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Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Investigations and Monitoring Group

Lake Forsyth/Wairewa

A literature review

Report No. R13/106
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Report prepared for Environment Canterbury by

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Hydrosphere Research Ltd

December 2013

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Lake Forsyth/Wairewa:

A Literature Review

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Prepared for Environment Canterbury - July 2013

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Executive summary

Lake Forsyth/Wairewa is a shallow coastal lake/lagoon that has undergone eutrophication since at least the early 1900s.

We undertook a review of the published literature on the lake to summarise what is known about its environmental history, its ecological values, its current ecological condition and recent trends in ecological condition. The literature was summarised in terms of studies on the lake's environmental history and on the lakes current condition and recent trends in condition. The lake and its catchment have undergone major natural and anthropogenic changes in hydrological modification and major anthropogenic changes in nutrient enrichment.

A list of biota that have used the lake as habitat is provided. While the lake has undergone serious degradation, some ecological values persist, such as the moderately diverse fishery, the use of the lake by crested grebes, and the occasional presence of native macrophytes.

We analysed the recent ecological condition of the lake in relation to its inferred reference condition and found that it has degraded substantially since land use impacts began. At present, the lake is in a poor (hypertrophic) condition.

We examined the current monitoring programme of the lake as carried out by Environment Canterbury, which was found to be adequate in terms of statutory and reporting requirements. However, we suggest that monitoring of ecological health could be improved by monitoring water quality at a central lake station and by including the monitoring of aspects of the macrobenthos and macrophyte communities.

A study carried out on shallow New Zealand lakes that have undergone rapid regime shifts from clear water to turbid states indicates that the land use intensity of the catchment of Lake Forsyth/Wairewa is consistent with a moderate to high probability of regime shifts. This suggests that catchment land use intensity is a cause of regime shifting behaviour and that reductions in pasture area of the catchment could help stabilise the lake from continuing regime shifts and could restore macrophyte communities.

We suggest that management efforts and efforts to restore the ecological values of the lake should focus on reducing internal and external nutrient loading and on optimising the opening regime for ecological recovery.

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1. BACKGROUND AND SCOPE OF THE REPORT

1.1 BACKGROUND

Prior to European settlement of the area around Banks Peninsula, the basin of Te Wairewa was a tidal inlet also known as Mowry Harbour (Andersen 1927 as cited in Jolly & Brown 1975). By the 1840s, a barrier bar naturally formed at the mouth of the inlet, and Te Wairewa also became known as Lake Forsyth, a shallow intermittently closed and open lake/lagoon or ICOLL (Fig. 1). It has long been an important water body for the gathering of mahinga kai (Davie 2005a) and is especially known for its resource of eels/tuna. Since the early 1900s, the lake has been reported to be eutrophic, suffering from intermittent blooms of cyanobacteria, including the toxic species, *Nodularia spumigena* (Carmichael et al. 1988; Main 2002). A combination of natural and anthropogenic factors facilitates algal blooms and the resulting turbid water of the lake inhibits the growth of aquatic macrophytes. However, the lake undergoes intermittent periods of substantial macrophyte regrowth and improved water clarity. This type of regime shifting is fairly common in shallow eutrophic lakes (Schallenberg & Sorrell 2009). Mahinga kai gathering has suffered as a result of the degraded ecological condition of the lake (Davie 2005a). Currently, interest is building to improve management and undertake ecological restoration of the lake.

Figure 1. Location of Lake Forsyth/Wairewa in relation to Christchurch and the Banks Peninsula.

1.2 SCOPE OF THE REPORT

This study reviews the available scientific literature concerning the environmental history and present condition of the lake, as a basis for reviewing current SOE monitoring and for informing future restoration efforts. The report includes:

- Summaries of scientific information from peer-reviewed journals, reports, and other sources of information
- Summaries of current research projects being undertaken on the lake,
- An evaluation of the current ecological integrity of the lake (in relation to other NZ ICOLLs),
- Information on salinity and nutrient thresholds relevant to the ecological condition of the lake,
- Information on potentially useful indicators of the ecological condition of the lake.

2. INFORMATION SOURCES

The information sources used within this report were found using:

- An internet search of the article database Web of Science, using combinations of keywords Lake Forsyth, Wairewa, Canterbury, Banks Peninsula and brackish lake.
- A search in Google and Google Scholar using the same keywords.
- Examining the reference list of all papers and reports found.
- Discussions with limnologists knowledgeable about the lake

3. SUMMARY OF STUDIES ON THE LAKE

3.1 ENVIRONMENTAL HISTORY

PYLE (1992)

This thesis uses Lake Forsyth as a case study in proposing a new method of lake management focusing on combining science, traditional knowledge, anecdotal information and "strong observation" toward the creation of important ecosystem links. In doing so, the author compiled historical environmental information summarised below.

Anecdotes supporting information on the environmental history of the system include:

'Soils on the valley floor are especially fertile': Supporting scientific evidence that the bedrock and derived soils have a relatively high phosphorous content (see Lynn 2005, below).

'Streams running white with whey': Supporting historical reports that a dairy factory operated in the catchment (Jolly & Brown 1975).

"Lake Forsyth looks like a hay paddock": Supporting evidence of weed and algal blooms resulting from increased nutrient input.

Algal blooms and fish kills were reported to occur as early as 1907, with locals recording the presence of green, dirty water and the hundreds of eels and trout lying dead on the lakeshore.

Pyle concluded that phosphate fertilizers associated with farming activities were probably not a major source of phosphorus to Lake Forsyth/Wairewa, because small quantities were used by farmers in Little River.

Reforestation has been occurring in the catchment with an estimated tenfold increase in catchment vegetation from 1900-1990. Much of this reforestation has been in the upper gullies and riparian reaches, however riparian margins in the low lying developed area remain largely bare and prone to erosion.

SOONS ET AL. (1997)

The Kaitorete spit/barrier system was dated using morphological, stratigraphical, micro-palaeontological and radiocarbon methods. The authors found the barrier system to be a result of fluvial gravel transport from the Waimakariri River and concluded the spit has existed for the last 8000 years. It is suggested that approximately three alterations between lacustrine and estuarine/lagoon system have occurred in the Lake Ellesmere/ Lake Forsyth area since the early/mid Holocene, the latest of which (c. 450 years BP) created the most recent barrier system that has remained since. There are patchy records of rapid gravel accumulation at the cliffs of Birdlings Flat on the eastern end of the Kaitorete Spit since 1830, suggesting the Kaitorete barrier spit system is still highly active and continues to produce a growing barrier at Lake Forsyth/Wairewa.

SOONS (1998)

This report examined coastal changes that have occurred on Banks Peninsula and their resulting impact on the Lake Forsyth/Wairewa barrier system. It includes an examination of historical maps, traditional and anecdotal evidence for the barrier formation, and compares these with photographic evidence and ^{14}C dating of the Kaitorete Spit.

The barrier isolating Lake Forsyth/Wairewa from the Pacific Ocean was determined to be in place approx. 6000 years ago with significant gravel accumulation taking place 2000 years later. In 1852 the barrier was reported to be 10 metres wide, with natural openings occurring through history until 1866 when manual opening procedures were established. The barrier appears not to have changed substantially in the past 150 years with an accretion rate of 1.6-2m/year over this period.

MAIN (2002)

This article describes Lake Forsyth as a case study for lake management, focusing on nuisance *Nodularia spumigena* blooms and relating them to the historical environmental condition of the lake and its catchment.

Deforestation was linked to an increase in nutrients and sediment to the lake, with the streams said to be 'filled with silt' during the late 19th century. The vegetation clearance in the catchment was said to be so intense up to 1886, that Little River was known as the 'Valley of a Thousand Fires'. It was after the vegetation had been cleared that dairying began and for many years whey was reportedly discharged into catchment streams.

REID ET AL. (2004)

This report describes palaeolimnolgical investigatiions carried out on Lake Forsyth/Wairewa. The authors found that the sedimentation rate prior to European settlement c. 1860AD was as low at 0.1 mm/y, whereas the sedimentation rate post European settlement increased to c. 2.4 mm/y, with recent rates as high as 3.8 mm/y. This represents a roughly 30-fold increase in sediment infilling. The authors noted a change in diatoms from periphytic species (attached to plants) to planktonic species in more recent times. The diatom analysis did not support the suggestion that the ICOLL was an open embayment prior to the 1840s, as has been reported in some historical records.   However, the authors did indicate that they thought there was differential preservation of diatom frustules at different strata in the core. In general, these results are similar to those reported in Woodward & Shulmeister (2005) and those reported by Schallenberg et al. (2012) for the tidal Lake Waihola (Otago).

