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MAITAI RESERVOIR AND NORTH BRANCH HABITAT SURVEY 2013

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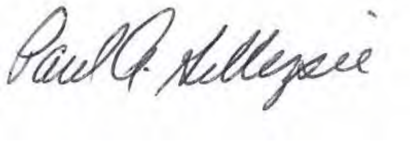
DAVID KELLY, KAREN SHEARER

Prepared for Nelson City Council

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



REVIEWED BY:
Paul Gillespie

APPROVED FOR RELEASE BY:
Rowan Strickland

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EXECUTIVE SUMMARY

The Maitai Reservoir has been operated by Nelson City Council (NCC) on the North Branch of the Maitai River just above the Forks to augment the Nelson municipal water supply since 1987. In anticipation of the re-consenting process in 2017, NCC has requested an assessment of the status of the Maitai Reservoir in terms of providing for the functioning and ecological health of the Maitai Catchment. This investigation conducted ecological surveys in the Maitai Reservoir and its major inflow, the North Branch tributary, in April 2013. The purpose of these field investigations were to:

- Assess if there were significant effects of North Branch drainage from mineral rich geological areas in the Dun mountain mineral belt area on the Manganese (Mn) and iron (Fe) levels in the Maitai Reservoir, which have been reported to be high.
- Assess aquatic communities inhabiting the Maitai Reservoir and North Branch since the formation of the Maitai Dam in 1987. This included assessments of phytoplankton, zooplankton, periphyton, aquatic macrophytes, macrobenthic invertebrates, and fish.
- Use ecological metrics based on biological datasets to assess the ecological health of the reservoir and the North Branch in comparison to the wider Maitai Catchment, as well as other systems in the region and on the South Island (for the reservoir).
- Evaluate reservoir habitats in the context of the Maitai Dam operations to better understand how these factors affect aquatic communities in the reservoir.
- Make recommendations on improving dam operations for aquatic community health in the reservoir and North Branch, and identify where further ecological survey work is required leading up to the re-consenting process in 2017.

Maitai North Branch

- Manganese (Mn) and iron (Fe) concentrations in inflows did not appear to be influenced significantly by the Dun Mountain mineral belt area, which have been measured at high levels in the Maitai Reservoir during anoxic periods. However, more sampling in the North Branch would need to be undertaken to determine the natural background levels of metals, as this finding is based on only one sampling event.
- Water quality (dissolved oxygen, conductivity, temperature and pH), periphyton and macroinvertebrate communities were similar to those at the upstream control biomonitoring site in the South Branch.
- There was no indication that the degraded biological conditions downstream of the backfeed discharge were the result of follow through impacts of water quality in the North Branch inflow.
- Fish passage may be an issue for longfin eels (not found in the North Branch) and koaro (a whitebait species found in low density in the North Branch). Koaro is the second most important species in the whitebait catch. Landlocked lake populations of this species can occur, but any koaro in the North Branch would historically have been from a sea-run population. The finding of only a few very large individual koaro

in the North Branch suggests uncertainty regarding whether migrants could be bypassing the dam face to access the upper catchment.

Maitai Reservoir

- Water levels in the reservoir are operated over a reasonably narrow range by comparison to operations of most reservoirs with a mean (1994-2013) drawdown of 1.4 m, typically in late summer. The lowest lake level, being 3.06 m below the spillway height, occurred in 2006. These reservoir level operations are anticipated to maintain healthy ecological conditions in the lake-edge littoral community, which extends to the euphotic depth of around 6 m.
- Water quality in the reservoir can be characterised as a low productivity oligotrophic system, an overall Trophic Level Index (TLI) score of 2.0. Water clarity was relatively high (Secchi of 4.2) by comparison to other small South Island lakes, and is mediated mainly by humic tannin staining (DOC of 4.2 mg/l). The reservoir is influenced by limestone geology of several rock formations (principally Dun Mountain, Stephen's argillite) in its catchment, and thus has high calcium cation concentrations and pH (8.2 in surface waters).
- Thermal stratification in the reservoir between December and April contribute to deoxygenaton in its hypolimnion, and was nearly anoxic between 10 and 25 m depth during April 2013 field survey. This is not entirely uncharacteristic of deep lakes in New Zealand, however is uncommon for low nutrient lakes such as the Maitai Reservoir. Dissolved oxygen declines are most likely related to dystrophic processes in the hypolimnion from the breakdown of organic materials that were either flooded or washed into the reservoir basin. DO declines present ecological issues associated with the backfeed of reservoir water to the South Branch of the Maitai River during stratified periods.
- Phytoplankton communities present in the reservoir are characteristic of low productivity systems, dominated by small celled cyanobacteria. Although one of the dominant species is known to produce cyanotoxins (*Aphanocapsa sp.*) further testing suggested there were no genetic markers for toxin producing strains of this species, and the overall biovolume concentrations for *Aphanocapsa* were low.
- The zooplankton community was entirely native species, dominated by the daphnids *Daphnia carinata* and *Ceriodaphnia dubia*. These species would be effective phytoplankton grazers and promote good water quality in the reservoir should phytoplankton increase in spring following winter turn-over.
- Surprisingly there were no submerged macrophyte species in the reservoir, despite a suitable reservoir level operating regime. Possibly little colonisation has occurred due to the isolated nature of the reservoir and lack of macrophytes occurring in upstream inflows which are steep and bouldery in nature. The lack of macrophytes in the reservoir does mean poorer habitat quality for reservoir aquatic fauna, however this minimises use by waterfowl that could contribute to faecal bacteria loads that compromise human drinking water quality.
- The littoral macroinvertebrate community in the Reservoir was of intermediate abundance and relatively low diversity by comparison to other South Island lakes,

most likely related to the limited diversity of habitats and no submerged macrophytes being present.

- Fish populations consisted of four species, numerically dominated by common bullies, followed by upland bullies and longfin eels. Koaro were found in the river and juveniles may inhabit the reservoir, but were not detected. Brown trout are also present in the reservoir but were not caught in the present survey principally due to survey methods used (fyke nets, gee-minnow traps).
- Anoxic conditions in the hypolimnion limited fish to the shallow portions of the reservoir, and no fish were caught below 5 m depth. The heavily skewed size class structure of longfin eels towards large (>600 mm) adult individuals indicates that limited or possibly no recruitment is occurring to the reservoir from upstream juvenile migrants.

Recommendations

- More detailed work should be conducted around the development of anoxia in the hypolimnion of the reservoir, and associated nutrient and contaminant cycling processes from reservoir sediments during periods of anoxia. This would include examining sediment processes and organic matter breakdown in the hypolimnion.
- More detailed work around stratification development over summer to provide the NCC better informed options on suitable reservoir layers for sourcing backfeed water discharged to the South Branch over anoxic periods.
- Phytoplankton composition and biomass be measured as part of the wider water quality study in the reservoir to better document if potentially toxin producing cyanobacteria can proliferate during spring/summer when production is at its maximum.
- More detailed investigations need to be conducted into facilitating upstream fish passage for diadromous species (koaro and longfin eel principally) into the North Branch system over the dam face, and possible engineering options.
- The NCC could consider a macrophyte establishment programme for the Maitai Reservoir to enhance habitats for invertebrate and fish populations. This would need to be weighed against risk of increased waterfowl use and possible faecal sources.

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1. THE MAITAI CATCHMENT WATER SUPPLY SCHEME

The Maitai Reservoir was built by Nelson City Council (NCC) on the North Branch of the Maitai River just above the Forks (confluence with the Maitai South Branch) to augment the Nelson municipal water supply, and has been operational since 1987. The reservoir water quality at times can be poor in comparison to the quality of the water in the South Branch of the Maitai River. Consequently, under normal flow conditions drinking supply water is abstracted directly from the South Branch of the Maitai River at the intake weir. This water is replaced by water from the Maitai Reservoir (termed the 'Backfeed') which is discharged at the foot of the intake weir (Figure 1). When the river is turbid, such as in flood conditions, the Nelson City supply is fed directly from the North Branch Reservoir. Some water is also drawn from the reservoir during normal river flow to meet Nelson city's peak demand.

