Ecological Values and Condition of the Kaihoka Lakes and Lake Otuhie, Northwest Nelson

By: Marc Schallenberg

University of Otago

Lake Kaihoka #1 (Eastern) (*photo: M. Schallenberg*)

Lake Otuhie, taken from the outflow (*photo: M. Schallenberg*)

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Author's contact details: Department of Zoology, University of Otago, P.O. Box 56, Dunedin. Ph: 03-479-8403. Email: marc.schallenberg@otago.ac.nz.

Summary

- This study assesses the limnological and ecological values of the Kaihoka Lakes (both East and West) and Lake Otuhie, Northwest Nelson.
- The study uses a comprehensive dataset collected from 46 shallow coastal lakes around New Zealand from 2004-08, which included the three lakes. Prior to this study, little scientific data was available on these lakes.
- The values examined include water quality, phytoplankton, aquatic plants, zooplankton, macroinvertebrates, fish and ecological integrity.
- Other published and unpublished information on these lakes is also assessed.
- All three lakes are relatively unmodified, compared to other shallow coastal lakes in New Zealand
- The Kaihoka Lakes have a number of special and unique features including: i) landlocked populations of banded kokopu, ii) unusually large freshwater mussels, iii) a lack of exotic zooplankton, macrophytes and fish and iv) a macroinvertebrate community made up of species common to both freshwater and brackish conditions. The presence of freshwater mussels and banded kokopu is culturally important.
- The Kaihoka lakes have unusual fish, zooplankton and invertebrate communities, reflecting interesting biogeographic histories and the present isolation of these lakes from the ocean.
- Lake Otuhie is a good example of a humic-stained, relatively unmodified shallow, coastal lake. The strong humic staining and relatively low mineral content result in the lake having a restricted distribution of aquatic plants. Its fish and invertebrate communities resemble those of unmodified shallow coastal lakes on the west coast of the South Island.
- Ecological integrity was assessed in relation to nativeness, pristineness, biodiversity and resilience to human induced pressures. Kaihoka 1 (East) was identified as having an overall ecological integrity in the top 10% of shallow coastal lakes sampled, while Otuhie and Kaihoka 2 (West) were in the top 25%, respectively.
- Of potential concern is the possibility that mercury from historical gold works in the Lake Otuhie catchment could be contaminating eels, shags and other organisms high up in the lake food chain.
- The main threats to these lakes is increased external nutrient loading from land use activities in the catchments and the potential for invasion of the lakes by exotic zooplankton, macrophytes and fish. If nutrient loading to these lakes were to increase or if invasive macrophytes and/or fish colonised the lakes, a rapid degradation of the ecological values of these lakes would likely occur.
- A number of knowledge gaps were identified and these could be targeted with funding, depending on management priorities.

Contents

1. Scope of this report

This report collects, summarises and interprets ecological data and information about the two Kaihoka Lakes and Lake Otuhie from various sources with the aim of providing an understanding of the freshwater ecological condition and values of these lakes. It is anticipated that this information will assist the Tasman District Council with future management of the lakes and their catchments. All three lakes are promoted as sites of interest in terms of their relatively pristine ecology and scenic beauty.

2. Glossary of terms

Alkalinity: The acid neutralising capacity of water. Influenced by the natural organic acids, biocarbonate, carbonate and silicate anions.

Diadromous: Diadromous organisms migrate between fresh and salt water.

Ecological integrity: An overall assessment of the degree to which the ecology of a lake exhibits nativeness, pristineness, biological diversity and resilience to human pressures. Refer to Schallenberg et al. (2011) for more details.

Euphotic depth: Depth in the lake at which light penetration is 1% of the light reaching the lake's surface. The deeper the euphotic depth, the clearer the water.

Macroinvertebrates: animals lacking backbones, such as insect larvae, worms and mussels.

Macrophytes: Macroscopic aquatic plants, usually attached to the lake bed.

Phytoplankton: Microscopic aquatic plants which live suspended in lake water.

Theoretical water residence time: The average time it takes a molecule (or a drop) of lake water to be flushed out of the lake. Calculated as the lake volume divided by the rate of inflowing water. In this report, the rate of inflowing water was modelled for each lake using the hydrological model called TOPNET (NIWA Ltd).

Trophic state: Level of nutrient enrichment and algal proliferation in a lake. **Oligotrophic** = low level of enrichment, close to pristine. **Mesotrophic** = moderate level of enrichment. **Eutrophic** = highly enriched, polluted.

Zooplankton: Small animals (mainly crustaceans) living in the open water of lakes.

3. Background information about the lakes

The Kaihoka Lakes

The Kaihoka Lakes are a pair of small sand dune lakes located south of Farewell Spit, on a narrow peninsula between the Tasman Sea and Westhaven/Whanganui Inlet (Fig. 1). They adjoin a scenic reserve administered by the Department of Conservation. Lake Otuhie is a larger, but shallower sand dune lake located south of Whanganui Inlet. Part of its shoreline and catchment is protected by a QEII convenant.

In this report, I refer to the eastern Kaihoka lake as Kaihoka 1, but this lake also has a Maori name, Tinawhu (Moore et al. 1963). I refer to the western lake as Kaihoka 2, which has the Maori name, Whupa (Moore et al. 1963). As they have no outlets or permanent inflows, the hydrology of both lakes is mainly controlled by rainfall and seepage (springs, groundwater flows). This unusual hydrology can be explained by the origin of the lake basins, which appear to have been created by the wind-induced shifting of coastal sand dunes. It is uncertain how old the lakes are, but they are probably at least several hundred years old, because remnants of a flooded forest are no longer visible in the shallow waters. Because of the importance of coastal sand in their formation, the lakes are probably not older than 4000-6000 years, the time period when sea level reached its present level and the coastline stabilised at its present location (Gibb 1986). In addition to the importance of sand in the geological context of these lakes, their catchments are situated in a geologic region dominated by limestone (Takaka Limestone Formation), which is a relatively soluble rock, imparting some cations (e.g. Ca, Mg, etc.) and alkalinity to surface and groundwaters.

Because the lakes are situated in a scenic reserve administered by the Department of Conservation, the small catchments of the Kaihoka Lakes still retain a moderate cover of natural vegetation, with agriculture taking up only around 5% of the catchment areas (Table 1; Fig. 2). The lakes have high scenic value due in part to the predominance of native bush around the lakes and the presence of stands of *Typha orientalis* (Raupo) on the lake margins. Visitors can drive to an access point on Kaihoka 1, but must walk along a 1.3 km path to access Kaihoka 2. Alternatively, with permission from the local farmer, vehicle access to Kaihoka 2 may be obtained via a farm track, which crosses a sheep farm. Presently, the main form of agriculture in the catchment is sheep farming.

The small catchment area compared to the lake volume of Kaihoka 1 results in a theoretical water residence time greater than 1 year, whereas that for Kaihoka 2 is around 7 months (Table 1). The lack of surface outflows means that stable water levels can only be achieved by the evaporation of water from the lake surface and the outward seepage of water through the sand dunes surrounding the lakes.

Table 1. Morphometric, hydrological and catchment data for the Kaihoka Lakes. Data are from Drake et al. (2009, 2010) and from D. Kelly (Dept. of Conservation, unpubl. data) except lake maximum depth, lake length and lake width, which were reported in Moore et al. (1963). Note: Lake volumes and water residence times are only estimates based on modelled lake bathymetry (using a digital terrain elevation model) and catchment flows using the TOPNET model (http://www.niwa.co.nz/news-and-publications/publications/all/wru/2008-26/available). Catchment data are from the Land Cover Data Base 2 (Ministry for the Environment). N and P loading estimates are from the CLUES model (http://www.maf.govt.nz/environment-natural-resources/water/clues).

	Kaihoka 1 (eastern)	**Kaihoka 2 (western)**
Altitude	38 m a.s.l.	52 m a.s.l.
Lake length	483 m	635 m
Lake width	353 m	257 m
Lake area	6.8 ha	5.3 ha
Maximum depth	14.75 m	13.5 m
Lake volume	227000 m^3	446000 m^3
Lake water residence time	416 days	230 days
Catchment area	83.7 ha	83.7 ha
N loading	0.05 T/ha/year	0.06 T/ha/year
P loading	0.01 T/ha/year	0.01 T/ha/year

