be expected that shallow coastal lakes are naturally more productive than deep glacial lakes. This raises the following questions: 1. Do mid-range Chlorophyll a concentrations indicate higher EI than low Chlorophyll a concentrations? 2. Should food webs be of intermediate size and invertebrate populations be of intermediate diversity? Accordingly it was recommended that this study be exploratory in nature.

In summary, the goals of this work were to:

1) Collect detailed physical, chemical and biological data for a representative group of shallow, coastal New Zealand Lakes.

2) Compare these data to catchment-scale WONI human pressure gradients previously identified by the freshwater CDRP Technical Advisory Group.

These are: catchment impervious area, removal of indigenous vegetation from the catchment, nitrogen and phosphorus loading adjusted for water residence time, and invasive aquatic macrophyte indices (see Appendix A for a specific description of relevant milestones).

3) Evaluate the robustness of these data and their usefulness as a calibration set for a regression tree model which relates the WONI human pressure gradients to a suite of shallow lake chemical, biological or physical measures. A useful model should be applicable to unsurveyed shallow coastal lake ecosystems in New Zealand and should produce information for managers to prioritize operational management decisions for conservation.

Specific milestones described in the contract that are addressed in this report are reproduced in Appendix A.

At the onset of this project in 2004, the CDRP shallow coastal lake technical advisory group identified 4 broad components of lake ecological integrity and a list of metrics that might (or might not) be used as indicators of the properties (Table 1; described more completely in a review article by Schallenberg et al. in review). Field collections and analyses in this study included as many of these potential indicators as was feasible.

1.3. Related research outside of New Zealand

Programmes in Europe (Water Framework Directive) and the US (Environmental Monitoring and Action Plan; EMAP) include directives for the quantification of human impact of surface waters. The European Union's WFD is the more comprehensive of these programs and requires member states to assess ecological status of surface water bodies. European researchers have a population of 400+ lakes with which to assess reference conditions (e.g. Phillips et al. 2008 and 2003). The WFD approach is to classify lakes by type, and then build an empirical model based on the reference lakes within a type. The determination of type reference conditions depends on condition of the sites available for a lake type. Where pristine conditions prevail, a validated, spatial data network is produced, and if degraded conditions prevail then a model is developed to quantify the relationship between anthropogenic stress and ecological response. A WFD-type methodology may eventually be applicable in New Zealand lakes, but will require the development of new databases (for example this study) and the improvement of existing lake databases (for example the Freshwater Biodata Information System (FBIS) which is also currently under development). One of the challenges for New Zealand of such an approach is to

Table 1: **Suggested indicators for the assessment of the four components of ecological integrity in shallow coastal New Zealand lakes – these indicators are likely to be the most responsive to anthropogenic pressures. Reproduced from Schallenberg et al. (in review). We note that none of these potential relationships are quantified.**

General property of ecological integrity	Indicator	Examples of resulting problems
Nativeness		
Structural	Proportion of shoreline covered by native macrophytes	Invasion by / introduction of exotic species
	% Native species richness (macrophytes, fish, benthic invertebrates, zooplankton)	Invasion by / introduction of exotic species
	Absence of invasive macrophytes / fish / macroinvertebrates / zooplankton	Invasion by / introduction of exotic species
	Native fish catch per unit effort of native fish / benthic invertebrates)	Invasion by / introduction of exotic species
	Weighted invasiveness score accounting for invasiveness of individual exotic species (fish / macrophytes)	Invasion by / introduction of exotic species
Pristineness		
Structural	Macrophyte depth limit	Eutrophication
	Zooplankton and phytoplankton community composition	Invasion by / introduction of exotic species
Functional	Bloom-forming cyanobacteria presence/absence	Eutrophication
	Rate of redox potential change in sediments	Eutrophication, change in land use, over grazing by introduced species
	Water column Dissolved Oxyen fluctuation	Eutrophication
	Frequency of visible, surface cyanobacterial blooms	Eutrophication
	Intactness of hydrological regime	Abstraction, irrigation
	Continuity of passage to sea for migrating fish	Artificial human barriers
	Diadromous fish composition	Artificial human barriers
Physico-chemical	pH, TN, TP, Secchi disc transparency, Chlorophyll *a*, Tropic Level Index	Specific N and P enrichment, eutrophication
Resilience		
Structural	Food chain length, complexity and/or redundancy	Multiple disturbances
	N:P ratio compared to Redfield ratio	Risk of cyanobacterial blooms
	Instance/frequency of native macrophyte collapse	Eutrophication
	Number of trophic levels	Susceptibility to invasion
Functional	Recorded regime shifts between clear water and turbid states	Risk of regime shift
	Euphotic depth compared to macrophyte depth limit	Equilibrium between water clarity and macrophyte colonisation depth
	Compensation depth compared to mean depth	Potential for light or nutrient limitation of phytoplankton growth
Diversity		
Structural	Diversity indices	
	Richness indices	

describe pristine reference conditions for areas where extensive land modification and exotic species introductions have extensively modified all, or almost all shallow coastal lakes.

1.4. Related research in New Zealand

The WONI programme requires quantification of lake and stream EI for conservation planning and prioritization, and is aimed at identifying a suite of waterbodies in the best present ecological integrity covering a full range of biological and physical habitat diversity.

A lack of quantitative information about what comprises EI and how human pressures are related to EI has resulted in an initial approach for river catchments in which EI is inferred from surrogate landscape-scale measures of human pressure, each converted to a weighted EI value (Leathwick and Julian 2007). River EI, in this case, is a unitless index value. The EI value associated with each pressure for each catchment was calculated using descriptive response functions. Function shapes (e.g. logistic curves or exponential responses) and EI weights for each pressure were derived by expert assessment.

De Winton (et al (2009) subsequently used the response functions developed for river catchments (Leathwick 2007) for the development of human pressure measures for lakes. In both cases the inability to objectively quantify EI is noted as a significant but inevitable limitation, and is "an approximation of reality".

Water quality is arguably a major component of lake EI. An assessment of the current state and trends in lake water quality throughout New Zealand (Sorrell et al. 2006) used Trophic Level Index (TLI) as an indicator of water quality, although EI was not specifically addressed. TLI is a composite metric based on nutrient and Chlorophyll *a* concentrations and Secchi depth – and is commonly used to monitor lake water quality. In Sorrel et al. (2006), water quality was strongly correlated with land cover (pasture vs. native vegetation). Deep, high-altitude lakes tended to be unproductive and have high water quality (low TLI), while lowland lakes, especially small, shallow and warm lakes in modified catchments, were more likely to be productive and have low water quality (high TLI).

2. Methods

2.1. Study design

Our approach was to measure a large number of variables in a small but representative set of shallow coastal lakes to establish relationships between the measured variables (Table 2) and WONI pressure gradients. There was no quantitative, *a priori* connection between measured variables, pressure gradients, and EI. Approximately 50 shallow, coastal lakes (including dune, riverine, and peat lakes) were initially selected from the Fresh Water Ecosystems of New Zealand (FWENZ, Snelder et al. 2006) database using several criteria: Measured (or modelled) maximum depth was ≤10 m, lakes were usually within 25 km of the coast, and study lakes covered as many lowland regions of the country as possible, and lake-catchment land cover by pastoral agriculture covered as wide a gradient (preferably 0-100%) as was available for the region (Figures 1 and 2). Several of the candidate lakes were not visited due to logistic considerations, and two lakes were much deeper than expected and were excluded from the study. Several candidate lakes were not included due to the presence of toxic cyanobacterial blooms at the time of field surveys. Ultimately, 45 of the c. 900 shallow coastal lakes in New Zealand comprised the sample set (Figures 1 and 2). We recognised that, with one exception (6 Foot Lake on Campbell Island), the shallow lakes in the study were in modified catchments and therefore we were not able to list pristine lakes that would be expected to have a high EI.

2.2. Assumptions

1) The 45 lakes of our dataset are representative of New Zealand's ~900 shallow coastal lakes.

2) Shallow coastal lakes are a discrete group of lakes, are systematically different from other lake types (e.g. deep glacial) and respond to human pressures in a similar way within the shallow coastal group. These responses do not vary systematically with region.

3) Changes in lake condition are detectable against background variation.

4) The current condition of lake ecosystems is indicative of their ecological integrity – EI is quantifiable from current, measurable lake variables.

Table 2: **Measurements (potentially related to shallow coastal lake EI) collected during surveys in this study.**

Physical	**Macrophytes**
Measured maximum depth (m)	% cover (exotic + native)
Hydrologically altered (y/n)	Simpson Diversity index
Water quality	Weighted Simpson Index (accounts for exotics)
Conductivity µS/cm	**Macroinvertebrates**
pH	Density
Turbidity (ntu)	Richness
Absorbance at 440 nm	Evenness
Cl (g/m^3)	Diversity indices
Ca (g/m^3)	Invasive (index)
Mg (g/m^3)	**Rotifers**
Dissolved organic carbon (g/m^3)	Density
Light attenuation coefficient, K_d (m^{-1})	Richness
Chlorophyll *a* (mg/m^3)	Evenness
Total N (mg/m^3)	Diversity indices
Total P (mg/m^3)	**Metainvertebrates**
Total N/Total P	Density (Biomass)
Trophic Level Index (TLI)	Richness
NO_3-N (mg/m^3)	Evenness
SRP (mg/m^3)	Diversity indices
NH_4-N (mg/m^3)	**Food Web Metrics**
Euphotic depth A_{eu} = 4.6/Kd	Δ^{15}N Range
Bloom forming? Y/N	Δ^{13}C Range
Fish	Total food web area
Exotic fish catch per unit effort (CPUE)	Mean distance to centroid
Native fish catch per unit effort (CPUE)	Mean nearest neighbour distance
% Native fish	Foodchain length

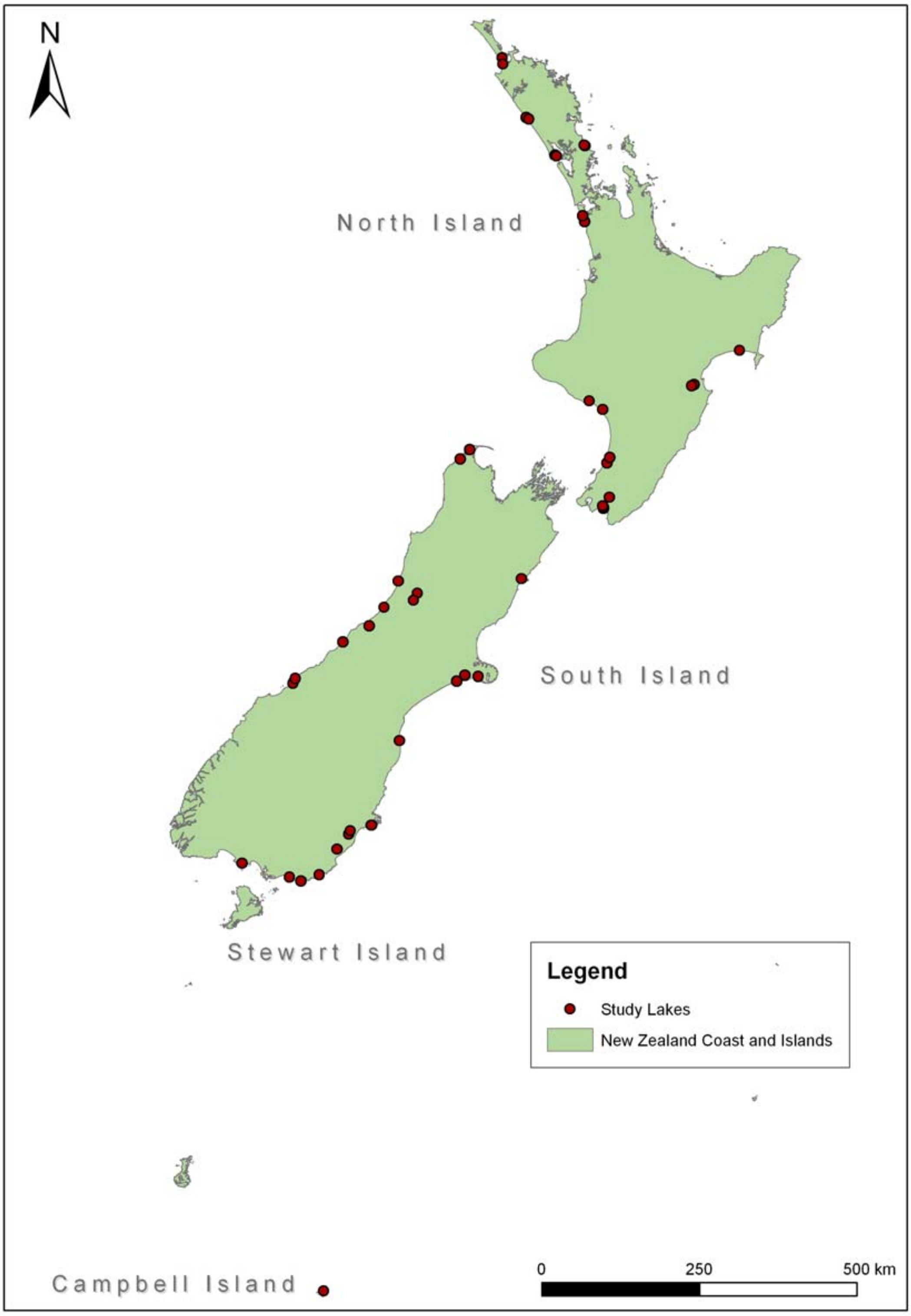

Figure 1: Locations of the 45 study lakes.

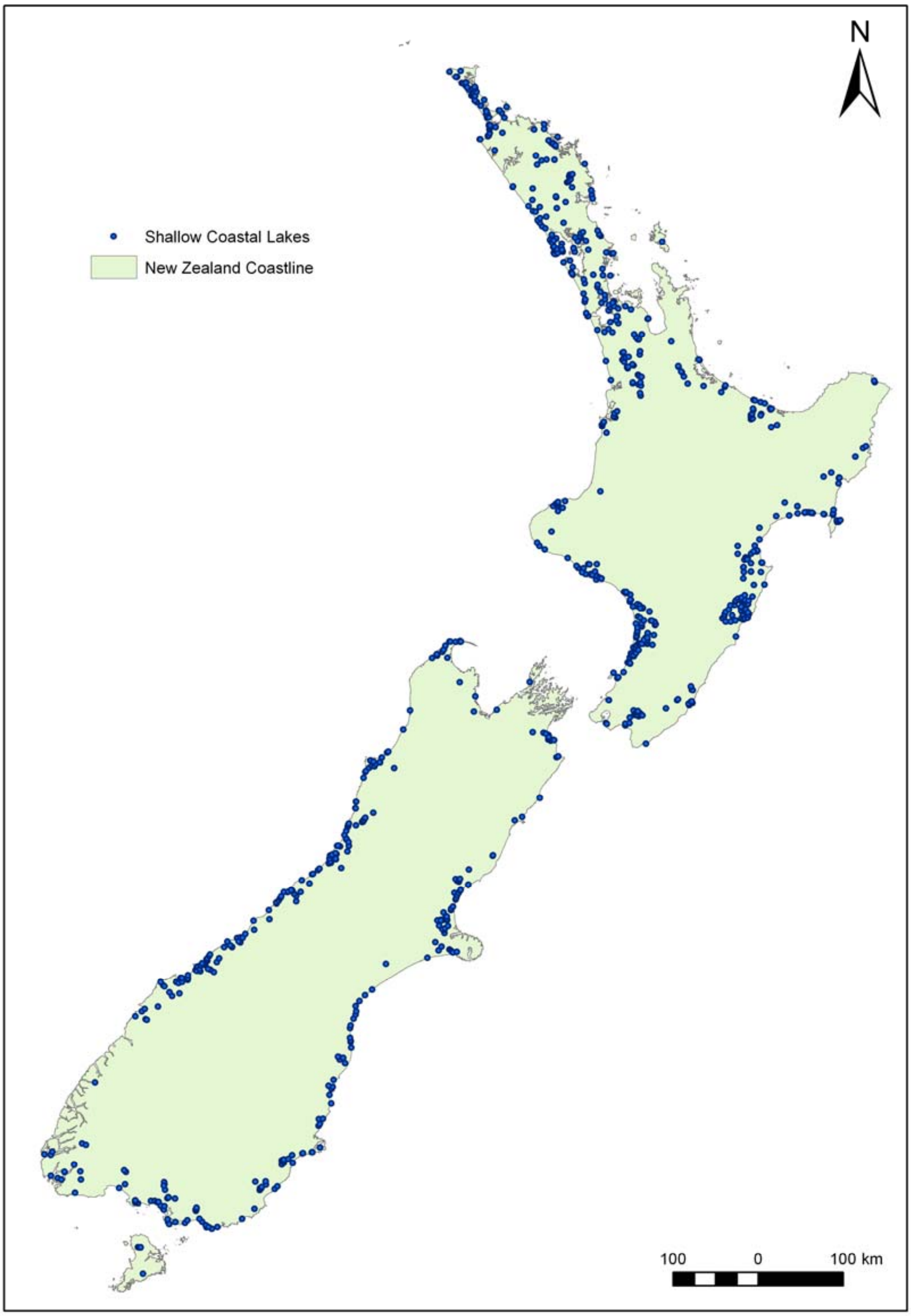

Figure 2: Locations of the approximately 900 known shallow, coastal lakes in New Zealand (lakes in the subantarctic islands, and the Chatham Islands, including Six Foot Lake, are not shown).

2.2.1. Disturbance Data (Human Pressure Gradients)

Six WONI human pressure gradients were identified by the shallow coastal lakes CDRP technical advisory group as potential drivers of lake characteristics (measured variables). We did not differentially weight the different land use pressures even though some land uses may have greater influence than others.

2.2.2. Impervious area in catchments

The percent of the lake catchment area covered by impervious surfaces (roads, buildings, etc) divided by lake area (obtained from De Winton et al. in preparation).

2.2.3. Native vegetation removal in catchments

The percent of the catchment converted to non-native forest or pasture *(*from De Winton et al. in preparation).

2.2.4. Surface water N load

Annual loads of total N (kg) from tributary streams was derived using the recently-improved Catchment Land Use for Environmental Sustainability (CLUES) model (http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/clues/). Loads are calculated from average N contributions to surface waters from categories of land cover - native and exotic forest, hill and high country (scrub, tussock, urban areas). Contributions from sediment, point-sources, rainfall, drainage and pasture (categorized into dairy, deer, sheep and beef) are also calculated. Pasture values were derived form stocking densities, provided from OVERSEER, an Ag-Research/MAF/fertilizer industry joint model that calculates catchment-scale N losses from these pastoral land uses. The annual N loading was then multiplied by water residence time (days) (calculated by the FWENZ model) in the lake to account for the time N was available for biological uptake.

2.2.5. Surface water P load

Surface water P load is the annual load of total P (kg) from tributary streams and was derived from the (recently improved) CLUES model. P loading is a function of catchment % pasture (dairy and other pasture), non-pasture area, vegetation type (forests, scrub), sediment load, and point sources. The annual P loading was multiplied by water residence time (days) in the lake to account for the time P was available for biological uptake.

2.2.6. Invasive macrophyte pressure

Invasive macrophyte pressure is the Aquatic Weed Risk Assessment Method (AWRAM) score derived by Champion and Clayton (2000). This is based on the highest-scoring or "weediest" invasive macrophyte present in a lake from records in the Freshwater Biodata Information System (FBIS). Invasive macrophyte scores were available for only 18 of the 45 study lakes. This pressure gradient is the subject of a separate report (Willis et al. 2009).

2.2.7. Invasive fish pressure

This pressure gradient was not identified in the contract for analyses (Appendix A) due to the limited extent of New Zealand lakes for which pest fish data were available. Pest fish scores for the surveyed lakes were derived from the New Zealand freshwater fish database using a scoring system derived by Wilding and Rowe (2008) and were available for 29 of the 45 lakes.