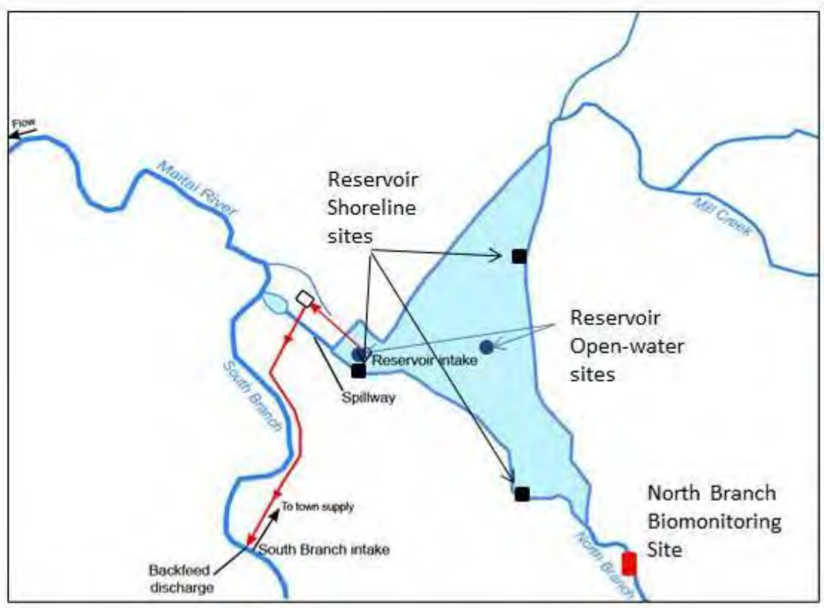

Figure 1. Diagram of the Maitai Water Supply Scheme with the water supply intake (labelled 'South Branch intake') and backfeed to the Maitai South Branch shown. Also shown are the Maitai Reservoir open water (blue-circles) and shoreline (black squares) sites, and the North Branch biomonitoring site (red rectangle) where sampling for water chemistry, macroinvertebrates and fish occurred.

1.1. Historical monitoring

Routine monitoring reports have shown that water with elevated manganese concentrations is discharged into the Maitai River from the Maitai Reservoir as part of the operation of the Nelson City water supply scheme (Holmes 2010). While it is generally well known that Manganese (Mn) and iron (Fe) can be solubilised from lake sediments during anoxic conditions in the hypolimnia of lakes (McQueen & Lean 1986), it is possible that Mn is entering the lake via the metals-rich geology of the upper North Branch catchment of the Maitai River (Holmes 2010). While the moderately increased levels of manganese (and iron) in the reservoir's discharge indicate only a moderate chance of direct or chronic toxicity to the river's aquatic life, there is concern that the Mn (and Fe) may be encouraging the dominance of (potentially toxic) cyanobacterial communities over diatom-based communities in the Maitai River.

Historical monitoring in the Maitai Reservoir has focused solely on collection of water quality data. This has included documenting thermal stratification and deoxygenation cycles in the reservoir (*e.g.* Holmes 2009, Olsen 2010, Holmes 2012), and was largely driven by issues around anoxic conditions in the reservoir hypolimnion. Limited sampling effort has been made examining nutrient concentrations in reservoir water, and limited to analyses of nutrient concentrations in water being transferred from the backfeed into the South Branch to better understand if periphyton proliferations below the backfeed discharge were nutrient related (NCC Unpublished data). Stark (1998) did some quite detailed analyses relating spring nutrient concentrations in the Maitai Reservoir to possible summer chlorophyll concentrations. This investigation was limited to a short (two month) sampling period, and hypolimnetic anoxia appears to have intensified since this time. Thus these earlier findings may have limited applicability to current water quality conditions.

More detailed analyses of metal concentrations in reservoir water transferred through the backfeed were conducted by Holmes (2010) in response to a breach of consent conditions for Mn concentration of 1 g/m^3 in May 2006 (1.7 g/m^3) and May 2007 (1.2 g/m^3) in the Maitai South Branch below the discharge (Wilkinson & Olsen 2007). This and other Maitai Reservoir consent monitoring reports indicated that the reservoir can at times discharge high concentrations of Mn and Fe (Holmes 2010).

1.2. Purpose of this report

The consents held by NCC for the operation of the Maitai Reservoir expire in 2017. In anticipation of the re-consenting process, NCC has requested an assessment of the status of the Maitai Reservoir in terms of providing for the functioning and ecological health of the Maitai Catchment. As part of this assessment it was decided that the scope should also consider the North Branch of the Maitai River upstream as this could have a strong influence on water quality and fisheries in the reservoir. This report provides an inventory of the current water levels, water quality, biotic communities, and fisheries of the Maitai Reservoir and North Branch tributary around the inflow.

As this is somewhat of a scoping nature, additional ecological surveys and, in some cases, operational modifications are also suggested to better understand how the operations of the Maitai Reservoir could be improved to minimise ecological effects.

1.2.1. Study scope

Maitai North Branch

A one-off ecological survey of the North Branch of the Maitai River was undertaken on 18 April 2013. The primary purposes of the survey were to:

- Assess if there were significant effects of drainage from the Dun mountain mineral belt area on the Mn and Fe levels in the Maitai Reservoir by analysing water from the North Branch above the reservoir and the South Branch above the discharge site. This will also help determine the natural background levels of some potential contaminants.
- Compare the North Branch results with those of two consent biomonitoring sites in the South Branch of the Maitai River, *i.e.* a "control" site above an intake/reservoir backfeed weir structure and a site below the structure ("site B") to:
    - assess whether the biological conditions downstream of the backfeed discharge are the results of the reservoir and not an influence of the tributary inflows.
    - evaluate whether any degraded conditions seen below the reservoir (based on comparison with Site B) are reflected upstream of the reservoir in the North Branch.
- Gain baseline information on the biology and ecology of the North Branch of the Maitai River, as (to the authors' knowledge) this branch has not been sampled since the inception of the dam.

Maitai Reservoir

A one off ecological survey was conducted of the Maitai Reservoir on 3-4 April 2013. The primary purposes of the survey were to:

- Assess aquatic communities that have colonised the Maitai Reservoir since its formation in 1987. This included assessments of phytoplankton, zooplankton, aquatic macrophytes, macrobenthic invertebrates, and fish.
- Use ecological metrics based on biological datasets to assess the ecological health of the reservoir in comparison to other small lakes present in the region and on the South Island.
- Evaluate reservoir habitats in the context of the Maitai Dam operations to better understand how these factors affect aquatic communities in the reservoir. This included evaluation of reservoir level fluctuations, physic-chemical profiles of the water column in the reservoir (dissolved oxygen [DO], temperature, pH), and water chemistry of surface waters.

- Make recommendations on improving Dam operations for aquatic community health in the reservoir, and where further ecological survey work is required leading up to re-consenting in 2017.
- Make recommendations around management of Maitai Dam operations to improve aquatic communities in the upper Maitai River (*e.g.,* fish passage), and advise where further ecological survey work is required leading up to re-consenting in 2017.

2. STUDY SITE

The North Branch of the Maitai River drains a predominantly native forest (mainly *Nothofagus* sp.) and bush (Figures 2 and 3). One site was surveyed in the river (E2541775, N5989600) approximately 150 m upstream from the outlet to the Maitai Reservoir.

The streambed comprised mainly bedrock, cobbles and gravels in the lower portion of the river, changing to bedrock, boulders and cobbles further upstream (figures 2 and 3). The lower portion of the river (to approximately 200 m upstream) was mainly pool/run habitat with one riffle present. Further upstream the river was confined by steep banks, the substrate was boulder with some bedrock, and the main habitat present was cascades/pools (*e.g.* Figure 3). There was no instream aquatic plant (macrophyte) cover present. The river flow in the North Branch at the time of sampling was 0.44 m^3/s.