LYNN (2005)

This paper focuses on past nutrient enrichment and its influence on the current condition of the lake. Phosphorus sources to the lake are discussed and the authors considered it highly likely that the bedrock and soils of the catchment as well as internal nutrient cycling contributed substantial amounts of phosphorus to the water column of the lake. These phosphorus sources are relevant to the blooms of *Nodularia spumigena,* which is a nitrogen fixer and thus, may be inherently phosphorus-limited.

The basement rocks in the Little River area are mainly basaltic lava flows and pyroclastic deposits which have a high phosphorus content, the weathering of which results in phosphorous rich soils. In fact, basaltic parent soil has shown to have 4-5 times more total and elemental P than the greywacke derived loess that also contributes to the soil. The analysis of soil and geological maps confirmed the strong presence of basalt and basalt-derived soils in the catchment, indicating that the erosion experienced during and after deforestation may have been a major source of phosphorus to the lake sediments.

WOODWARD & SHULMEISTER (2005)

This report describes a multiproxy palaeobiological study involving the retrieval and analysis of a 1.2m sediment core from Lake Forsyth. Pollen species and condition, invertebrate remains and foraminifera were identified among other indicators, allowing approximate dates of changes in natural and anthropogenic induced environmental history to be determined. The authors found changes in salinity, sedimentation and an increase in nutrients to be anthropogenic effects distinguishable from natural phenomena and those which have dictated the lake's recent environmental history.

Major deforestation occurred in the surrounding steep catchment, peaking around 1895, as indicated in the core by a decline in pollen of canopy vegetation, an increase in charcoal and an increase in exotic grass pollen. This deforestation likely resulted in increased freshwater overland flow entering the lake causing salinity fluctuations. The deforestation of surrounding hillsides appears to have coincided with the isolation of the lake from the Pacific Ocean during the creation of the natural gravel barrier, therefore creating difficulty in determining a realistic historical salinity baseline.

A secondary effect of deforestation, linked through the sediment core to impacts on lake condition, was catchment erosion. The sediment accumulation rate pre-1840's was 0.88 mm/y, increasing 4-fold to 3.7 mm/y as a result of vegetation removal. The particularly steep slopes of the Lake Forsyth catchment are thought to have been especially vulnerable to slips and erosion during deforesting, which may have brought excess nutrients into the lake system.

Following the clearance of vegetation, a large portion of the low lying catchment was converted to dairy farms, no doubt further increasing nutrient and sediment input and contributing to the first bloom of *Nodularia spumigena* in 1907. This and subsequent blooms may have also been influenced by artificial openings of the lake barrier, the first of which occurred in 1866. *N spumigena* is a halotolerant species which can peak during periods of high salinity, while most naturally occurring freshwater taxa inhabiting the lake decline in abundance.

The authors of this study generally agreed with Pyle (1992) and recommended restoration of what was once a wetland at the northern head of the lake, which probably acted as a natural “filter” of nutrients and suspended sediment lost from catchment soils before they enter the lake. Replanting of the steep slopes of the catchment, particularly of the riparian margins was also suggested to reduce sediment input, however all restoration efforts may require patience due to the shallow nature, and continual wind-induced entrainment of the sediment into the water column.

3.2 ENVIRONMENTAL CONDITION

MCDOWALL (1970)

This paper mentions the presence of the smelt species, *Retropinna retropinna,* in Lake Forsyth/Wairewa in 1970 and it has since been caught in the lake in 2004 (M. Schallenberg, unpublished data).

JOLLY & BROWN (1975)

This book called, “New Zealand Lakes”, summarised information on a large number of New Zealand lakes. Some aspects of water chemistry of Lake Forsyth/Wairewa were summarised in Chapter 7 (by V. Stout). Chapter 11 (by AMR Burnett & DA Wallace) mentioned that the lake was not a favourable habitat for trout due to its highly eutrophic condition. These authors also presented data on phytoplankton productivity indicating that rates of carbon fixation ranged between 200 and 1000 μg C/L/h. These rates could be stimulated by modifications to alkalinity and pH during the experiments, suggesting that carbon and/or phosphorus limitation of primary productivity. Chapter 12 (by EA Flint) mentioned some historical changes to the lake and provided a list of phytoplankton species found in the lake. Chapter 15 (by MA Chapman, JD Green and VH Jolly) mentioned the presence of the estuarine copepod, *Gladioferens pectinatus,* in the lake. Chapter 19 (by MJ Winterbourn and MH Lewis) mentioned the presence of a number of species of *Potamopyrgus* snail in the lake and Chapter 21 (by RM McDowall, CL Hopkins and M Flain) mentioned the presence of smelt (*Retropinna retropinna*) in the lake.

PYLE (1992)

Nutrient status and possible contributing factors to the current hypertrophic state of the lake are described in this thesis. Potential phosphorus inputs into the system from fertilizer, septic tanks and historic activities are considered.

The environmental history described in this thesis indicates a large historical input of P into the lake, however most present inputs appear to be small. The rate of application of fertilizers to dairy, sheep and beef farms in the catchment and neighbouring valleys during the 1960s-70s was suggested to be low, peaking at 1041 tons in 1978 and declining through the 1980s, although rates of fertilizer application within more specific parts of the catchment were difficult to determine.

The author suggested that the P input associated with historical deforestation, erosion and dairy conversion of the lower catchment has provided enough P to be continually recycled in the lake under certain conditions, contributing to the hypertrophic status of the lake. This internal nutrient cycling from the sediment generally occurs under two scenarios, one or both of which may occur in Lake Forsyth/Wairewa. The internal nutrient load from a shallow lake can be mobilized by high winds causing the bottom sediment to mix particles and nutrients into the water column, which the author believes is highly likely to occur in Lake Forsyth. Internal nutrient cycling may also occur under calm deoxygenated conditions during which sediments release nutrients into the water; however it was unknown whether this is occurring in Lake ForsythWairewa.

The author of this study suggested that the former wetland at the head of the lake was probably an important "filter" for nutrients and sediments lost from the catchment soils. Thus, he suggested that the lake could be restored by replanting a wetland at the head of the lake and re-vegetating the riparian margins, particularly on the valley floor.

HAMILTON & MITCHELL (1996)

This paper presents an empirical model for sediment resuspension in shallow lakes, using data from seven shallow lakes, of which Lake Forsyth/Wairewa was one. Variables associated with the physical forces caused by wave action were individually identified and regressed with physical data collected at 2-3 week intervals over a period of at least 12 months.

The mean suspended solid concentration following calm periods in Lake Forsyth was 78.5mg/L which was the second highest compared to the remaining six lakes, with Lake Ellesmere/Waihora having the greatest concentration (186 mg/L).

The sediment resuspension at Lake Forsyth/Wairewa was found to best correlate with local and combined benthic sheer stresses (r^2= 0.742 and 0.725 respectively).

HAMILTON & MITCHELL (1997)

This paper examines relationships between wind energy, benthic shear stress, suspended sediments, TN, TP and chlorophyll a in a number of shallow lakes including Lake Forsyth/Wairewa. The data show that TN, TP and chlorophyll *a* concentrations in the water of Lake Forsyth/Wairewa are strongly related to wind-induced benthic shear stress. Data in this paper also show that benthic shear stress is lower in Lake Forsyth than in the other shallow lakes, confirming that the lake is quite sheltered from most prevailing winds.

RIDLEY & SULLIVAN (1998)

This study examined the effects of different land uses around Lake Forsyth/Wairewa on the use of the lake by crested grebes. They found that farming activities and traffic (roads) were negatively related to grebe densities, suggesting that these activities could limit grebe numbers on the lake. In contrast, houses and recreational uses were not related to grebe densities on the lake.

CHAMPION & CLAYTON (2000)

This publication mentions the unique presence of the characean macrophyte, *Tolypella nidifica.* at Lake Forsyth/Wairewa. The aquatic plant was not reported from any other site within New Zealand and the authors suggested that it had been brought to the area by migratory birds.

MAIN (2002)

This case study mentions the current condition and issues surrounding the health of Lake Forsyth/Wairewa. The lake has a large eel fishery, populations of inanga, common smelt, common bully, black flounder and at one time provided a good habitat for trout and perch. Historic nutrient loading resulting from deforestation and dairy discharge have no doubt established a high internal P load in the lake sediment which is thought to now repeatedly cycle within the system. The major concern associated with the current lake condition is the annually blooming cyanobacterium, *Nodularia spumigena,* which has been associated with a decline in fish populations.

The current environmental condition of the lake is particularly favourable to *N. spumigena,* which normally blooms during increases in dissolved reactive phosphorous and nitrogen concentrations in the water. Increases in these nutrients are sometimes linked to periods of calm weather (when daily mean wind speeds over the preceding week are less than about 3 m/s) and low turbidity. Lake Forsyth/Wairewa is sheltered from most winds by it steep catchment. Periods of low turbidity are also associated with the presence of the macrophytes, *Ruppia spp*. and *Potamogeton pectinatus*. Conditions of increasing available nutrients in the lake, coupled with salinity fluctuations from artificial barrier openings and overwash create conditions for the proliferation of *N. spumigena*, which tolerates salt water.