2.3. Field Methods

Lake surveys were conducted between 2005 and 2008 - each lake was visited once in the late summer (February-April) the most likely time of peak temperature, macrophyte biomass, primary productivity, animal diversity, and occurrence of toxic cyanobacterial blooms. Three shoreline sites were chosen in each lake to represent a range of habitats and a gradient of shoreline exposure to the prevailing wind and wave action. A 50 m transect extending perpendicular from the shore was sampled at each site. Deeper water (offshore) sites were also selected. During the first two years of field work in the South Island, three sites were sampled per lake. Due to a high degree of correspondence among physico-chemical parameters within lakes, we subsequently sampled two offshore sites in North Island and Campbell Island lakes. Sites were selected to include as many habitat types as possible.

2.3.1. Water quality

Sampling of physico-chemical variables and plankton was undertaken at sub-littoral sites in each lake. *In situ* lake measurements included: conductivity, Secchi depth and temperature (Table 2). Light profiles were measured at each site. Depth-integrated water samples were collected from the top ~2 m of the water column using a 150 mm diameter, tube sampler with a spring-valve. Water was collected into clean 20 L buckets on the boat and subsamples were collected for phytoplankton analyses, turbidity, nutrient analyses, dissolved organic carbon analysis, pH, and water colour analysis. Water was stored in clean, 5 litre polyethylene bottles. The bottles were kept in the dark, at ambient temperature for up to 5 hours until processing (filtering and freezing) at field laboratories. Field laboratory facilities were not available at several of the most remote field sites and water samples from those lakes were processed within 24 hours. Zooplankton was quantitatively sampled by two methods depending on site depth. At sites < 2 m deep, water containing zooplankton was collected using the integrated tube sampler and a known volume of the lake water was then passed through a 50 micron mesh net. At sites > 2 m deep, zooplankton was collected by vertical hauls through the entire (macrophyte-free) water column using the same net. Zooplankton was preserved in 2% formalin. Phytoplankton was preserved in acid Lugol's iodine. Phytoplankton collections made for this study have not been able to be analysed within the scope of this project and will be reported on separately.

2.3.2. Benthic invertebrates

Benthic invertebrates samples were collected in triplicate at two locations along each shoreline transect: the littoral zone (5-10 m from shore), and the offshore zone (~50m offshore). Benthic grab samples were collected with either a Wisconsin Grab (2004, 0.1 m^2) or with Ponar dredge (2004-08, 0.0225 m^2) in cases where toxic cyanobacterial blooms were occurring and physical contact with the water was potentially hazardous. Material from the triplicate benthic grabs was combined (for each sampling point), sieved through a 400 µm mesh sweep net, and preserved in 70% isopropanol for taxonomic analysis. Live macrophyte material contained in grabs was washed of adhering invertebrates, dried and weighed to provide an estimate of macrophyte standing stock at each location.

2.3.3. Fish surveys

Fish surveys were conducted using two trapping methods. At each of three sites, two lines of 10, baited gee-minnow traps (mesh size ~ 5 mm) were deployed overnight, extending perpendicular from the shoreline toward the centre of the lake. Three 10 m fyke nets were also deployed overnight at each site. In several very small lakes, only one trap line and fyke net were deployed at each of the three sites. Fish were counted, fork-lengths to 1 mm were recorded and fin clips were collected from up to 10 individuals of each species. Fish tissue samples were frozen as soon as possible (usually within 5 hours) for N and C isotope analyses. Lateral muscle tissue (approximately 5 g) and/or caudal fin material was collected and frozen. For eels, both muscle and fin tissues were collected from the first 14 lakes, and a relationship between muscle and fin isotopic signatures determined. Following this (for the remaining 31 lakes) only fin tissue was collected from eels and the resulting isotope ratio data were converted to muscle equivalents.

2.3.4. Food web collections

Macrophyte material and invertebrates for stable isotope analysis were obtained from littoral areas of wadeable depth using a 400μm mesh sweep net, and from Ponar grabs collected from the littoral and offshore areas. Between 5-10 individuals of the most common invertebrate taxa were sorted live into 25 ml vials filled with lake water, left overnight to allow gut contents to clear, and frozen. Terrestrial detritus (e.g., leaves, grasses, wood) samples were obtained at each site from the dominant riparian species along the lake shore, and detritus (coarse benthic organic matter, CBOM) was also collected using a sweep net. Detritus samples were thoroughly washed to remove all live invertebrates. Fine benthic organic matter (FBOM) was obtained at each site by collecting surface sediment samples from littoral (5-10 m from the shore) and offshore (50 m) areas using a Ponar grab. Coarse organic materials such as wood or leaves were removed from the surface sediment layer. Seston was filtered onto ashed, 0.45 μm glass fibre filters until clogged and frozen for isotope determination. All material was placed in separate vials and stored frozen.

2.3.5. Submerged macrophytes

Submerged macrophytes were quantified via standardized diving survey methods (Braun-Blanquet cover estimates) during 2005-2006 field seasons. But due to logistical constraints submerged macrophytes were surveyed from the lake surface during the 2007 and 2008 field seasons. Macrophyte cover, canopy height, and plant species composition were quantified at 5m intervals along the 50 m transects at each site. Lake-bed surface substrate was also visually categorized into % cobble, sand, and silt.

2.4. Laboratory Methods

2.4.1. Water quality and zooplankton

Usually within 5h, but sometimes within 24h, lake water subsamples were processed and then frozen for laboratory determinations of various solutes. Water was passed through GF/F filters, filtrate volume recorded, and filters were then frozen for fluorometric Chlorophyll-*a* and phaeophytin determinations (Turner Model 450 fluorometer). Additional subsamples were filtered through acid-washed GF/F filters and frozen for determination of dissolved reactive phosphorus (DRP), nitrate (NO_3-N) and ammonium (NH_4-N) using an autoanalyser and standard chemistries (Skalar San System autoanalyser). Whole water samples were also frozen for total phosphorus (TP) and total nitrogen (TN) analysis after wet oxidation. Nitrogen and phosphorus were subsequently measured on a Skalar colorimetric autoanalyser using standard chemistries. Subsamples were also filtered through 0.45 µm pore size Millipore membrane filters and frozen for the determination of dissolved calcium, magnesium and chloride ion concentrations as well as dissolved organic carbon and water colour. Chloride ion concentration was subsequently measured by flow injection analysis using a Foss Tecator FIASTAR 5000, and calcium and magnesium ion concentrations were measured by flame ionisation atomic absorption spectrophotometry using a Varian SpectrAA 220FS atomic absorption spectrophotometer. Dissolved organic C (DOC) was analysed using a Shimadzu TOC analyser, and light absorbance at 440 nm using a 10 cm quartz cell in a Shimadzu Mini 1240 UV-vis spectrophotomer. Zooplankton taxa, including rotifers, were identified and enumerated and wet weight biomass was determined.

2.4.2. Benthic invertebrates

Benthic invertebrates were identified to the lowest taxonomic level possible - in some cases to species level, but some groups were identified only to phylum (nematodes), class (oligochaetes and mites), or family (dipterans). Taxonomic samples were subsampled using a barrel splitter, and >25% of the entire sample was identified until 100 individuals of the most abundant taxa were counted.

2.4.3. Food web (isotope) analyses

Macrophyte materials were freeze-dried, homogenized with a mortar and pestle, and weighed into tin capsules for mass spectrometer isotopic analysis. Whole invertebrates (typically >5 individuals, fewer for some rare taxa) were freeze-dried, homogenized, and lipid-extracted before being weighed into capsules for isotopic analysis. Invertebrates such as snails and caddis flies were removed from cases or shells prior to processing. Surface sediments were treated with 5% HCl to remove carbonate deposits (e.g., snail shells), freeze-dried, and processed as for macrophytes. Fish muscle and fin tissue was freeze-dried, and processed as for invertebrates. Lipids were extracted from all animal tissues on a Dionex ASE 200 Accelerated Solvent Extractor (Dionex Corporation, Sunnyvale, California) using 100% dichloromethane. Samples were extracted twice in cells heated to 70°C at 2000 psi with static hold periods of 5 min and a 100% flush volume, after which they were dried at 40°C for 12 h to evaporate residual solvent. $\delta^{15}N$ and $\delta^{13}C$ were determined by mass spectrometry on a Finnigan MAT Delta Plus Continuous Flow Mass Spectrometer (Thermo Finnigan, San Jose, California, USA). Results are reported as the relative difference between the sample and international standards of C and N (Pee Dee Belemnite for C, and air for N) with an analytical precision of 0.1‰. All isotope analyses were performed at the Water and Aquatic Sciences Research Program, University of Victoria British Columbia.

All water chemistry analyses, and taxonomic analyses of zooplankton and phytoplankton were performed at the University of Otago, Dunedin. Macroinvertebrate species analysis taxonomy was performed within NIWA.

2.4.4. Expert Assessment of E1

Expert assessment EI was determined after all field work was completed (in 2008). There was no *a priori* definition of EI for coastal shallow lakes. Three freshwater ecologists (two career ecologists and one senior technician) who had visited most or all of the study lakes independently ranked all lakes from 1 (highest integrity) to 45 (lowest integrity) using their own conceptions of "integrity". The three rankings were averaged for analysis.

2.5. Quantitative analyses

Standard deviations tended to increase with mean values of conductivity, nutrient and ion concentrations, Chlorophyll *a* and phaeophytin (although coefficients of variation did not). These data were transformed (ln) for correlation analyses.

All fish density and catch per unit effort calculations were adjusted for trap numbers and number of nights (rather than hours) deployed because fishes are move around and are much more likely to be caught at night – "overnight" is therefore a more accurate effort unit.

A pilot analysis of benthic invertebrate communities showed no statistical differences between shoreline and offshore sites, therefore taxonomic analysis of sub-littoral sites was not conducted for the majority of the lakes.

2.5.1. Diversity indices

We calculated both Shannon (H') and Simpson (D) diversity indices for benthic invertebrates, metazooplankton, and rotifers. Data were composited from the three sites in each lake.

The Shannon Index (H') was computed as

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Equation 1.

Shannon index where S is the number of species (richness) and p_i is the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

The Simpson's diversity index (D) was calculated as:

$$D = \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)}$$

Equation 2.

Where S is the number of species (richness), n_i is the number of individuals in species i, p_i is the fraction of all organisms, and N = the total number of individuals counted. A modified Simpson index was calculated for submerged macrophytes. A low Simpson index indicates high diversity, whereas a high value correlates to a lower diversity. Simpson indices were calculated for native species, and adjusted for the negative value of non-native macrophytes by adding a value of 0.25 for non-aggressive exotic species presence (eg. *Ranunculus trichophyllus, Aponogeton distachyus)*, 1.0 for aggressive exotic species (*Ceratophyllum demersum, Egeria densa*, and *Lagarosiphon major*), and 3.0 when no submerged macrophytes were found (as in highly disturbed lakes such as Ellesmere).

2.5.2. Trophic level index

Trophic level index (TLI) (Burns et al. 2000) was calculated by logarithmically transforming TN, TP, Secchi depth (Z_{sd}) and Chlorophyll *a* data so that each parameter was scored on a similar scale (after Burns et al. 2000). The average of the four component scores is TLI. Trophic state classes are defined based on the TLI range (Table 3). The formulae for the four component indices are:

$TLn = -3.61 + 3.01\log(TN)$

$TLp = 0.218 + 2.92\log(TP)$

$TLs = 5.10 + 2.27\log(1/Z_{sd} - 1/40)$

$TLc = 2.22 + 2.54\log(Chl\ a)$ Equation 3.

Table 3: **Trophic states based on range in average Trophic Level Index (TLI), and corresponding nutrient enrichment descriptions, as described by Burns et al. (2000).**

TLI	Trophic State	Nutrient Enrichment Description
< 1	Ultra-microtrophic	Practically Pure
1 – 2	Microtrophic	Very Low
2 – 3	Oligotrophic	Low
3 – 4	Mesotrophic	Medium
4 – 5	Eutrophic	High
5 – 6	Supertrophic	Very High
> 6	Hypertrophic	Saturated

2.5.3. Boosted Regression Trees (BRTs)

BRT models were fitted using “R” software (R Development Core Team 2006) version 2.3-1, using gbm package version 1.5-7 plus custom code developed by Elith et al. (2008). BRT is used here to identify variables with the most explanatory power (Elith et al. 2008). BRT builds and then merges results from multiple models – it uses both regression tree and boosting algorithms to combine a collection of models. BRTs are of particular value in controlling overfitting, a common pitfall when working with small datasets such as this one. The end BRT model is a program rather than an equation.

We constructed BRT models in two ways: initially the strongest correlates from among the ~40 measured variables (Table 2) were determined for each individual pressure gradient (i.e. the measurements were treated as predictors and pressure gradients were treated as responses). This was an iterative process in which subsets of 5 variables (the maximum recommended for a dataset of only 45 observations, J. Leathwick personal communication) were compared to the pressure gradient and only the strongest correlates were retained for further analyses. The iterative process was used because little is known about shallow coastal lakes, and had no *a priori* expectations about which variables might have the strongest explanatory power or links to the WONI pressure gradients.

We also constructed BRT models using the four pressure gradients (N loading, P loading, native vegetation removal, and imperviousness) as predictors for each of 27 measured lake variables as response. The 27 variables used in this second approach were those that showed the greatest potential in the correlation and first BRT analyses. The second BRT approach (in which pressure gradients are used as the predictors) is similar to the approach used to develop EI indicators in rivers (Clapcott et al in.

preparation) and is based on the assumption that measured variables are a proxy for EI.

The algorithm (essential part of the R program) that was used for the pilot analysis is:

```
lake.gbm <- gbm.step(data = lakes,
 gbm.x = min.preds,
 gbm.y = 6,
 family = "gaussian",
 learning.rate = 0.00025,
 tree.complexity = 3)
```

3. Results

3.1. CDRP lakes datasets

In this section we discuss the geographic range, quality, and robustness of the CDRP lakes datasets in terms of the pre-determined WONI pressure gradients: impervious area, native vegetation removal, N and P loading, and invasive macrophyte species (see milestones 5.1, 6.1, and 7.1; Appendix A).

3.1.1. Geographic range of the data

A limitation of the shallow coastal CDRP lakes dataset is the small number of study lakes (45). Data collection and analyses, however, are costly, the data sets for each lake are large and complex, and a meaningful expansion of the number of study lakes was not possible. The 45 lakes of our study set comprise approximately 5% of the c. 900 shallow coastal lakes in New Zealand. The geographic range represented by our study lakes was as broad as was possible, and the 45 lakes (Figures 1 and 2) are geographically representative of New Zealand's ~900 shallow coastal lakes. In the most intensively agricultural areas of New Zealand such as the Waikato and Canterbury, no shallow coastal lakes could be considered "minimally impacted" by human activities, but lakes were selected to represent the existing range of human disturbance (Table 4). The dataset is therefore relatively robust to regional or latitudinal bias.

Table 4: **Ranges and average values of WONI human pressure gradients for the 45 study lakes. Zero values reflect catchments with no or minimal human activity.**

	Catchment impervious (%)	Indigenous vegetation removal (%)	N load (T/ha/yr) * residence time (d)	P load (T/ha/yr_ * residence time (d)	Invasive macrophyte pressure (AWRAM score)
min	0.0	0.0	0.006	0.0	0.0
max	21.9	100.0	66633	2900	460.8
mean	3.7	57.8	2856	204	50.6

3.1.2. Quality of data collected for this study

The quality of field data collected for this study is generally high. Water chemistry samples from sites within each lake yielded relatively consistent results (e.g. average coefficient of variation for Chlorophyll *a* was 0.18, for TN was 0.12), and some difference between sites within lakes is expected due to wind, bathymetry and other lake characteristics. A pilot analysis of two South Island Lakes showed that benthic invertebrate assemblages were consistent between the paired littoral and offshore sites within each lake (D. Kelly personal communication). Offshore samples were therefore collected but not analysed in years 2-4 of the study. The complete data set contains relatively few missing data points (Appendix B), and our data are closely comparable to available, related data sets. For example, TLI derived during this study was strongly correlated with TLI derived from long-term datasets (r^2 = 0.81; Sorrell et al. 2006)]. One exception to the generally high quality of data collected here are submerged macrophyte data collected in 2007-2008. Due to logistical constraints, the 2007-2008 macrophyte surveys were conducted from the surface by a non-expert and not by a diver as in the first two years of the project.

3.1.3. Quality of the WONI Human Pressure Gradient data

Pressure factors were calculated for 3820 New Zealand Lakes > 1 ha in size by De Winton et al. (in preparation), and relevant data for the lakes of this study were extracted from the larger set. N and P loading rates for the 45 lakes of this study were calculated using the CLUES model. N and P loading rates were not calculated for two lakes of this study, Upper Onoke and 5-mile Lagoon, because these are not included in the FWENZ database. All pressure gradients for Six Foot Lake on Campbell Island were estimated – the impervious and indigenous vegetation removal pressure gradients were assigned 0 values because the island is uninhabited, and N and P loading were assigned low values (10th percentile). Seals and birds apparently provide a substantial nutrient subsidy to this lake (M. Schallenberg personal communication), and several of the other shallower (<4 m) lakes experienced resuspension of bottom sediments during sampling. Unfortunately, the CLUES model does not account for animal-mediated nutrient additions or within-lake nutrient loading. Thus the quantification of nutrient loading was limited to riverine sources calculated from the WONI pressure gradient estimates.

Most of the pressure gradients examined here were independent (not co-linear). The exceptions were that N and P-load pressures are strong covariates (Table 5) - these are both primarily a function of agricultural practices in the catchments and are therefore closely linked. The N and P pressure gradients also co-varied with the invasive fish pressure gradient. The impervious area, indigenous vegetation, and N and P load pressure gradients are co-linear at a national scale (De Winton, personal communication).

3.1.4. Impervious cover in the catchment

Values for this pressure gradient were derived from Landsat data and are, ostensibly, of high quality (accurate). A relatively large number of catchments had <10% impervious area (Figure 3a), indicating that only a relatively small portion of the gradient range was well represented. Previous studies suggest that most of the negative effects of imperviousness occur between 5-11% imperviousness, and catchments with >11-13% imperviousness are considered degraded (Morse et al. 2002; Miltner et al. 2003).

Table 5: Pressure gradients correlation matrix for the 45 lakes of this study. At larger scales (>> 45 lakes) the pressure gradients are known to co-vary. Absolute values > 0.3 suggest a possible relationship and are in bold.

	Pearson correlations				
Pressure gradients	**Impervious area n = 44**	**Indigenous vegetation removal n = 44**	**N load * residence time n = 44**	**P load * residence time n = 44**	**Invasive macrophytes n = 17**
Indigenous vegetation removal n=45	0.18	1.00			
N load * residence time n=45	-0.04	0.16	1.00		
P load * residence time n=45	-0.09	0.14	**0.93**	1.00	
Invasive Macrophytes n=17	0.28	0.06	-0.06	0.01	1.00
Invasive Fishes n=28	-0.10	0.04	**0.55**	**0.57**	-0.02

3.1.5. Loss of native vegetation from catchments

The native vegetation loss pressure gradient values were derived form the Land Cover Database 2. Not surprisingly, there were a disproportionately large number of lakes in catchments almost entirely converted to agriculture or forestry.

3.1.6. N and P loading

N and P loading pressure gradient values were derived from CLUES model output and were multiplied by lake water residence time (days) calculated in the FWENZ database from lake inflow, outflow and volume. Both models are based on a set of assumptions, and error is therefore multiplicative. We believe, however, that the resulting N and P loading rates are reasonable based on examination of lake characteristics and surrounding landscapes. The frequency distribution is skewed toward the lower end of the range, with two lakes (Ellesmere and Wairarapa) receiving N and P loads two to four orders of magnitude greater than all other lakes (Figures 3 c and d, Appendix B).