Figure 2. North Branch of the Maitai River approximately 150 m upstream from lake outlet (facing upstream). Macroinvertebrate samples were taken in the riffle (lower right corner of the photo) and in the cascade (boulders seen in the distance).

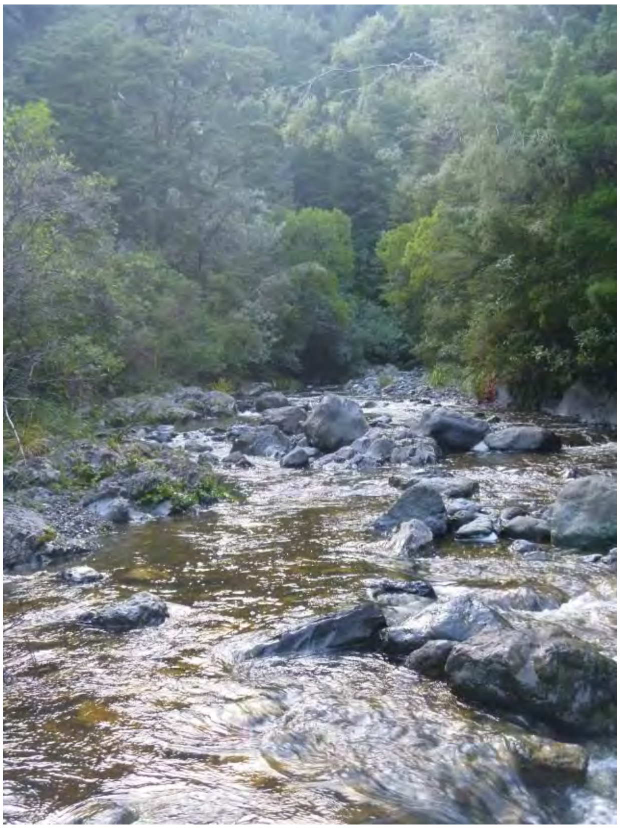

Figure 3. North Branch of the Maitai River approximately 200 m upstream from lake outlet (facing upstream).

The Maitai Reservoir, located immediately upstream of the junction of the Maitai North and South Branch confluence is approximately 32 hectares in area, has a maximum depth of 29 m near the dam, a mean depth of 7.6 m, and a total volume of 4.3 Mm^3 (Payne 2007). The inundation area of the valley was largely cleared of vegetation before flooding, and the substrate of the reservoir margins are predominantly sandy with more rocky areas towards the dam face (Figure 4). The margins of the reservoir are bush clad with either exotic forest or native forest saving the South margin of the reservoir where the dam is located (Figure 5).

Figure 4. Maitai Dam prior to infilling in 1985. Photo taken from the TheProw.org.nz. (http/www.theprow.org.nz/assets/enterprise/ maitai-dam-1985.jpg).

Figure 5. The Maitai Reservoir, 3 April 2013. Photo from the North-west Arm shoreline sampling site looking towards the Dam.

3. METHODS

3.1. Maitai North Branch

3.1.1. Water quality

Field measurements of water temperature, dissolved oxygen (% saturation and concentration), specific conductivity and pH were taken at both sites using a YSI EXO multiparameter datasonde. Water samples were also collected for analysis of turbidity, total hardness, total suspended solids, dissolved calcium (Ca), total Ca, total iron (Fe), dissolved magnesium (Mg), total Mg, total manganese (Mn), total potassium (K), total sodium (Na), chloride (Cl^-), total ammoniacal-N (NH_3-N), nitrite-N (NO_2-N), nitrate-N (NO_3-N), NO_2-N + NO_3-N, dissolved Kjeldahl nitrogen (DKN), total nitrogen (TN), dissolved organic nitrogen (DON), dissolved reactive phosphorus (DRP), Total phosphorus (TP), sulphate (SO_4), and dissolved organic carbon (DOC) (see Appendix 1). All water samples were immediately stored in the dark on ice and forwarded to Hill Laboratories (Christchurch) for analyses.

3.1.2. Periphyton

Periphyton sampling was conducted in conjunction with invertebrate sampling. The percentage cover of the streambed by periphyton was assessed using a modified Rapid Assessment Method 1 (RAM-1) described by Biggs & Kilroy (2000). As per the RAM-1 methodology, run habitat was split into 10 transects (spaced evenly along the length of the sampling area), and 10 stones selected randomly along each transect were assessed for periphyton coverage (*i.e.* 100 stones in total). We then assessed the periphyton coverage on the stones using the periphyton categories from the Rapid Assessment Method 2 (RAM-2) method (see Table 1). This allowed us to assess compliance with periphyton guidelines for the protection of aesthetic, recreational and fishing values (Biggs 2000), and calculate a periphyton enrichment score for the site following the methods of Biggs & Kilroy (2000).

The periphyton scoring ranges from 1 (highly enriched) to 10 (unenriched) and was initially designed for evaluating the degree of enrichment and water quality at a site. However, because the periphyton score is based on both the coverage of algae over a rock and the thickness of that cover, it can also be used as a proxy for algal biomass (C. Kilroy, NIWA, pers. comm.).

Table 1. Periphyton categories used in RAM-2 periphyton assessments, with enrichment indicator scores and taxa that could be expected to dominate the benthic periphyton biomass (*diatom epiphytes give the green filaments a brown colouring) (Biggs & Kilroy 2000). High periphyton enrichment indicator scores indicate species typically found in clean water.

Periphyton category (on exposed surfaces)		**Periphyton enrichment indicator score**	**Typical taxa**
Thin mat/film: (under 0.5 mm thick)	Green	7	*Cymbella*, *Achnanthidium*, *Cocconeis*, *Ulothrix*, *Stigeoclonium* (basal cells), young *Spirogyra*
	Light brown	10	Assorted diatoms and cyanobacteria (*Cocconeis*, *Fragilaria*, *Synedra*, *Cymbella*, *Lyngbya*, *Amphithrix*)
	Black/dark brown	10	Assorted cyanobacteria (*Schizothrix*, *Calothrix*, *Lyngbya*)
Medium mat: (0.5–3 mm thick)	Green	5	*Stigeoclonium*, *Bulbochaete*, *Chaetophora*, *Oedogonium*, *Spirogyra*, *Ulothrix*
	Light brown (± dark green/black bobbles)	7	*Gomphonema*, *Gomphoneis*, *Synedra*, *Cymbella*, , *Fragilaria*, *Navicula*, *Nostoc*
	Black/dark brown	9	*Tolypothrix*, *Schizothrix*, *Phormidium*, *Lyngbya*, *Rivularia*
Thick mat: (over 3 mm thick)	Green/light brown	4	*Navicula*, *Gomphoneis*, *Synedra*, *Rhoicosphenia*, *Ulothrix*, *Oedogonium*, *Microspora*, *Spirogyra*, *Vaucheria*
	Black/dark brown	7	*Phormidium*, *Schizothrix*, *Audouinella*, *Batrachospermum*, *Nostoc*
Filaments, short: (under 2 cm long)	Green	5	*Ulothrix*, *Oedogonium*, *Microspora*, *Spirogyra*, *Cladophora*
	Brown/reddish	5	*Cladophora**, *Oedogonium**, *Rhoicosphenia*, *Navicula*, *Batrachospermum*, *Diatoma*
Filaments, long: (over 2 cm long)	Green	1	*Ulothrix*, *Oedogonium*, *Microspora*, *Zygnema*, *Spirogyra*, *Cladophora*, *Rhizoclonium*
	Brown/reddish	4	*Melosira*, *Cladophora**, *Rhizoclonium**

3.1.3. Macroinvertebrates

Six replicate macroinvertebrate samples were collected using a Surber sampler (0.1 m^2 area, 0.5 mm mesh), following Protocol C3 of Stark *et al.* (2001). Samples were collected randomly in riffle and cascade habitat and were preserved with 70% ethanol in the field.