JELLYMAN ET AL. (2002)

Migration behaviour of the adult lamprey/kanakana (*Geotria australis*) was investigated in two streams, one being Okuti stream which drains into Lake Forsyth/Wairewa. Lampreys from this stream were found to have a maximum daily movement of 0.45 km and may only return from the sea to the stream when the gravel barrier has been artificially opened.

DAVIE (2005A)

This short report lists key research partners as well as research and development projects to do with Lake Forsyth/Wairewa. It also provides a short statement of the Maori historical information on mahinga kai in the catchment.

DAVIE (2005B)

This report examines the feasibility of developing Lake Forsyth/Wairewa into a Mahinga Kai Cultural Park. It provides information on land tenure in the catchment and examines different management and land ownership entities that could be set up to protect the mahinga kai values of the lake and its catchment.

RHODES ET AL. (2006)

This study establishes the presence of *Pfisteria shumwayae*, a fish-killing heterotrophic dinoflagellate species in Lake Forsyth/Wairewa during 2002-2003. The dominant microalgal genera found to be co-occuring with *P. shumwayae* are also listed.

FLINT (2007)

This report provides a detailed background to Lake Forsyth-Wairewa, with emphases on: i) historical changes to water quality and flora and fauna, ii) historical records of land use, population and industry in the catchment and iii) the association of the toxin-producing cyanobacterium, *Nodularia spumigena*, with the lake.

Historical sources in this report suggest that Lake Forsyth/Wairewa had nuisance macrophyte growths in the late 1800s and that the lake had become severely affected by cyanobacterial blooms by 1907. These changes were driven by rapid deforestation, severe and rapid sedimentation, and by intensive agriculture in the catchment. In addition, the catchment is mainly composed of basalt, which has a relatively high rate of phosphorus solublisation, and with greywacke-loess soils, which are highly erodible. Together, all of these factors probably made Lake Forsyth/Wairewa one of New Zealand's earliest severely eutrophied lakes, with regular intense blooms of cyanobacteria occurring since at least 1907.

SCHALLENBERG & SORRELL (2009)

These authors reported that Lake Forsyth/Wairewa is a regime shifting lake, undergoing alternating shifts between a clear water, macrophyte dominated state and a turbid, phytoplankton dominated state. They compiled evidence that 37 shallow lakes in New Zealand had undergone such regime shifts. By comparing catchment and in-lake biological characteristics of these lakes with a "control" group of 54 lakes which hadn't been reported to have undergone regime shifts, the authors were able to report statistically significant correlates of regime shifting behaviour. Factors related to regime shifting behaviour in lakes were, catchment development, the presence of the invasive macrophyte (*Egeria densa*), and the presence of some invasive herbivorous and benthivorous fish species (catfish, goldfish, rudd, tench and koi carp).

While Lake Forsyth/Wairewa doesn't contain any of the invasive species at present, the percentage of pasture in the catchment (69.4 % from LCDB2; Schallenberg & Sorrell 2009) puts the lake/lagoon into a moderate-to-high category for regime shifting (Fig. 2). The y-axis in Fig. 2 can be interpreted as a probability of regime shifting, placing Lake Forsyth/Wairewa at the transition between 40% and 85% probability of regime shifting behaviour. These data indicate that the regime shifting behaviour of the lake is related to catchment development, suggesting that the ecological instability of the lake could be mitigated by a reduction in the percentage of the catchment that is used for pasture.

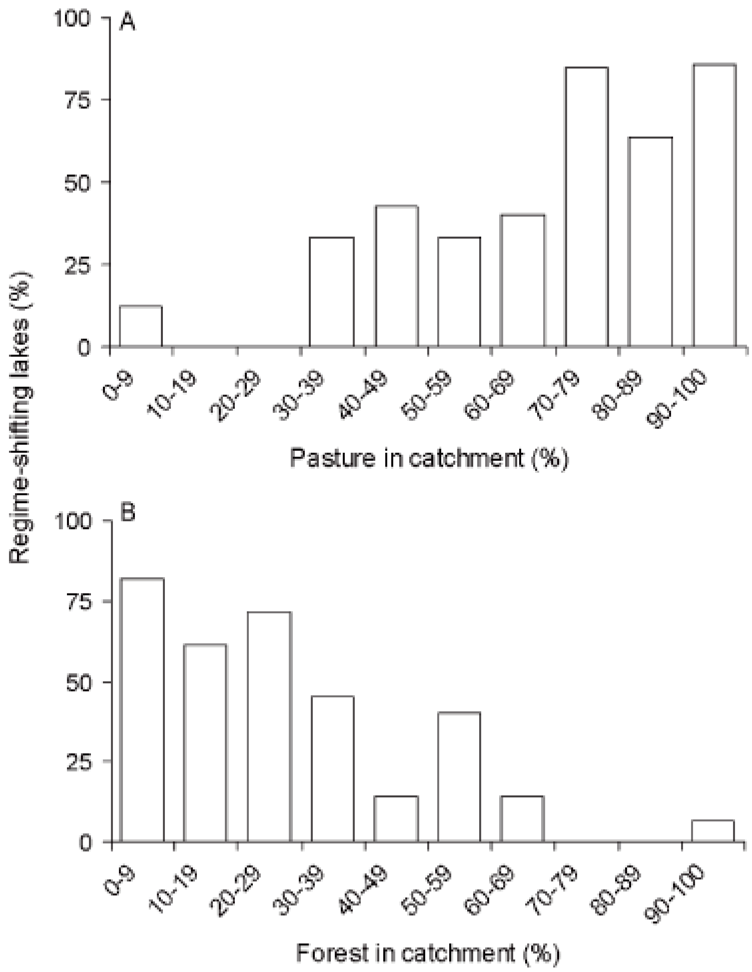

Figure 2. Percentage of lakes that underwent regime shifts by A, percentage of catchment in pasture and B, percentage of catchment in forest. Lakes were grouped into classes, based on percentage catchment land-use cover in the New Zealand Land Cover Database 2 (Terralink International Ltd). The catchment of Lake Forsyth/Wairewa contained 69.4% pasture and 29.9% forest at the time of this study. Figure from Schallenberg & Sorrell (2009).

VERBURG ET AL. (2010)

In this report for the Ministry for the Environment, the status and trends in water quality of a number of New Zealand lakes were assessed. Lake Forsyth/Wairewa was hypertrophic in the most recent period of analysis (2005-2009), but during that period, the trophic state (TLI) reduced significantly by 3.2% per year.

WOOD & DIETRICH (2011)

This paper analysed the presence and concentration of aerosolized forms of two cyanobacterial toxins present in lakeside areas during cyanobacteria blooms. Nodularin, the toxin excreted from *Nodularia spumigena* was analysed at the shore of Lake Forsyth during a *Nodularia* bloom and its aerosol was found in a concentration of 16.2 picograms per m^3 of air. This was not considered to be a health risk. However, it was noted that the aerosol concentration was high compared with that produced by a bloom of *Microcystis sp*. in Lake Rotorua.

Four cyanobacterial species were found in Lake Forsyth during the *Nodularia* bloom, *Aphanocapsa sp*., two *Merismopedia* species and *N. spumigena*. Concentrations of *N. spumigena* during the bloom were found to be between 190 and 5015 cells/mL.

ROBERTSON (2011) AND WEBSTER-BROWN ET AL. (2011)

This summer bursary study and conference poster focused on the short-term, diurnal variations in water quality parameters in Lake Forsyth/Wairewa. The parameters: dissolved oxygen, pH, conductivity, nitrate, dissolved reactive phosphorus and turbidity were measured in the lake. These were measured at different sites and at different time scales ranging from hourly to weekly. These parameters were also measured as depth profiles on a few occasions.

As expected, temperature, dissolved oxygen and pH showed distinct diel variations (both higher in the day than at night), but conductivity generally did not. Diel dissolved oxygen concentrations ranged as much as from 5 to 13 mg/L and pH ranged as much as from 7 to 9. Turbidty increased with wind speed, but nitrate and phosphate didn't appear to correlate with wind speed.

Nitrate could range from undetectable to around 1.0 mg/L over hourly time intervals while phosphate could range from around 0.2 to 2.7 mg/L. Depth profiling at mid-lake sites did not show evidence of vertical density stratification in the lake.

The extreme diel, and even shorter-term, variations in nitrate and phosphate measured in this lake are notable, unexplained anomalies.

BERRY & WEBSTER-BROWN (2012)

This summer bursary study attempted to develop a short-term, summer hydrological mass balance for Lake Forsyth/Wairewa. Hydrological inputs were dominated by river inputs (Okana and Okuti Rivers) in dry weather but rainfall directly on the lake contributed substantially to the lake's water budget during a moderate rainfall event. Outputs included seepage to groundwater, seepage to the sea, and evaporation.