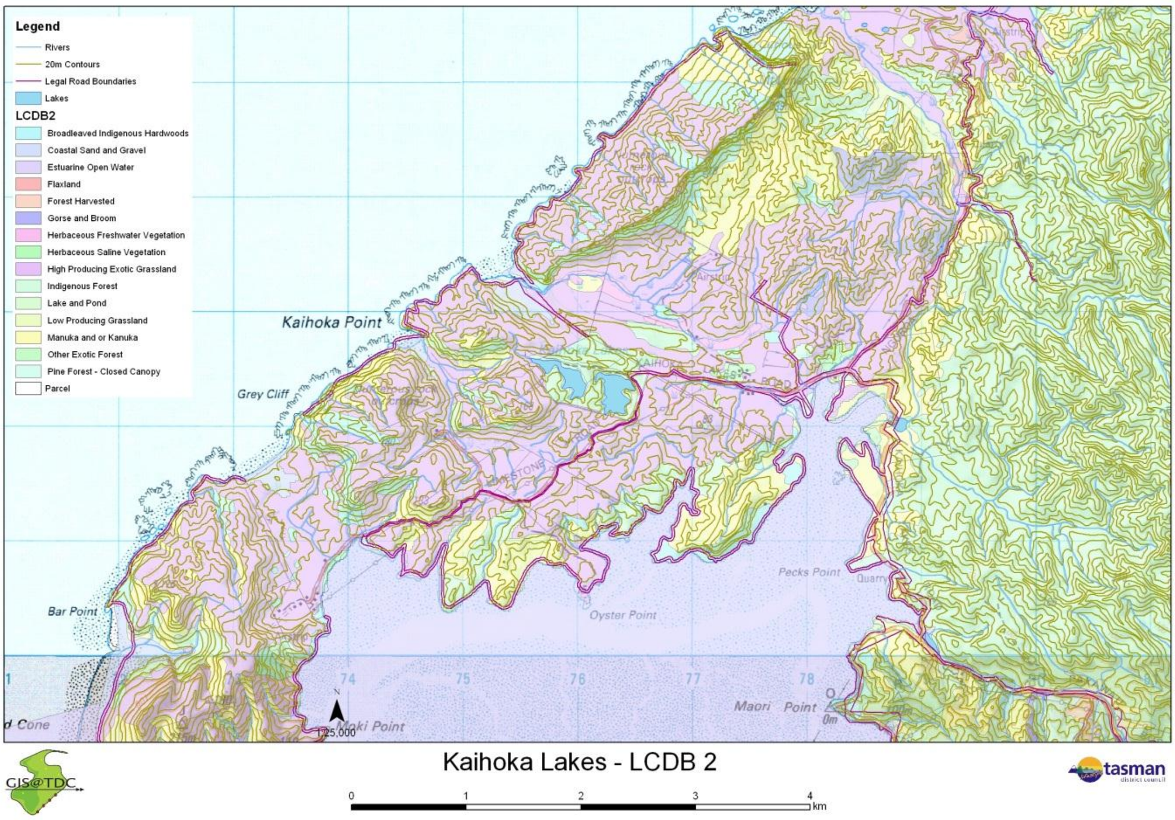

Figure 1. Locations of the Kaihoka Lakes, between the Tasman Sea (to the north west) and Westhaven/Whanganui Inlet (to the south). Land use information is from the Land Cover Data Base 2 (Ministry for the Environment). Map provided by the Tasman District Council.

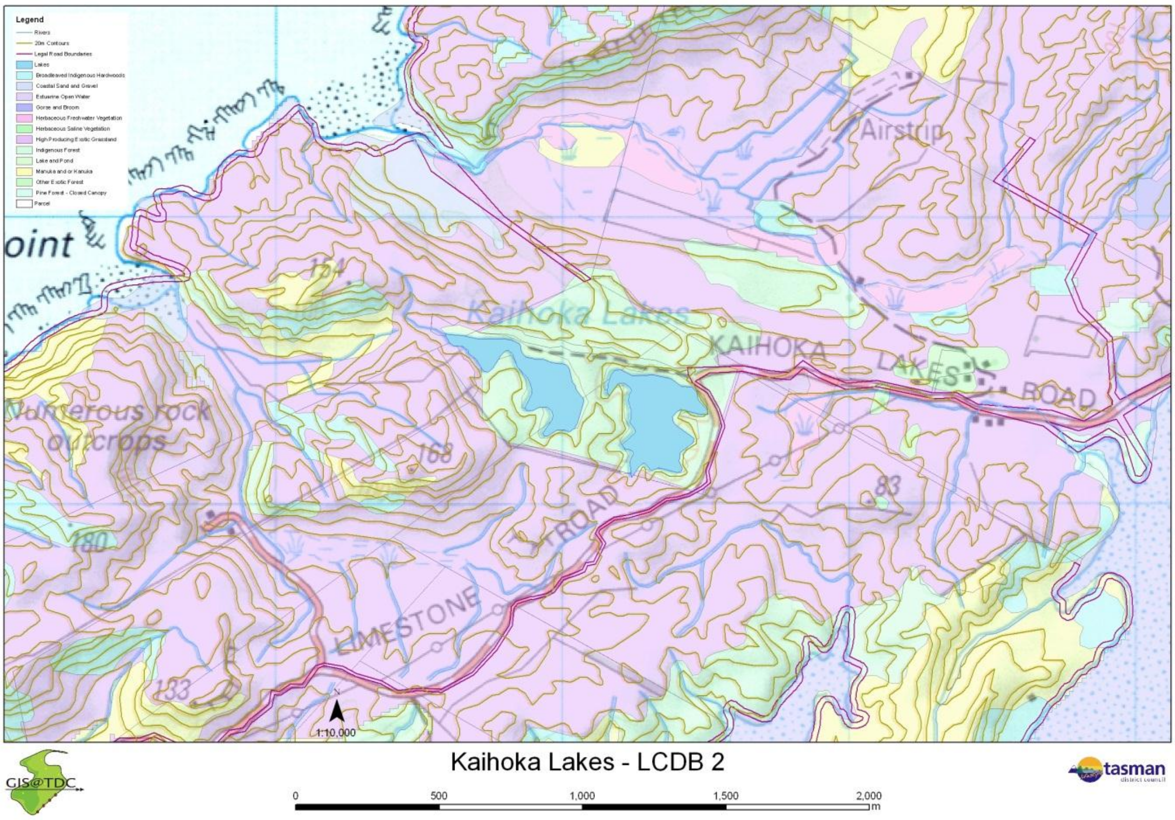

Figure 2. Catchments and local geographical features of the Kaihoka Lakes. Land use information is from the Land Cover Data Base 2 (Ministry for the Environment). Map provided by the Tasman District Council.

Lake Otuhie

Lake Otuhie is a shallow coastal lake located Westhaven/Whanganui Inlet and Kahurangi Point. The lake has three inflow tributaries and a surface outflow. The lake's catchment is influenced by limestone geology, as indicated by the limestone bluffs at the western end of the lake (Figs 3 and 4). These eroded bluffs suggest that the lake lies in a river basin that is quite old and that the lake was most likely formed by landslides from the steep limestone hills at the now western end of the lake.

The catchment was intensively mined for gold in the late 1800s at which time Sandhills Creek was dammed, raising the water level of the outflow to lake levels and expanding the size of the lake. The dam no longer exists. Presently, the catchment comprises 95% native vegetation and 5% pasture (Figs 3 and 4, Table 2). There are two small areas of lacustrine wetland and a small area of gorse and broom at the head of the lake (Fig. 4) and most of the bush immediately to the south and east of the lake appears to be regenerating in response to a past disturbance. Not indicated on Figures 3 and 4 is some farmland in the vicinity of the eastern tributary. The farmer who owns the land at the western end of the lake intends to protect the marginal strip on the edge of the lake under a Conservation Covenant. There is public access by foot and by kayak to the lake via the lake outlet and, with permission of the farmer, four wheel drive vehicles may access the lake near the outflow by use of a farm track.

The surface area of Lake Otuhie is over ten times the areas of the Kaihoka lakes, but being a relatively shallow lake and having a catchment area around 20 times larger than the lake area, the theoretical water residence time of the lake is only 29 days (Table 2).

Table 2. Morphometric, hydrological and catchment data for Lake Otuhie. Data are from Drake et al. (2009, 2010) and from D. Kelly (Dept. of Conservation, unpubl. data). Note: Lake volumes and water residence times are only estimates based on modelled lake bathymetry (using a digital terrain elevation model) and catchment flows using the TOPNET model (http://www.niwa.co.nz/news-and-publications/publications/all/wru/2008-26/available). Catchment data are from the Land Cover Data Base 2 (Ministry for the Environment). N and P loading estimates are from the CLUES model (http://www.maf.govt.nz/environment-natural-resources/water/clues).

	Otuhie
Altitude	5 m a.s.l.
Lake area	84.7 ha
Maximum depth	9.1 m
Lake volume	0.032 km^3
Lake water residence time	29 days
Catchment area	17.2 km^2
N loading	0.07 T/ha/year
P loading	0.01 T/ha/year