In the laboratory, all animals in the samples were identified to the lowest practical taxonomic level and counted following Protocol P3 (Full count: Stark *et al.* 2001). A binocular microscope (35x–160x magnification) was used to aid identification. The data were analysed for taxonomic richness, macroinvertebrate densities, and the following biotic indices: Macroinvertebrate Community Index (MCI), Quantitative

Macroinvertebrate Community Index (QMCI) and percentage Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddis flies) (EPT).

3.1.4. Electric-fishing

Electric-fishing was undertaken at both sites using a 350 W battery-powered backpack machine (Smith-Root, LR-24 Electrofisher), with a single pass over each site. Fish were caught after being stunned and swept downstream into a hand-held stop net. They were then removed from the net, identified, counted, measured and released.

3.2. Maitai Reservoir

3.2.1. Water quality and plankton

Sampling of physico-chemical variables and plankton was undertaken at two mid-lake sites selected to be representative of the open water environment. *In situ* lake measurements included: specific conductivity, Secchi depth, temperature, and light profiles. Specific conductivity, temperature, pH, dissolved oxygen, and oxidation reduction potential were analysed at approximately 0.2 m intervals between the reservoir surface and 25 m using a YSI EXO multiprobe datasonde. Water clarity was quantified both using a secchi disk, and by conducting underwater light profiles using a LICOR underwater LI-192SA PAR sensor (2π) so that PAR was measured from at least five depths.

Further water chemistry analyses of the surface waters were conducted to characterise physico-chemical conditions at the time of biological monitoring, and included analysis of turbidity, nutrients, chlorophyll-*a*, dissolved organic carbon (DOC), pH, metals (Mn and Fe), and major anions and cations. Water samples (from two sites) were collected from the top 10 m (integrated) of the mixed layer using a 20 mm diameter integrated tube sampler with a closure. Samples were collected into a clean 8 L bucket, from which subsamples for various water analytes were transferred, and stored in the dark on ice before shipping overnight to Hills Laboratory (Christchurch) for analytical processing.

Phytoplankton samples were immediately preserved in Lugol's solution. Sub-samples of 50 ml were settled in Utermohl chambers, with at least 300 cells per sample identified at 400x magnification. For colonial taxa, the estimated colony size was based on cell counts in up to 20 colonies. Identifications were made to the lowest practical taxonomic unit.

Zooplankton was quantitatively sampled at two sites by vertical tows at a depth of between 0 and 10 m using a 900 mm diameter plankton sampler with 120 μm netting.

Samples were washed into 1 l bottles and preserved in 2% formalin. Metazooplankton and rotifers were identified by staff at Otago University (Marc Schallenberg and Carolyn Burns) and enumerated using taxonomic guides by Chapman & Lewis (1976), Stemberger (1979) and Streble & Krauter (1988).

3.2.2. *Submerged macrophytes*

Submerged macrophytes were surveyed at each of three sites from the lake surface using either an underwater viewer (wadeable depths) or a ponar grab to collect macrophytes (unviewable depths). Macrophyte cover and species composition were quantified at 5 m intervals along 50 m transects extending from the lake shore at each site. Species identifications were made according to Johnson and Brooke (1989).

3.2.3. *Benthic macroinvertebrates*

Grab samples were collected from three shoreline sites (as per macrophytes) in triplicate with a Ponar dredge (0.0225 m^2) at a 10-m distance from shore within the littoral zone of the lake. Material from the triplicate benthic grabs at each site was pooled, sieved through a 400 µm mesh net, and preserved in 70% isopropanol for taxonomic analysis.

Macroinvertebrates were identified by EOS Ecology (Christchurch) to the lowest taxonomic level practical — in some cases this was species, but some groups were identified only to phylum (nematodes), class (oligochaetes and mites), or family (dipterans). Subsamples were separated using a splitter, and either > 25% of the entire sample was identified or 100 individuals of the most abundant taxa were counted. Invertebrates were identified using keys by Chapman *et al.* (2011), Winterbourn (1973) and Winterbourn *et al.* (2006).

3.2.4. *Fish*

Surveys were conducted at the same three shoreline sites as benthic locations using two trapping methods. At each site, two lines of 10 baited gee-minnow traps (mesh size ~ 5 mm) were deployed overnight, extending perpendicular from the shoreline toward the centre of the lake over a distance of 50 m. Three 4 m fyke nets were also deployed at each site. Fish were identified and counted, and fork-length measurements were recorded.

3.3. Data analyses

3.3.1. Stream biotic indices

The MCI and QMCI values were calculated according to the methods of Stark (1985, 1993). These biotic indices, which were developed for assessing enrichment in stony streams and rivers, rely on prior allocation of scores (between 1 and 10) to macroinvertebrate taxa (usually genera) based upon their tolerance to pollution or fine sediment. Taxa that are characteristic of unpolluted conditions and/or coarse stony substrates score more highly than taxa that may be found predominantly in polluted conditions or amongst fine organic sediments.

For each sample, the scores were summed (for each taxon present) and then divided by the number of scoring taxa and multiplied by 20 (a scaling factor) to give the MCI value. In theory, MCI values can range between 200 (when all taxa score 10 points each) and 0 (when no taxa are present). However, it is rare to find MCI values greater than 150 and only extremely polluted, sandy/muddy sites or extremely disturbed substrate sites score under 50.

QMCI values range from 0 to 10. Unlike the MCI, which is based on only the presence or absence of taxa, the QMCI includes percentage community composition to weight the overall index value towards the scores of the dominant taxa.

The interpretation of index values, when applied to stony streams throughout New Zealand, is given in Table 1.

Table 2. Interpretation of Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) values from stony riffle streams (adapted from Stark & Maxted 2007).

	MCI	**QMCI**
Excellent: Clean water	> 120	> 6
Good: Doubtful quality or possible mild pollution	100–120	5–6
Fair: Probable moderate pollution	80–100	4–5
Poor: Probable severe pollution	< 80	< 4

Percentage EPT (% EPT) is the percentage of the sample that comprises the following taxonomic orders: Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies). EPT taxa tend to be more ‘pollution sensitive’ than other macroinvertebrates (such as dipteran larvae and oligochaetes) so a higher % EPT generally is indicative of a community less impacted by pollution.

3.3.2. Diversity indices

The Shannon-Wiener diversity index (H´) was calculated for benthic lake invertebrates and metazooplankton. Data were composited from the three sites in each lake prior to diversity index calculations.

H’ was computed as

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad \text{Equation 1.}$$

where *S* is the number of species and *p* is the relative abundance of species *i* in the community (Shannon 1948).

3.3.3. Lake comparison data for the Maitai Reservoir

An extensive, multi-lake dataset collected between 2004-2008 (Drake *et al.* 2009; 2010) was used to compare water quality and ecological community data collected from the Maitai Reservoir. This was done to provide a better context for ecological data collected from the Maitai Reservoir, as in most cases there is no set of standards for water quality and biological data for New Zealand lakes. Methods used for collection of the data in the current study were identical to those used in the historical study explicitly for data comparison between the Maitai Reservoir and previously sampled lakes. The data were collected as part of a Cross Departmental Research Pool (CDRP) project and we reanalyse the data, acknowledging that it was collected under a joint Department of Conservation/NIWA/University of Otago research programme. The multi-lake dataset includes data from 46 small coastal lakes located from Northland to Campbell Island. For data comparison purposes we used only data from the South Island (refer to the Drake *et al*. (2009, 2010) for methodological details). Data for the Nelson region only included lakes in the Tasman district, the Kaihoka Lakes and Lake Otuhie previously reported in Schallenberg (2010).

Comparisons between the Maitai Reservoir and data from other South Island lakes were conducted for water quality parameters, macroinvertebrate diversity, and fish catch per unit effort (CPUE) and richness. Results of the between-lake comparison are displayed in tables as the percentile rank of the Maitai Reservoir datum in comparison to 18 other lakes in the dataset.