3.1.7. Invasive plants (submerged macrophytes)

This pressure gradient was derived from the Aquatic Weed Risk Assessment programme (AWRAM, Champion and Clayton 2000). The highest (weediest) invasive plant score recorded for each lake in the Freshwater Biodata Information System (FBIS). The AWRAM scores are not correlated with modified Simpson diversity indices calculated from the survey data collected during this study (Figure 4). According to the AWRAM scores, 6 of the 18 study lakes contained no exotic macrophytes or no macrophytes at all (Figure 3e) - this is consistent with our surveys. Because so few lakes are represented by the WONI pressure gradient, we have excluded the invasive macrophyte pressure gradient from the following analyses. However, see the related report focussing on national-scale patterns in invasive macrophytes (Willis et al. 2009).

The distribution of invasive macrophyte scores (Figure 3e) is clearly skewed toward the lower end of the scale. Additionally, highly disturbed lakes containing no macrophytes, notably Spectacle Lake, received 0 AWRAM scores (pristine). While it’s true that no exotic macrophytes grow in these lakes, this is only so because conditions are inhospitable to any and all macrophyte growth. No relationship (positive or negative) between the AWRAM score and the macrophyte index score derived in this study is evident (Figure 4). For analyses, a pressure index value of 500 was assigned to Spectacle Lake - a highly degraded lake which supports no growth of any submerged macrophytes whatsoever. The lack of a relationship is likely a result of the small number of lakes represented (18).

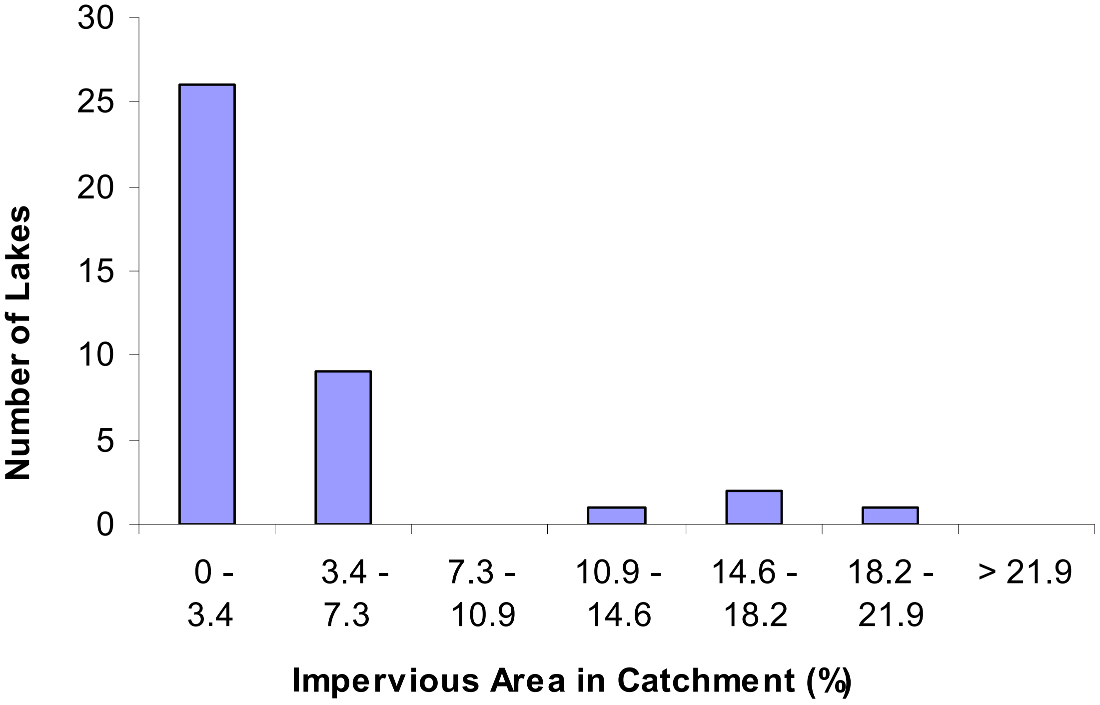

Figure 3a: Distribution of impervious area pressure gradient values for the lakes of this study.

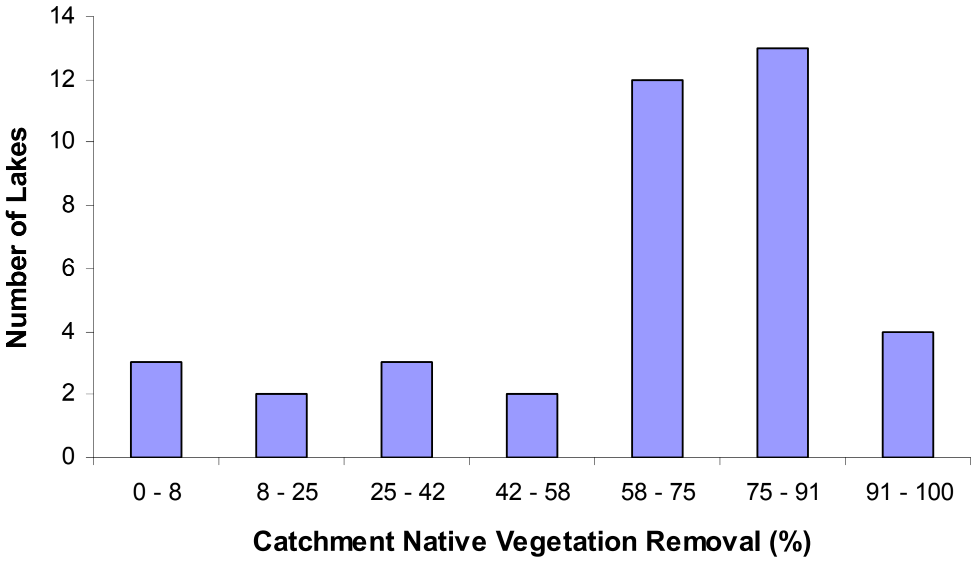

Figure 3b: The distribution of native vegetation removal pressure gradient values for the lakes in this study.

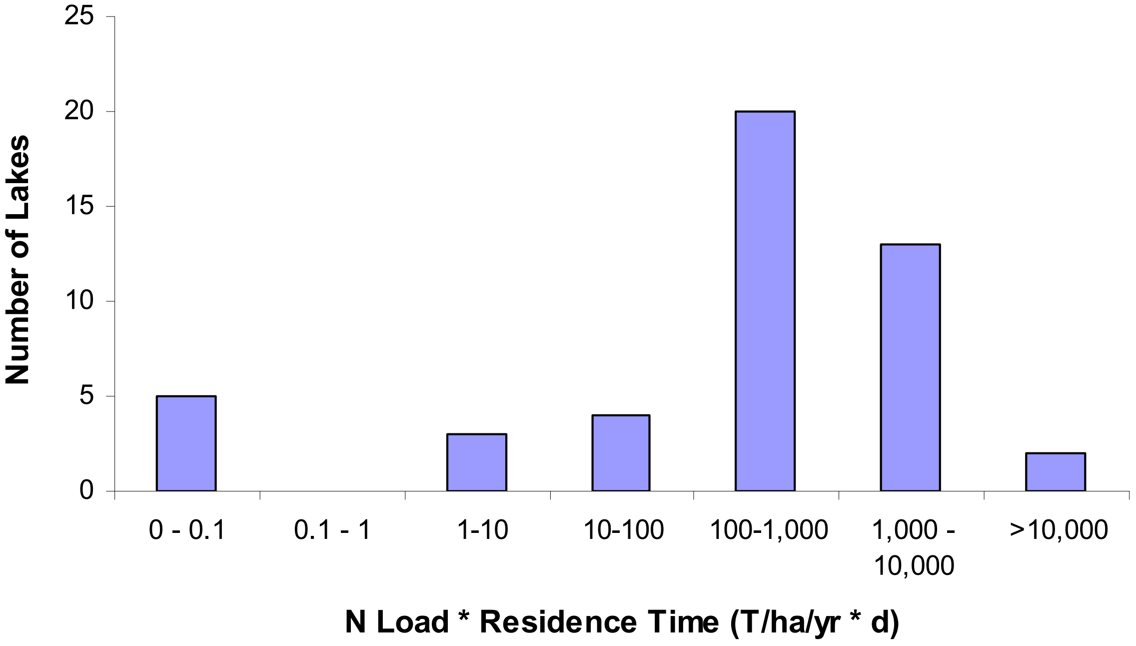

Figure 3c: **The distribution of the N loading pressure gradient values for the lakes of this study – X-axis values are on a log scale**

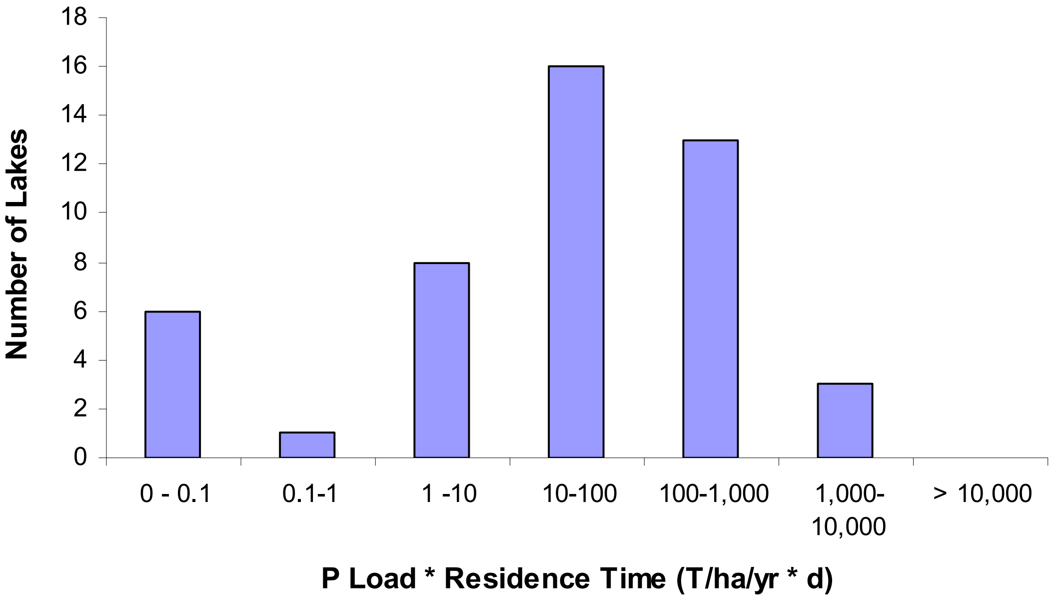

Figure 3d: **The distribution of the P loading pressure gradient values for the lakes of this study – X-axis values are on a log scale.**

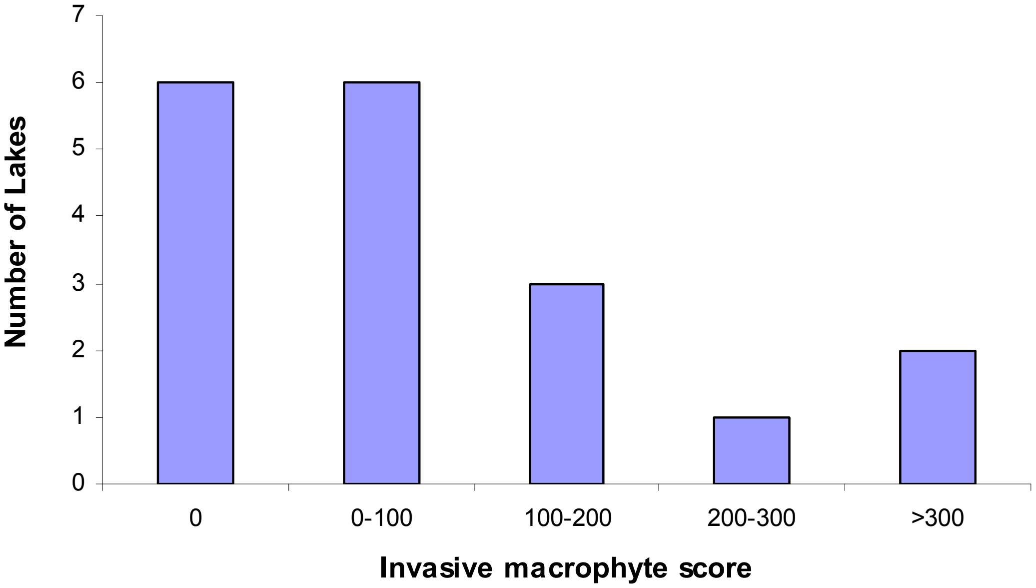

Figure 3e Distribution of the invasive macrophyte gradient values for the 18 lakes of this study that had AWRAM scores associated with them.

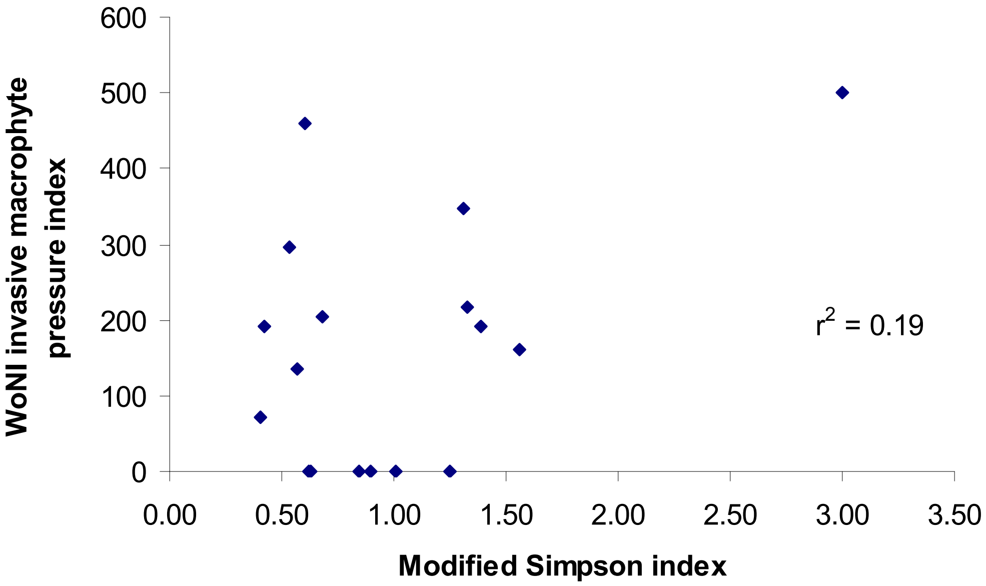

Figure 4: Invasive macrophyte pressure derived from AWRAM scores (on the Y-axis) compared to a weighted Simpson diversity index from this study that includes negative values for invasive species (on the X-axis).

Although analyses of the invasive fish WONI gradient are not specified in the relevant milestones (Appendix A), a brief discussion is warranted. Invasive fish scores were available for 29 of the 45 study lakes. Surprisingly these scores were not correlated with our survey data (% native fish or native fish CPUE: Appendix B). The WONI scores were, however, correlated with several water quality variables including salinity (lagoons tend to contain more invasive fishes), K_d and foodweb $\delta^{15}N$ range. The invasive fish score was also correlated with the invasive macrophyte, and the N and P loading WONI pressure gradients. Fish survey data collected for this study co-varied (Pearson's correction > 0.30) with many of the measured variables (Appendix C): native fish CPUE was correlated with the Macrophyte cover, Chl *a*, TN, TP, TLI, macroinvertebrate densities, meta-zooplankton and rotifer diversity measures. Native species % was correlated with macroinvertebrate diversity measures, and conductivity.

3.2. Robustness

Robustness refers to the sensitivity of a study's results to deviations in the assumptions (Section 2.2) that are made to obtain those results. The first and second assumptions are related and can be discussed together:

Assumption 1 - The 45 lakes of our dataset are representative of New Zealand's ~900 shallow coastal lakes.

Assumption 2 - Shallow coastal lakes are a discrete group of lakes, are systematically different from other lake types (e.g. deep glacial) and respond similarly (i.e. amongst coastal lakes) to human pressures. Responses do not vary systematically with region.

Assumption 1 is relevant because we intended to extrapolate from the data collected here to all of New Zealand's shallow coastal lakes. As discussed above, the geographic range represented by our study lakes was as broad as was possible, and the 45 lakes (Figures 1 and 2) are geographically representative of New Zealand's ~900 shallow coastal lakes. In the most intensively agricultural areas of New Zealand such as the Waikato and Canterbury, no shallow coastal lakes could be considered "minimally impacted" by human activities, but lakes were selected to represent a national-scale picture of the existing range of human disturbance (Table 4). The inclusion of lakes affected by a range of human pressures within each region renders the dataset relatively robust to regional or latitudinal bias. It is likely, however, that more accessible lakes are over-represented in this study relative to more remote lakes – accessible lakes are likely to experience higher rates of anthropogenic disturbance, which means that our assessments are skewed toward a disturbed condition. However, this is likely to be a minor consideration given the almost total lack of existing information on shallow coastal lakes in New Zealand – all new information, at this point, is valuable.

Also implicit in theses assumptions is the concept that pressure gradients in the lake catchments examined here do not vary systematically by region (and therefore do not include a climatic or geological covariate). ANOVA showed that the catchment impervious pressure gradient did not vary between regions (P = 0.20, F = 1.45), and nor did N loading (P = 0.49, F = 0.93). Native vegetation removal pressure, however, varied significantly between regions (P < 0.001, F = 5.23); the West Coast, Wairarapa, and Tasman regions comprise one group with low average removal of native vegetation (19.7-32.8%), and the rest of the regions comprise a second group with high average removal of native vegetation (63.2 – 86.0%). We believe, however, that the potential bias induced by this pattern is relatively minor because there is no obvious systematic climatic or geologic difference between the two groups of regions. We conclude that the data are relatively robust regarding assumptions 1 and 2.

Assumption 3 - Changes in condition are detectable against background variation.

This assumption is potentially violated if the range of variation in reference conditions in shallow coastal lakes is very high – for example, if many of the study lakes were naturally eutrophic (i.e. if high EI conditions included eutrophy) then human-derived nutrient loading will need to be separated from natural nutrient loading if this is to be considered as a driver of EI. For instance, Six-foot Lake (located on uninhabited Campbell Island) is undisturbed by humans but seabirds and sea lions using the lake were found to be responsible for a substantial nutrient influx. Probably because of this natural, animal-mediated nutrient loading, the TLI of Six-foot Lake was 5.23 - in the supertrophic category (Table 3). For comparison, the overall average TLI of all lakes in this study was 4.1.

We presently lack the historical information on reference conditions and background variation of New Zealand shallow lakes that are necessary to appropriately normalise measures of EI. Additionally, EI will vary with the natural condition and function of each lake, and may not be constant over extended time scales because lakes may change even without human interference (e.g. bog lakes that gradually fill up with vegetation and disappear).

This study included no *a priori* descriptions of how measured variables are related to EI. For example, are Chlorophyll *a* concentrations negatively correlated with EI? It might intuitively be considered that low Chlorophyll *a* is more likely to be found in minimally impacted lakes but this does not seem to be the case in coastal shallow lakes. Because we lack historical understanding of reference conditions of New

Zealand shallow lakes, we conclude that the current lakes data set is not robust in regard to this assumption.

Assumption 4 - The current condition of lake ecosystems is indicative of their ecological integrity –i.e. EI is directly quantifiable from current, measurable lake variables

Although the contract guiding this project states that we will "*define and quantify relationships between ecological integrity and human pressures on shallow coastal lakes*" the discussion under Assumption 3 above illustrates that there were difficulties in achieving this. While components of EI, and some potentially useful indicators of these were defined in Schallenberg et al. (in review), how the indicators are to be combined into a holistic EI score has yet to be determined. These difficulties relate to the fact that there are still no established guidelines to describe EI for shallow coastal lakes.

This project provides a significant advance in our understanding of New Zealand's shallow lakes and considerable effort has been expended to develop the list of qualities that may contribute to EI (Table 1), but there are still no established guidelines to describe EI.