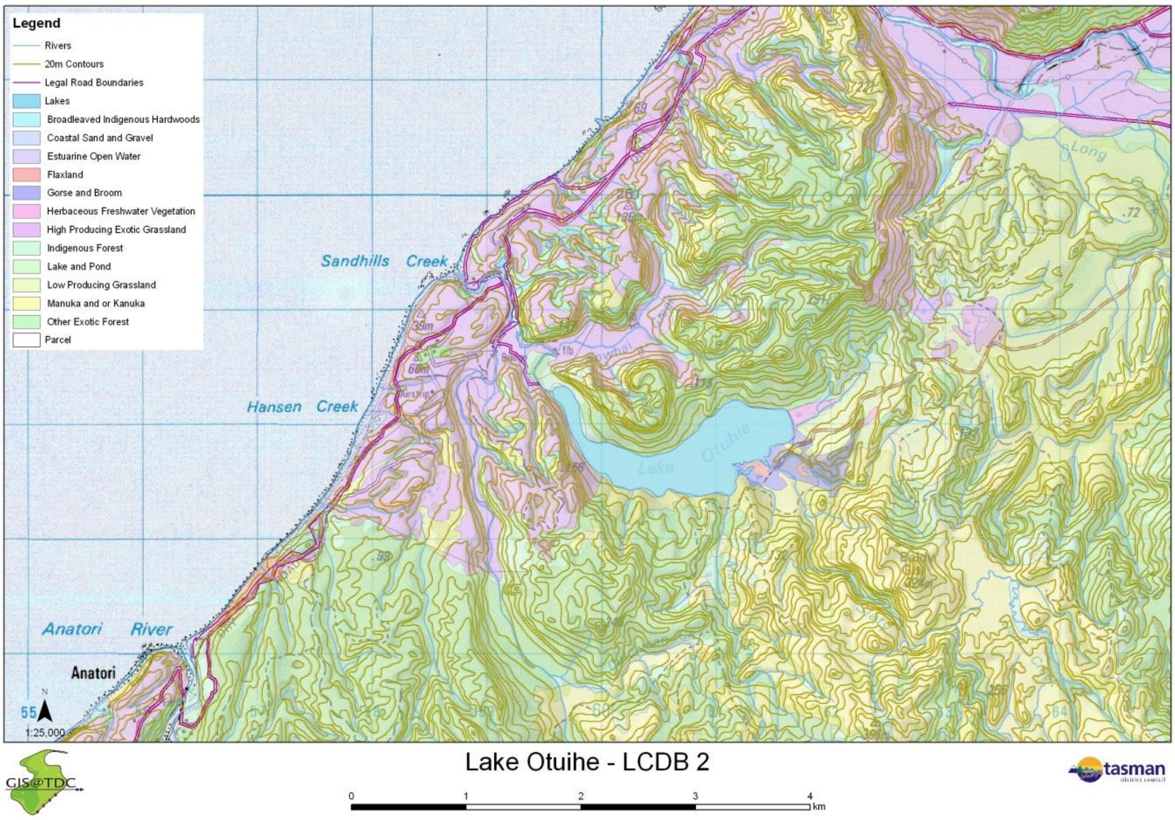

Figure 3. Location of Lake Otuhie. Land use information is from the Land Cover Data Base 2 (Ministry for the Environment). Map provided by the Tasman District Council.

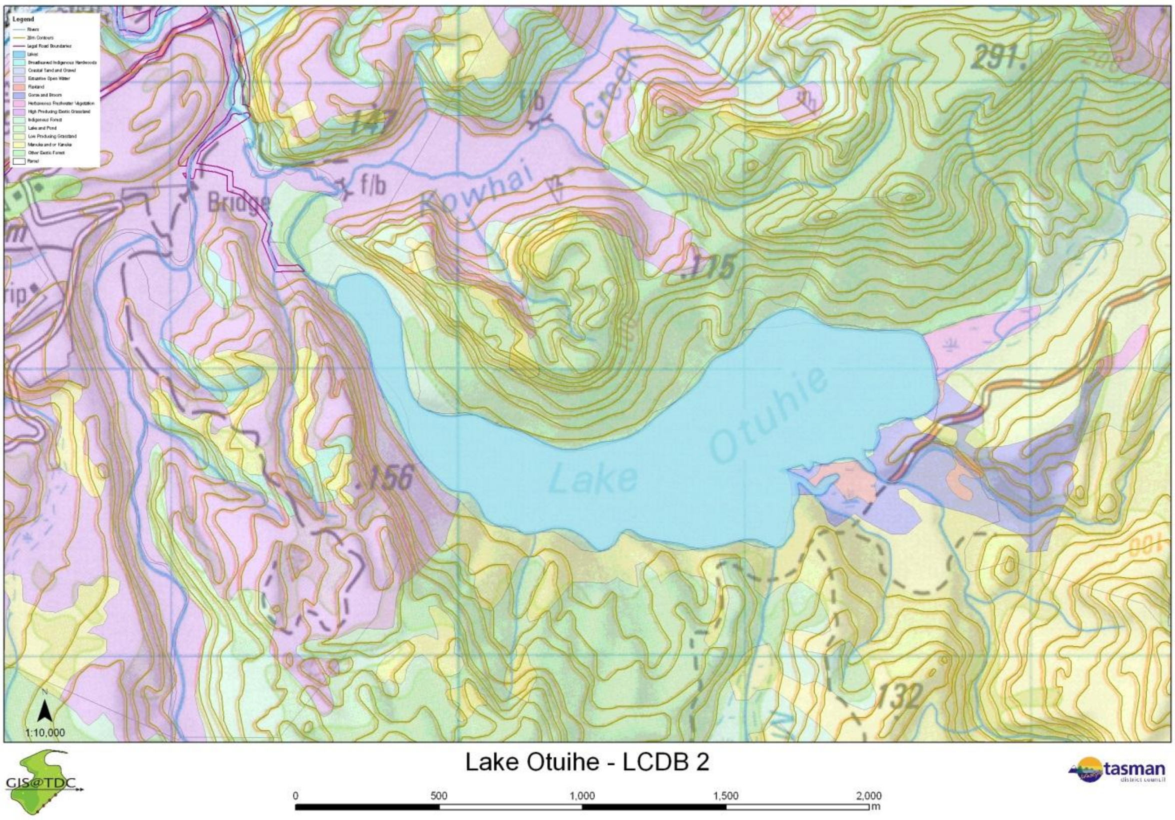

Figure 4. Catchment and local geographical features of Lake Otuhie. Land use information is from the Land Cover Data Base 2 (Ministry for the Environment). Map provided by the Tasman District Council.

4. Objectives

Due to the remoteness of the Kaihoka Lakes and Lake Otuhie, relatively few people visit the lakes and they have not been studied much. However, these lakes are becoming more recognised for their landscape values and their scenic beauty.

This report has a number of aims:

- To summarise published limnological and ecological data concerning these lakes
- To analyse a multi-lake dataset used by Drake et al. (2009, 2010) to compare the state of these lakes to other shallow coastal lakes around New Zealand. The data include water quality, zooplankton, invertebrates, fish, macrophytes and ecological integrity.
- To identify any special characteristics or features of these lakes which could merit special management
- To identify key knowledge gaps concerning the lakes

The information in this report will enhance the present understanding of the importance of these lakes in both a regional and national context.

5. Data sources

This study focuses mainly on a multi-lake dataset collected from 2004-2008 used in publications Drake et al. (2009, 2010). The multi-lake data presented here were only summarised in the publications and so the data in this report are referred to as the CDRP (Cross Departmental Research Pool) data, acknowledging that it was collected under a joint Department of Conservation/NIWA/University of Otago research programme. In addition, an attempt was made to collect all relevant data on the lakes from other published and unpublished sources.

The multi-lake dataset spans shallow coastal lakes from Northland to Campbell Island. Each lake was sampled once in late summer (February or March). Aspects studied include water quality, phytoplankton, zooplankton, fish, macrophytes, invertebrates, catchment land use and hydrology (refer to the Drake et al. (2009, 2010) publications for methodological details).

Sampling of Kaihoka Lakes and Lake Otuhie took place in March 2008 using methods listed in Drake et al. (2009, 2010).

6. Values

a. Water quality

So few data are available on the water quality of the Kaihoka Lakes or Lake Otuhie that it is not possible to robustly ascertain any temporal trends in water quality that may have occurred in the lakes. However, the CDRP data provide a useful comparison of the recent water quality of these lakes with a large number of shallow coastal lakes around New Zealand (Table 3; Fig. 5).

Table 3. Cross Departmental Research Pool (CDRP) water quality data. Samples and measurements of water quality variables were averaged from the surface water (0 - 1.5m integrated samples) at two open water sites in each lake on March 4, 5 and 7, 2008 from Kaihoka 1 (K1), Kaihoka 2 (K2) and Otuhie, respectively. Measurements are presented as well as the percent rankings of each measurement for each lake in relation to the rest of the lakes in the dataset (usually 46 lakes). Rankings below or equal to 10th percentile are highlighted in red, those between the 11th and 25th percentiles are highlighted in pink, those between the 75th and 89th percentiles are highlighted in turquoise and those above or equal to the 90th percentile are highlighted in blue.

		Values			Percentile rank			Number of lakes
Variable	Unit	K1	K2	Otuhie	K1	K2	Otuhie	
Conductivity	µS/cm	107	142	30	13	22	4	46
pH		6.9	7.1	6.0	23	36	7	45
Turbidity	NTU	0.7	1.4	2.2	25	54	62	25
Secchi depth	m	3.8	2.8	0.7	88	83	26	43
Water colour	Abs/10 cm	0.027	0.032	0.448	11	15	98	46
Cl-	mg/l	33.4	34.0	12.1	31	33	11	46
Ca++	mg/l	2.0	4.0	1.3	22	40	20	46
Mg+	mg/l	2.5	2.6	0.8	20	27	9	46
DOC	mg/l	3.2	5.2	13.8	2	26	72	46
Euphotic depth	m	8.9	5.7	1.3	93	78	17	42
Chlorophyll a	µg/l	1.6	11	0.7	22	76	4	46
TN	µg/l	151	325	235	2	38	11	46
TP	µg/l	6.6	18.5	7.4	13	53	20	46
NO3	µg/l	1.3	1.2	9.7	64	62	84	46
NH4	µg/l	15.7	15.0	19.6	40	38	55	46
SRP	µg/l	1.1	1.1	0.7	54	57	61	46
DON	µg/l	231	191	274	38	31	44	46
DOP	µg/l	undet.	0.1	0.7	0	7	11	46
DIN:TP		3.9	0.9	4.2	87	38	11	46
TLI_N		2.95	3.95	3.53	2	38	11	46
TLI_P		2.60	3.92	2.75	13	53	20	46
TLI_{Chla}		2.74	4.87	1.83	22	76	4	46
TLI_{Secchi}		3.69	4.00	5.42	12	17	74	46
TLI		3.00	4.18	3.38	4	58	20	46

While a number of the lakes in the CDRP dataset were tidal and connected to the sea, resulting in substantial marine influence, the three lakes showed little (Kaihoka Lakes) or no (Lake Otuhie) marine influence, based on the electrical conductivity of their waters. Lake Otuhie showed a particularly low conductivity and pH. The lake has a low water residence time and is flushed monthly (on average) with freshwater. Weathering of rocks in the catchment appears to have little influence on the ionic strength (hardness) of the lake waters (e.g. low calcium and magnesium levles). The low pH of the lake probably reflects both the strong influence of humic acids (e.g. high water colour and moderately high dissolved organic carbon measurements) and the low primary productivity (e.g. low chlorophyll a) of the lake. In terms of whole lake metabolism, the lake is probably net heterotrophic, resulting in higher levels of carbon dioxide production from respiration compared to oxygen production from photosynthesis. This would result in disproportionately high carbonic acid production and a low pH in such a weakly buffered lake.