3.3.4. Multi-dimensional scaling ordinations

A comparison of macroinvertebrate community taxonomic data between the Maitai Reservoir and 18 other small lowland lakes (Drake *et al.* 2009) was conducted using multi-dimensional scaling (MDS) ordination techniques. For this analysis macroinvertebrate taxonomic density data (abundance per m^2 of lake bottom) was transformed using a logarithmic transformation (log x+1) to normalise the data. Bray Curtis similarities matrices of the community data were calculated for the 19 lake data set, and subsequently plotted in an MDS ordination that graphically represents the similarity of lake invertebrate communities between lakes in ordination space. Stress values for the ordination analyses were calculated and determined to be within acceptable levels (< 0.1).

4. RESULTS AND DISCUSSION

Due to the wide scope of materials contained in this report, it was felt that discussion of results was best conducted in the section they are presented, and as such results and discussion are combined into a single section. This was done for ease of interpretation by the reader. A conclusions and recommendations section is provided at the end to summarise key findings and recommendations. Sections of the report are separated into subsections on the Maitai North Branch and Maitai Reservoir, respectively.

4.1. Maitai North Branch

4.1.1. Water quality

In the context of aquatic ecosystem health, the spot measurements of dissolved oxygen (% saturation and mg/L), were well within acceptable limits for aquatic life (Table 3). The only parameters that exceeded ANZECC (2000) guidelines were pH and Nitrate-N, although this is not an issue given that the guidelines presented in Table 3 are the strictest that can be used for protection of freshwater ecosystems (*i.e.* protection of 99% of species). High pH is likely linked with drainage from limestone rich rock formations present in the upstream drainage. The Dun Mountain mineral belt is rich in the Wooded Limestone formation, and the Stephen's argillite area also has outcroppings of limestone (DSIR 1964). Thus limestone weathering may contribute to the observed elevated concentrations of calcium (15.9 g/m^3) and pH readings through calcium carbonate enrichment.

Table 3. Water chemistry of the North Branch and in the South Branch of the Maitai River at a site upstream (control) and downstream (site B) of the Maitai Reservoir backfeed. ANZECC (2000) water quality guidelines are also provided for New Zealand upland waters. '–' indicates data either not recorded or not available.

Water chemistry parameters	**Units**	**Maitai North Branch**[1]	**Maitai South Branch (control site)**[2]	**Maitai South Branch (site B)**[3]	**ANZECC (2000) trigger values**
Spot field measurements					
Temperature	°C	11.17	5.2 -1 3.6	7 - 16.5	-
Conductivity	$\mu S/cm^{-1}$	147	13.2 - 27.8	7.5 - 26	-
Dissolved oxygen	%	102.3	-	-	99-103[a]
Dissolved oxygen	mg/L	11.24	10.3 -1 5.2	9.3 – 14.1	-
pH		8.05	7.6 - 8.5	5.7 – 8.8	3.0-8.0[a]
Water sample					
Turbidity	NTU	1.52	-	-	4.1[b]
Total hardness	g/m^3 as $CaCO_3$	59	-	-	-
Total suspended solids	g/m^3	< 3.0	-	-	-
Dissolved calcium	g/m^3	14.3	-	-	-
Total calcium	g/m^3	15.9	-	-	-
Total iron	g/m^3	0.28	-	-	Insufficient data[c]
Dissolved magnesium	g/m^3	5.7	-	-	-
Total magnesium	g/m^3	6.6	-	-	-
Total manganese	g/m^3	0.004	-	-	1.200[c]
Total potassium	g/m^3	0.240	-	-	-
Total sodium	g/m^3	3.1	-	-	-
Chloride	g/m^3	4.0	-	-	-
Total Ammoniacal-N	g/m^3	< 0.005	-	-	0.320[c]
Nitrite-N	g/m^3	< 0.002	-	-	0.170[a]
Nitrate-N	g/m^3	0.021	-	-	0.017[c]
Total nitrogen	g/m^3	0.126	-	-	0.295[a]
Dissolved organic nitrogen (DON)	g/m^3	0.110	-	-	-
Dissolved reactive phosphorus	g/m^3	< 0.002	-	-	0.009[a]
Total phosphorus	g/m^3	< 0.004	-	-	0.026[a]
Sulphate	g/m^3	1.2	-	-	-
Dissolved organic carbon (DOC)	g/m^3	5.4	-	-	-

[1]Measurements taken on 18 April 2013 at 09:52
[2]Measurements taken on 10 sampling occasions during consent biomonitoring fieldwork (2010-2013)
[3]Measurements taken on up to 54 sampling occasions during consent biomonitoring fieldwork (1989-2013)
[a]Trigger levels for slightly disturbed systems – upland river (Table 3.3.10 of the ANZECC (2000) water quality guidelines)
[b] Trigger levels for slightly disturbed systems – upland river (Table 3.3.11 of the ANZECC (2000) water quality guidelines)
[c]Toxicants trigger value for 99% protection of freshwater ecosystem (Table 3.4.1 of the ANZECC (2000) water quality guidelines).

There was no indication that heavy metals such as manganese, which can be high in the reservoir backfeed (up to 1.2 g/m^3), was present in levels in excess of normal background levels (Table 3). Similarly iron concentrations (total iron 0.24 g/m^3) were not high, although greater than a median that has been reported for New Zealand waters (0.12 mg/m^3) (Daughney 2003). Nickel and chromium are known to be associated with the Dun Mountain mineral belt (Holmes 2010, Sneddon & Elvines 2012), however these were not measured as the focus was mainly in regards to high manganese outputs from the Reservoir backfeed.

4.1.2. Periphyton

Periphyton coverage in the North Branch of the Maitai River was 83.6% and comprised thin films and medium mats dominated by light brown algae, which is usually associated with periphyton communities consisting of diatoms and cyanobacteria (Biggs and Kilroy 2000). No didymo (*Didymosphenia geminata*) or cyanobacterial mats (*e.g. Phormidium)* were sighted during the course of the survey.

A periphyton score of 9.2 (out of a 10) was recorded in the North Branch of the Maitai River on the 18 April 2013. This high score is indicative of low periphyton biomass consistent with low nutrient enrichment (*i.e.* good water quality) and possibly also due to an intermediate sized flood disturbance approximately 16 days prior to sampling on 2, April 2013.

The periphyton score in the North Branch was more comparable with the control site (upstream of the backfeed) than site B in the South Branch of the Maitai River (Table 4). However, the coverage of periphyton in the North Branch was closer to Site B (downstream of the backfeed).

Table 4. Periphyton coverage and enrichment score in the North Branch of the Maitai River (18 April 2013) and the South Branch of the Maitai River at a site upstream (control) and downstream (site B) of the Maitai Reservoir backfeed (2010–2013).

	Periphyton % coverage of substrate	**Periphyton Enrichment score (1-10)**
Maitai North Branch		
18 Apr 2013	83.6	9.20
Maitai South Branch – control		
1 Jun 2010	26.1	7.68
16 Nov 2010	11.0	8.73
25 May 2011	56.9	8.57
16 Mar 2012	80.1	6.95
30 Jun 2012	95.4	6.59
28 Mar 2013	67.4	8.84
Maitai South Branch – site B		
1 Jun 2010	60.4	7.61
16 Nov 2010	47.4	5.63
25 May 2011	62.6	8.31
16 Mar 2012	89.6	6.20
30 Jun 2012	84.4	6.58
28 Mar 2013	99.4	7.96

4.1.3. Macroinvertebrates

Forty four taxa were collected from the North Branch of the Maitai River on 18 April 2013 (Appendix 2). The common mayfly *Deleatidium* spp. was the most abundant taxa, followed by the caddis fly *Aoteapsyche* spp. and the dipteran larvae *Tanytarsus* spp. (Appendix 2). Thirty five taxa in the North Branch were common to both of the Maitai South Branch biomonitoring sites. The exceptions were the fly taxa Anthomyiidae and Chironomidae (North Branch only); the fly taxa Eriopterini, *Polypedilum* sp., and the caddis fly *Psilochorema macroharpax* (North Branch and control site only); the beetle larva Ptilodactylidae, caddis flies *Hydrobiosis parumbripennis* and *Paroxyethira* sp. and roundworm Nematoda (North Branch and Site B only). In all cases the taxa listed were rarely found and in low numbers, suggesting overall that the composition of the taxonomic communities amongst the three sites were similar.