There are two potential responses/solutions to this problem: EI can be obtained by "expert assessment" and/or EI can be obtained from a composite suite of metrics relating to lake condition if these cover a wide enough range from (say) pristine to highly degraded.

(1) If EI is integral to policy development, and/or operational management decision-making processes for select individual lakes, it can be "quantified using 'expert assessment'. In this study an expert assessment derived EI averaged from three freshwater ecologists who visited most or all of the study lakes was strongly correlated with the indigenous vegetation pressure gradient, and weakly correlated with impervious area, N and P loading pressure gradients (see next section). The qualitative integrity rankings made independently by the three experts were in strong agreement (average $r^2 = 0.79$), and were correlated with many of the measured variables (Table 6 contains some examples, also see next section). The expert assessment derived EI integrates many processes and factors that are difficult to capture with "one point in time" measurements. It includes the benefit of years of experience, integration of lake and landscape characteristics, and integration of time-related processes (e.g. experts can account for samples collected on a windy day, or at the end of a long, hot spell).

(2) Instead of providing a single composite measure of EI, WONI pressure gradients could be related to various indicators of lake condition. This allows a more objective focus on better-defined measurements of lake condition such as ecological status (as used by the European Water Framework Directive, e.g. Cabecinha 2009) and known mechanisms of degradation captured by the WONI pressure gradients. This is possible as shown in Section 3.4 below. The evidence shows that when all four WONI pressure gradients used here are high, the lake is in a degraded state. There are some lakes in this study while arguably not "pristine" are clearly in a good ecological condition and in these cases the WONI pressure gradients are low. It is not clear whether a "composite EI metric" (which is the approach confirmed by the TAG) should be a single number, or a suite of additive condition scores. The condition metrics could be simply added if each component has the same weight, or alternatively the ecological condition scores could be weighted by the number of significant correlations with WONI pressure gradients and then summed.

Table 6: Examples of variables (mean value +/- standard deviation) in lakes ranked highest using expert assessment EI (the most pristine lakes, including Six-foot Lake) and the rest of the lakes (medium to low expert assessment EI).

	Chl *a* (mg/m^3)	NH_4-N (mg/m^3)	TN (mg/m^3)	TP (mg/m^3)	Metazooplankton biomass (mg wet l^{-1})	Rotifer Shannon index
20% of lakes with highest EI	1.9 ± 2.1	17.7 ± 6.8	376 ± 175	14 ± 7	7.6 ± 1.02	-4.5 ± 10.8
80% of lakes with lowest EI	2.7 ± 3.06	47.9 ± 117.7	1079 ± 819	110 ± 143	4.5 ± 1.49	-11 ± 31.2

3.3. Exploratory (correlation) analysis

3.3.1. Redundancy/Collinearity:

Pearson's correlations indicated that many of the measured variables covaried (Appendix C). Ion concentrations Ca, Cl and Mg co-varied strongly (average correlation of ~ 0.86) and concentrations were therefore averaged to produce one variable termed "ions". Chlorophyll *a (*Chl *a)* concentration, phaeophytin concentration, and light attenuation coefficient (K_d) also covaried strongly (average correlation = 0.74). Because phaeophytin is a product of Chl *a* degradation (Pearson's correlation = 0.82), we used Chl *a* only in the BRT analyses. Chl *a* and K_d also covaried (Pearsons correlation = 0.73), but we retained both in the quantitative analyses because these are distinct and viable alternatives for monitoring. We note however that Chl *a* is more easily and more commonly measured than K_d in standard state of environment monitoring conducted by agencies such as regional councils. TLI is calculated from TN, TP, Chl *a* and Secchi depth. TLI is valuable as a composite score and was, in fact, correlated with many other measured variables: native fish CPUE (0.48), % macrophyte cover (-0.56), macrophyte weighed Simpsons index (0.31), pH (0.48), DOC (0.60), K_d (0.57), metazooplankton biomass (0.38), and expert assessment EI (0.75). Because the components of TLI do not co-vary strongly, however, we retained all as predictors

The indigenous vegetation removal pressure gradient was correlated ($P > 0.30$) with 7 of the measured variables – more than any of the other pressure gradients (Table 7). The N load pressure gradient was correlated with 4 variables, P load was correlated with 5 variables, and the catchment impervious pressure gradient was weakly correlated (Pearsons coefficient > 0.30 and < 0.35) with rotifer diversity indices and macroinvertebrate richness (Appendix C). We note that expert assessment EI was strongly correlated with the vegetation pressure gradient (Table 8, Pearson correlation = 0.78, $r^2 = 0.60$), and perhaps weakly correlated with all three other pressure gradients (Pearson correlations = 0.25). Expert assessment EI was correlated with 11 measured variables – more than any of the pressure gradients (Table 7). Thus expert assessment EI is integrative of both predictors and responses in this study.

\Most of the correlations shown in Tables 7 and 8 were positive – for example, as the P load pressure increases, so does conductivity, the light attenuation coefficient (K_d), and Chlorophyll *a* concentration – but rotifer diversity decreases (is negatively correlated) with increasing P load. We note that these trends are all typical symptoms of eutrophication. The N and P load pressure gradients are both positively correlated with the adjusted Simpson's macrophyte index, indicating that higher nutrient loads were associated with decreasing diversity of native macrophytes, increased incidence of invasive macrophytes and, at the highest N and P loads, the loss of all submerged macrophytes. We note that the loss of indigenous vegetation was correlated with TN and TP concentrations, but surprisingly, N and P loading pressures were not correlated with in-lake TN and TP. Reasons for this include:

1) Nutrient concentrations in shallow lakes at a point in time are influenced by processes other than just loading rate such as internal nutrient recycling, wind-driven re-suspension and sedimentation.

2) The CLUES model predictions of loading rates may not be accurate in the often small catchments that feed the study lakes. However, the relatively strong correlations between Chl *a* and K_d and the N and P loading pressures, do suggest that the loading pressures elicit environmental responses. We note that the signs of these correlations generally conform to expectations (i.e. condition deteriorates with increasing pressure).

Table 7: Summary of correlation coefficients equal to and greater than 0.30 relating the WONI pressure gradients to measured variables and expert assessment EI.

	Macrophyte weighted Simpson index	Ln conductivity	Ions (mean for Ca, Cl, Mg)	pH	Absorbance at 440 nm (ABS440)	Chl *a*	Ln TN	Ln TP	Rotifer Simpson index	Macro-invertebrate richness	δ15N range	% Native fishes	Expert assessment EI
Catchment impervious pressure									-0.34	-0.32			0.25
Indigenous veg removal pressure		0.34		0.71	-0.47	0.30	0.56	0.47				-0.36	0.78
N load * residence time	0.51	0.55	0.62			0.47							0.25
P load * residence time	0.40	0.49	0.53			0.56			-0.33				0.25
Invasive macrophyte pressure						-0.45	-0.43	-0.38					-0.30
Invasive fish pressure	0.46		0.45								0.38		0.20

Table 8: Pearson's correlation analysis suggests that 13 of the variables measured in this study were related to expert assessment EI rank (Pearson's correlation coefficients ≥ 0.30). We note, however, that K_d and Chl *a* co-vary, as do Chl *a* and TLI, and TN and TP.

	Correlation (Pearson's) with expert assessment EI
% macrophyte cover	-0.48
Macrophyte Simpson's index	0.43
Ln conductivity (µS/cm)	0.42
TLI	0.75
pH	0.67
Abs 440	-0.3
Kd (m^{-1})	0.34
Chl a (mg/m^3)	0.52
Ln TN (mg/m^3)	0.59
Ln TP (mg/m^3)	0.49
DOC (g/m^3)	0.33
% of fish species native	-0.34
CPUE native eels and bullies	0.32

3.4. Boosted Regression Tree Analyses

BRT analyses are potentially more powerful and inclusive than standard regression analyses because they recognise non-linear relationships (step functions, parabolic curves, etc). As discussed above, however, the sample size used here (45) was suboptimal (optimal = 150 +). Bootstrapping was not used because of the limited number of study sites (small sample size). Here we discuss variables that explained more than 10% of the variance in pressure gradients. Measured variables in lakes explained 49.5 – 83.2% of the variation in the WONI pressure gradients with 2-3 variables being most useful or important in each case (Table 9).

3.4.1. Catchment impervious area

BRT analyses did not identify any strong, non-linear predictors of the impervious area pressure gradient. 49.5% of the total variance in the impervious area pressure gradient was explained: macrophyte cover accounted for 28% of the variance, % native fish accounted for 11.2% of the variance, and the Shannon diversity index for rotifers accounted for 10.3% of the variance. The predictors are related to impervious area by step functions (Figure 5a). For example, the model suggests that macrophyte cover is categorically related to impervious area, with 60-100% macrophyte cover in catchments with the lowest impervious area, 20-60% cover in catchments with medium impervious area, and < 20% macrophyte cover in catchments with the highest impervious area. The second step function suggests that lakes with fish assemblages comprised of 80-100% native fish were associated with low impervious area, and fish assemblages with <80% native fish were found in catchments with higher impervious area. All of the predictors, however, are still only weakly related to the impervious pressure gradient. In summary, the results of both BRT and the correlation analyses suggest that impervious area in catchments is not a strong driver of lake condition in our dataset and is not a good proxy for, or predictor of lake EI.

Table 9: **Summary of BRT results indicating best explanatory variables for predicting WONI pressure gradients.**

	Cross-validated correlation with the four best predictors (measured variables)	**Best explanatory variables**	**Cross-validated correlation (%) explained by best explanatory variables**
Catchment impervious area	49.5%	Macrophyte cover	28.0%
		Native fish (%) in total assemblage	11.2%
		Rotifer diversity	10.3%
Indigenous vegetation removal	83.2%	Rotifer diversity	67.9%
		pH	15.4%
N-loading	76.8%	Absorbance at 440 nm	35.3%
		Mean distance to food web centroid	34.3%
		Kd	10.4%
P-loading	56.8%	Kd	35.2%
		Mean distance to food web centroid	21.6%

3.4.2. Indigenous vegetation removal

83.2% of the native vegetation removal pressure gradient was explained by 2 predictors: the Shannon diversity index for rotifers explained 67.9% of the variance, and pH explained 15.4 % of the variance (Figure 5b, Table 9). These predictors both appear to be step functions.

3.4.3. N load

76.8% of the N load pressure gradient was explained by 3 BRT predictors: absorbance at 440 nm (35.3%), the (isotope-based) foodweb metric distance to centroid (this variable is an indicator of total foodweb size or complexity (34.3%), the light attenuation coefficient K_d (10.4%; Figure 5c, Table 9). Macrophyte cover explained the remaining 7.2% of the variance, and although a weaker relationship (< 10%) is perhaps worth noting here because macrophyte pressure is potentially related to both impervious area and P loading pressure.

3.4.4. P load

56.8%, of the P load pressure gradient was explained by 2 BRT predictors, these predictors were similar to the N load predictors identified here: the light attenuation coefficient K_d explained 35.2% of variance in the P-load gradient, the foodweb metric distance to centroid explained 21.6% of the variance. We note that macrophyte cover is the third predictor identified by BRT, but it explains <10% of the variance in the response (Figure 5d, Table 9).

Our second BRT approach, where measured variables were used as responses, yielded fewer useful, cross-validated relationships between the measured variables and the WONI pressure gradients (Table 10). Only a few of the indices showed a good correspondence - % native fish, pH, Ln Chl *a*, TLI (a correlate of Chl *a*) and expert assessment EI showed the strongest relationship to the WONI pressure gradients.

4. Discussion

Several of the variables measured in this study were related to more than one pressure gradient or were identified using more than one analytical approach. The following variables were the most consistently linked to the pressure gradients for shallow lakes in the correlation and BRT analyses:

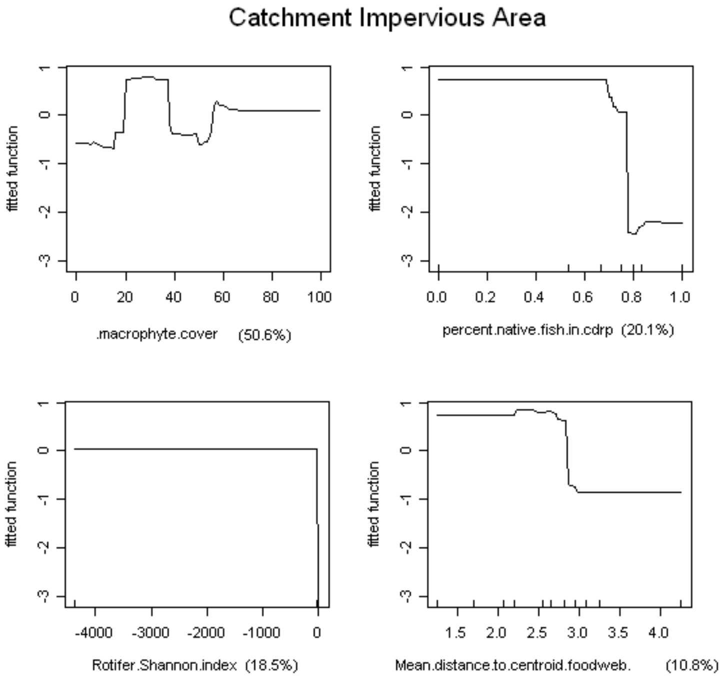

Figure 5a: BRT models summarizing the four best predictors and their function shapes for each catchment impervious area (response). Note that the % in the lower right of each panel corresponds to the proportion of total variance explained – i.e. these proportions are scaled to the total variance explained (column 2 in Table 9).

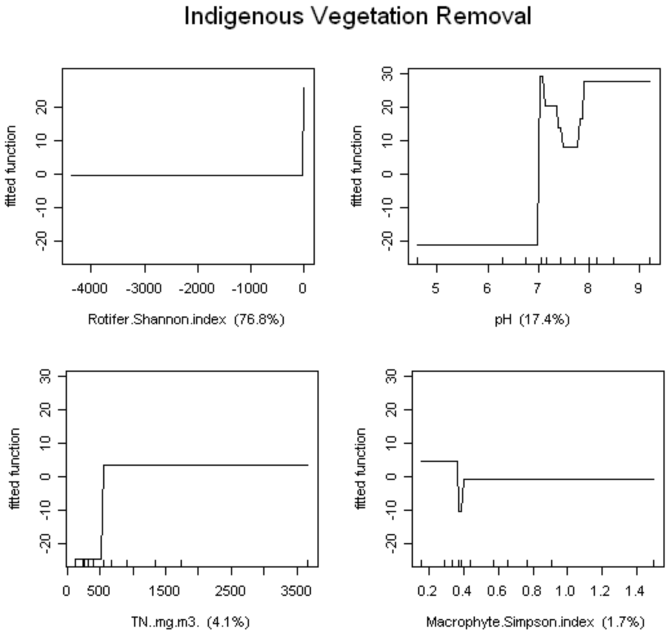

Figure 5b: BRT models summarizing the four best predictors and their function shapes for each the indigenous vegetation removal pressure gradient (response).

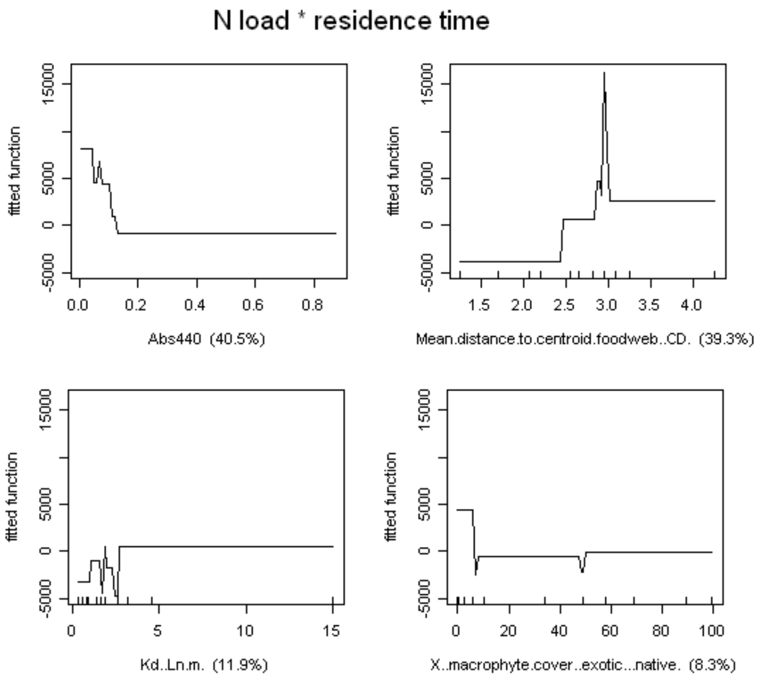

Figure 5c: **BRT models summarizing the four best predictors and their function shapes for each the N load pressure gradient (response).**

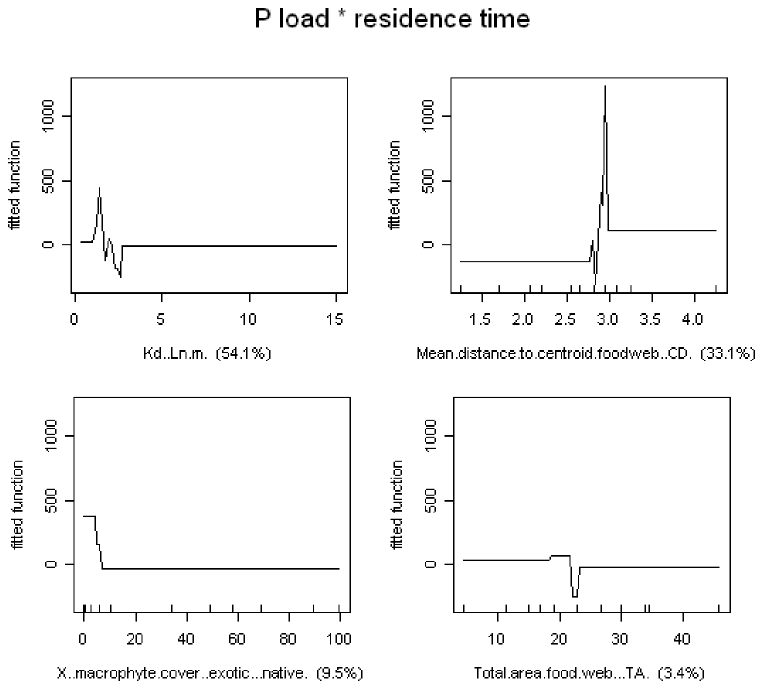

Figure 5d: **BRT models summarizing the four best predictors and their function shapes for each the P load pressure gradient (response).**

Table 10: **Cross-validated correlations of BRT models built using WONI pressure gradients (native vegetation removal, imperviousness, N load and P load) as predictors. A value of 0 indicates that no model could be fitted, and negative values indicate that the model diverged during cross validation and didn't fit satisfactorily. Good correspondences (> 0.3) are in bold. The WONI pressure gradients were very strong predictors of expert assessment EI.**

Measured variable	Cross-validated correlation with the 4 WONI pressure gradients (BRT Modeled)
Native fish species % in CDRP survey	**0.302**
Native fish CPUE (common bully + shortfin+ longfin individuals)	0.235
Conductivity µS/cm	0.000
Benthic Inverts Pilieu Evenness	-0.045
Benthic Inverts Shannon diversity H'(loge)	0.000
Benthic Inverts Margalef richness	0.010
% macrophyte cover (exotic + native)	0.000
Macrophyte weighed Simpson index	0.098
pH	**0.653**
Abs 440	0.031
DOC (g/m^3)	0.000
K_d (Ln m^{-1})	0.231
TN (mg/m^3)	0.000
TP (mg/m^3)	0.000
NO_3-N (mg/m^3)	0.000
SRP (mg/m^3)	0.000
NH_4-N (mg/m^3)	0.000
TN:TP /Redfield N:P	0.204
Z_{eu}	0.000
Metazooplankton biomass (average mg w.w. L^{-1})	0.000
Metazooplankton diversity Shannon index	0.000
Rotifer diversity Shannon index	0.000
Hydrologically altered (y/n)	0.000
Foodweb mean dist to centroid	0.115
δ^{15}N range	0.058
Chl *a* (mg/m^3)	**0.360**
TLI	**0.421**
Expert assessment	**0.772**

1. Macrophyte cover (natives + exotics)
2. Native fish in the total fish assemblage
3. Mean distance to centroid (a food web metric)
4. Rotifer diversity (Shannon index)
5. Chlorophyll *a* concentration
6. Light attenuation coefficient (K_d) – a covariate of Chlorophyll *a* concentration in some lakes
7. pH

Interestingly, this list includes variables that respond and change over very short time periods (Chlorophyll *a* concentration, light attenuation, pH), long-lived organisms that reflect conditions over much longer time periods (fish, macrophytes, food web structure) and intermediate time-scale indicators (rotifers). This list also includes indicators listed under each of the four components of EI described by Schallenberg et al. (in review): % native fishes are included in the "*nativeness*" component, pH, Chlorophyll *a* and light attenuation are included in the "*pristineness*" category (although see the following paragraph), the food web metric is included in the "*resilience*" component, and rotifer diversity is included in the "*diversity*" component (Table 1). Most of these relationships are not strong (Table 7, 9, Appendix E). These indicators are the best candidates for additional research, closer examination, and potential formulation of a multi-metric predictor.