PARRY (2012)

This summer bursary study investigated the organic matter and trace element concentrations in the sediment at 20 sites in Lake Forsyth/Wairewa. Organic content was quite low (i.e. generally <10%), suggesting high inorganic sediment loading to the lake bed. Trace elements concentrations (g/kg) were strongly correlated to % organic content of the sediment. Raw trace element concentrations were lower than ANZECC interim sediment quality guidelines and lower than concentrations in sediment from Lake Ellesmere/Te Waihora and Lake Taupo (North Island).

DAVIE (UNDATED)

This Powerpoint presentation examines the potential drivers of toxic cyanobacterial blooms in Lake Forsyth/Wairewa. It presented preliminary results suggesting that naturally high phosphorus levels in the bedrock geology result in high natural fluxes of total phosphorus to the lake during high river flows. It also suggests that high dissolved reactive phosphorus fluxes are less affected by hydrological variation and, thus, may be due to leaky septic tanks. The high phosphorus inputs probably favour nitrogen fixing cyanobacteria, such as the toxin-producing *Nodularia spumigena*, which is common in the lake.

DEPARTMENT OF CONSERVATION (UNDATED)

This short document lists the conservation values, threats, management issues and management priorities of Lake Forsyth/Wairewa. Among the values listed are notable plants, birds and fish species.

WOODWARD ET AL. (UNDATED)

This Powerpoint presentation describes a detailed palaeolimnological analysis of a sediment core from Lake Forsyth/Wairewa. The results are described in Woodward & Shulmeister (2005), above.

3.3 SUMMARY OF STUDIES ON LAKE FORSYTH/WAIREWA

A summary of the ecological information reported in the journal articles, reports, dissertations and theses reviewed is provided in Table 1.

Table 1. Summary of studies on Lake Forsyth/Wairewa

Source	Study type	Data on Lake Forsyth/Wairewa
Peer-reviewed journal articles		
McDowall (1970)	Critically analyses a new taxonomy put forth for Retropinnidae.	This paper mentions the presence of diadramous smelt in Lake Forsyth/Wairewa.
Hamilton & Mitchell (1996)	Comparative study of sediment resuspension in shallow lakes.	This paper gives measurements of mean suspended solid concentrations, mean sediment water content and mean annual macrophyte density sampled in 1995.
Hamilton & Mitchell (1997)	Modelling of phosphorus input to the lake and effects of wind-induced sediment resuspension on water quality.	This paper provides a model estimate for the annual TP input into the lake. Measurements of Chl. A, TP, TN, PO4-P, nitrate, ammonia, TN:TP ratio, benthic shear stress and the percent of total N and P in sediment are given (from 1995 data).
Soons et al. (1997)	Describes the evolution of the Kaitorete Spit barrier system.	Contains core data from two short cores taken from Lake Forsyth along with gravel accumulation rates taken near the lake mouth.
Ridley & Sullivan (1998)	Examined effects of land use and recreation on crested grebe densities.	Data on crested grebe densities in relation to land use and recreation.
Soons (1998)	Describes evidence for the conversion of Lake Forsyth/Wairewa from an inlet to a brackish/freshwater lake.	Gravel accumulation rate at Birdlings Flat.
Champion & Clayton (2000)	Identifies potential aquatic weed dispersal pathways into New Zealand.	Reports the presence of the macrophyte, *Tolypella nidifica.*
Jellyman et al. (2002)	Analysed habits and movements of tagged lampreys/kanakana.	Lists the presence of the lamprey, and gives data on upstream and downstream movements and preferred habitat.
Woodward & Shulmeister (2005)	Palaeolimnological reconstruction of the environmental history of the lake and its catchment.	Inferred data on historical salinity and trophic state.
Rhodes et al. (2006)	Studyied the geographic distribution of *Pfiesteria piscicida* and *P. shumwayae* across Canterbury and Tasman regions.	Measurements of salinity, temperature, ammonia, nitrate, nitrite, TN, DRP and TP are given for each season at Lake Forsyth during 2002-2003. Phytoplankton taxa are also listed.
Schallenberg & Sorrell (2009)	Study on regime shifting in New Zealand lakes including Lake Forsyth/Wairewa.	Catchment land use, regime shifting behaviour.
Wood & Dietrich (2011)	Looked at the effect of aerosolized forms of nodularin, the toxic compound of *Nodularia spumigena.*	Lists the presence and concentration of cyanobacterial species in the lake.

Dissertations and technical reports		
Pyle (1992)	A thesis developing a lake management approach based on Gaia hypothesis and traditional Maori world view.	Number of historical dairy farms and quantity of fertilizer used in the catchment. Vegetation cover in the catchment.
Main (2002)	Case study mentioned most major historical impacts on lake ecology.	Includes turbidity data for Lake Forsyth.
Reid et al. (2004)	Palaeolimnological study on the lake.	May be the same dataset as described in Woodward & Shulmeister (2005).
Lynn (2005)	Determines the potential inputs of phosphorous into the Lake.	The geological rock units and soil types found in the catchment. Phosphorous content of bedrock units is given.
Verburg et al. (2010)	Report on water quality status and trends of New Zealand lakes.	Trophic state and trend.
Parry (2012)	Measured organic matter and trace element concentrations in sediment at 20 sites.	Organic matter and trace element concentrations in sediment.
Berry & Webster-Brown (2012)	Modelled hydrological balance during short summer period including both dry period and period of moderate rainfall.	Hydrological fluxes during short summer period.
Department of Conservation (undated)	Brief report on ecological inventory and status	Description of notable plant, bird and fish species present. Descriptions of values, threats and management issues.
Other		
Jolly & Brown (1975)	Book on inland waters that examines Lake Forsyth/Wairewa among many other New Zealand lakes	Lists condition of lake with respect to certain biota, phytoplankton production and water chemistry
Davie (2005a)	Lists research partners and projects on the lake	Provides a brief cultural history from a mahinga kai perspective
Davie (2005b)	Policy document examining potential mechaisms for the establishment of a Cultural Mahinga Kai Park.	No data
Davie (undated) - Powerpoint presentation	Catchment nutrient fluxes	Catchment hydrology and nutrient fluxes
Woodward et al. (undated) - Powerpoint presentation	Environmental history	Sedimentation rates, salinity changes, trophic level changes

3.4 CURRENT STUDY ON LAKE FORSYTH/WAIREWA

University of Canterbury PhD student, Sean Waters, is carrying out a study on the phosphorus dynamics and bloom initiation/maintenance in Lake Forsyth/Wairewa. Sean has another season of field work to go, and should be writing up his thesis in 2014. He is producing a comprehensive data set on oxygen, pH, thermal stratification, inflows, phosphorus and phosphorus speciation, chlorophyll *a*, etc.

During studies on the lake in the summer of 2012/2013, vigorous growth of a mix of freshwater and brackish macrophyte taxa (*Elodea, Myriophyllum, Ruppia, Potamogeton*) was observed across c. 30% of the lake, which in turn attracted thick growths of epiphytic *RIvularia* (no toxins). Macrophyte areas were significantly less turbid than non-macrophytes areas (Ian Hawes, University of Canterbury, pers. comm.).

4. DISCUSSION

4.1 THE CONDITION OF THE LAKE

Historical information on the lake gleaned from numerous sources, above, indicate that the lake has suffered from eutrophication since at least the early 1900s. The lake has undergone regime shifts, alternating between a macrophyte-dominated state in which water clarity is relatively high to a phytoplankton-dominated state in which water is turbid and light is presumably insufficient to support plant growth over much of the lake bed. Such regime shifts are characteristic of shallow lakes that have undergone nutrient enrichment (Scheffer 2004; Schallenberg & Sorrell 2009). Another factor contributing to variable conditions in the lake is the intermittent connection to the sea. This provides for flushing of sediments and nutrients from the lake, but also limits biodiversity by restricting the fauna and flora that inhabit the lake to those taxa that tolerate severe salinity variations. For example, such salinity variations probably prevent the filter feeding zoolplankter, *Daphnia* sp. (Schallenberg et al. 2003), the benthic filter-feeding freshwater mussel (*Echyridella menziesii*), and numerous freshwater macrophytes from establishing populations in the lake. On the other hand, the salinity variations limit the potential for invasive pest species to colonise the lake.

Table 2 summarises the biota recently reported to inhabit the lake and the trophic state of the lake. Based on this limited information, the condition of the lake appears to be poor. However some ecological values have also been retained (e.g. a moderately diverse fishery, presence of crested grebes, occasional presence of seagrasses and charophytes).

Table 2. Condition and biota of the lake ecosystem as summarised from the studies, above and unpublished data. * biota reported from M. Schallenberg, unpublished data from 2004.