The MCI and QMCI scores suggested that the water quality in the North Branch of the Maitai River was good–excellent (Table 5). The percentage of EPT taxa (by taxa and abundance) was moderate / high (Table 5).

In regards to whether mineral rich drainage from the Dun Mountain area could be affecting the North Branch, Clapcott *et al.* (2012) examined the sensitivity of stream macroinvertebrate community metrics to mineral rich and mined areas on the West Coast of the South Island. They observed that macroinvertebrate richness, and to some degree MCI, were sensitive to mining. These streams tended to coincide with high mineral concentrations, and thus could be used to compare with the Maitai North Branch to better understand if it may be affected by drainage from the mineral rich geology in the catchment. MCI scores in mining affected areas were on average around 80, and invertebrate richness around 10 (Clapcott *et al.* 2012). By contrast, in the Maitai North Branch, scores for MCI and invertebrate richness were on average 113 and 22, respectively. Thus invertebrate communities in the Maitai North Branch are indicating significantly better water quality than those sites affected by mining and mineral drainage in this previous investigation.

Table 5. Summary of five replicate macroinvertebrate samples collected from the North Branch of the Maitai River on 18 April 2013

	Range	**Mean (± S.E.)**
Taxa richness	15-30	22.2 (± 2.0)
Densities (animals/m^2)	630-5520	2003.3 (± 723.9)
$\%EPT_{Taxa}$	50-62	57.8 (± 1.8)
$\%EPT_{Abundance}$	55-84	74.4 (± 4.3)
MCI	111-116	113.1 (± 0.8)
QMCI	5.19-7.08	6.41 (± 0.29)

Community metrics for the North Branch such as species richness, $EPT_{Abundance}$ and QMCI, are indicative of an invertebrate community of a pristine nature, similar to that of the South Branch control site (Figure 6). However, the MCI scores in the North Branch were more similar to the South Branch B site (Figure 6). Potential differences between the North Branch and the South Branch could include high pH, which exceeded the ANZECC (2000) trigger value for moderately disturbed upland rivers (Table 3). Further work and greater sampling effort would be required to confirm any potential effects.

Periphyton coverage (and indirectly nitrate concentration) in the North Branch indicated some degree of enrichment compared to the South Branch control site and these could possibly be why there are differences between the biotic indices at the North Branch compared to the two South Branch sites. The EPT_{Taxa} and MCI score rely on the presence or absence of taxa in a sample. In the North Branch the presence of algal associated taxa (that have lower MCI scores) would be similar to Site B (*e.g.* dipteran larvae such as Orthocladiinae and *Maoridiamesa*, and the net-spinning caddis fly genera *Aoteapsyche*). The $EPT_{Abundance}$ and QMCI incorporate not only the presence of a taxon, but its relative abundance in a sample. So, although there are more algal-associated taxa in the North Branch than the control site, the relative abundance of these taxa is low compared to the relative abundances of other higher scoring taxa in the samples. Hence the North Branch EPT_{Taxa} and MCI score are similar to Site B, while the $EPT_{Abundance}$ and QMCI score are similar to the control site (Figure 6).

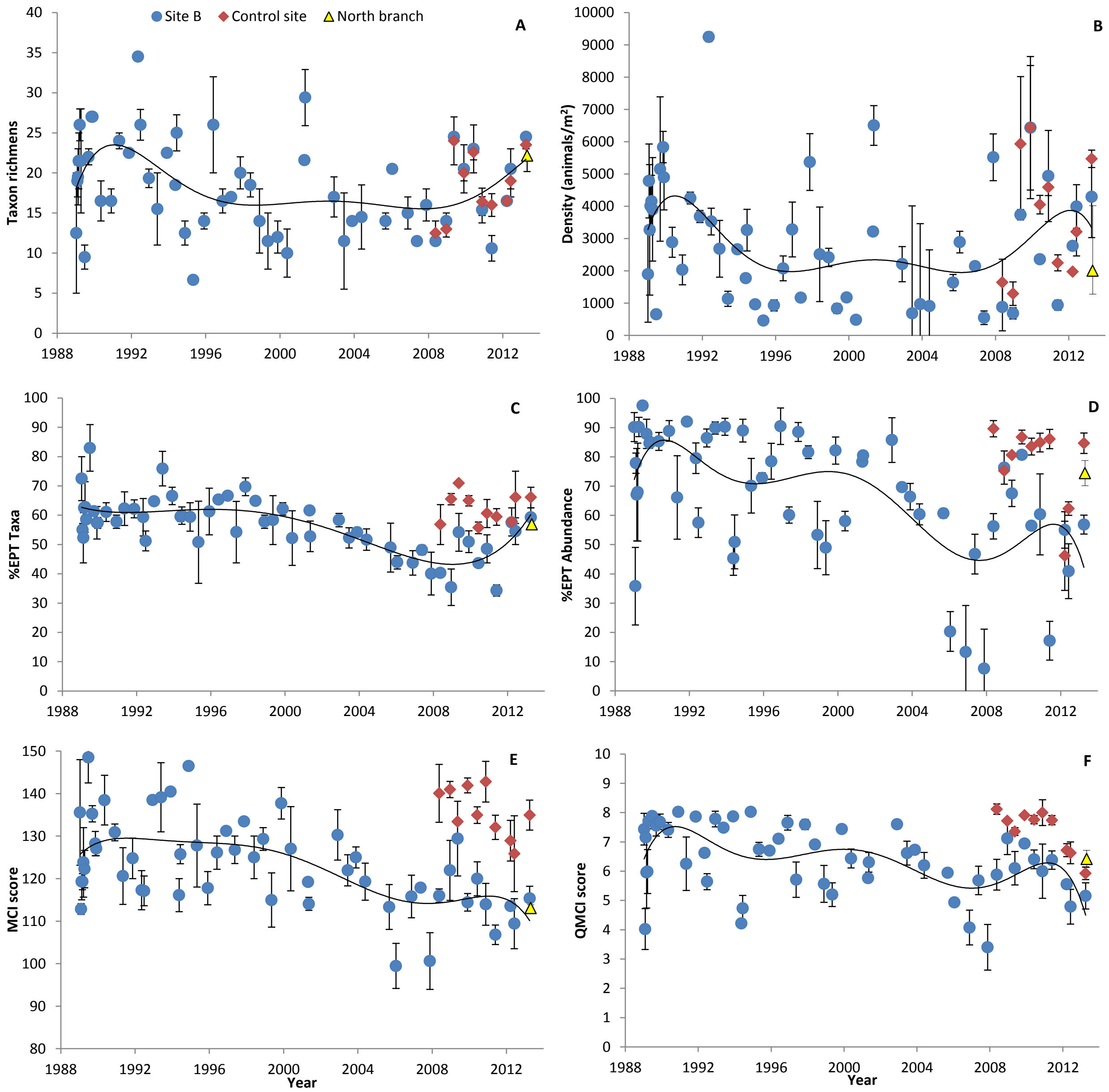

Figure 6. A) Taxa richness, B) mean macroinvertebrate densities, C) %EPT taxa, D) %EPT abundance, E) Macroinvertebrate Community Index (MCI), and F) Quantitative Macroinvertebrate Community Index (QMCI) from Site B in the Maitai River (blue circles) for 54 occasions between 1989 and 2013, from the control site (upstream of intake - red diamonds) on ten occasions between 2008 and 2013, and from the Maitai River North Branch site (yellow triangles) on 18 April 2013. Fitted lines (black) are polynomial curves (order 6) fitted to Site B data only. Error bars represent standard errors.

4.1.4. Fish

Three species of fish were found in the North Branch of the Maitai River: brown trout (*Salmo trutta*), upland bully (*Gobiomorphus beviceps*), and koaro (*Galaxias brevipinnis*), (Table 6). Sizes of the fish are presented in Appendix 3.