Kaihoka 1 had the lowest dissolved organic carbon levels of all the lakes sampled. This is somewhat surprising considering the lake is surrounded by native vegetation. However, Kaihoka 1 has a water residence time of 416 days. As Rasmussen et al. (1989) showed, lakes with water residence times greater than 1 year tend to have low levels of dissolved organic acids because the relatively long water residence time allows for the substantial microbial degradation and photo-oxidation of dissolved organic matter in water. This situation contrasts with the situation in Lake Otuhie, which has a very short water residence time and a high organic acid content.

Kaihoka 1 was one of the lakes in the CDRP dataset with the lowest nutrient and algal biomass (i.e. low chlorophyll a) concentrations and the highest water clarity (as indicated by the euphotic depth), and consequently it has one of the lowest trophic lake index (TLI) scores (Fig. 5). Based on the four indicators of trophic state (Burns et al. 2000), the lake is on the border between low enrichment (oligotrophic; TLI between 2.0 and 3.0) and moderate enrichment (mesotrophic; TLI between 3.0 and 4.0), but based on nutrient and chlorophyll levels, the lake is oligotrophic (TLI is between 2.0 and 3.0). Lake Otuhie is also in the low enrichment category based on nutrient and chlorophyll a levels, but its low water clarity due to humic acids puts the lake into the category of moderately enriched (mesotrophic; TLI is between 3.0 and 4.0). On the other hand, Kaihoka 2 was more typical of other shallow coastal lakes in its water clarity and trophic state scores (Fig. 5), mainly because it had a fairly high chlorophyll a level, indicating substantial nutrient enrichment compared to its oligotrophic neighbour, Kaihoka 1. The TLI of Kaihoka 2 was in the range of eutrophic lakes (TLI is between 4.0 and 5.0), mainly due to its high chlorophyll a level. Note however that these results are based on a 1-off sampling whereas TLI classifications should be supported by data from monthly or seasonal samplings (Burns et al. 2000).

In terms of water quality, the lake most similar to Kaihoka 1 in the CDRP dataset was Kaiwi Lake in Northland (18 in Fig. 5) and that most similar to Lake Otuhie was Lake Manihapua in Westland (1 in Fig. 5).

The only other water quality data available for the Kaihoka Lakes comes from the study of Moore et al. (1963), who reported temperature and oxygen profiles over the deepest sites (this was not done in the 2008 study) as well as concentrations of some ions and the pH of the lakes. The reported chloride and sulphate concentrations confirmed some minor marine influence on the Kaihoka Lakes (probably from sea spray) and their measurements also confirmed that bicarbonate was the main buffering anion. Their calcium concentrations for the lakes were slightly higher than the CDRP data but the magnesium concentrations were very similar to the CDRP data. Their nitrate data were all below detection limit and their total phosphorus data were many times higher than the CDRP data. This might suggest that the phytoplankton in the lakes at the time had sufficient phosphorus but insufficient nitrate for growth (i.e. the phytoplankton were nitrogen limited). However, chemical methods have improved greatly since 1963 and this interpretation is not supported by the recent CDRP data.

Of greatest interest in the Moore et al. (1963) data are the temperature and oxygen depth profiles, which showed that Kaihoka 1 was thermally stratified at the time, with a thermocline depth of around 10 – 12 m, resulting in a small but distinct layer of bottom water. The isolation of the bottom waters from the atmosphere was confirmed by their oxygen readings which showed declines from 8.8 mg O_2/l in the upper mixed layer to 1.4 mg O_2/l in bottom water, just above the lake bed. These findings are important because they indicate that a small area of the lake bed could become anoxic during summer stratification, potentially releasing bound phosphorus from the sediments into the overlying water. This type of internal loading of phosphate is typical of lakes with anoxic bottom water and can fuel algal blooms once the lake fully mixes, as surface waters cool. Algal blooms eventually die off and settle to the lake bed, where their organic matter then fuels further deoxygenation. Such feedback dynamics can result in persistent cycles of algal blooms and bottom water deoxygenation.

The water quality data for the lakes shows that Kaihoka 1 and Otuhie have low algal productivity, with Kaihoka 1 having very high water quality values including very high water clarity compared to other shallow lakes. Considering that Kaihoka 2 has very similar morphology to Kaihoka 1, data showing that Kaihoka 2 has much higher levels of phytoplankton biomass and lower water clarity, suggests that this lake may already be impacted by nutrient inputs, possibly due to farming activities in the catchment and/or to greater numbers of water fowl visiting the lake. The slightly greater depth (and perhaps more sheltered location) of Kaihoka 1 resulted in the thermal stratification of the lake in 1963 and the decrease in oxygen content of the bottom waters. This indicates that the health and ecological values of the lake could be particularly sensitive to climate variations and external nutrient loading. Kaihoka 2 may also stratify in some years, but was not stratified during the sampling in 1963.

While Lake Otuhie does not show any signs of nutrient enrichment, its water is naturally stained by natural organic acids.

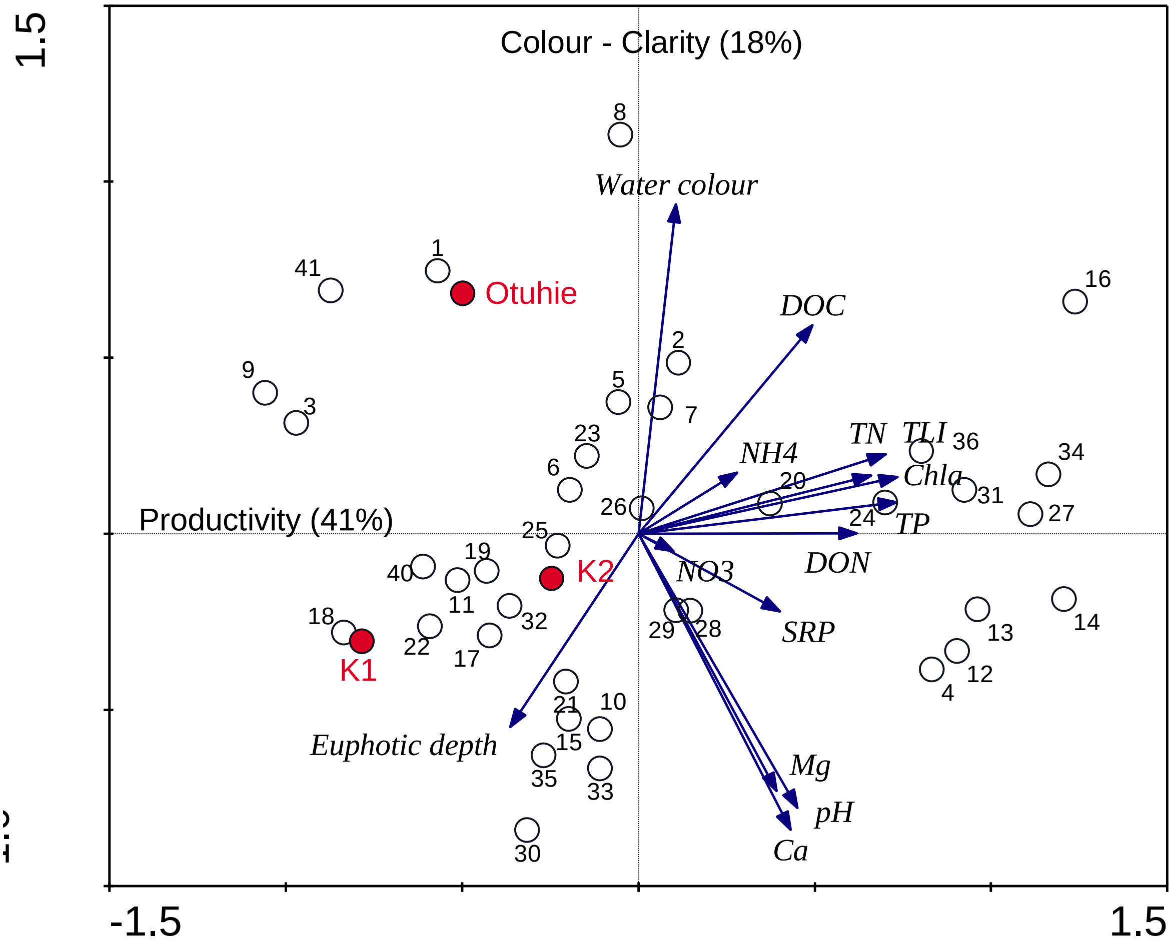

Fig. 5. Ordination plot of a principal components analysis of water quality data for 46 shallow coastal lakes. Arrows indicate correlations and loadings of water quality variables. Circles indicate lakes. Axis 1 can be interpreted as a productivity or lake enrichment axis, which explained 41% of the variation in the water quality variables. Axis 1 can be interpreted as a gradient of water clarity (down) and humic acid content (colour; up), which explained a further 18% of the variation in water quality variables. This ordination explained 59% of the variation in water quality among the lakes. The red circles indicate the positions of the three lakes in relation to the two water quality gradients.

b. Phytoplankton

Phytoplankton species and biomass can be highly dynamic in lakes, changing over weekly and monthly time scales (e.g. Marshall & Peters 1989). Therefore, one must be prudent in interpreting phytoplankton data from 1-off samplings. However, some phytoplankton species are of interest due to: i) their ability to develop into nuisance blooms (e.g. some cyanobacteria, dinoflagellates, green algae, etc), ii) their potential toxicity to wildlife and humans (e.g. some cyanobacteria) and iii) their edibility (e.g. small green algae and diatoms) or inedibility (e.g. colonial algae) by herbivore grazers such as zooplankton.