Phytoplankton	Assemblage characteristic of eutrophic conditions, with occasional blooms of cyanobacteria (including *Nodularia spumigena**)
Protozoan	*Pfisteria shumwayae* (fish-eating heterotrophic dinoflagellate)
Macroalgae	*Enteromorpha intestinalis**
Macrophytes	When macrophytes are present, *Ruppia* sp.*, *Potamogeton pectinatus* and *Tolypella nidifica* have been reported.
Benthic invertebrates	*Potamopyrgus* sp., caddisfly larva* (Oecetis unicolor), chironomids*, mysid (*Tenagomysis chiltoni*)*, amphipod (*Paracalliope fluviatilis*)*, ostracods*, leeches*, dragon fly larva (*Procordulia* sp.)*, moth larva (*Hygraula nitens*)*, oligochaetes*, leeches*
Zooplankton	*Gladioferens pectinatus* (estuarine copepod), cyclopoid copepods*, harpactacoid copepods*
Fish	Longfin eel*, shortfin eel*, common bully*, black flounder, smelt*, inanga, lamprey, perch*
Water birds	Crested grebe
Water quality	TLI = 6.4 (hypertrophic)
Regime shift	Lake undergoes regime shifts

4.2 REFERENCE CONDITION AND ECOLOGICAL INTEGRITY

Reference state or condition has been defined in a number of ways: i) a minimally disturbed condition, ii) a historic condition, iii) the least disturbed condition and iv) the best attainable condition (Stoddart 2006). Lee et al. (2005) defined reference condition in a New Zealand context as the ecological condition of an ecosystem immediately prior to its first anthropogenic impacts.

The reference condition of a lake can be inferred by palaeo-limnological examinations of microfossil indicators and biogeochemical markers in accurately dated sediment strata, as described in the studies in Section 3.1. It can also be inferred, using modern datasets comprising a large number of lakes and describing a wide range of conditions across a broad gradient of anthropogenic impact. Such relationships can indicate the conditions that lakes would have exhibited under minimal or no anthropogenic impact. In this type of analysis, lakes which currently reflect reference conditions are those exhibiting the highest ecological integrity and/or those with a predominant proportion of their catchments in native vegetation.

Schallenberg et al. (2011) explored the concept of freshwater ecological integrity (EI) and concluded that the EI concept assumes an ideal ecological state or condition absent of any anthropogenic impacts (Schallenberg et al. 2011). Thus, by this reasoning, lakes with high EI approach their reference condition and, as lakes depart from their reference condition, their EI decreases.

Schallenberg et al. (2011) defined freshwater EI in the New Zealand context as comprising four components:

- **Nativeness** is the degree to which the structural components of an ecosystem represent the native biota which would have been representative of the region.
- **Pristineness** is the degree to which functional, structural and physico-chemical components of an ecosystem reflect the processes that would be expected in an unmodified ecosystem. Pristineness also requires that the natural connectivity within and between ecosystems is maintained.
- **Diversity** is the degree of taxonomic diversity or taxonomic richness of an ecosystem.
- **Resilience** is the degree to which structural and functional components of an ecosystem can return the ecosystem to its stable state after a perturbation. Resilience relates to self-renewal capacity and long term ecological viability.

Schallenberg et al. (2011) suggested a number of freshwater indicators for quantifying the four EI components. Lakes with high EI must score highly in all four characteristics. The indicators of EI must be benchmarked to some values reflecting a desired condition and the use of the pre-human, non-modified reference condition is one way to normalise the EI components and to assess the degree of lake degradation.

4.3 ECOLOGICAL INTEGRITY OF THE LAKE IN RELATION TO OTHER NEW ZEALAND ICOLLS, BASED ON SCHALLENBERG (IN PRESS)

While EI is a composite index of four components (nativeness, pristineness, diversity and resilience), methods for combining indicators of these components into a quantitative assessment of EI have not been worked out. Nevertheless, EI has been assessed by other methods. For example, three experts independently ranked the EI of 43 New Zealand lakes, which had been visited in a sampling campaign. The three rankings were similar, with coefficients of determination (r^2) between the three independent rankings of around 0.80 (Drake et al. 2010). The average rank of the three experts was used as a robust assessment of the EI of the lakes that had been sampled and EI determined in this way correlated well with measures of water quality and biotic characteristics of lakes as well as with anthropogenic pressures (Drake et al. 2010). Schallenberg (in press) also used this EI expert ranking to estimate reference condition for the 43 lakes sampled.

Of the 43 lakes sampled in Drake et al. (2010), ten were brackish - either tidal lakes or intermittently closed and open lakes/lagoons.   EI assessed by expert ranking correlated well with the percentage of each lake's catchment in native vegetation (Fig. 3). Examination of the data showed that Lake Forsyth/Wairewa had the lowest ecological integrity, as determined by expert ranking and had one of the lowest percentages of catchments in native vegetation. Below we show how the condition of Lake Forsyth/Wairewa compared to the other brackish lakes with respect to indicators of nativeness, pristineness, diversity and resilience as analysed in Schallenberg (in press).

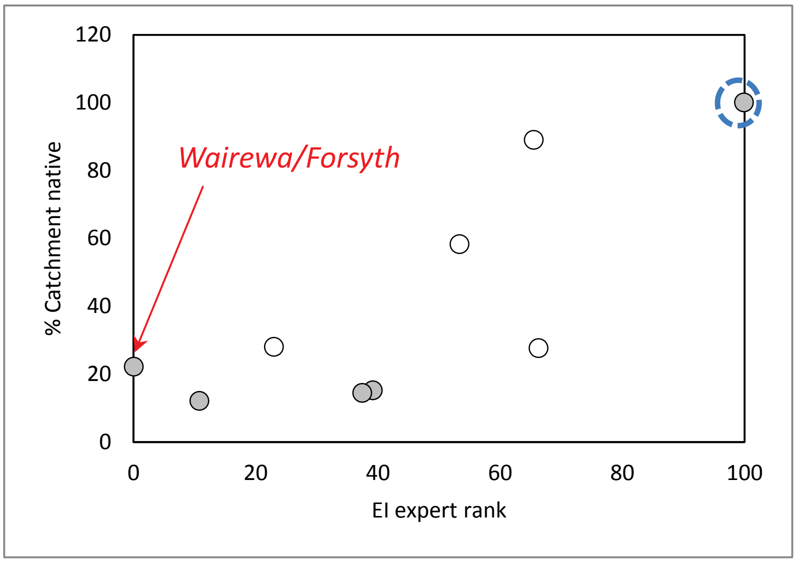

Figure 3. The positive relationship between the normalised expert rankings of EI and percentage of the catchment in native vegetation. The blue circle shows the reference lake (Five Mile Lagoon, south Westland). Filled circles are South Island lakes/ICOLLs. Open circles are North Island lakes/ICOLLs. Data from Schallenberg (in press).

Nativeness

The dynamic nature of brackish lakes resulted in relatively weak relationships between indicators of nativeness and indicators of reference condition (Table 3; Fig. 4). Thus, none of the relationships provided useful thresholds defining reference conditions (Table 3). Nevertheless, Schallenberg (in press) considered that a threshold of 100% nativeness in macrophyte species could be a criterion for reference condition, because the presence of non-native macrophytes could result in proliferations of monocultures of these, as has occurred in many New Zealand lakes (Champion et al. 2002).

Table 3. Nativeness reference condition threshold for shallow brackish lakes and lagoons. The utility of the proposed threshold is indicated by the percentage of non-reference lakes excluded by the threshold. Outliers are reference lakes that fall outside the range of reference conditions.

Indicator	Units	Range for all lakes	Threshold	% non-reference lakes excluded	Outliers
% native macrophyte species	%	50-100	100	29 %	none

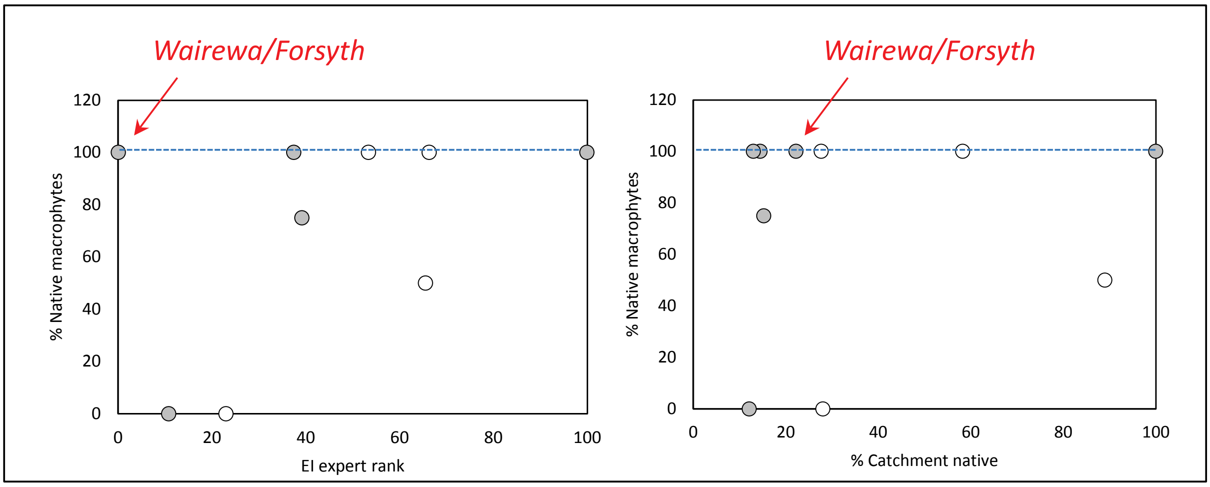

Figure 4. Relationships between the percentage of macrophytes that are native species vs indicators of EI. Filled circles are South Island lakes/ICOLLs. Open circles are North Island lakes/ICOLLs. Blue dashed line shows the reference condition threshold. Data from Schallenberg (in press).