High Chlorophyll a concentrations (i.e. high trophic status) are generally associated with low EI and a lack of "pristineness" – yet natural conditions might, in some cases, include high nutrient loads (e.g. Six-foot Lake, which probably received a large natural subsidy of marine-derived nutrients discussed above). A more intensively studied example is the nutrient subsidy supplied to freshwater ecosystems by natural salmon migrations – salmon nutrients can constitute as much as 70% of the annual nitrogen load (Naiman et al. 2002) and 30% - 60% of the annual phosphorus load (Koenings and Burkett 1987; Krohkin 1975) to North American Pacific Coast lakes and streams. On the other hand, lake TLI is correlated with catchment area in pasture (%) in New Zealand (Sorrell et al. 2006). High nutrient inputs to surface water from agriculture, are clearly not part of a pristine ecosystem. We suggest that anthropogenic N input (calculated using the CLUES model in this study) is a better candidate indicator of EI than Chlorophyll *a*, TN or TP responses concentrations in lake water - i.e. the pressure gradients are better indicators than measurements.

The variables listed above are the best correlates of pressure gradients produced by this study, and with the probable exception of Chlorophyll *a*, are possible candidates for quantifying EI in shallow coastal lakes. But the relative costs and effort required for data collection will be important considerations for managers. For example, calculation of the rotifer diversity index requires specialised taxonomic identification skills, and calculation of food web metrics requires relatively intensive field sampling (collection of at least 10 types of organisms and organic matter fractions), sample processing (see methods) and isotopic analyses of all samples (minimum ~$NZ10 per sample). As components of a monitoring programme, the predictive power of these variables must be weighed against cost-effectiveness.

Lakes are complex ecosystems (e.g. Besiner et al. 2003). Their condition at any point in time is sensitive to the age of the lake in the landscape, the hydraulic residence time of water (3 to 1926 days in the lakes of this study) which allows development of distinctive, system-specific chemical conditions and biological assemblages, and the surrounding landscape: e.g. underlying geology, catchment vegetation, catchment use, topography, and fire frequency. Additionally, the data collected for this study represent only one point in time in the progression and development of these systems. The CDRP definition of 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 minimally impacted reference condition*" (Schallenberg et al. 2008) is intuitively appealing. However, EI under this definition requires clear knowledge of a "*minimally impacted reference condition"*. It may be impossible to determine this without a detailed understanding of conditions prior to the European or Maori colonization of New Zealand. Paleoecological studies are likely the best source of objective, long-term system-specific data and should be considered for developing a better understanding shallow coastal lake EI. The shallow lakes CDRP group recognised the problems relating to the lack of long-term understanding, and modified their working definition of EI to reference "desired conditions", but this is still problematic when "desirable conditions" are not defined. It may be desirable for shallow coastal lakes to be clear and to contain low concentrations of bioactive N and P. However, we should reasonably expect shallow coastal lakes to be somewhat more productive and nutrient-rich than large deep lakes, but how much more productive should they be before EI begins to decline? How diverse should rotifer communities be? In spite of the size and complexity of this data set, the relationships we have identified (Appendix E) are not strong enough to provide clear answers to such questions.

The results of this study suggest that, at this point in time and in the absence of long-term data there are two approaches to use: (1) WONI pressure gradients - We have shown that the WONI pressure gradients for shallow lakes are related to measurements of lake condition. Management needs for conservation prioritization may be met simply by an analysis of the four pressure gradients; (2) Expert assessment – in selected cases expert assessment may be the most robust and integrated measure of EI available to managers of shallow coastal lakes, provided that there are clear and agreed conservation management objectives in place for lowland lakes, and measures for assessing their effectiveness when implemented. This is especially true if a standardized approach to expert assessment is developed, and if it can be accompanied by a validation process (as suggested by Phillips et al. (2008).

Expert assessment is gaining acceptance amongst professionals and in resource management: for example, it is used within the European Water Framework (EWF). In the EWF, biological reference conditions for aquatic ecosystems may be based on modelling or spatial comparisons. When it is not possible to use these methods, Member States use "expert judgement" to describe reference conditions (http://www-nrciws.slu.se/REFCOND/7th_REFCOND_final.pdf). Expert assessment is used in related studies in New Zealand (e.g. Leathwick et al. 2007, de Winton et al. in preparation – see introduction). A similarity in approach may be drawn from the Cultural Health Index (Tipa and Teirney 2006) a new tool used for incorporating cultural perspectives and values into river management and decision making. The Cultural Health Index is a set of protocols that allow a panel to assign point values to rivers that include: catchment land use, mahinga kai, vegetation, birds, modification of shores and banks, water clarity, and diversity of habitats (Appendix D). The panel is therefore led to the same conclusion as experts.

A standard framework for assessing condition (similar to the Cultural Health Index, Appendix D) should be developed and results compared to quantify consistency or bias between practitioners. The expert assessment could also be compared to best indicators identified by this study, or directly to pressure gradients.

There is clearly a remaining need to improve the quantitative basis of EI determination, or to move to a more quantitative, science-informed policy development and operational management decision-making process for management of New Zealand's shallow coastal lakes. This should be followed by regular assessment of lake status against stakeholder agreed outcomes. We hope that this study is a contribution towards that endeavour.

5. Acknowledgements

This research was supported by DOC grant # DOCDM 99556 and NIWA Capability Fund Projects CRBD085 (2007-2008) and CRAU095 (2008-2009). We thank John Leathwick, John Harding, Lindsay Hawke, Julian Sykes, Ned Norton, Matt Enright, Calum MacNeil, and Paul Lampert, for their contributions in the field, laboratory, and

quantitative analyses. The experts that subjectively assessed EI were Marc Schallenberg, Dave Kelly and Julian Sykes.

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Appendix A. Summary of contract (DOCDM 99556) milestones relevant to this report.

Milestone 5	**Analyse CDRP lakes datasets for relationships with % natural vegetation cover**	
5.1	Evaluate the quality, robustness, and geographic range of CDRP lakes datasets in terms of providing a range of EI indicators as related to % natural vegetation cover.	Provide a report to the TAG including an examination of CDRP lakes dataset robustness
5.2	Examine relationships between EI variables and % natural cover using the complete CDRP Lakes datasets and a boosted regression tree analysis. Evaluate the capability of the model to extrapolate to environment types not included in the CDRP lakes dataset	Provide a draft internal report on the relationships between EI and % natural vegetation
Milestone 6	**Analyse CDRP lakes datasets for relationships with nutrient loading**	
6.1	Evaluate the quality, robustness, and geographic range of CDRP lakes datasets in terms of providing a range of EI indicators as related to nutrient loading.	Provide a report to the TAG including an examination of CDRP lakes dataset robustness.
6.2	Examine relationships of EI variables with N and P loading (CLUES outputs) using complete CDRP lakes datasets and boosted regression tree analysis	Provide a report on the relationships between EI and CLUES-derived N and P loading to CDRP lakes.
Milestone 7 (revised)	**Analyse CDRP lakes datasets for relationships with invasive macrophytes, and compile a spatially referenced database for invasive macrophytes in shallow coastal lakes.**	
7.1	Evaluate the quality, robustness, and geographic range of CDRP lakes datasets in terms of providing a range of EI indicators as related to the WONI invasive species pressure gradient.	Provide a report (a) to the TAG including an examination of CDRP lakes dataset robustness

Appendix B: Data (page 1 of 8)

Pressure Gradients

Lake Identification number (FWENZ)	Lake name	Region	Percent Catchment Impervious pressure (%)	Indigenous Catchment Veg removal pressure (%)	N load * residence time	P load * residence time	Invasive Macrophyte Pressure (Max AWRAM SCORE)	Invasive fish pressure
50401	Humuhumu	Northland	0.198	59.275	2140.83	242.36	0.00	0.00
50413	Rotokawau	Northland	0.023	87.098	148.35	2.63	217.60	0.00
21912	Shag	Northland	0.116	64.501	2202.65	252.21	0.00	14.00
21918	Kaiiwi	Northland	4.940	26.512	295.24	4.07	0.00	51.00
13467	Waiparera	Northland	0.545	65.553	893.29	61.39	192.00	14.00
23691	Ngatu	Northland	6.134	59.347	599.86	74.27	348.00	59.50
49294	Whatihua	Waikato	4.941	97.588	525.47	20.22	460.80	0.00
22999	Spectacle	Northland	3.157	83.707	0.00	0.00	0.00	53.50
21871	Tomarata	Northland	1.434	59.452	0.00	0.00		45.00
49337	Pokorua	Waikato	3.825	74.390	675.19	32.68	204.80	0.00
47568	Coopers	Canterbury	3.295	100.000	3.67	0.00		
48177	Ellesmere	Canterbury	3.955	87.867	66633.04	2900.47		87.50
47579	Forsyth	Canterbury	2.546	77.768	1042.41	105.26		27.00
44391	Waihola	Otago	3.885	84.749	3611.71	408.54		41.00
44746	Tomahawk	Otago	16.957	85.531	138.82	25.24		
44747	Tomahawk 2	Otago	16.957	85.531	11.74	0.78		
12469	Wainono	Canterbury	4.420	87.701	4088.18	203.74		
44599	Tuakitoto	Otago	2.463	87.573	811.54	27.89		41.00
38955	Poerua	West Coast	2.075	27.884	712.02	537.11	297.16	17.00
25994	Rotorua	Canterbury	0.000	50.066	48.95	1.81		
39109	Ryan	West Coast	21.883	66.158	9.56	4.63		8.50
38421	Mahinapua	West Coast	1.611	23.191	1052.49	274.28	161.00	49.50
43649	Vincent	Southland	3.297	93.724	146.35	2.44		0.00
43668	Reservior	Southland	1.354	66.295	240.32	11.07		
28543	George	Southland	3.149	57.445	404.57	14.41		
46301	Ship	South Westland	3.353	0.307	11.16	3.22		0.00
44694	Waipori	Otago	3.873	73.536	267.95	15.90		41.00
44210	Wilke	Otago	12.500	0.000	8.09	1.28		0.00
34665	Whakaki	Hawkes Bay	3.368	71.954	1386.10	78.82	0.00	8.50
36215	Runanga	Hawkes Bay	1.561	81.468	7781.79	1309.81		
36096	Oingo	Hawkes Bay	0.013	86.657	3381.70	170.86		8.50
1974	Papaitonga	Manawatu	3.023	59.187	2128.69	253.27	0.00	14.00
831	Waitawa	Manawatu	2.766	88.140	1021.18	115.80	190.95	51.00
15930	Marahau	Manawatu	2.734	90.377	647.91	67.57	70.40	
18936	Kaitoke	Manawatu	3.549	96.890	873.22	57.85	0.02	8.50
1	Onoke	Wairarapa	2.201	72.363	4062.67	265.78		24.00
229	Pounui	Wairarapa	0.478	5.910	948.87	174.58		24.00
1708	Wairarapa	Wairarapa	1.670	41.734	19056.06	1392.24	134.67	59.50
10	Upper Onoke	Wairarapa	0.496	11.005	0.00	0.00		
no id	5-mile	West Coast	0.005	0.500	0.00	0.00		
46265	Maori	West Coast	0.000	0.000	109.84	5.95		
25519	Otuhie	Tasman	0.248	5.316	177.73	24.68		
25790	Kaihoka 1	Tasman	0.000	24.543	141.37	20.79		
25789	Kaihoka 2	Tasman	9.360	32.759	78.24	11.51		
no LID	Six Foot	Campbell Island	0.000	0.000	0.00	0.00		

Appendix B. Data (page 2 of 8)

Metadata

Lake name	Trophic Level Index TLI	Measured Max depth (m)	Lake area m2	Ammended Volume (model output)	Catchment flow m^3	Residence time days	Catchment Area m^2	Catchment Perim (m)
Humuhumu	3.19	15.0	1395675	6978376	4414063	577.0	8793000	17940
Rotokawau	3.10	11.0	256965	942203	7858808	43.8	14898600	27120
Shag	4.15	0.0	174099	1673002	300723	1681.4	532800	4320
Kaiiwi	2.99	16.0	267665	1427544	2559004	203.6	4855500	12960
Waiparera	3.90	6.0	1085771	2171542	2582036	307.0	7043400	14760
Ngatu	3.11	6.5	516915	1119982	715553	571.3	1722600	6000
Whatihua	3.33	3.2	38613	286850	737530	126.4	1059300	5700
Spectacle	6.02	7.0	438438	1023022			3690000	7740
Tomarata	3.51	5.0	143559	239265			948600	3900
Pokorua	5.19	1.2	259233	388850	2488400	79.7	4860900	14280
Coopers	3.90	0.5	17362	168877	21510	313.3	1054800	4140
Ellesmere	6.92	2.1	197810300	138467179	454790939	111.1	2482517504	416760
Forsyth	6.53	4.0	5587550	7450066	107215487	25.4	112867200	68100
Waihola	3.42	2.2	6075574	4455421	13733088	118.4	70547400	51960
Tomahawk	5.35	1.2	187883	75153	282564	97.1	2433600	11760
Tomahawk 2	5.36	0.9	102338		190910.4	78.3	1606176	7740
Wainono	5.82	3.0	3985140	3985140	10851902	134.0	136632608	73380
Tuakitoto	4.68	3.0	1317384	1317384	28795795	16.7	144339296	90060
Poerua	2.83	7.8	2126994	5494733	56757330	35.3	19737900	31440
Rotorua	6.59	3.0	432387	432387	870517	181.3	3914100	9540
Ryan	5.08	3.0	34523	34523	843525	14.9	499500	3120
Mahinapua	3.34	10.0	3937688	13125625	75106984	63.8	35953200	33660
Vincent	3.49	5.0	172081	286801	2145854	48.8	3141900	10380
Reservior	4.54	5.0	355269	592115	3902953	55.4	5728500	16440
George	4.30	2.0	908101	605401	11650274	19.0	29115000	35220
Ship	2.65	3.0	101616	101616	5652207	6.6	2034000	4980
Waipori	3.19	1.0	1836802	612267	128025494	1.7	561327296	218700
Wilke	4.42	4.0	10305	88352.36	88352.36	42.6	146700	1800
Whakaki	7.21	0.4	4748870	132119550	21365152	74.4	32156100	42000
Runanga	7.21	0.9	1105240	24383233	1838711	1926.2	7686900	17700
Oingo	3.64	1.8	851493	254423	235721	711.9	862200	5520
Papaitonga	5.61	1.1	514817	6726785.126	701720	603.0	3222000	7860
Waitawa	5.68	6.3	157779	394448.125	613901	350.9	2432700	8460
Marahau	4.28	5.3	97912	489559.6875	2181751	79.5	7722000	18420
Kaitoke	6.77	1.0	253152	2928240.059	7157705	60.3	32647500	41880
Onoke	3.12	5.0	6223842	168017354	2892042338	2.0	3428414976	555720
Pounui	3.52	6.5	459534	6290800	4424558	205.4	7179300	13380
Wairarapa	3.38	2.5	77371040	64475867	640641597	36.7	654440384	203520
Upper Onoke	3.18		518654					
5-mile	2.45	1.1	208132				6497100	
Maori	1.85	0.6	368165	13148476.42	42398113.79	31.3	64640700	11700
Otuhie	3.38	2.1	846515	31890032.64	31890032.64	29.4	17200800	32940
Kaihoka 1	3.00	10.2	67570	227416.288	190910.4	415.8	837000	3000
Kaihoka 2	4.18	11.5	52772	446110.816	13148476.42	230.1	837000	4620
Six Foot	5.23	1.9						

Appendix B. Data (page 3 of 8)

Metadata

Lake name	Catchment Beech %	Catchment Ann Temp C	Catchment June Sol Rad W / m^2	Catchment Dec Sol Raiation	Catchment Elev (m)	Lk Elev (m)	Percent Catchment Impervious
Humuhumu	0.00	14.4	665	2351	69	51	0.20
Rotokawau	0.00	14.4	664	2353	70	60	0.02
Shag	0.00	14.3	683	2342	90	77	0.12
Kaiiwi	0.00	14.4	681	2342	85	78	4.94
Waiparera	0.00	15.8	723	2357	37	31	0.55
Ngatu	0.00	15.8	720	2356	46	37	6.13
Whatihua	0.00	14.0	635	2355	115	112	4.94
Spectacle	0.00	0.0	675	2363	56	16	3.16
Tomarata	0.00	0.0	675	2364	47	33	1.43
Pokorua	0.00	14.3	638	2363	52	15	3.83
Coopers	0.00	11.7	490	2280	4	7	3.29
Ellesmere	0.85	11.0	500	2288	179	17	3.96
Forsyth	0.00	10.9	493	2260	287	3	2.55
Waihola	0.00	9.8	405	2149	100	12	3.88
Tomahawk	0.00	10.4	413	2143	87	14	16.96
Tomahawk 2	0.00	10.3	567	2100	102	5	
Wainono	0.00	10.5	471	2177	139	21	4.42
Tuakitoto	0.00	9.7	395	2138	111	95	2.46
Poerua	0.00	10.1	504	2206	348	28	2.07
Rotorua	0.00	12.1	543	2395	81	3	0.00
Ryan	0.00	11.9	509	2222	6	14	21.88
Mahinapua	0.00	11.3	499	2205	54	19	1.61
Vincent	0.00	10.0	369	2116	28	13	3.30
Reservior	0.00	9.9	369	2104	48	10	1.35
George	37.03	9.7	372	2148	56	10	3.15
Ship	0.00	11.3	491	2176	5	3	3.35
Waipori	3.25	8.3	416	2160	444	7	3.87
Wilke	0.00	10.0	566	2095	240	20	
Whakaki	0.00	14.2	611	2376	30	20	3.37
Runanga	0.00	13.3	603	2371	71	38	1.56
Oingo	0.00	12.8	579	2334	135	91	3.95
Papaitonga	0.00	12.77	547	2312	28	20	3.02
Waitawa	0.00	12.74	546	2309	36	20	2.77
Marahau	0.00	12.91	566	2338	97	60	2.73
Kaitoke	0.00	12.72	564	2339	99	16	3.55
Onoke	14.60	11.3	531	2321	289	0	2.20
Pounui	54.44	12.4	532	2327	119	14	0.48
Wairarapa	20.05	11.8	530	2326	207	1	1.67
Upper Onoke	15.00				295		
5-mile		9.9	494	2203	28	10	0
Maori	10.25	11.2	491	2175	211	14.69	0
Otuhie	17.72	11.8	588	2334	206	4.75	0
Kaihoka 1	0.00	12.8	591	2360	63	37.50	0
Kaihoka 2	0.00	12.7	592	2370	63	52.40	0
Six Foot							