Only two studies have looked at phytoplankton from the Kaihoka Lakes and only the CDRP study has also sampled Lake Otuhie. The CDRP data are averages from two depth-integrated samples collected at two open water sites in the lakes.

The algae present in Kaihoka 1 are typical of those found in oligotrophic to mesotropic lakes. The phytoplankton of Kaihoka 1 was predominantly made up of a colonial cyanobacterium (*Microcystis* sp.), a colonial green alga (*Oocystis* sp.) and moderate numbers of diatoms and small flagellated green algae. The presence of *Microcystis* sp. is common in many lakes, but this cyanobacterium can form nuisance blooms in eutrophic lakes. Occasionally when *Microcystis* blooms, it can produce harmful levels of cyanobacterial toxins. Therefore, while there is no reason to be concerned about *Microcystis* in this lake at present, its presence in the lake indicates the potential for harmful cyanobacterial blooms if conditions alter to favour these phytoplankters.

Kaihoka 2, which had a substantially higher level of phytoplankton biomass (chlorophyll a, Table 3) had a bloom of dinoflagellates (*Peridinium* sp.) while *Microcystis*, diatoms (e.g. *Fragilaria*), and green algae were also present. *Peridinium* is a flagellated, motile alga, which often exhibit circadian rhythms by migrating vertically throughout the water column to take full advantage of light and nutrients.

The phytoplankton of Lake Otuhie consisted mainly of small green algae, usually smaller than 5 μm in diameter. In general, the phytoplankton communities of soft-water, oligotrophic lakes tend to be dominated by small algae.

The phytoplankton of Kaihoka 1 Kaihoka 2 and Lake Otuhie contained a variety of small green algae which were only found in the pristine Five Mile Lagoon and the Maori Lakes (Southwestland) and Six Foot Lake (Campbell Island).

In her samples of "net" phytoplankton collected on Jan.1, 1986, Burns (1987) found that Kaihoka 1 had *Kirchneriella* sp., *Tetraspora* sp., and *Staurastrum* sp. (all green algae) while Kaihoka 2 had *Staurastrum* sp. and detritus. While the CDRP data reported *Staurastrum* in samples from other lakes, it was not found in the Kaihokas or Lake Otuhie. Neither *Kirchneriella* nor *Tetraspora* were found in any of the CDRP lakes. Therefore, the CDRP samples were very different to those collected by Burns. While it is not unusual for the phytoplankton community in lakes to be dynamic and changing over time, such changes may reflect or cause changes to the environmental conditions or food webs of lakes. Changes in the phytoplankton community have implications for energy flow in aquatic food webs because phytoplankton are an important food source for mussels and zooplankton and some phytoplankton species are more edible/grazable than others. Thus, changes in the phytoplankton community can affect the food supply to higher organisms.

c. Aquatic Macrophytes

Aquatic macrophytes play many important roles in the ecology of shallow lakes. They provide good habitat for zooplankton, invertebrates and fish, often providing a refuge to these animals from predators. They help dampen turbulence in the water, reducing erosion of lake beds and shorelines by waves and currents, contributing to the maintenance of clear water. Aquatic macrophytes and the microscopic algae that grow on them absorb nutrients from the water, competing against phytoplankton for nutrient resources. However, aquatic macrophytes can also become nuisance organisms if their growth and proliferation becomes excessive, as has occurred when certain exotic macrophytes have colonised shallow lakes in New Zealand. In recognition of the importance of macrophytes in the health status of lakes, NIWA have developed the lake health index, LakeSPI, which is based on submerged macrophyte communities (http://lakespi.niwa.co.nz/index.do).

The only aquatic macrophyte data available for the Kaihoka Lakes and Lake Otuhie are from three surveys (Moore et al. 1963; CDRP data; Rohan Wells, NIWA Hamilton, pers. comm.). Wood and Mason (1977) simply reported the presence of the cosmopolitan charophyte, *Nitella pseudoflabellata*, in Kaihoka 2. Unfortunately, these surveys were not exhaustive; nevertheless, the data do provide some insights into the macrophyte communities of the lakes.

According to the reports, none of the three lakes contained any exotic macrophytes (Table 4). Thus, all species reported are natives and are desirable from a biodiversity and lake health point of view.

Table 4. Aquatic macrophytes reported from the Kaihoka Lakes and Lake Otuhie.

Survey	Kaihoka 1	Kaihoka 2	Otuhie
Moore et al. (1963) – sampled in March 1963.	Few large localised beds of *Isoetes* and *Myriophyllum*.	Only one weed bed was found, consisting mainly of *Myriophyllum*	Not sampled
R. Wells (pers. comm.) – sampled in July 1997.	- *Typha orientalis* (emergent) - *Glossostigma submersum* - *Nitella pseudoflabellata* - *Nitella hookeri*	- *Typha orientalis* (emergent) - *Glossostigma submersum* - “pratia-like species”	Not sampled
CDRP data – sampled in March 2008.	- *Typha orientalis* (emergent) - *Lilaeopsis* sp. - *Chara* sp. - *Nitella* sp.	- *Typha orientalis* (emergent) - *Glossostigma* sp. - *Lilaeopsis* sp. - *Potamogeton* sp. - *Chara* sp. - *Nitella* sp.	- Rushes (emergent) - Flax (emergent) - *Eliocharis* sp. (emergent) - *Typha orientalis* (emergent) - *Lilaeopsis* sp.

It is unclear how Moore et al. (1963) sampled macrophytes. Their sampling was conducted in March, when macrophyte development is at a seasonal high.

Wells spent 30 minutes diving in Kaihoka 1. Water clarity at the time was > 3 m. He reported that plants were present to 2 m depth and that mean and maximum vegetative covers in the vegetated zone were 6-25% and 51-75%, respectively. Unfortunately water clarity at Kaihoka 2 was only around 0.3 m at the time, limiting the ability to carry out a thorough survey. Wells made his observations in July, when macrophyte development tends to be somewhat limited.

In contrast, the CDRP sampling was conducted in March at three sites per lake and involved sampling with a benthic grab sampler along 50 m transects perpendicular to the lake shore. The maximum macrophyte depth limit in Kaihoka 1 was around 4 m (*Nitella* sp.), in Kaihoka 2 was > 5.1 m (*Nitella* sp.), and in Otuhie was around 0.8 m (*Lilaeopsis* sp). In the vegetated zones, percent cover in Kaihoka 1 and 2 was between 45% and 90%. In Lake Otuhie, much of the lake margin was occupied by emergent macrophytes and the only submerged macrophyte reported, *Lilaeopsis* sp., showed only around 30% cover at one site.

Many lowland lakes in New Zealand are degraded to the extent that aquatic macrophyte cover is absent or highly restricted (Schallenberg & Sorrell 2009). Based on transects sampled in the 41 lakes sampled in the CDRP programme, 15 lakes (37% of the lakes) had macrophytes absent or highly restricted macrophyte cover (< 10% of the lake bed). Furthermore, the lowland lakes in which macrophytes still persist, it is uncommon for the macrophyte communities to be free of exotic species (Mary De Winton, NIWA Hamilton, pers. comm.). This highlights a special characteristic of the Kaihoka Lakes.

The apparent near absence of macrophyte beds In Kaihoka 2 in 1963 contrasts with the macrophytes observed in 2008 and indicates that the lake has undergone a recovery from a period of macrophyte stress. This indicates that the macrophyte community in this lake may be vulnerable to serious decline and perhaps collapse.

d. Zooplankton

Zooplankton are small animals (usually crustaceans) which live suspended in the open water of lakes. They are important grazers of phytoplankton, thereby contributing to water clarity. Zooplankton are also important food items for larger invertebrates and vertebrates, such as fish. Thus, they occupy an important role in transferring energy from algae to fish. In the past decade, a number invasive exotic zooplankters have appeared in some New Zealand lakes and these have rapidly spread to other lakes. A number of invasive species are from the genus, *Daphnia*. In most cases, the native *Daphnia* (*D. carinata*), has been unable to compete with the exotic species (*D. dentifera*, *D. pulex*) and has disappeared from the invaded lakes.

Three studies have examined zooplankton in the Kaihoka Lakes – Moore et al. (1963), Burns (1987) and the CDRP study of 2008. The latter two studies reported the native calanoid coepeod *Calamoecia lucasi* to be in lakes (Table 5). This copepod is widely distributed in the North Island, but is substituted by calanoids of the genus *Boeckella* in almost all South Island lakes. The Kaihoka Lakes, Lake Otuhie and another small lake in the northern South Island (Lake Rotoua near Kaikoura) were the only South Island lakes in the CDRP dataset to contain this species. This represents and interesting biogeographic anomaly, as Burns (1987) pointed out. Burns also found another unusual occurrence in the Kaihoka Lakes, namely the co-existence of two species of calanoid copepods – *C. lucasi* and *Boeckella propinqua*. It is generally rare to find more than one species of calanoid in a lake, but the large size discrepancy between the two species in the Kaihoka Lakes probably allows the species to co-exist (Burns 1987). The CDRP study only found *B. propinqua* in Kaihoka 1, not Kaihoka 2. The only other lakes in the CDRP dataset in which *B. propinqua* was found were in Northland.