At the time of sampling, Lake Forsyth/Wairewa had *Ruppia* sp. and *Enteromorpha* sp. present and these are both native species. So despite having low values of EI indicators, Lake Forsyth/Wairewa met the nativeness criterion (Fig. 4), one of the four EI components. Lake Forsyth/Wairewa is a lake that undergoes regime shifts, whereby macrophytes can be abundant in some years and virtually absent in others (see Section 3.2), signifying ecological instability. At the time of sampling, the sampling sites (all within 50m of the shoreline) only showed 3% cover by macrophytes. Nevertheless, the macrophytes, at the time of sampling, did consist only of native species and the lack of invasive non-indigenous macrophytes is a positive characteristic of the lake.

Pristineness

Pristineness indicators consist mainly of physico-chemical variables, although some bio-indicators can be related to physico-chemical and habitat conditions in lakes (see Schallenberg et al. 2011). Pristineness indicators such as physico-chemical variables and bio-indicators of water quality were related to EI (Fig. 5) and, thus, reference conditions thresholds for these could be defined (Table 4). As only one of the brackish systems sampled was in a pristine or reference condition, no indication of the variability among pristine (reference) lakes/lagoons could be determined. So the reference condition thresholds in Table 3 should be considered provisional.

Indicators of nutrient enrichment showed clear trends with ecological integrityand % catchment native vegetation. In addition, a benthic macroinvertebrate indicator of pristineness (the % of the macrobenthic community abundance comprised of ephemeropterans, plectopterans and odonates or "% EPO"), the depth limit of macrophytes, and the percentage macrophyte cover in the systems were also related to EI (Fig. 5). Bioindicators such as these provide time-integrated indications of the condition of lakes and lagoons, which are informative in very dynamic systems such as brackish lakes and lagoons.

Table 4. Pristineness reference condition thresholds for brackish lakes and lagoons. The utility of the proposed threshold is indicated by the percentage of non-reference lakes excluded by the threshold. Outliers are reference lakes that fall outside the range of reference conditions.

Indicator	Units	Range for all lakes	Threshold	% non-reference lakes excluded	Outlier
Chlorophyll a	μg/L	0.3-80	≤ 0.3	100 %	none
TN	μg/L	128-2163	≤ 128	100 %	none
TP	μg/L	2.4-510	≤ 2.4	100 %	none
TLI		2.5-7.2	≤ 2.5	100 %	none
% EPO (abundance)	%	0-1.1	≥ 1.1	100 %	none
Macrophyte depth limit	m	0.2-2.3	≥ 1.9	88 %	Upper Onoke

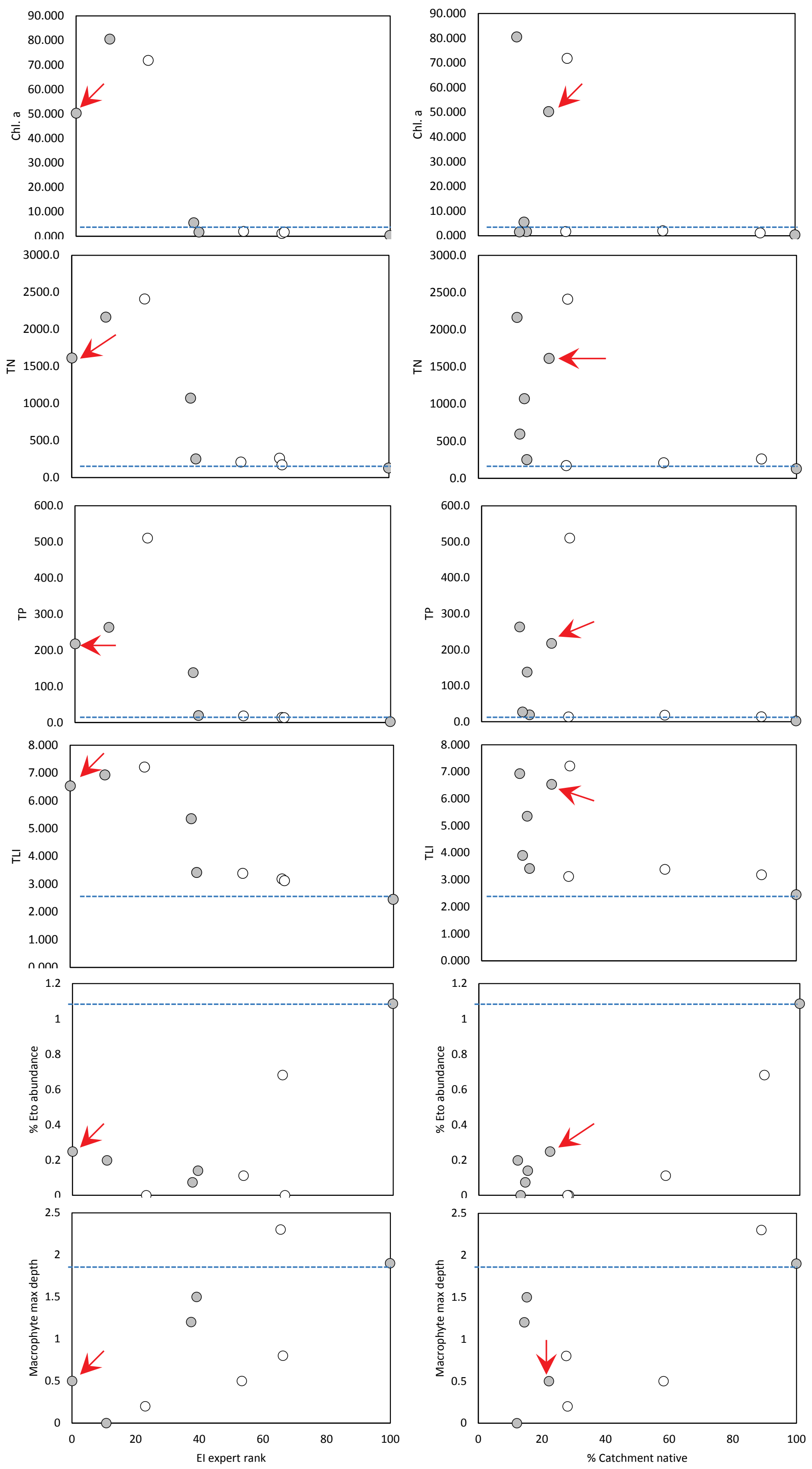

Figure 5. Relationships between indicators of pristineness and indicators of EI. Arrows show the data for Lake Forsyth/Wairewa. Filled circles are South Island lakes/ICOLLs. Open circles are North Island lakes/ICOLLs. Blue dashed line shows the reference condition threshold. Data from Schallenberg (in press).

As Lake Forsyth/Wairewa had low EI values, it also tended to exhibit large departures from the proposed reference condition threshold of brackish lakes and lagoons (Fig. 5). The one brackish system that was assessed as having high EI was Five Mile Lagoon in south Westland and it is only on the basis of this lagoon that the reference condition threshold has been proposed. Unfortunately, no brackish systems on the East Coast of the South Island were available and, therefore, no assessment of reference conditions more appropriate to brackish systems in this region could be determined by this analysis. More appropriate estimates of reference conditions may be obtained by palaeolimnological study of Lake Forsyth/Wairewa and other similar brackish systems (see Section 3.1).

Diversity

The one reference lake, Five Mile Lagoon, had low phytoplankton diversity and a high benthic invertebrate diversity relative to the other brackish lakes (Fig. 6; Table 5). The higher benthic invertebrate diversity in the reference lake/lagoon suggests that in the absence of human pressures, brackish lakes and lagoons have diverse benthic habitats (probably with macrophyte beds covering a substantial proportion of the lake/lagoon bed).