Appendix B. Data (page 4 of 8)

Measured variables

Lake name	Native fish sp caught in CDRP survey	Pest fish sp caught in CDRP survey	CPUE bullys + shorrtfin + longfin eels	Cond us/cm CDRP	Pilieu Evenness macroinvertebrates	Shannon diversity H'(loge) Macroinverts	Simson Diversity 1-Lambda' Macroinverts	Margalef richness macroinverts
Humuhumu	3	0	0.583	215	0.683	2.094	0.827	2.308
Rotokawau	2	0	0.690	140.5	0.702	2.013	0.780	1.918
Shag	3	1	0.810	290	0.800	2.165	0.849	1.820
Kaiiwi	2	1	2.891	196.5	0.636	1.559	0.703	1.358
Waiparera	4	1	0.128	293	0.788	1.385	0.596	1.395
Ngatu	2	1	0.133	196	0.782	2.171	0.847	2.056
Whatihua	2	2	0.111	351.00	0.748	2.184	0.817	0.067
Spectacle	3	1	0.432	303.4	0.865	1.824	0.806	1.310
Tomarata	4	1	0.199	197.5	0.755	1.849	0.782	1.439
Pokorua	3	0	0.238	140.5	0.360	1.000	0.409	1.542
Coopers	3	0	0.663	226.3	0.258	0.693	0.296	1.312
Ellesmere	2	0		11050.0	0.556	1.048	0.560	0.629
Forsyth	4	1	0.237	7923.3	0.413	0.913	0.492	0.804
Waihola	6	2	0.021	7433.3	0.514	1.209	0.572	0.872
Tomahawk	3	2	1.422	5833.3	0.671	1.186	0.619	0.558
Tomahawk 2	4	2		3537.7				
Wainono	6	1		1241.0				
Tuakitoto	2	2	0.001	162.7	0.610	1.615	0.703	1.264
Poerua	4	1	0.465	34.0	0.475	1.241	0.497	1.368
Rotorua	4	0	1.188	150.7	0.664	0.831	0.404	0.465
Ryan	3	1	3.028	133.3	0.563	0.809	0.396	0.547
Mahinapua	5	1	0.059	37.0	0.837	0.687	0.451	0.327
Vincent	4	1	0.017	282.0	0.304	0.726	0.317	0.952
Reservior	3	0	0.857	248.0	0.517	1.081	0.531	0.906
George	3	1	0.089	182.3	0.409	0.990	0.447	1.043
Ship	5	0	0.214	41.0	0.426	1.059	0.475	0.967
Waipori	5	3		850.3				
Wilke	0	0		223.0	0.531	1.453	0.664	1.235
Whakaki	2	0	9.766	414.5	0.427	1.010	0.542	0.982
Runanga	4	1	4.029	354.0	0.352	0.638	0.359	0.530
Oingo	3	1	0.668	374.0	0.664	1.809	0.777	1.721
Papaitonga	3	4	9.194	472.0	0.592	1.681	0.656	2.044
Waitawa	2	1	1.313	305.0	0.620	2.410	0.875	2.322
Marahau	2	2	0.190	333.0	0.673	1.982	0.805	1.949
Kaitoke	5	1	3.418	415.0	0.443	1.130	0.498	1.190
Onoke	5	1	1.078	9875.0	0.476	1.235	0.521	1.397
Pounui	4	0	1.169	192.0	0.513	1.442	0.625	1.781
Wairarapa	3	2	3.736	3055.0	0.527	1.798	0.740	1.927
Upper Onoke	5	2	3.526	5835	0.474	1.324	0.557	1.628
5-mile	4	0	0.832	3340.0	0.495	1.420	0.546	1.456
Maori	3	0	0.113	17.0	0.520	1.414	0.601	1.142
Otuhie	4	0	0.315	30.3	0.583	1.609	0.675	1.369
Kaihoka 1	2	0	0.001	106.5	0.543	1.457	0.599	1.176
Kaihoka 2	1	0	0.000	142.5	0.570	1.592	0.677	1.337
Six Foot				566.0				

Appendix B. Data (page 5 of 8)

Measured Variables

Lake name	% Macrophyte cover (exotic + native)	Macrophyte Simpson index	Macrophyte Weighed Simpson index	pH	Abs440	Cl (ppm)	Ca (ppm)	DOC (ppm)	Mg (ppm)
Humuhumu	95.2	0.76	1.01	7.6	0.03	20.95	5.72	13.09	5.875
Rotokawau	42.0	0.32	1.32	7.1	0.01	26.6	1.25	5.0775	2.325
Shag	50.7	0.38	0.63	6.6	0.05	41.4	2.08	10.2155	2.525
Kaiiwi	67.3	0.65	0.90	6.5	0.01	12.6	1.18	5.125	1.04
Waiparera	90.3	0.39	1.39	7.0	0.10	46.2	7.32	16.495	7.015
Ngatu	91.3	0.31	1.31	6.6	0.02	27.05	3.65	9.551	2.59
Whatihua	59.2	0.36	0.61	8.0	0.04	47.95	9.00	17.9	11.21
Spectacle	0.0	1.50	3.00	7.8	0.06	39.15	14.27	16.2	6.32
Tomarata	5.3	0.53	0.78	7.3	0.06	37.95	5.72	9.9485	3.075
Pokorua	47.3	0.43	0.68	7.1	0.06	58.05	7.89	14.125	7.58
Coopers	48.3	0.88	0.88	8.2	0.04	41.7	11.33	3.8	4.0
Ellesmere	0.0	1.50	3.00	8.1	0.07	3813.5	83.00	12.5	188.7
Forsyth	3.0	0.88	1.13	8.4	0.07	2364.1	31.00	10.7	100.7
Waihola	4.5	0.67	0.79	7.8	0.04	2653.9	42.03	5.7	108.3
Tomahawk	21.0	0.58	0.83	8.4	0.08	2636.2	52.67	14.5	110.7
Tomahawk 2				9.1	0.09	1281.5	27.33	14.5	61.0
Wainono	2.0			8.2	0.10	385.0	13.50	9.6	31.0
Tuakitoto	0.8	0.68	0.68	8.8	0.16	26.7	6.80	13.5	5.1
Poerua	97.0	0.28	0.53	7.0	0.30	8.6	1.17	4.0	0.8
Rotorua	0.0			7.0	0.22	29.0	3.87	33.8	3.9
Ryan	83.0	0.37	0.62	7.2	0.20	34.0	0.90	8.7	2.6
Mahinapua	34.0	0.31	1.56	6.2	0.38	9.8	0.50	11.8	0.7
Vincent	86.0	0.40	0.65	7.5	0.15	56.0	3.30	8.8	5.1
Reservior	10.0	0.46	0.58	7.3	0.27	64.3	2.73	10.7	5.1
George	0.5	0.33	0.33	7.1	0.19	43.3	2.97	11.5	4.0
Ship	65.3	0.36	0.36	5.6	0.08	11.3	0.50	4.0	0.8
Waipori				7.4	0.08	149.0	3.40	4.2	12.5
Wilke	56.7	0.91	0.91	4.6	0.88	66.7	0.50	22.6	4.4
Whakaki	1.5	1.00	1.25	8.4	0.12	794.0	22.98	18.0	6.2
Runanga	1.7	0.58	0.58	8.5	0.06	15.5	8.68	15.6	6.4
Oingo	73.3	0.77	1.77	9.2	0.15	60.5	12.43	12.5	7.4
Papaitonga	6	0.60	0.85	8.5	0.18	61.5	13.73	20.7	8.4
Waitawa	52	0.42	0.42	7.1	0.21	62.5	7.99	4.0	9.4
Marahau	69	0.16	0.41	7.7	0.08	63.5	12.21	7.0	10.4
Kaitoke	8	0.37	0.62	8.1	0.15	64.5	14.76	16.7	11.4
Onoke	7.6	0.37	0.62	7.9	0.02	1598.0	39.55	2.7	8.4
Pounui	68.7	0.19	0.44	7.5	0.07	38.4	4.96	5.1	9.4
Wairarapa	3.0	0.57	0.57	7.6	0.03	716.0	22.53	3.7	10.4
Upper Onoke	42.5	0.45	1.45	8.0	0.04	63.2175	64.22	4.9	11.4
5-mile	99.5	0.90	0.90	6.5	0.32	1015	36.69	9.3	56.7
Maori	54.8	0.34	0.34	5.6	0.37	5.25	0.91	9.5	0.5
Otuhie	10.5	0.22	0.22	6.0	0.45	12.1	1.33	13.8	0.8
Kaihoka 1	19	0.40	0.40	6.9	0.03	33.4	2.01	3.2	2.5
Kaihoka 2	34	0.26	0.26	7.1	0.03	34	3.96	5.2	2.6
Six Foot	0.1	1.00	1.00		0.19	257.6	10.62		19.3

Appendix B. Data (page 6 of 8)

Measured Variables

Lake name	Kd (Ln m)	Chla (ppb)	Phaeo (ppb)	TN (mg/m3)	TP (mg/m3)	NO3-N (mg/m3)	SRP (mg/m3)	NH4-N (mg/m3)	hydrologically altered
Humuhumu	0.7	2.0	3.3	257.3	7.0	1.0	1.5	11.0	n
Rotokawau	0.7	1.6	4.7	314.0	6.8	0.6	1.3	17.8	n
Shag	1.6	7.2	15.8	581.7	11.8	0.3	1.0	7.5	n
Kaiiwi	0.4	1.7	2.6	317.9	5.0	0.3	1.3	6.6	n
Waiparera	0.8	3.2	6.8	620.9	13.0	0.8	1.3	12.4	y
Ngatu	0.6	1.4	2.0	529.7	4.6	1.3	1.5	27.2	n
Whatihua	0.4	1.8	2.9	416.1	8.1	7.9	1.4	13.6	y
Spectacle	4.5	42.2	22.1	1337.8	89.2	0.7	1.3	10.3	y
Tomarata	0.9	4.5	12.7	361.5	6.4	13.9	1.2	32.1	n
Pokorua	1.9	19.2	16.5	851.9	39.6	2.0	2.7	11.3	y
Coopers	0.4	1.0	4.1	1380.7	16.0	1061.9	0.2	39.2	y
Ellesmere	15.0	80.4	84.8	2163.3	263.3	0.3	0.2	50.2	y
Forsyth	3.1	50.2	60.2	1612.0	217.7	5.8	0.2	32.7	y
Waihola	1.9	1.7	6.6	251.3	19.3	1.3	0.2	26.3	y
Tomahawk	1.5	5.5	6.3	1071.7	138.0	0.3	17.9	27.7	n
Tomahawk 2	2.3	15.2	20.3	1013.0	61.7	0.6	50.0	31.0	n
Wainono	2.53	18.9	28.5	915.0	187.3	0.3	76.8	26.3	y
Tuakitoto		3.2	14.7	952.3	54.3	0.3	0.2	13.3	y
Poerua	1.1	1.7	4.4	245.0	8.0	0.2	0.2	13.2	y
Rotorua	3.2	17.0	35.6	3672.0	270.0	17.7	59.6	640.5	n
Ryan	2.6	10.1	66.0	696.3	66.3	0.2	0.2	17.2	y
Mahinapua	1.7	1.9	5.4	322.7	10.3	4.4	0.2	22.6	n
Vincent	1.6	1.0	4.3	562.7	14.7	24.1	0.2	21.5	n
Reservior	1.8	10.3	39.5	615.0	20.7	0.3	0.2	17.8	y
George	6.8	6.2	15.7	434.0	26.7	0.3	0.2	9.7	n
Ship	1.2	0.7	3.4	260.0	6.3	0.3	0.2	16.5	y
Waipori	2.6	1.0	4.7	255.0	17.5	4.4	0.2	6.3	n
Wilke	3.9	5.7	11.6	692.0	23.3	0.6	0.2	29.5	n
Whakaki		71.8	228.0	2409.0	510.3	1.0	0.1	64.1	n
Runanga	7.4	116.0	148.0	2438.6	335.4	0.3	1.7	17.4	y
Oingo	0.9	1.5	8.3	797.7	10.0	0.3	1.5	11.2	y
Papaitonga	2.9	12.5	53.3	1784.2	72.5	100.1	3.5	40.7	y
Waitawa	1.5	6.5	14.2	1462.6	188.8	31.3	117.1	368.3	n
Marahau	0.8	3.1	11.8	673.6	31.5	15.6	6.3	16.1	y
Kaitoke	7.8	35.3	127.0	1666.7	491.9	0.3	227.0	1.5	n
Onoke	0.9	1.7	4.4	170.1	13.7	0.6	3.9	27.6	y
Pounui	0.7	3.2	5.4	277.3	11.7	2.2	3.1	11.6	y
Wairarapa	1.4	2.0	2.8	209.0	18.0	0.7	4.2	5.6	y
Upper Onoke	1.8	1.1	2.2	261.2	14.0	0.3	1.8	22.6	y
5-mile	2.9	0.3	0.15	128.0	2.4	0.3	0.6	25.0	n
Maori	4.6	0.9	2.75	227.6	3.7	0.3	0.6	9.1	n
Otuhie	3.5	0.7	1.85	235.4	7.4	9.7	0.7	19.6	y
Kaihoka 1	0.5	1.6	4.85	151.2	6.6	1.3	1.1	15.7	n
Kaihoka 2	0.8	11.0	22.35	325.2	18.5	1.2	1.1	15.0	n
Six Foot		9.6	23.7	471.9	79.1	0.3	2.5	20.9	n

Appendix B. Data (page 7 of 8)

Lake name	average expert assessment rank	Euphotic depth Z_{eu}	Metazooplankton biomass (average mg w.w. l^{-1})	Meta-zooplankton Simpsons index (exc nauplii)	Meta-zooplankton Shannon index (exc nauplii)	Rotifer Simpsons index	Rotifer Shannon index	δ ^{15}N Range (per mil)
Humuhumu	9.1	6.5	8.91	0.29	1.33	1.33	0.29	6.49
Rotokawau	19.9	6.6	0.95	0.48	0.78	0.78	0.48	5.61
Shag	29.2	2.9	0.70	0.34	1.15	1.15	0.34	8.38
Kaiiwi	11.8	12.1	1.21	0.52	0.90	0.90	0.52	8.62
Waiparera	17.1	5.6	6.44	0.32	1.30	1.30	0.32	5.97
Ngatu	21.0	7.8	8.40	0.36	1.15	1.15	0.36	6.07
Whatihua	23.8	11.9	2.55	0.42	1.02	1.02	0.42	6.20
Spectacle	45.4	1.0	0.76			1.09	0.49	6.31
Tomarata	21.5	5.1	4.20	0.40	1.02	1.02	0.40	8.95
Pokorua	39.6	2.4	1.54	0.29	1.31	1.31	0.29	8.15
Coopers	24.9	11.9	0.01	0.21	1.75	1.75	0.21	9.65
Ellesmere	40.3	0.3	1.66	0.50	0.69	0.69	0.50	7.35
Forsyth	44.5	1.5	0.07	0.45	0.90	0.90	0.45	8.36
Waihola	29.2	2.4	1.40	0.44	0.90	0.90	0.44	7.69
Tomahawk	29.9	3.1	0.03	0.45	0.94	0.94	0.45	6.90
Tomahawk 2	30.0	2.0	0.03	0.58	0.78	0.78	0.58	
Wainono	42.9	0.6	0.01	0.48	0.78	0.78	0.48	
Tuakitoto	37.2		1.82	0.28	1.38	1.38	0.28	7.62
Poerua	14.0	4.3	0.17	0.87	0.33	0.33	0.87	7.39
Rotorua	36.6	1.4	22.43	0.53	1.03	1.03	0.53	9.80
Ryan	33.1	1.8	3.11	0.78	0.52	0.52	0.78	5.68
Mahinapua	13.8	2.7	0.25	0.31	1.27	1.27	0.31	8.54
Vincent	19.1	2.9	0.28	0.38	1.15	1.15	0.38	7.25
Reservior	28.3	2.6	1.47	0.90	0.25	0.25	0.90	9.04
George	17.3	0.7	0.56	0.49	0.74	0.74	0.49	7.65
Ship	4.6	3.7	0.04	0.31	1.29	1.29	0.31	6.51
Waipori	28.1	1.8	0.14	0.40	1.04	1.04	0.40	
Wilke	9.8	1.2	0.25	0.49	0.76	0.76	0.49	4.91
Whakaki	35.5		49.79	0.50	0.69	0.69	0.50	5.23
Runanga	43.9	0.6	56.32	0.47	0.83	0.83	0.47	6.94
Oingo	37.8	5.4	0.11	0.27	1.44	1.44	0.27	9.15
Papaitonga	37.2	1.6	1.05	0.64	0.82	0.82	0.64	6.35
Waitawa	27.9	3.1	15.84	0.26	1.36	1.36	0.26	7.03
Marahau	32.5	5.8	7.99	0.27	1.40	1.40	0.27	7.23
Kaitoke	36.0	0.6	283.77	0.34	1.24	1.24	0.34	7.36
Onoke	18.6	4.9	2.22	0.50	0.71	0.71	0.50	7.38
Pounui	4.1	6.7	5.96	0.28	1.32	1.32	0.28	7.12
Wairarapa	23.7	3.3	25.52	0.50	0.69	0.69	0.50	9.36
Upper Onoke	18.9	2.6	2.05	0.50	0.70	0.70	0.50	6.06
5-mile	5.5	1.6	0.33	0.49	0.76	0.76	0.49	6.86
Maori	4.7	1.0	0.12	0.33	1.28	1.28	0.33	7.46
Otuhie	8.7	1.3	0.49	0.42	1.01	1.01	0.42	4.94
Kaihoka 1	4.1	8.9	0.42	0.25	1.47	1.47	0.25	7.34
Kaihoka 2	11.9	5.7	0.82	0.36	1.29	1.29	0.36	5.57
Six Foot	4.2		0.00	0.00	0.00			

Appendix B. Data (page 8 of 8)

Measured Variables

Lake name	δ^{13}C Range (per mil)	Total food web area	Foodweb mean distance to centroid	Foodweb mean nearest neighbour distance	St dev food web nearest neighbour distance	Foodchain length
Humuhumu	9.66	34.63	1.78	4.26	2.30	3.66
Rotokawau	8.91	26.95	2.21	4.69	1.97	3.23
Shag	8.35	42.32	2.09	4.80	1.99	4.19
Kaiiwi	7.85	39.30	2.11	5.38	2.29	3.88
Waiparera	4.74	17.29	1.41	3.17	1.27	3.50
Ngatu	6.81	19.67	1.51	3.68	1.55	2.99
Whatihua	8.72	32.17	2.04	4.40	1.80	3.22
Spectacle	5.65	22.51	1.28	3.36	1.52	3.25
Tomarata	5.08	25.77	1.26	3.79	1.88	3.39
Pokorua	7.67	27.50	1.70	4.48	2.18	3.74
Coopers	5.56	21.32	2.69	3.83	1.98	4.32
Ellesmere	9.21	7.45	2.96	4.25	2.37	3.40
Forsyth	4.10	16.77	2.91	4.23	2.20	4.15
Waihola	3.73	14.57	2.34	3.40	1.74	3.69
Tomahawk	5.05	18.14	2.65	3.88	1.77	3.64
Tomahawk 2						
Wainono						
Tuakitoto	9.51	33.79	3.25	4.68	2.01	3.58
Poerua	12.25	33.30	2.90	5.32	2.50	3.93
Rotorua	10.47	26.97	3.67	5.25	2.73	4.64
Ryan	8.91	23.37	2.82	4.11	1.84	3.40
Mahinapua	5.43	23.25	3.22	4.40	2.02	3.43
Vincent	8.16	26.76	2.66	3.90	1.80	3.71
Reservior	12.53	45.86	3.60	5.36	2.80	3.65
George	4.40	13.41	2.21	3.31	1.64	3.85
Ship	5.59	18.95	2.19	3.35	1.57	3.73
Waipori						
Wilke	4.16	6.10	2.24	3.48	1.61	3.09
Whakaki	5.37	12.14	2.03	3.11	1.41	3.39
Runanga	10.79	33.86	3.11	4.56	2.27	3.91
Oingo	5.62	14.92	3.00	4.28	1.91	4.09
Papaitonga	9.28	4.57	3.09	4.61	2.51	3.68
Waitawa	5.22	11.38	2.55	3.64	1.78	3.88
Marahau	8.30	22.86	2.92	4.38	2.30	3.90
Kaitoke	5.73	19.24	2.77	3.79	1.79	3.61
Onoke	9.82	33.84	3.01	4.24	1.88	3.78
Pounui	7.41	29.97	3.01	4.21	1.88	3.86
Wairarapa	10.40	34.22	3.41	4.92	2.46	3.79
Upper Onoke	8.21	30.47	3.11	4.27	2.02	3.49
5-mile	6.59	10.31	2.76	4.23	1.85	3.53
Maori	5.83	15.22	2.65	3.80	2.02	3.85
Otuhie	5.06	16.45	2.65	3.75	1.72	3.15
Kaihoka 1	11.41	44.16	4.26	6.02	2.92	3.38
Kaihoka 2	5.28	15.15	2.07	3.13	1.42	3.26
Six Foot						

Appendix C: Correlation matrix showing potential relationships between WONI pressure gradients (first 6 columns) and measured variables of this study. Correlations between measured variables were used to identify redundancies between predictors. Correlations greater than 0.30 are in noted bold and indicate a potential relationship.