In addition to the presence of *C. lucasi*, the cosmopolitan cladoceran, *Bosmina meridionalis*, was present in the CDRP samples from all three lakes.

In contrast to the samples collected by Burns (1987) and the CDRP study, those collected by Moore et al. (1963) contained an abundance of *Daphnia carinata,* as well as some unidentified calanoid copepods and water mites. The presence of *Daphnia* can be episodic (they produce resting/dormant eggs) and it is possible that the samplings in 1986 and 2008 occurred during seasonal absences of *Daphnia* in the lakes, however the present occurence of *Daphnia* in the lakes could only be confirmed by more thorough sampling at different times of the year.

Table 5. Zooplankton collected from the lakes.

Study	Kaihoka 1	Kaihoka 2	Otuhie
Moore et al. (1963)	- *Daphnia carinata* - Calanoid copepod - Mite (*Unionicola* sp.)	- *Daphnia carinata* - Calanoid copepod - Mite (*Unionicola* sp.)	
Burns (1987)	- *Calamoecia lucasi* - *Boeckella propinqua*	- *Calamoecia lucasi* - *Boeckella propinqua*	
Drake et al. (2009, 2001)	- *Calamoecia lucasi* - *Boeckella propinqua* - *Bosmina meridionalis* - *Ceriodaphnia dubia*	- *Calamoecia lucasi* - *Boeckella propinqua* - *Bosmina meridionalis* - *Ceriodaphnia dubia*	- *Calamoecia lucasi* - Cyclopoid copepod - *Biapertura* sp. - *Bosmina meridionalis*

The detrended correspondence analysis presented in Fig. 6 clearly shows the distinctiveness of the zooplankton communities in Kaihoka 1 and Kaihoka 2, dominated by *B. propinqua* and *C. lucasi*. The lakes with the most similar zooplankton communities to the Kaihoka Lakes were Kaiwi (10), Ngatu (15) and Humuhumu (6), all of which are located in Northland. The analysis also shows that the zooplankton community of Lake Otuhie was not particularly distinctive.

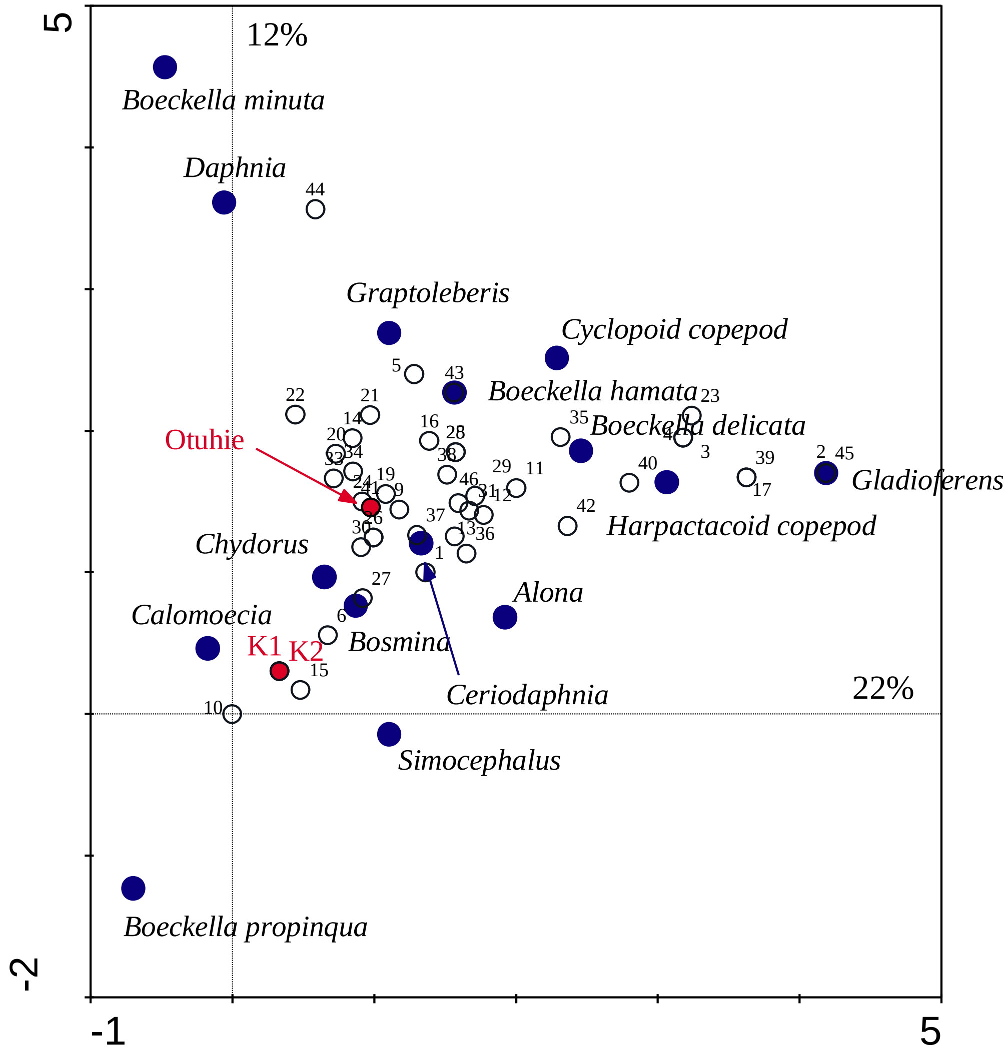

Fig. 6. Ordination diagram of a detrended correspondence analysis on the presence/absence of zooplankton species in 46 shallow coastal lakes around New Zealand. Black filled circles represent zooplankton species and open circles represent lakes. Red circles represent the three lakes which are the focus of this study. Kaihoka 1 and Kaihoka 2 had the same zooplankton communities and, therefore, their circle markers overlap.

e. Macroinvertebrates

Macroinvertebrates, which live either on the lake bed or on aquatic macrophytes, represent a community of aquatic organisms which are of interest from a biodiversity point of view. There are a number of notable species of macroinvertebrates and some are culturally important, such as koura (freshwater crayfish) and kakahi (freshwater mussels, *Hyridella/Echyridella menziesii*). Although no lake macroinvertebrate metrics reflecting lake health have been developed yet in this country, the composition of the macroinvertebrate community is probably also an indicator of lake health (as the MCI, or macroinvertebrate community index, is in streams). Macroinvertebrates are an important food for adult fish. Filter-feeding clams and mussels can play an important part in removing phytoplankton from lake water (Ogilvie & Mitchell 1995). The action of some macroinvertebrate species increases the oxygenation of the lake bed, and other species graze biofilms growing on the surfaces of macrophytes, rocks and sediments.

From a cultural point of view, the existence of good populations of koura and kakahi in the Kaihoka Lakes is significant. In comparing the morphology of kakahi from lakes and rivers around New Zealand, Dell (1953) found that the kakahi from the Kaihoka Lakes were unusually "obese", or very wide in terms of the thickness of the paired valves (shells). He speculated that they could be a distinct species of *Hyridella* but stated rather that they were more likely to be a distinct "ecotype".

Table 6 lists the notable invertebrates sampled from the Kaihoka Lakes and Lake Otuhie during the CDRP study.

Table 6. Invertebrates collected from the lakes during the CDRP study in March 2008.

Kaihoka 1	Kaihoka 2	Otuhie
Amphipods	Amphipods	Amphipods
Isopods	Isopods	
Back swimmers	Back swimmers	Back swimmers
Freshwater mussels		Freshwater mussels
Crayfish	Crayfish	
Clams (incl. *Hyridella*)		Clams (incl. *Hyridella*)
Limpets		
Damselfly larvae	Damselfly larvae	Damselfly larvae
Dragonfly larvae	Dragonfly larvae	Dragonfly larvae
	Snails	Snails
Worms (incl. polychaetes)	Worms (incl. polychaetes)	Worms
Caddisfly larvae	Caddisfly larvae	Caddisfly larvae
Beetle larvae		
Water boatmen		Water boatmen
Midges	Midges	Midges
Nematodes	Nematodes	Nematodes
		Flatworms
		Leeches
Mites	Mites	Mites

Also of particular note in the Kaihoka Lakes was the diverse amphipod communities (4 species in Kaihoka 1 and 3 species in Kaihoka 2) and the presence of polychaete worms. These taxa suggest that a much stronger connection to the sea than the salinity (conductivity) of the lake waters would indicate. It is quite unusual for lakes to have both a typical freshwater insect larva community together with a diversity of amphipods and a typical brackish amphipod/isopod/polychaete community. The macroinvertebrate community of

Lake Otuhie does not share this characteristic with that in the Kaihoka Lakes. This distinctiveness of the Kaihoka Lakes is clearly illustrated in the ordination plot presented in Fig. 7. Lakes with the most similar invertebrate communities to the Kaihoka lakes were the brackish Wairarapa lakes, Lake Wairarapa (40) and Lake Onoke (17). The macroinvertebrate community of Lake Otuhie was not as distinctive as those of the Kaihoka Lakes.