Table 5. Diversity reference condition thresholds for brackish lakes and lagoons. The percentage of non-reference lakes excluded by the threshold is a measure of the strength of the threshold in distinguishing reference lakes from non-reference lakes. Outliers are reference lakes that fall outside the range of reference conditions.

Indicator	Units	Range for all lakes	Threshold	% non-reference lakes excluded	Outliers
Benthic invertebrates	species richness	8-31	≥ 31	100 %	none
Phytoplankton	species richness	9-27	≤ 10	75 %	Whakaki, Onoke

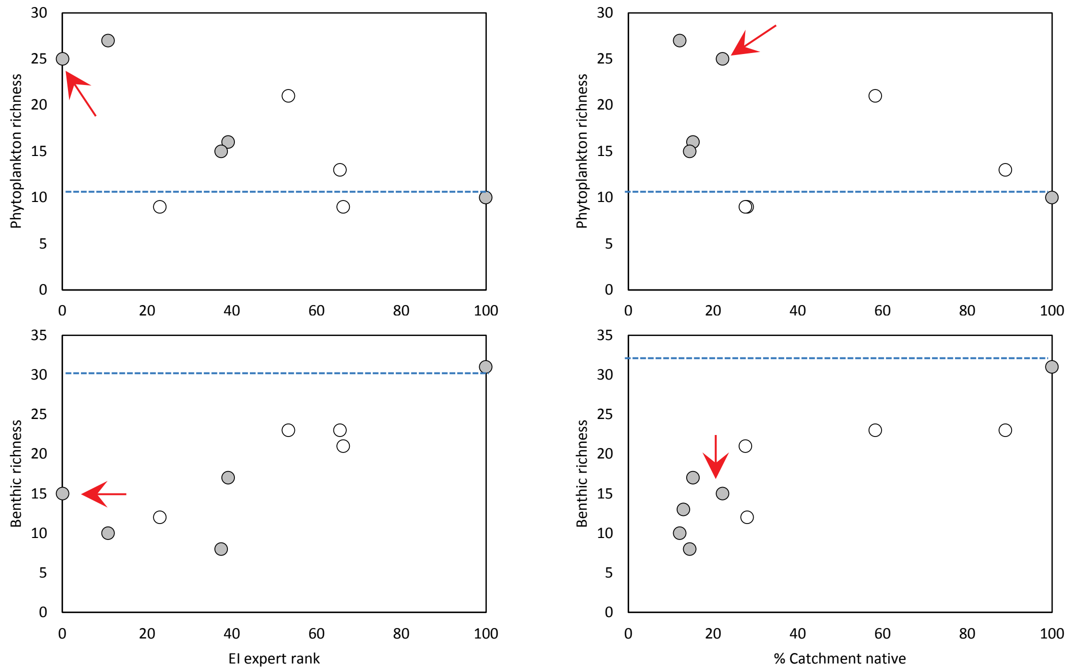

Fig. 6. Relationships between indicators of diversity and indicators of EI. Arrows show the data for Lake Forsyth/Wairewa. Filled circles are South Island lakes/ICOLLs. Open circles are North Island lakes/ICOLLs. Blue dashed line shows the reference condition threshold. Data from Schallenberg (in press).

Lake Forsyth showed relatively large departures from the reference condition threshold for indicators of diversity (Fig. 6). Its high phytoplankton diversity at the time of sampling was typical of its high nutrient concentrations and high phytoplankton biomass. Its low benthic macroinvertebrate diversity was also typical of other eutrophic systems with low EI.

Resilience

Cyanobacteria have a strong bloom potential under certain conditions. Therefore, the presence of bloom forming cyanobacteria in lakes could indicate a potential for blooms to occur. Because some cyanobacteria can fix atmospheric nitrogen into their cells, these types of cyanobacteria can dominate under conditions of nitrogen limitation (e.g. high phosphorus availability). The lack of cyanobacteria can reflect a low probability of cyanobacterial blooms occurring in the system, and thus, can indicate resilience to cyanobacterial blooms.

In the lakes studied, cyanobacterial abundance in the water column of brackish lakes and lagoons was correlated with EI (Fig. 7). Schallenberg (in press) considered that cyanobacterial densities below a typical detection limit for cyanobacterial counts (e.g. < 500 cells/ml) indicated that lakes were unlikely to have cyanobacterial blooms and were therefore resilient to cyanobacteria bloom formation (Table 6).

Table 6. Resilience reference condition thresholds for brackish lakes and lagoons. The percentage of non-reference lakes excluded by the threshold is a measure of the strength of the threshold in distinguishing reference lakes from non-reference lakes. Outliers are reference lakes that fall outside the range of reference conditions.

Indicator	Units	Range for all lakes	Threshold	% non-reference lakes excluded	Outliers
Cyanobacteria	cells/mL	<500-940000	<500	100 %	none

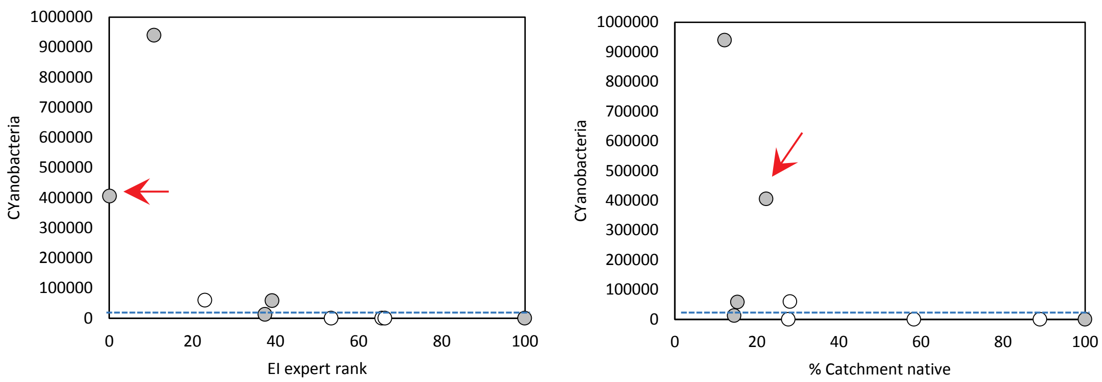

Fig. 7. Relationships between cyanobacterial density and indicators of EI. Filled circles are South Island lakes/ICOLLs. Open circles are North Island lakes/ICOLLs. Blue dashed line shows the reference condition threshold. Arrows show the data for Lake Forsyth/Wairewa. Data from Schallenberg (in press).

The only resilience indicator that showed a relationship with EI was cyanobacterial density. Lake Forsyth/Wairewa is known to have occasional cyanobacterial blooms (see Sections 3.1 and 3.2). At the time of sampling, there were substantial densities of cyanobacterial cells (including *Microcystis minutissima*, *Merismopedia minima*, *Lyngbya* sp. and *Phormidium mucicola*), both nitrogen fixers and potential toxin producers. Therefore, this resilience indicator reflects that the lake is susceptible to cyanobacterial blooms, nitrogen fixation and toxin production and has a poor ecological resilience with respect to cyanobacterial impacts.

Summary of EI analysis

In summary, the substantial departures of Lake Forsyth/Wairewa from most reference condition thresholds for brackish lakes/lagoons indicates that the lake/lagoon has low ecological integrity for this type of system (Table 7). While there is little doubt from this analysis, from historical records, and from palaeolimnoligcal analyses that the lake has departed substantially from its reference condition, the degree of departure is somewhat uncertain. This is because reference condition was determined based only on one brackish lake/lagoon from a different geological and climatic zone (south Westland) due to of a lack of unperturbed brackish systems on the east coast of the South Island. Historical reports suggest that initial anthropogenic impacts may have co-incided with major changes to the hydrology of the system (i.e. closing of a permanently open coastal inlet) and to the degree of marine influence on the system, although evidence for this wasn't apparent in palaeolimnological studies (Reid et al. 2004; Woodward & Shulmeister 2005). If this were the case, then Lake Forsyth/Wairewa became an ICOLL only after European settlement in the area, and the concept of reference condition may not be readily applied to this lake.

Table 7. Summary of departures of Lake Forsyth/Wairewa from reference condition for brackish lakes/lagoons, based on EI relationships of 10 brackish lakes/lagoons. Data from Schallenberg (in press).

Indicator	Departure from reference threshold (fold*)	Departure from reference condition (order of magnitude**)
Percentage macrophyte species native	0	
Chlorophyll *a*		2.22 order of magnitude increase
Total nitrogen		1.06 order of magnitude increase
Total phosphorus		1.95 order of magnitude increase
TLI	2.6 fold increase	
% macrobenthic taxa EPO	4.3 fold decrease	
Macrophyte maximum depth		0.45 order of magnitude decrease
Phytoplankton diversity	2.1 fold increase	
Macroinvertebrate diversity	2.5 fold decrease	
Cyanobacterial density		2.91 order of magnitude increase

* fold changes reflect the linear relationships of these variables
** order of magnitude reflects the log-linear relationships of these variables.