Page 1 of 9	Percent Catchment Impervious pressure (%)	Indigenous Catchment Veg removal pressure (%)	N load * residence time	P load * residence time	Invasive Macrophyte Pressure (Max AWRAM SCORE)	Invasive fish pressure	Residence time days	Catchment Alluvial (%) FWENZ
Residence time days	-0.22	0.12	0.02	0.21	-0.28	-0.06	1.00	
Catchment Alluvial (%) FWENZ	0.00	**0.34**	**0.48**	**0.36**	-0.27	**0.41**	-0.09	1.00
TLI CDRP	0.22	**0.46**	-0.18	-0.20	0.28	0.29	-0.49	0.12
Catchment Peat (%) FWENZ	-0.02	-0.01	-0.04	-0.06	-0.24	0.01	-0.09	-0.03
% Native fishes	-0.28	**-0.36**	0.10	0.05	-0.14	-0.23	-0.07	0.25
CPUE bullys + shortfin + longfin eels	0.11	0.04	0.27	0.27	**-0.48**	-0.10	0.17	-0.10
Conductivity us/cm CDRP	0.11	**0.34**	**0.55**	**0.49**	-0.07	**0.41**	-0.17	0.25
Pilieu Evenness Macroinvertebrates	-0.01	0.03	-0.04	-0.10	0.11	0.31	0.14	**-0.38**
Shannon diversity H'(loge) Macroinverts	-0.17	0.03	-0.09	-0.13	0.17	0.11	0.17	**-0.39**
Simson Diversity 1-Lambda' Macroinverts	-0.12	0.04	-0.02	-0.07	0.04	0.25	0.16	**-0.41**
Margalef richness Macroinverts	**-0.32**	-0.08	-0.14	-0.13	-0.29	0.01	0.17	-0.20
% Macrophyte cover (exotic + native)	0.11	-0.19	-0.24	-0.24	0.45	-0.40	0.05	-0.12
Macrophyte Weighed Simpson index	-0.06	0.23	**0.51**	**0.40**	-0.18	**0.46**	0.02	**0.30**
pH	0.07	**0.71**	0.17	0.20	-0.26	0.10	0.13	0.23
Abs440	0.12	**-0.47**	-0.12	-0.13	0.06	-0.19	-0.20	-0.09
Cl (ppm)	0.24	0.25	**0.61**	**0.54**	-0.19	**0.44**	-0.18	0.29
Ca (ppm)	0.11	0.18	**0.59**	**0.51**	-0.32	**0.47**	-0.13	**0.34**
Mg (ppm)	0.23	0.25	**0.66**	**0.56**	-0.02	**0.46**	-0.14	**0.36**
DOC (ppm)	0.10	0.15	-0.01	-0.03	-0.15	-0.24	0.12	-0.05
Kd (Ln m)	0.02	0.12	**0.71**	**0.67**	**-0.46**	**0.40**	0.06	0.34

Appendix C. Correlation Matrix.

Page 2of 9	Percent Catchment Impervious pressure (%)	Indigenous Catchment Veg removal pressure (%)	N load * residence time	P load * residence time	Invasive Macrophyte Pressure (Max AWRAM SCORE)	Invasive fish pressure	Residence time days	Catchment Alluvial (%) FWENZ
Chla (ppb)	0.01	**0.30**	**0.47**	**0.56**	**-0.45**	0.25	**0.39**	0.17
Phaeo (ppb)	0.08	0.27	0.22	0.28	**-0.41**	-0.07	0.21	0.05
Ln TN (mg/m3)	0.04	**0.56**	0.26	0.28	**-0.43**	0.14	0.23	**0.32**
Ln TP (mg/m3)	0.05	**0.47**	0.25	0.27	**-0.38**	0.04	0.11	0.11
NO3-N (mg/m3)	-0.02	0.21	-0.05	-0.07	-0.17	-0.06	0.04	**0.74**
SRP (mg/m3)	0.07	0.28	-0.05	-0.07	-0.18	-0.03	-0.07	0.00
NH4 (mg/m3)	-0.10	0.05	-0.01	-0.04	0.09	0.23	-0.01	0.10
Expert assessment EI	0.17	**0.78**	0.24	0.26	**-0.30**	0.20	0.21	0.20
Euphotic depth Zeu	-0.10	0.04	-0.20	-0.23	**0.43**	-0.10	0.02	0.10
Metazooplankton biomass (average mg w.w. l-1)	-0.04	0.21	0.00	0.04	-0.27	-0.13	0.04	-0.05
Metazooplankton Simpsons index (exc nauplii)	0.29	0.05	0.09	0.15	0.10	-0.01	-0.16	-0.05
Meta- zooplankton Shannon index (exc nauplii)	-0.17	0.19	-0.16	-0.20	-0.10	-0.09	0.15	0.12
Rotifer Simpsons index	**-0.34**	0.08	-0.20	**-0.33**	-0.11	-0.08	0.15	0.12
Rotifer Shannon index	**0.31**	-0.06	0.08	0.13	0.07	0.00	-0.16	-0.06
15N Range (per mil)	-0.23	0.19	0.10	0.13	-0.16	**0.38**	0.08	**0.35**
13C Range (per mil)	-0.18	0.04	0.19	**0.30**	0.17	-0.02	0.20	0.04
Total food web area	-0.24	0.02	-0.18	-0.07	0.08	-0.07	0.24	-0.13
Foodweb mean distance to centroid	-0.14	-0.13	0.15	0.22	-0.09	0.12	-0.04	0.17
Foodweb mean nearest neighbour distance	-0.26	-0.07	0.07	0.15	0.07	0.08	0.17	-0.01
Foodchain length	-0.29	0.16	-0.06	0.02	-0.41	-0.09	0.24	0.26

Appendix C. Correlation Matrix

Page 3 of 9	TLI CDRP	Catchment Peat (%) FWENZ	% Native fishes	CPUE bullys + shortfin + longfin eels	Conductivity us/cm CDRP	Pilieu Evenness Macroinvertebrates	Shannon diversity H'(loge) Macroinverts	Simson Diversity 1-Lambda' Macroinverts
Residence time days								
Catchment Alluvial (%) FWENZ								
TLI CDRP	1.00							
Catchment Peat (%) FWENZ	0.01	1.00						
% Native fishes	-0.05	-0.12	1.00					
CPUE bullys + shortfin + longfin eels	**0.48**	-0.04	-0.19	1.00				
Conductivity us/cm CDRP	0.15	-0.08	-0.04	0.00	1.00			
Pilieu Evenness Macroinvertebrates	-0.13	-0.17	**-0.32**	-0.20	-0.17	1.00		
Shannon diversity H'(loge) Macroinverts	**-0.30**	-0.13	**-0.37**	-0.12	-0.20	0.62	1.00	
Simson Diversity 1-Lambda' Macroinverts	-0.21	-0.15	**-0.38**	-0.09	-0.13	0.72	**0.96**	1.00
Margalef richness Macroinverts	-0.28	-0.05	-0.10	0.07	-0.19	0.15	**0.66**	**0.57**
% Macrophyte cover (exotic + native)	**-0.56**	-0.20	0.03	-0.28	**-0.30**	0.10	0.23	0.12
Macrophyte Weighed Simpson index	**0.31**	-0.15	0.02	0.07	**0.34**	0.36	0.00	0.13
pH	**0.48**	-0.02	**-0.40**	**0.37**	**0.34**	-0.13	-0.06	-0.03
Abs440	-0.05	0.11	0.18	-0.04	-0.23	-0.04	-0.14	-0.12
Cl (ppm)	0.29	-0.08	0.00	0.02	**0.90**	-0.13	-0.23	-0.12
Ca (ppm)	0.25	-0.10	-0.07	0.23	**0.89**	-0.14	-0.16	-0.09
Mg (ppm)	**0.33**	-0.07	0.00	-0.08	**0.80**	-0.08	-0.20	-0.09
DOC (ppm)	**0.60**	0.05	-0.07	0.28	-0.17	0.23	-0.08	-0.03
Kd (Ln m)	**0.57**	0.26	0.15	0.28	**0.35**	-0.21	**-0.34**	-0.26

Appendix C. Correlation Matrix.

Page 4 of 9	TLI CDRP	Catchment Peat (%) FWENZ	% Native fishes	CPUE bullys + shortfin + longfin eels	Conductivity us/cm CDRP	Pilieu Evenness Macroinvertebrates	Shannon diversity H'(loge) Macroinverts	Simson Diversity 1-Lambda' Macroinverts
Chla (ppb)	**0.77**	-0.05	0.15	**0.47**	0.23	-0.24	**-0.36**	-0.27
Phaeo (ppb)	**0.74**	-0.03	0.14	**0.71**	0.04	-0.29	**-0.36**	-0.29
Ln TN (mg/m3)	**0.85**	-0.06	0.04	**0.47**	0.08	-0.12	**-0.33**	-0.28
Ln TP (mg/m3)	**0.83**	-0.07	0.11	**0.57**	0.13	-0.24	**-0.32**	-0.25
NO3-N (mg/m3)	-0.03	-0.03	0.14	-0.01	-0.08	**-0.33**	-0.23	**-0.31**
SRP (mg/m3)	**0.42**	-0.06	-0.03	0.13	-0.06	-0.06	0.03	-0.01
NH4 (mg/m3)	**0.33**	-0.05	0.10	0.04	-0.05	0.10	-0.03	-0.07
Expert assessment EI	**0.75**	-0.07	**-0.34**	**0.32**	0.22	0.01	-0.13	-0.07
Euphotic depth Zeu	**-0.47**	-0.18	-0.06	-0.21	-0.23	0.16	0.34	0.28
Metazooplankton biomass (average mg w.w. l-1)	**0.38**	-0.05	0.03	0.30	-0.09	-0.18	-0.13	-0.14
Metazooplankton Simpsons index (exc nauplii)	0.11	0.07	-0.07	0.33	0.16	-0.11	-0.25	-0.23
Meta- zooplankton Shannon index (exc nauplii)	-0.20	-0.14	0.06	**-0.36**	-0.28	0.12	0.20	0.16
Rotifer Simpsons index	-0.16	-0.14	0.06	**-0.36**	**-0.34**	0.13	0.20	0.16
Rotifer Shannon index	0.17	0.07	-0.07	0.33	0.15	-0.09	-0.24	-0.22
15N Range (per mil)	0.19	0.03	-0.01	-0.22	0.07	-0.09	-0.21	-0.20
13C Range (per mil)	0.04	-0.18	-0.03	0.13	-0.04	-0.05	0.01	-0.06
Total food web area	-0.25	-0.18	0.01	-0.21	-0.17	0.08	0.07	0.04
Foodweb mean distance to centroid	0.07	-0.06	0.02	0.13	0.19	**-0.32**	**-0.34**	**-0.35**
Foodweb mean nearest neighbour distance	-0.11	-0.19	-0.06	0.01	-0.05	0.04	0.02	-0.01
Foodchain length	0.15	0.08	0.02	-0.01	0.04	-0.30	-0.27	-0.32

Appendix C. Correlation matrix

Page 5 of 9	Margalef richness Macroinverts	% Macrophyte cover (exotic + native)	Macrophyte Weighed Simpson index	pH	Abs440	Cl (ppm)	Ca (ppm)	Mg (ppm)	DOC (ppm)
Residence time days									
Catchment Alluvial (%) FWENZ									
TLI CDRP									
Catchment Peat (%) FWENZ									
% Native fishes									
CPUE bullys + shortfin + longfin eels									
Conductivity us/cm CDRP									
Pilieu Evenness Macroinvertebrates									
Shannon diversity H'(loge) Macroinverts									
Simson Diversity 1-Lambda' Macroinverts									
Margalef richness Macroinverts	1.00								
% Macrophyte cover (exotic + native)	0.30	1.00							
Macrophyte Weighed Simpson index	-0.08	-0.12	1.00						
pH	-0.04	**-0.36**	0.25	1.00					
Abs440	-0.14	0.09	-0.12	**-0.57**	1.00				
Cl (ppm)	**-0.30**	**-0.33**	**0.36**	**0.34**	-0.18	1.00			
Ca (ppm)	-0.14	-0.28	**0.47**	**0.44**	-0.24	**0.82**	1.00		
Mg (ppm)	**-0.31**	-0.26	**0.42**	**0.32**	-0.14	**0.95**	**0.80**	1.00	
DOC (ppm)	**-0.30**	-0.24	0.26	0.06	0.38	-0.04	-0.05	0.02	1.00
Kd (Ln m)	**-0.34**	**-0.44**	**0.40**	0.10	0.17	0.43	**0.42**	**0.52**	**0.32**

Appendix C. Correlation Matrix

Page 6 of 9	Margalef richness Macroinverts	% Macrophyte cover (exotic + native)	Macrophyte Weighed Simpson index	pH	Abs440	Cl (ppm)	Ca (ppm)	Mg (ppm)	DOC (ppm)
Chla (ppb)	**-0.34**	**-0.44**	**0.37**	**0.36**	-0.13	0.33	**0.31**	**0.35**	**0.33**
Phaeo (ppb)	-0.29	**-0.40**	0.15	**0.35**	-0.05	0.16	0.16	0.13	**0.36**
Ln TN (mg/m3)	-0.29	**-0.43**	0.35	**0.38**	-0.02	0.19	0.19	0.23	**0.71**
Ln TP (mg/m3)	-0.29	**-0.46**	0.18	**0.37**	-0.06	0.25	0.25	0.25	**0.47**
NO3-N (mg/m3)	0.03	0.04	-0.01	0.14	-0.10	-0.08	-0.03	-0.07	-0.15
SRP (mg/m3)	0.06	-0.18	-0.13	0.16	0.02	-0.05	0.01	0.00	0.28
NH4 (mg/m3)	-0.08	-0.15	-0.05	-0.05	0.11	-0.03	-0.04	-0.02	**0.59**
Expert assessment EI	-0.18	**-0.43**	**0.39**	**0.67**	-0.28	0.28	0.28	**0.30**	**0.39**
Euphotic depth Zeu	0.17	**0.41**	-0.13	0.01	**-0.39**	-0.25	-0.24	-0.28	**-0.34**
Metazooplankton biomass (average mg w.w. l-1)	-0.05	-0.19	-0.08	0.17	-0.03	-0.08	0.00	-0.07	0.22
Metazooplankton Simpsons index (exc nauplii)	-0.25	-0.04	-0.01	0.04	0.17	0.14	0.12	0.10	0.09
Meta- zooplankton Shannon index (exc nauplii)	0.23	0.27	-0.12	-0.03	-0.19	-0.25	-0.25	-0.21	-0.04
Rotifer Simpsons index	0.23	0.21	-0.07	-0.03	-0.19	-0.29	-0.29	-0.23	-0.04
Rotifer Shannon index	-0.25	-0.13	0.04	0.05	0.21	0.14	0.11	0.10	0.10
15N Range (per mil)	-0.08	-0.20	-0.03	0.22	-0.22	0.07	-0.01	0.06	-0.08
13C Range (per mil)	0.03	0.01	-0.11	0.17	-0.20	-0.15	-0.05	-0.17	-0.08
Total food web area	0.00	0.03	-0.24	0.06	**-0.37**	**-0.30**	-0.26	**-0.36**	-0.31
Foodweb mean distance to centroid	-0.21	-0.26	-0.22	0.20	0.14	0.11	0.15	0.09	-0.07
Foodweb mean nearest neighbour distance	0.00	-0.03	-0.13	0.08	-0.11	-0.11	-0.10	-0.10	-0.09
Foodchain length	0.01	-0.04	-0.24	0.25	-0.18	0.02	-0.03	0.00	0.05

Appendix C. Correlation Matrix

Page 7 of 9	Kd (Ln m)	Chla (ppb)	Phaeophytin (ppb)	TN (mg/m3)	TP (mg/m3)	NO3-N (mg/m3)	SRP (mg/m3)	NH4 (mg/m3)	Expert assessment EI
Chla (ppb)	**0.73**	1.00							
Phaeo (ppb)	**0.68**	**0.82**	1.00						
Ln TN (mg/m3)	**0.50**	**0.69**	**0.67**	1.00					
Ln TP (mg/m3)	**0.64**	**0.77**	**0.88**	**0.79**	1.00				
NO3-N (mg/m3)	-0.13	-0.08	-0.07	0.14	-0.07	1.00			
SRP (mg/m3)	0.24	0.11	0.28	**0.34**	**0.58**	-0.04	1.00		
NH4 (mg/m3)	0.03	0.04	0.06	**0.62**	**0.32**	0.02	**0.33**	1.00	
Expert assessment EI	**0.36**	**0.57**	**0.49**	**0.67**	**0.55**	0.03	0.26	0.18	1.00
Euphotic depth Zeu	**-0.59**	**-0.40**	**-0.43**	**-0.32**	**-0.44**	**0.40**	-0.24	-0.13	-0.36
Metazooplankton biomass (average mg w.w. l-1)	**0.35**	**0.31**	**0.53**	**0.32**	**0.66**	-0.05	**0.81**	0.02	0.22
Metazooplankton Simpsons index (exc nauplii)	0.14	0.13	0.19	0.11	0.06	-0.19	-0.07	0.03	0.23
Meta- zooplankton Shannon index (exc nauplii)	-0.26	-0.20	-0.23	-0.01	-0.12	0.34	0.13	0.07	-0.03
Rotifer Simpsons index	-0.25	-0.22	-0.26	-0.04	-0.13	**0.36**	0.12	0.06	-0.13
Rotifer Shannon index	0.15	0.14	0.21	0.10	0.07	-0.22	-0.10	0.02	0.16
15N Range (per mil)	-0.06	-0.08	-0.17	0.15	-0.05	**0.30**	0.08	0.25	0.23
13C Range (per mil)	-0.02	0.07	0.03	0.07	-0.06	-0.11	-0.12	0.09	0.07
Total food web area	**-0.38**	-0.14	-0.18	-0.25	-0.24	-0.07	-0.13	-0.10	-0.10
Foodweb mean distance to centroid	0.12	0.03	0.06	0.17	0.11	0.04	0.10	0.22	0.03
Foodweb mean nearest neighbour distance	-0.14	-0.08	-0.14	0.01	-0.14	-0.08	-0.08	0.13	0.02
Foodchain length	-0.05	0.03	-0.01	0.36	0.13	**0.32**	0.14	**0.43**	0.24