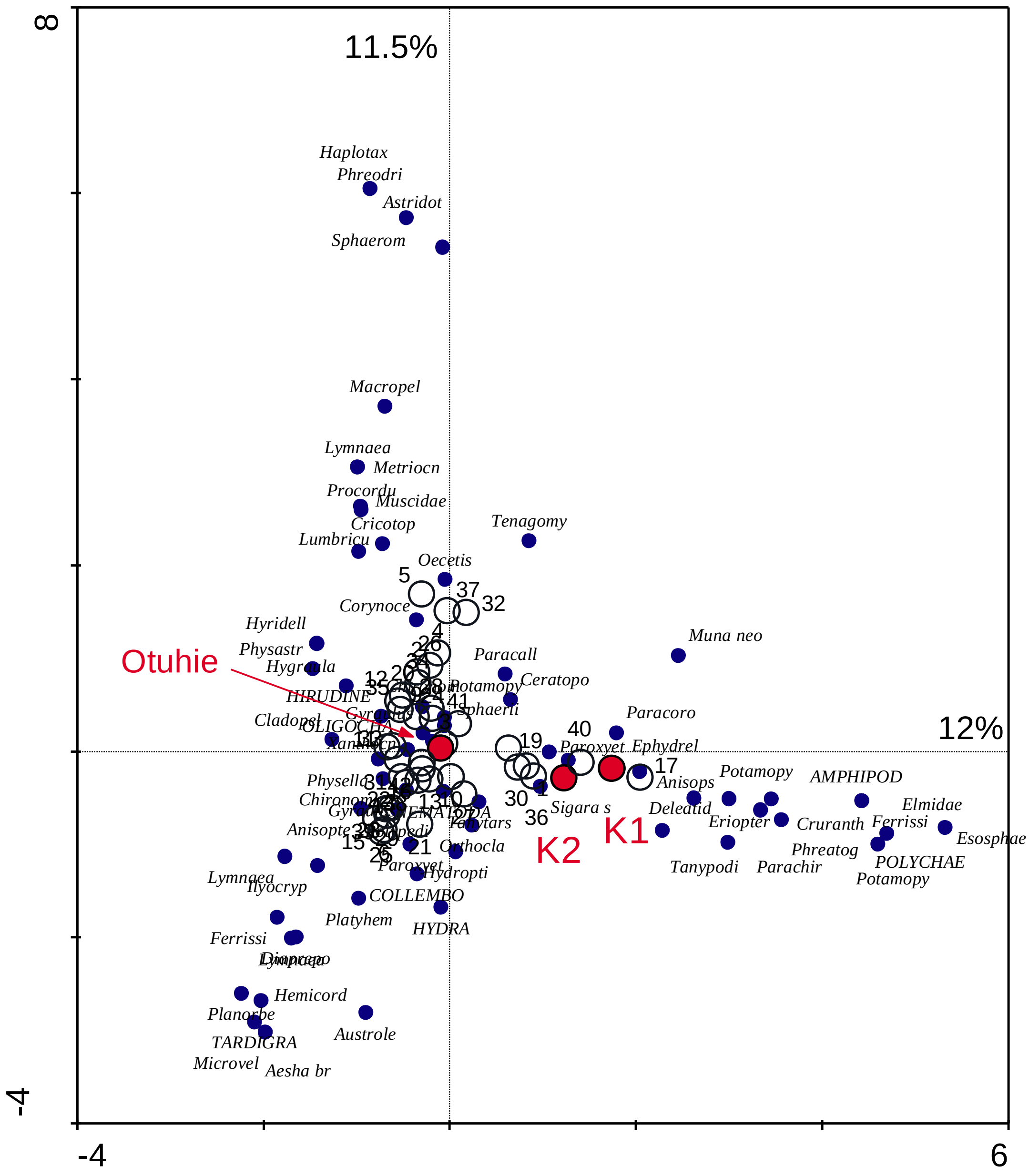

Fig. 7. Ordination plot of a correspondence analysis of macroinvertebrate species from 41 shallow coastal lakes. Filled dots represent invertebrate species and open circles represent lake communities.

The study of Moore et al. (1963) reported that samples dredged from the bed of Kaihoka 1 consisted almost entirely of oligochaete worms, but that koura were also plentiful on the lake bed as were dytiscid beetles and backswimmers (*Anisops* sp.) were also present in the weed beds. No freshwater mussels were collected from Kaihoka 1. Dredge samples from Kaihoka 2 contained worms, while freshwater mussels and koura were reported as being plentiful on the bed of the lake.

The macroinvertebrate communities from these lakes are quite diverse and contain some important species, including koura and kakahi. Freshwater mussels were not reported for Kaihoka 2 in the 2008 sampling and koura were not reported for Lake Otuhie, though these may exist in the lakes, simply eluding sampling at the time. On the other hand, the inability to find kakahi in Kaihoka 2 in 2008 may be indicative of biological interactions occurring in the lakes. For example, kakahi larvae are parasitic on certain fish species (e.g. koaro or *Galaxias brevipinnis;* McDowall 2002). The fish communities of the Kaihoka Lakes are almost exclusively made up of banded kokopu (*Galaxias fasciatus*; see section f, below), a fish that is normally not resident in lakes. Thus, the banded kokopu may not be a good host for parasitic kakahi larvae, thereby making the kakahi populations in the lakes rather fragile due to poor kakahi recruitment. This hypothesis would be supported if size distributions of kakahi in the Kaihoka Lakes were skewed towards large individuals. Dell (1953) found that the size of typical mussels in the Kaihoka lakes to be large compared to other lakes, but the study did not analyse enough individuals to allow for a robust comparison of population size structures. No other kakahi size distribution data are available for the Kaihoka Lakes.

The apparent loss of kakahi from Kaihoka 2 in 2008 may also affect water quality in the lake because kakahi are effective grazers of phytoplankton in shallow lakes (Ogilvie & Mitchell 1995). Thus, the apparent recent loss of kakahi could have reduced the grazing pressure on phytoplankton, possibly contributing to the rather high chlorophyll levels observed in the lake in 2008.

The macroinvertebrate communities of the Kaihoka Lakes are unusual for low salinity, seepage lakes because they contain species typical of both freshwater and brackish lakes. Kakahi from the Kaihoka lakes are unusually large, possibly due to isolation and genetic differentiation, however genetic analysis would be required to confirm this.

f. Fish

The Kaihoka Lakes have long been recognised as having rare landlocked populations of banded kokopu (Moore et al. 1963; McDowall et al. 1975). Such populations also exist in some west coast North Island dune lakes and in Lake Okataina (North Island). Genetic analysis of the Kaihoka populations and those of other South Island river and stream (diadromous) populations revealed that the Kaihoka Lake populations are the least genetically variable populations of the species, indicating genetic isolation. However, the analysis did not reveal when (or how) the populations became landlocked (Allibone & Wallis 1993). Thus, the alternate possibilities of human dispersal of fish or a natural isolation event (e.g. a land slip or sand dune development across the outflows of the lakes) are mechanisms potentially responsible for the isolation of the lake populations.

Moore et al. examined the gut contents of banded kokopu obtained from Kaihoka 1 and found that the fish had been feeding on zooplankton, midge larvae, backswimmers and beetles.

While Allibone et al. (2010) classified the status of banded kokopu as "not threatened" in New Zealand, landlocked populations are rare and the Kaihoka Lakes were the only shallow coastal lakes of the 42 sampled in the CDRP programme in which banded kokopu were caught. Interestingly, apart from one very large long finned eel caught in Kaihoka 1, no other fish were caught from either of the Kaihoka Lakes, indicating that banded kokopu are the dominant fish present in the lakes (Table 7). The restricted genetic variation exhibited by the Kaihoka banded kokopu populations suggests that the populations will be less adaptable to changing environmental and ecological conditions and, hence, more vulnerable to environmental change or change due to the introduction of new species to the system.

The status of New Zealand longfin eels is listed as "declining" nationwide (Allibone et al. 2010). Thus, it is of note that longfin eels were found in both Kaihoka 1 and Lake Otuhie. A single large eel (1.20 m in length) was caught from Kaihoka 1, indicating that the population is probably non-recruiting due to its isolation from the sea. In contrast, a number of longfin eels (340 – 500 mm) were caught in Lake Otuhie, indicating that the population there is recruiting.

Compared to fish communities of other shallow coastal lakes, the current fish communities of the Kaihoka Lakes are quite unusual, due to the almost exclusive dominance of banded kokopu (Fig. 8). In contrast, the fish community of Lake Otuhie is more typical of healthy, shallow coastal lakes with unimpeded connection to the sea.

Although they were not caught in Lake Otuhie, giant kokopu have been recorded in Otuhie Creek near the outlet of Lake Otuhie (NZ Freshwater Fish Database).

Table 7. Fish collected from the lakes.