Table 6. Species and abundance of fish caught by electric-fishing approximately 70 m^2 in the North Branch of the Maitai River, 18 April 2013. Densities (fish/m^2) are presented in parentheses. The habitat the fish were collected in is also presented.

	Brown trout	**Upland bully**	**Koaro**
Abundance (Density No.m^2)	4 (0.06)	37 (0.53)	1 (0.01)
Habitat type	Riffle/Cascade	Riffle/Pool/Run	Cascade

Brown trout and upland bullies have been found in the South Branch of the Maitai river, but not koaro (Table 7). Longfin eels were also a common feature of the South Branch biomonitoring site, but were not collected in the North Branch in the 18 April 2013 (Table 7).

Table 7. Species of fish caught by electric-fishing in the North and South Branches of the Maitai River.

	North Branch	**South Branch**	
		Control	**Site B**
Brown trout (*Salmo trutta*)	✓	✓	✓
Longfin eel *(Anguilla dieffenbachii*)	×	✓	✓
Upland bully (*Gobiomorphus breviceps*)	✓	×	✓
Redfin bully (*Gobiomorphus huttoni*)	×	×	✓[1]
Koaro (*Galaxias brevipinnis*)	✓	×	×

[1]Found on only two of 54 sampling occasions.

Koaro is commonly found in swift flowing, tumbling, rocky (boulder/cobble) mountainous streams in native forest (McDowall 1990). Habitat in the North Branch stream was very characteristic of these habitats, but less characteristic of the South Branch biomonitoring sites. Koaro is the second most important species in the whitebait catch, and has a conservation status of being ‘in decline (Allibone *et al*. 2010). Thus there are recreational and biodiversity values associated with these species. Koaro are diadromous (*i.e.* have a sea-going phase in their life cycle), although lake populations do exist in which the fish do not go to sea and juveniles recruit to lakes (McDowall 1990). Prior to the construction of the Maitai Dam, koaro were present in the North Branch. It is possible they have now formed a lake dwelling population, although juveniles were not detected during this survey (discussed in

Section 4.2.5). Thus it is likely to be important to maintain migratory connection for sea-derived koaro to access the upper North Branch. While the dam presents a considerable barrier to migration, koaro are known to be exceptionally good climbers, and are often found above steep falls. Further work around facilitating upstream fish passage needs to be conducted to better understand ways of enabling this.

Although longfin eels were not found in the electric fishing survey of the North Branch, it is probable they would occur in this stream. Large adult longfin eels were found in the Maitai Reservoir upstream of the dam. As with koaro, this species is an effective climber, and thus future works around fish passage over the dam could be done in combination for the two species.

4.2. Maitai Reservoir

4.2.1. Reservoir level fluctuations

Water levels in the Maitai Reservoir are maintained between the spillway height of 173.75 m and potentially as low as 167.75 m, with a range of water use restriction measures within this range to prevent significant draw-down of reservoir water levels. Measures around water use restrictions are listed in points A-F below and displayed on the hydrograph of Figure 7.

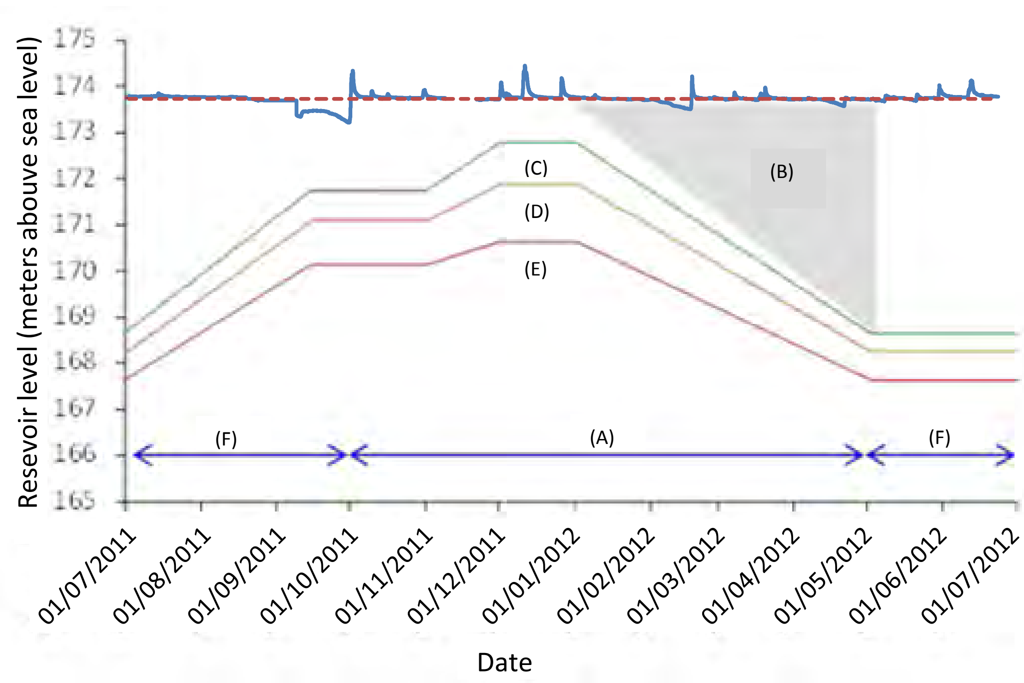

Figure 7. Maitai Reservoir water level for 1 July 2011 June 2012 super-imposed upon a graph of rules for operation of the water supply system. See the text below for a description of the lines and letters on the graph.

Letters (A) to (F) on the graph represent:

(A) The period when the summer minimum flow conditions apply.

(B) During the period 1 January–1 May, when the water level is in this range (grey shaded triangle area), water will be released from the reservoir into the Maitai River (via the 'backfeed') as required by the "surplus water" requirement of Consent No. RM025151/2 (previously Water Right No. 820540).

(C) When the water level is in this range, sprinkler restrictions will be put in place. As a minimum restriction, odd-numbered properties would be able to water on odd-numbered days and even-numbered properties on even-numbered days. Advertising will be run to remind the public of these restrictions. Flushing of mains will be reduced.

(D) When the water level is in this range, a sprinkler ban will be put in place. The only exception will be high-value areas such as bowling greens, golf course greens, cricket pitches and high profile public gardens. Advertising will be run to remind the public of this ban.

(E) When the water level is in this range, housing restrictions will be introduced. Depending on the severity of the situation these measures could include:

- A complete ban on residential housing.
- Restrictions on industrial and commercial use of water (*e.g.* close down automatic car washes, stop washing cars in sale yards).
- Approaches to major industries to explain the severity of the situation and request co-operation through minimal water use.
- Increased advertising.
- Establishment of a 'Hot Line' for residents to report non-compliance with water restrictions.
- Water mains only flushed in response to water quality complaints.

(F) The period when the winter minimum flow conditions apply. If during the period 1 May to 30 October the minimum flow is reduced in accordance with a variation to Water Right 820540, the response shall be the same as for item (E).

Although water-use restriction measures are in place to limit the extent of reservoir level fluctuations, in practice these restrictions have rarely been imposed in recent years (See Appendix 4). Between 2004 and 2013, reservoir levels remained reasonably close to the spillway height with a mean annual minimum reservoir level of 172.35, or 1.4 m below spillway height. Only in very dry years were reservoir levels lowered significantly more than 1.5 m, which typically only occurred during the late summer season period. The lowest reservoir level over the 10 year period was approximately 3.5 m below the spillway height in April 2006. At the time the present biological surveys were conducted (April 2013), the reservoir was drawn-down approximately 1.25 m to the lowest level it had been since April 2010 (Figure 8).