Appendix C. Correlation Matrix

Page 8 of 9	Euphotic depth Zeu	Metazooplankton biomass (average mg w.w. l-1)	Meta-zooplankton Simpsons index (exc nauplii)	Meta-zooplankton Shannon index (exc nauplii)	Rotifer Simpsons index	Rotifer Shannon index	δ^{15}N Range (per mil)
Chla (ppb)							
Phaeo (ppb)							
Ln TN (mg/m3)							
Ln TP (mg/m3)							
NO3-N (mg/m3)							
SRP (mg/m3)							
NH4 (mg/m3)							
Expert assessment EI							
Euphotic depth Zeu	1.00						
Metazooplankton biomass (average mg w.w. l-1)	-0.18	1.00					
Metazooplankton Simpsons index (exc nauplii)	-0.30	-0.06	1.00				
Meta- zooplankton Shannon index (exc nauplii)	**0.40**	0.09	-0.59	1.00			
Rotifer Simpsons index	**0.39**	0.07	-0.92	**1.00**	1.00		
Rotifer Shannon index	**-0.30**	-0.08	**1.00**	**-0.92**	**-0.92**	1.00	
15N Range (per mil)	0.10	0.00	-0.06	0.15	0.15	-0.07	1.00
13C Range (per mil)	0.13	-0.06	**0.44**	**-0.34**	**-0.34**	**0.43**	0.20
Total food web area	0.40	-0.05	0.12	-0.05	-0.05	0.11	**0.36**
Foodweb mean distance to centroid	-0.15	0.06	0.22	-0.13	-0.14	0.19	**0.34**
Foodweb mean nearest neighbour distance	0.23	-0.10	**0.30**	-0.19	-0.19	0.29	**0.46**
Foodchain length	-0.03	0.02	-0.06	0.18	0.17	-0.07	**0.72**

Appendix C. Correlation Matrix

Page 9 of 9	δ^{13}C Range (per mil)	Total food web area	Foodweb mean distance to centroid	Foodweb mean nearest neighbour distance
Chla (ppb)				
Phaeo (ppb)				
Ln TN (mg/m3)				
Ln TP (mg/m3)				
NO3-N (mg/m3)				
SRP (mg/m3)				
NH4 (mg/m3)				
Expert assessment EI				
Euphotic depth Zeu				
Metazooplankton biomass (average mg w.w. l-1)				
Metazooplankton Simpsons index (exc nauplii)				
Meta- zooplankton Shannon index (exc nauplii)				
Rotifer Simpsons index				
Rotifer Shannon index				
15N Range (per mil)				
13C Range (per mil)	1.00			
Total food web area	**0.69**	1.00		
Foodweb mean distance to centroid	**0.52**	0.25	1.00	
Foodweb mean nearest neighbour distance	**0.81**	**0.70**	**0.62**	1.00
Foodchain length	**0.16**	0.19	**0.35**	**0.31**

Appendix D: An example of a framework for standardizing the development of expert opinion – the Cultural Health Index Assessment form. Reproduced with permission from Tipa and Teirney 2006 (Page 1 of 2).

CULTURAL STREAM HEALTH ASSESSMENT Date: Site no:

INDICATORS	UNHEALTHY				HEALTHY
1 Catchment land use	1. Land heavily modified Wetlands, marshes lost	2	3	4	5. Appears unmodified
2 Vegetation – banks & margins (100m either side)	1. Little or no vegetation - neither exotic or indigenous	2	3	4	5. Complete cover of vegetation – mostly indigenous
3. Use of the river banks + margins (100m either side)	1. Margins heavily modified	2	3	4	5. Margins unmodified
4. Riverbed condition (sediment)	1. Covered by mud/sand slime, weed	2	3	4	5. Clear of mud/sand/sediment/weed
5. Changes to river channel	1. Evidence of modification eg stopbanks, straightening, gravel removal, shingle build up	2	3	4	5. Appears unmodified
6. Water quality	1. Appears polluted eg foams, oils slime, weeds etc	2	3	4	5. No pollution evident
7. Water Clarity	1. Water badly discoloured	2	3	4	5. Water is clear
8 A variety of habitats	1. Little or no current, Uniform depth and limited Variety of flow related habitatst .	2	3	4	5 Current and depth varies creating a variety of different flow related habitats

Appendix D: An example of a framework for standardizing the development of expert opinion – the Cultural Health Index Assessment form. Reproduced with permission from Tipa and Teirney 2006 (Page 2 of 2).

9. How would you describe the overall health of the river at this site?

1. Very unhealthy 2 3 4. 5. Very healthy

Please explain your answer______________________________

____

____

BIRDS: Please list the mahinga kai bird species that you can see at this site

1.__________ 2.__________ 3.__________ 4.__________
5.__________ 6.__________ 7.__________ 8.__________

PLANTS: Please list the mahinga kai plant species that you can see at this site

1.__________ 2.__________ 3.__________ 4.__________
5.__________ 6.__________ 7.__________ 8.__________

10. ACCESS: Do you consider access to this site is sufficient to harvest mahinga kai?

1. Not able to gather at this site 2. 3. 4. 5. Able to gather - no restrictions

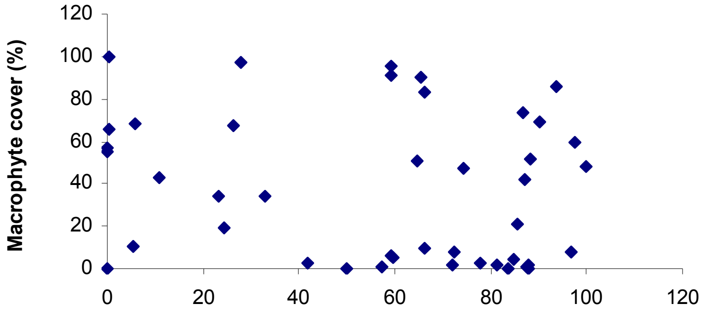
Please explain your answer______________________________

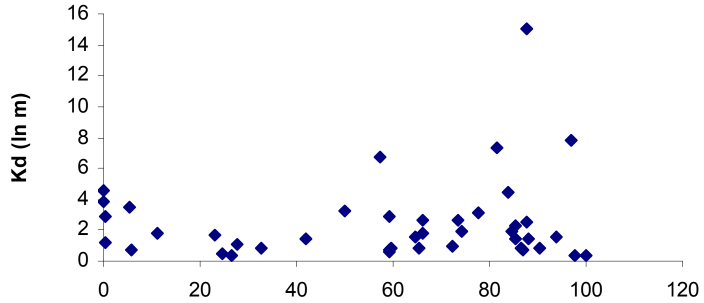
____

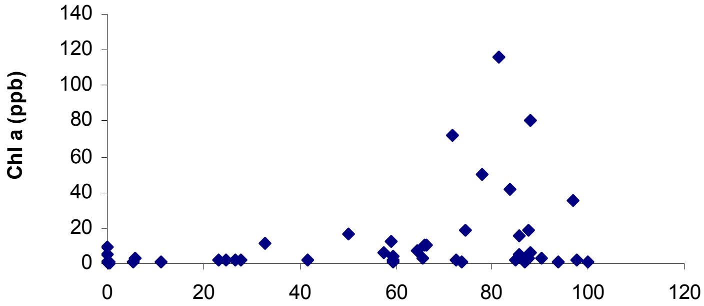
11. Would you return to this site in the future?

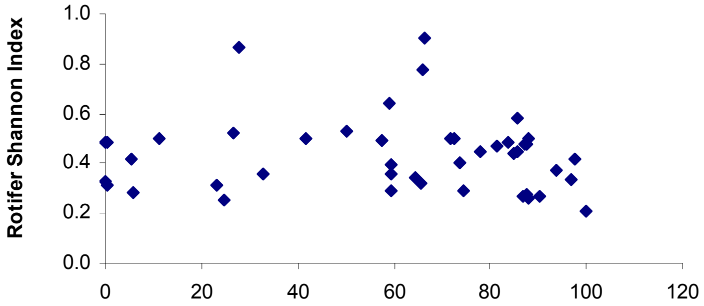
1. NO 5. YES.

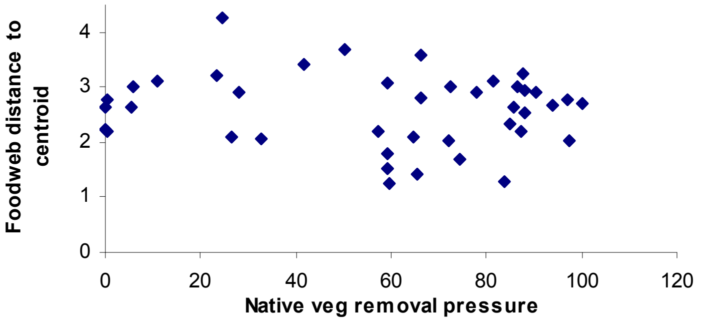
Appendix E: Scatter plots comparing best candidate measured variables to pressure gradients. Page 1 of 5.



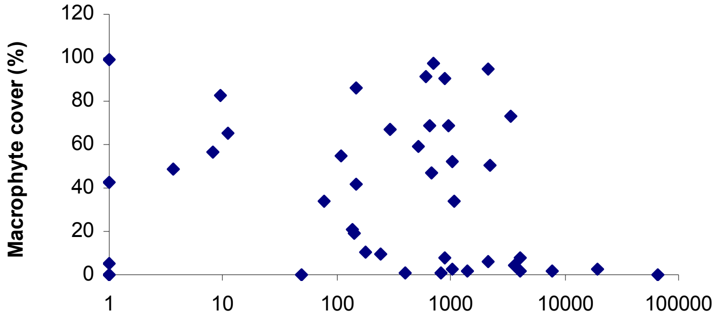


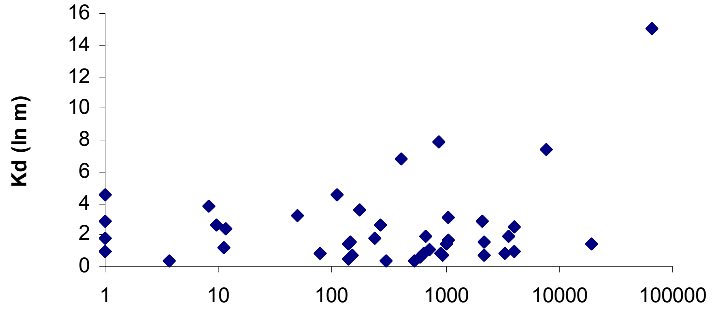


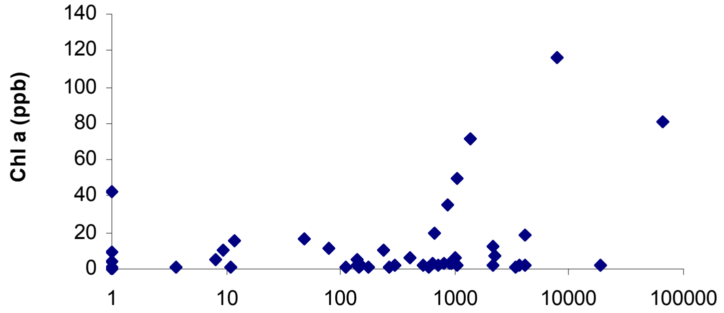


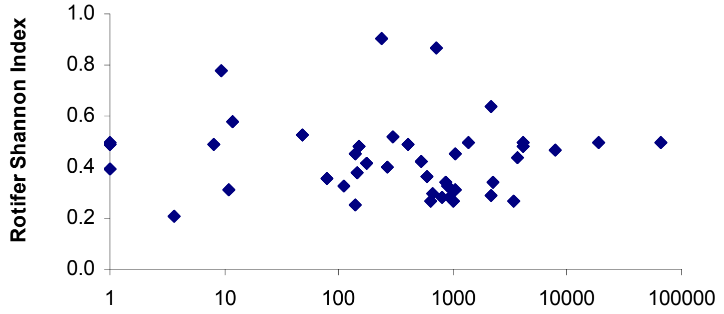


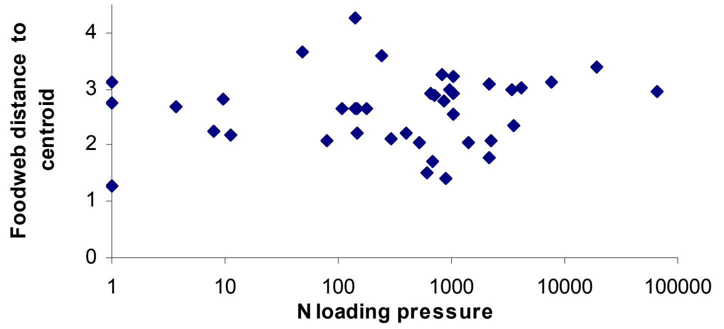
Appendix E: Scatter plots comparing best candidate measured variables to pressure gradients. Page 2 of 5.



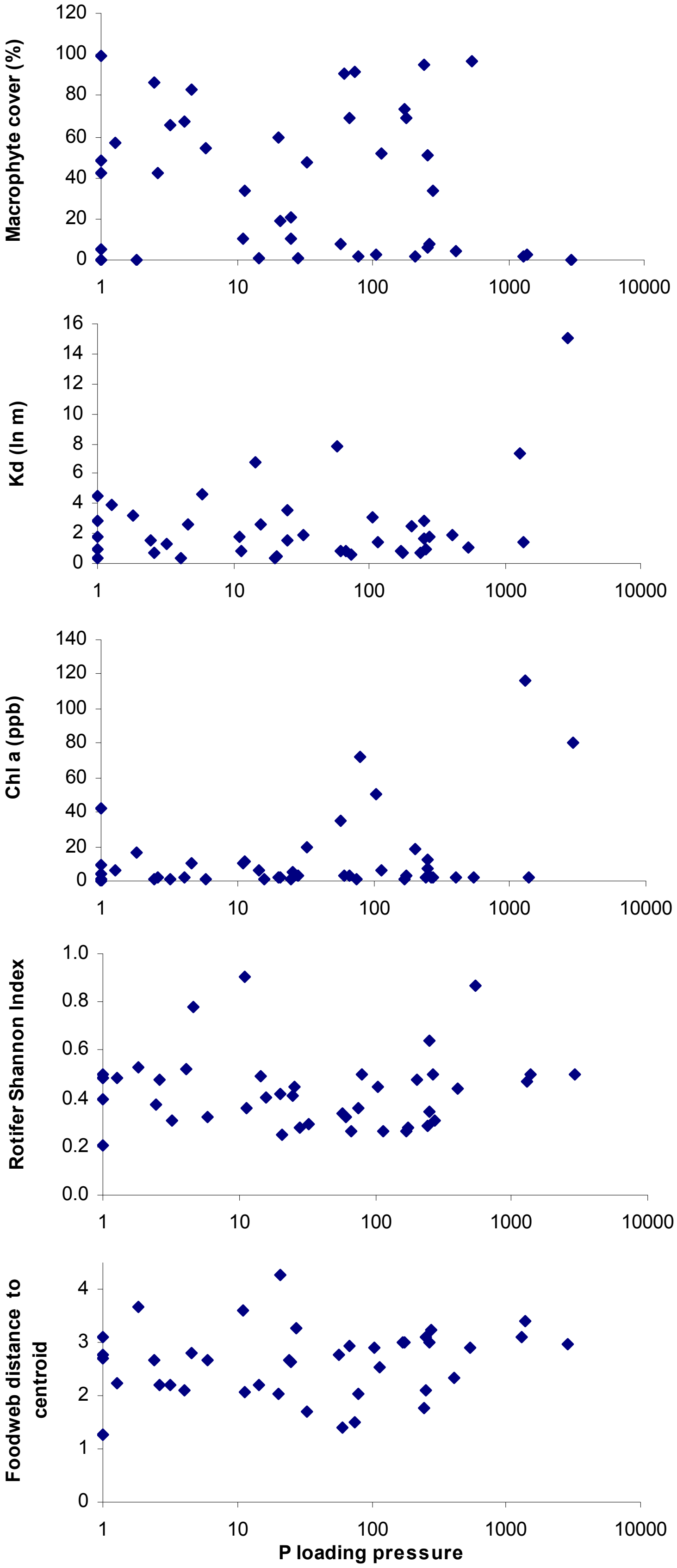




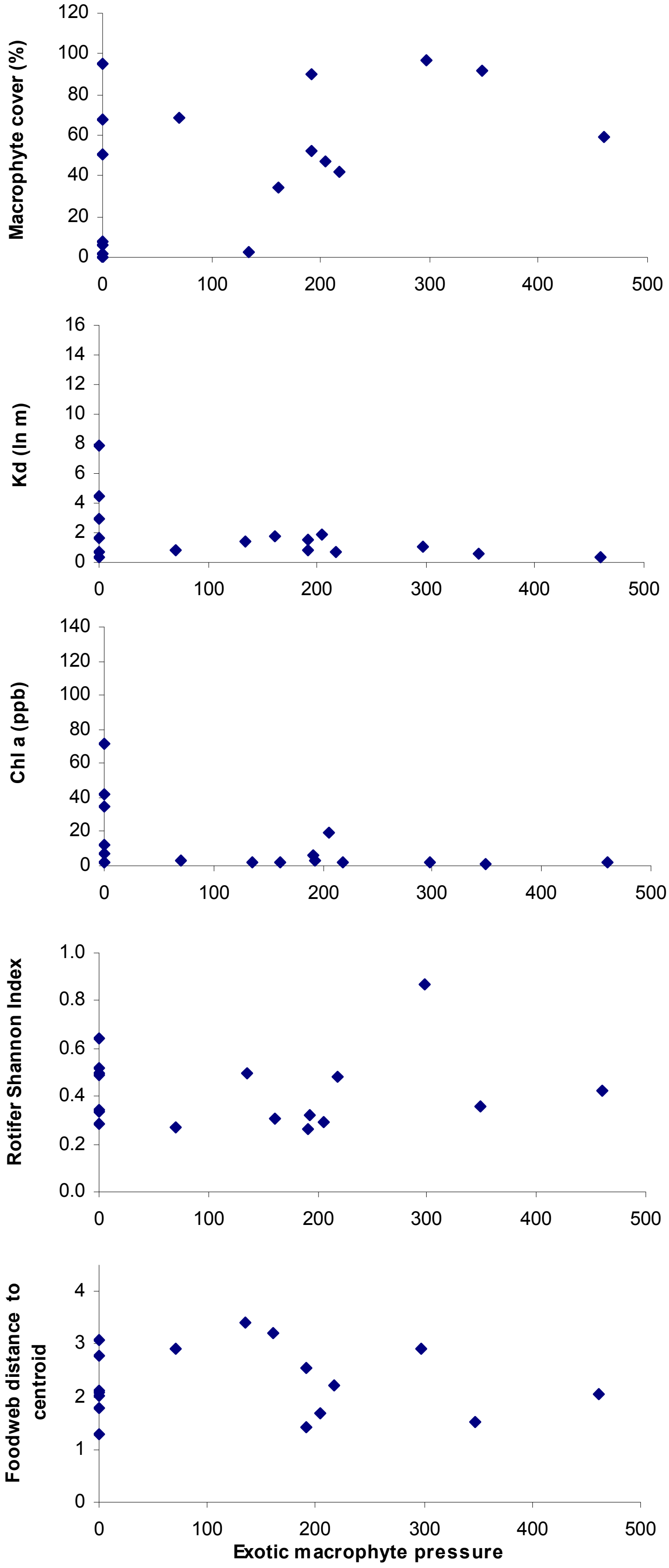




Appendix E: Scatter plots comparing best candidate measured variables to pressure gradients. Page 3 of 5.



Appendix E: Scatter plots comparing best candidate measured variables to pressure gradients. Page 4 of 5.



Appendix E: Page 5 of 5.