Study	Kaihoka 1	Kaihoka 2	Otuhie
Moore et al. (1963)	- Banded kokopu	- Banded kokopu - Brown trout	
Drake et al. (2009, 2010) (CDRP data)	- Banded kokopu - Long finned eel	- Banded kokopu	- Long finned eel - Short finned eel - Inanga - Common bully

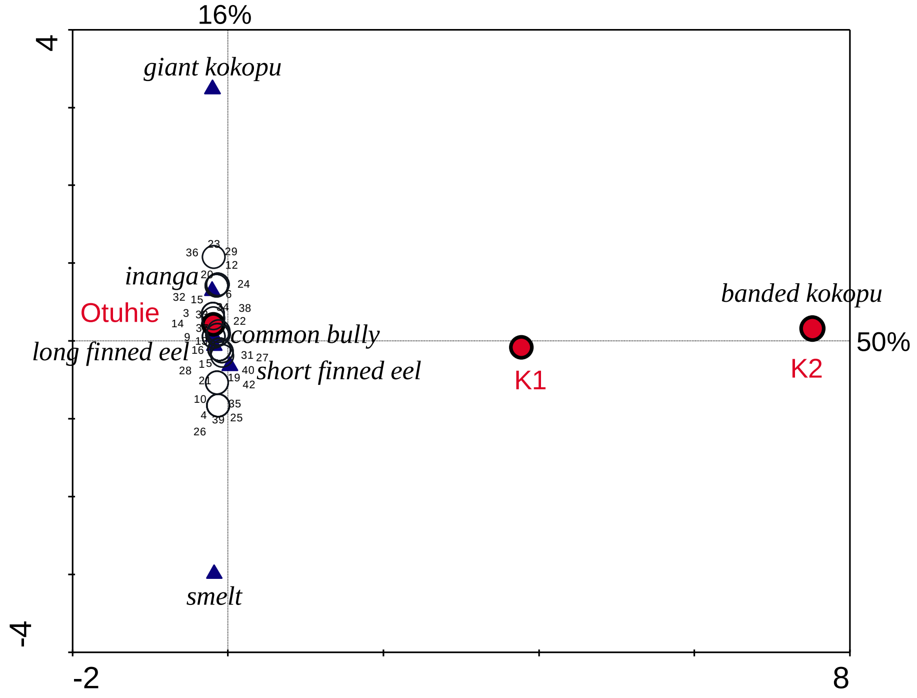

Fig. 8. Ordination diagram of a correspondence analysis of the presence/absence of native fish species in 42 shallow coastal lakes. Triangles represent fish species. Circles represent lakes. The symbol for Kaihoka 2 obscures the symbol for banded kokopu.

The lack of introduced sport fish or pest fish in these lakes is an important point of distinction compared to other shallow lakes. However, brown trout have been caught in both Kaihoka 2 (Moore et al. 1963) and Lake Otuhie (Martin Rutledge, Department of Conservation Nelson office, pers. comm.). Moore et al. (1963) caught two large trout (541 and 488 mm), which had been feeding almost exclusively on koura in Kaihoka 2. There are no suitable trout spawning sites in the catchments of Kaihoka 1 and Kaihoka 2 and so, the trout must have been introduced and then died out naturally due to a lack of recruitment in the lake. Two brown trout (350 and 500 mm) were caught in fyke nets in Lake Otuhie in 1999. It was considered that, as the lake is not suitable for trout recruitment, the fish were either sea run trout which had entered the lake or were fish from a previous liberation of trout which had been unable to recruit in the lake (M. Rutledge pers. comm.). The lack of stable trout populations in these lowland lakes confers an added ecological significance to the lakes as their food webs and their communities of native aquatic fauna are largely unaffected by trout.

Many species of native freshwater fish are currently under threat in New Zealand (Allibone et al. 2010) and major efforts are being mounted by the Department of Conservation to protect some of these species. One of the threats to native fish is the spread of exotic and invasive fish species among lakes. These species include sport fish such as trout and perch, which feed on native fish, as well as coarse fish species such as carp, rudd, etc., which can radically alter the ecology of lakes by their destructive feeding on macrophytes or their disruptive foraging behaviours (e.g. stirring up of bottom sediments).

g. Ecological Integrity

Freshwater ecological integrity has recently been defined as an amalgam of values incorporating nativeness, pristineness, biodiversity and resilience to human induced pressures (Schallenberg et al. 2011). While a definitive approach to combining these into an overall measure of ecological integrity has yet to be developed, Drake et al. (2010) reported that expert assessment (opinion) of ecological integrity can correlate well with human induced pressures and objective measures of lake health. In addition, this approach was given some credibility by the fact that independent rankings of the subjective determination of ecological integrity of the CDRP lakes by three scientists (who visited all the lakes) were strongly inter-correlated. Thus, expert assessment of ecological integrity appears to be a useful way to integrate a wide range of values into an assessment of the relative ecological value of different lakes and this should be useful for management and conservation prioritisation.

The rankings for the Kaihoka Lakes and Lake Otuhie by the three freshwater scientists shows that these lakes are considered to have ecological values in the top 25% of shallow coastal lakes sampled in the CDRP survey, with Kaihoka 1 exhibiting ecological values in the top 10% of the lakes surveyed.

Table 8. Expert assessment of ecological integrity of the lakes. Averages and standard deviation are from three experts' rankings of 42 lakes surveyed. Rankings were not influenced by analyses or data collected, only by site visits and observations of the catchments, characteristics of the water and the aquatic fauna and flora present.

Lake	**Average rank** out of 42 lakes	**Standard deviation** in rank units	**Percentile** of average rank
Kaihoka 1	4.3	2.5	10
Kaihoka 2	10.3	1.2	25
Otuhie	7.7	1.2	18

The Department of Conservation has recently completed a conservation ranking of all lakes in New Zealand over 1 hectare in size (Leathwick et al. 2010). For the analysis, catchment pressure scores from the Freshwater Ecosystems of New

Zealand (FENZ) geodatabase were used (http://www.doc.govt.nz/conservation/land-and-freshwater/freshwater/freshwater-ecosystems-of-new-zealand/). Kaihoka 1 had the lowest overall catchment pressure (highest pressure score) and the highest conservation ranking (5th) of the 134 lakes assessed in the Norwthwest Nelson-Paparoa region, but ranked slightly lower on a national basis than Lake Otuhie. This is likely related to Lake Otuhie being in a larger lake class (large shallow coastal) than the Kaihoka Lakes, a class which is generally more degraded on a national basis. Expert ranks of lowland lakes in the CDRP survey aligned well with FENZ cumulative catchment pressure scores (D. Kelly, Department of Conservation, pers. comm.).

Table 9. FENZ (Freshwater Ecosystems of New Zealand) cumulative catchment pressure calculations and regional (Northwest Nelson-Paparoa) and national conservation ranks for the Kaihoka Lakes and Lake Otuhie (Source: FENZ, Leathwick et al. 2010). Conservation rankings were based only on FENZ catchment pressure scores.

Lake	FENZ cumulative catchment pressure score (0 to 1)	FENZ regional conservation rank out of 134 lakes	FENZ national conservation rank out of 3821 lakes
Kaihoka 1	0.916	5th (4th percentile)	844th (22nd percentile)
Kaihoka 2	0.869	11th (8th percentile)	1359th (36th percentile)
Otuhie	0.839	26th (19th percentile)	804th (21st percentile)

7. Knowledge gaps

Little limnological and ecological data exists on the Kaihoka Lakes and Lake Otuhie. All samplings have been one-off collections and so little information exists on seasonal variability.

Only one depth profile of temperature and oxygen exists for each of the Kaihoka Lakes and so almost nothing is known about their thermal stratification, oxygen dynamics and the potential for the seasonal internal loading of phosphorus to the water column.

There is no water balance for the Kaihoka Lakes and, therefore, their unusual hydrology and the major pathways of external nutrient loading to the lakes are not understood.

No palaeolimnological studies have been undertaken and so the ages of the lakes and historical changes to their conditions are not known.

No information is available on levels of contaminants such pesticides or heavy metals for these lakes. Past gold mining activity in the Lake Otuhie catchment and accounts of elemental mercury observed in the stream bed (T. James, Tasman District Council, pers. comm.) suggest that levels of mercury and/or arsenic might be elevated in Lake Otuhie, especially levels of mercury in eels (see Redmayne et al. 2000). The conditions in Lake Otuhie probably facilitate the methylation of mercury, converting this toxic metal into methyl-mercury, which can bioaccumulate in organisms at the top of the food chain, such as eels and shags.

While some genetic work has been carried out on the landlocked banded kokopu of the Kaihoka Lakes, no genetic work has been carried out on the kakahi. However, based on the work on the kokopu, the kakahi may also not show strong genetic differentiation to kakahi elsewhere.

The apparent disappearance of kakahi from Kaihoka 2 could indicate difficulties in recruitment, possibly as a result of banded kokopu not effectively serving as a host for parasitic kakahi larvae. Quantitative sampling and analysis of size distributions of kakahi from the lakes would help determine how well kakahi recruit in the Kaihoka Lakes.

The fate of *Daphnia carinata*, which was reported in 1963 to be abundant in the Kaihoka Lakes is an interesting issue. More zooplankton sampling might reveal that *Daphnia carinata* do still occur at certain times. If they no longer occur in the lakes, then examination of sediment cores for resting eggs could indicate when and why the *Daphnia* died out.

Table 9. Summary of knowledge gaps concerning the lakes.

Lake	Knowledge gap
All lakes	Seasonal variability in phytoplankton, zooplankton and temperature, oxygen and nutrient dynamics (esp. Kaihoka 1 and Kaihoka 2)
Kaihoka Lakes	Water balance and nutrient pathways
All lakes	Ages of lakes and times of isolation from the sea (esp. Kaihoka 1 and Kaihoka 2)
Lake Otuhie	Mercury levels in top predators
Kaihoka Lakes	Genetic differentiation of banded kokopu and kakahi
Kaihoka Lakes	Population size and recruitment success of kakahi
Kaihoka Lakes	Fate of *Daphnia carinata*

8. Summary and some management implications

The Kaihoka Lakes and Lake Otuhie are among the least modified shallow coastal lakes in New Zealand. This report details a number of limnological and ecological values that make these lakes special and of interest for prudent management and conservation. The greatest threats to these lakes are colonisation by invasive macrophytes and/or fish and nutrient enrichment by activities in the catchments (Schallenberg & Sorrel 2009). These threats could cause rapid declines in the ecological values of these lakes. Experiences from other lakes in New Zealand and abroad indicate that such trajectories are often very difficult and expensive to reverse.

9. Acknowledgements

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