4.4 RECOMMENDED INDICATORS FOR LAKE HEALTH MONITORING AND REPORTING

The literature review and analysis of unpublished data presented here provides a basis for examining useful indicators for monitoring the health of Lake Forsyth/Wairewa, particularly if restoration efforts are to be undertaken.

CURRENT ECOLOGICAL INDICATORS USED FOR MONITORING BY ENVIRONMENT CANTERBURY

Environment Canterbury currently monitors three sites in Lake Forsyth/Wairewa (Fig. 8). A site near the water level recorder has been used as the main site for monitoring water quality in the lake since 1993. A suite of water quality variables are measured including oxygen, temperature, pH, suspended solids, turbidity, phytoplankton biomass (chlorophyll *a*), nutrients, *E. coli*, and cyanobacterial toxins (when cyanobacterial blooms are present). Sampling is monthly unless there is a phytoplankton bloom, at which time sampling is more frequent (e.g. weekly). Lake water level is monitored at the recorder site. In addition to the monitoring at the recorder site, two other sites have been monitored mainly for phytoplankton and cyanobacteria species and density and cyanobacterial toxins when blooms are present. These sites have been monitored since 2006 and sampling also includes the measurement of temperature, oxygen and salinity. Samples are taken fortnightly at these sites.

This is a reasonable level of monitoring for water quality and threats to public health via contact recreation and is sufficient for complying with statutory regulations and reporting requirements. A shortcoming of the main water quality sampling station is that it is on the lake margin as opposed to in the middle of the lake. Some biases can result from sampling on the lake margin (e.g. effects of wind blowing floating phytoplankton blooms toward or away from the sampling site, effects of wind on sediment resuspension from near shore zones, etc).

While Environment Canterbury has produced reports on the condition of inflowing streams, no reports on the condition of Lake Forsyth/Wairewa have yet been produced. The lake water quality dataset archived by Environment Canterbury is of sufficient size and quality that it could analysed statistically for trends. However, the lake is very dynamic (e.g. intermittent connection to the sea, regime shifts) and statistical analyses done on the water quality dataset should account for the state of connection to the sea and the levels of macrophyte cover and/or biomass.

Figure 8. Image of Lake Forsyth/Wairewa, showing locations of Environment Canterbury monitoring sites. The middle site is the recorder site. Image supplied by Environment Canterbury.

POTENTIALLY USEFUL EI INDICATORS FOR LAKE FORSYTH/WAIREWA

This report discusses a number of indicators of lake health that could be considered for improving the monitoring of the health of Lake Forsyth/Wairewa. Table 7 summarises a number of useful indicators for monitoring the ecological integrity of brackish lakes and Tables 3-6 provide estimates of the reference condition of brackish lakes with respect those indicators. Environment Canterbury already monitors some of these indicators (e.g., chlorophyll *a*, total nitrogen, total phosphorus, TLI, cyanobacterial cell counts and phytoplankton species composition/diversity). These indicators cover aspects of pristineness, diversity and resilience. Other suggested indicators include macrobenthic diversity (both taxonomic richness and %EPO species) and aspects of the macrophyte community. Monitoring the latter can be problematic in regime shifting lakes because macrophytes may be extremely rare in some years. However, during years when macrophytes are present, LakeSPI (Clayton et al. 2002) surveys could provide useful information on the state and condition of macrophyte community present (e.g., see Table 7).

4.5 KEY MANAGEMENT ISSUES FOR LAKE FORSYTH/WAIREWA

NUTRIENT LOADING

It is clear from our literature review that there are at least two key management issues related to the current poor condition of the Lake Forsyth/Wairewa. One issue is the nutrient load to the lake, both from the catchment and from the legacy of phosphorus and nitrogen loads which are now in the lake's sediments, contributing to nutrient enrichment of the water column. Another is the opening regime, which flushes nutrients and sediments out of the lake and dilutes nutrient-enriched lake water with seawater. Lake openings change the salinity, affecting both the chemistry of the water and the lake as a habitat for biota. Nutrient loads and the opening regimes typically affect the ecological condition of the lake and ICOLLs elsewhere in New Zealand (e.g. Schallenberg et al. 2010) and overseas (Viaroli et al. 2008). For example, a literature review of seagrass declines in ICOLLs and coastal embayments worldwide indicated that there is a nitrogen loading rate threshold for such systems, above which seagrasses (e.g. *Ruppia* sp.) are unable to flourish (Schallenberg & Schallenberg 2012). The threshold of 100 kg N/ha/y is expressed per hectare of ICOLL/lagoon surface area and is supported by at least seven studies which have documented seagrass collapses from brackish ICOLLs/lagoons around the world (Fig. 9).

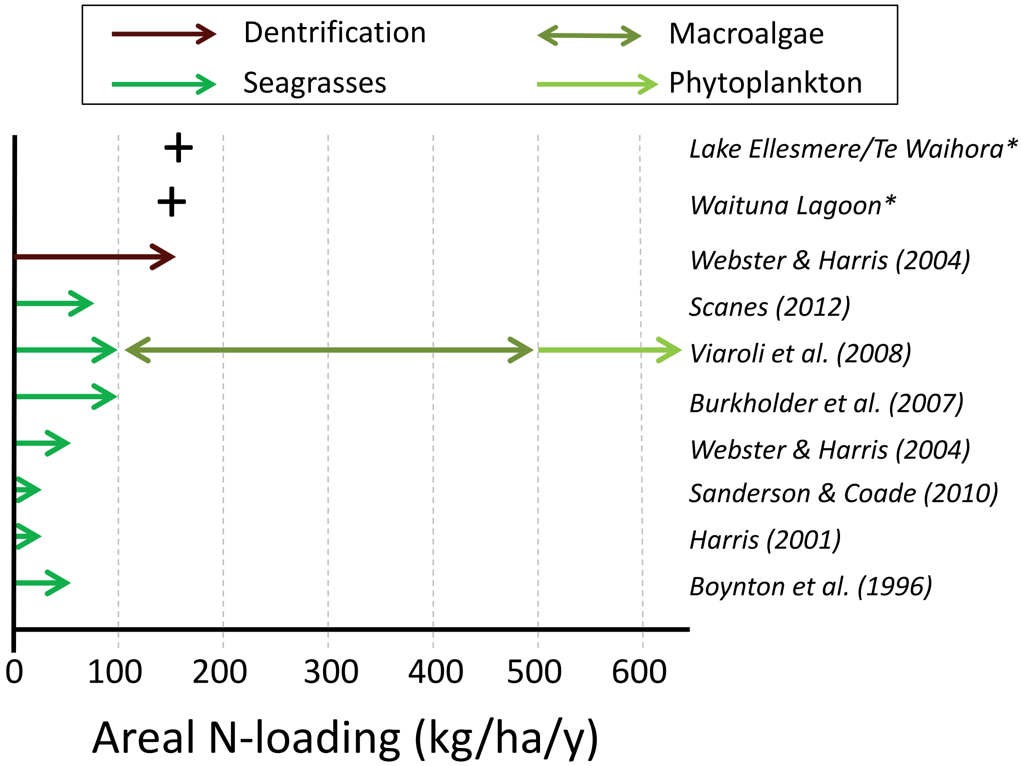

Figure 9. Key nitrogen loading thresholds from international studies. * estimates of nitrogen loading from tributaries of Lake Ellesmere/Te Waihora and Waituna Lagoon from Schallenberg et al. (2010). Redrawn from Schallenberg & Schallenberg (2012).

Unfortunately, no estimates of N loading to Lake Forsyth/Wairewa were reported in the studies reviewed here, so it is yet not possible to place the ICOLL in an international context with regard to the effects of the nitrogen load on seagrass biomass and health.

OPENING REGIME

The opening regime of Lake Forsyth/Wairewa determines a number of drivers of ecological health of the ICOLL (Schallenberg et al. 2010). It principally determines water level and tidal marine ingress which affects salinity, nutrient concentrations and flushing, sediment resuspension and the potential for salinity stratification and bottom water anoxia/phosphorus release. In addition, the timing and degree of saline intrusions affects the germination and growth of aquatic macrophytes such as *Ruppia* (Gerbeaux 1993), which grow in brackish water.

In recognition of the key role that the opening regime plays in ICOLL ecology, Environment Southland is developing guidelines to help manage the opening regime in Waituna Lagoon to safeguard macrophyte communities and the overall ecology of the ICOLL. Many factors have gone into the development of the opening regime guidelines (e.g., preferred time of year, duration of opening, location of opening) and we suggest that a similar re-assessment of the opening regime of Lake Forsyth might bring benefits to the ecology of the ICOLL.

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