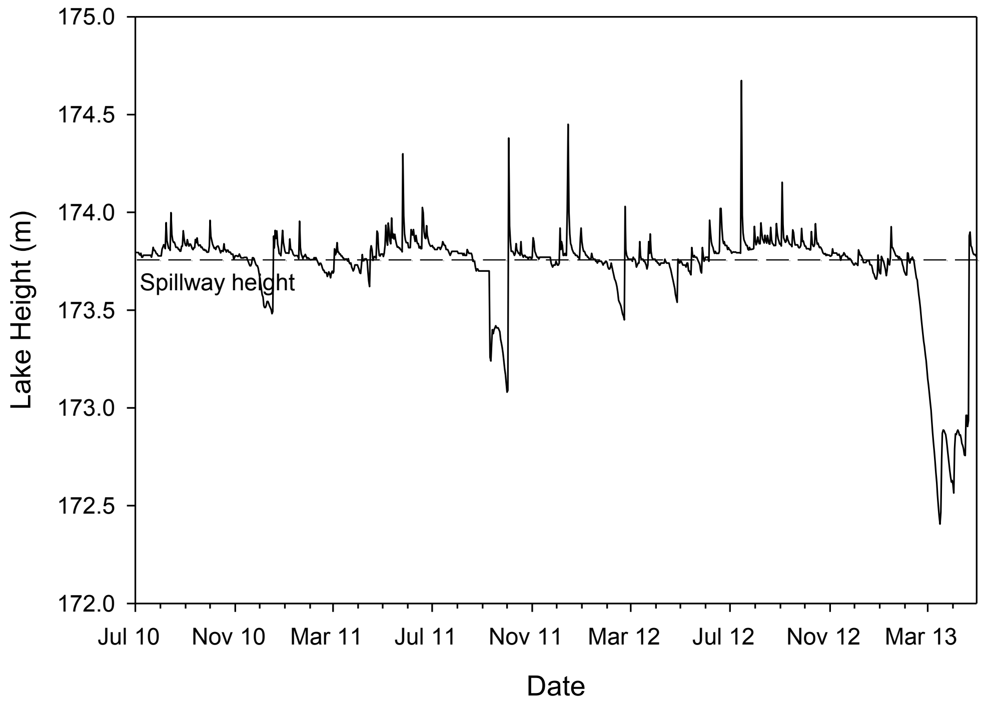

Figure 8. Water level fluctuations in the Matai Reservoir between July 2010 and April 2013.

The extent of water level fluctuations are not considered large by comparison to other reservoirs in New Zealand. Extreme examples where storage reservoirs are used for hydroelectric generation have much greater operating ranges (*e.g.* 22.3 m for Lake Hawea, and 13.8 m for Lake Pukaki, James *et al.* 2002). Moreover, the frequency of draw-downs in the Maitai Reservoir was typically only once per annum in comparison to frequent (sometimes daily) fluctuations in other hydroelectric and irrigation storage reservoirs. This is likely to reflect patterns of water level fluctuations observed in many New Zealand lakes.

The extent to which reservoir level fluctuations are likely to affect the ecology and biological communities in the system can depend on several factors (James *et al.* 2002). This would include the extent of wave mixing around the margins of the lake and its potential to enhance shoreline erosion, particularly around high water levels. However the small overall area (32 ha) and fetch (1 km) of the reservoir as well as the protected high-sided nature of its valley would act to minimise any wind-induced waves. Thus it is unlikely that shoreline erosion would be an issue, and no obvious signs of shoreline erosion were evident.

Water clarity is an important factor in determining the extent (or depth) to which aquatic plants and their associated animal communities (macroinvertebrates and fish) can colonise the lake along its shoreline edges, termed the littoral zone (Kelly & McDowall 2004). This is an important zone for productivity and diversity of lake biota, and has strong linkages to fisheries in most lakes (James *et al.* 1998; Kelly and McDowall 2004). Lakes that have either low water clarity, or very high water level fluctuations (or a combination of both) tend to be poorly suited for colonisation by most biota (particularly plants), because the depths that remain permanently wetted are too deep for light to penetrate during some portions of the year (James *et al.* 2002). This is particularly evident for lakes such as Lake Pukaki which has a euphotic depth of less than 1 m, but a dam operating range of over 13 m. Thus most of its shoreline is comprised of substrates not colonised by plants and has limited invertebrate populations (Weatherhead & James 2001).

In the case of the Maitai Reservoir, although data measuring water clarity is limited as discussed in the next section, the data would suggest that light penetration is sufficient to allow aquatic plants to grow to depths of up to 6.1 m. Thus, the annual Maitai Reservoir level fluctuations of on average 1.4 m would still enable the more permanently wetted depths between 1.4 and 6.1 m to be conducive for colonisation by littoral plants and animals. James *et al.* (2002) in an analysis of water level fluctuations nationally, suggested that lakes with water level fluctuations of less than 3 m tend to have diverse and healthy aquatic plant communities. Thus water level fluctuations in the Maitai Reservoir appear to provide an environment conducive to colonisation by a healthy littoral shoreline community.

4.2.2. *Water quality*

Water quality in the Maitai Reservoir has been discussed in several reports that have evaluated consent condition monitoring data collected between 2004 and 2012 (*e.g.* Olsen & Stark 2007, Holmes 2009, Holmes 2012, Holmes & Kelly 2012). This was not the focus of the present investigation, however it does provide an important context relating to habitat conditions for aquatic biota in the Maitai Reservoir, and thus it is discussed briefly here with some comparisons made to other small lakes in the region and nationally.

Since its construction, there has been a consistent pattern of mid- to late-summer thermal stratification in the reservoir. Stratification is the process by which lakes and reservoirs develop separate layers: the epilimnion (surface layer), thermocline maximum (temperature/density gradient) and hypolimnion (bottom layer). Anoxic conditions can occur in the hypolimnion once it is isolated from mixing with surface waters and re-aeration. Typically, from January until turn-over (break-up of stratification) in April-May, water in the hypolimnion below the thermocline can be reduced in dissolved oxygen, and can become near-anoxic towards the end of the stratification cycle in March through May. The release of lake sediment-bound toxicants such as manganese and iron can result in elevated concentrations of these trace metals in hypolimnetic waters (Holmes 2010). Other toxicants associated with anaerobic metabolism in anoxic bottom waters, such as hydrogen sulphide gas, may also form in in hypolimnetic waters, although it has not been quantified and is part of further investigation in 2013–14.

During biological survey work conducted as part of this study, the reservoir was thermally stratified with a strong thermocline evident at both sites between a depth of approximately 9 and 11 m (Figure 9). Dissolved oxygen saturation declined with depth, particularly below 5 m, and was nearly anoxic below the depth of the thermocline. This would render most of the deeper portions of the reservoir unsuitable for fish and most invertebrate species. Generally 50% saturation is considered a cut-off value for most fish species (Hay *et al.* 2006), and thus depths below 7 m at the mid-lake site and 11 m at the tower intake site would be considered unsuitable for fish. This effect was evident in fish trap catches, with no fish being caught in traps > 5 m in depth at any sites. This is discussed in greater detail in the fisheries section. The pattern of significant oxygen depletion in lakes with relatively low surface water production (*i.e.* low chlorophyll) is uncommon (Hamill & Verburg 2010). However, lakes that contain significant amounts of organic materials in their basins can experience DO declines from the breakdown of these organics into dissolved compounds (Wetzel 1983). Lakes of this nature are described as dystrophic lakes, and are usually characterised by low nutrient status and highly tannin stained waters. The basin of the reservoir was cleared of forest during construction of the Maitai Dam, so it would be expected that much of the organic material would have been removed from the reservoir basin prior to flooding. However, the consistent trend for summer deoxygenation would support that breakdown of organic material is important, and humic staining is relatively high in the reservoir by comparison to inflow tributaries. Observations of large amounts of detritus and wood material along marginal areas during low reservoir levels (*e.g.*, 1992) suggest input of materials by tributaries (during floods) since the time of its initial construction (Alex Miller, Personal communication, 26 July 2013). Further work around understanding the main causes of hypolimnetic deoxygenation is recommended, which could better inform management options for controlling anoxia. This would include sediment redox surveys of the reservoir and quantifying organic materials in the lake bottom.

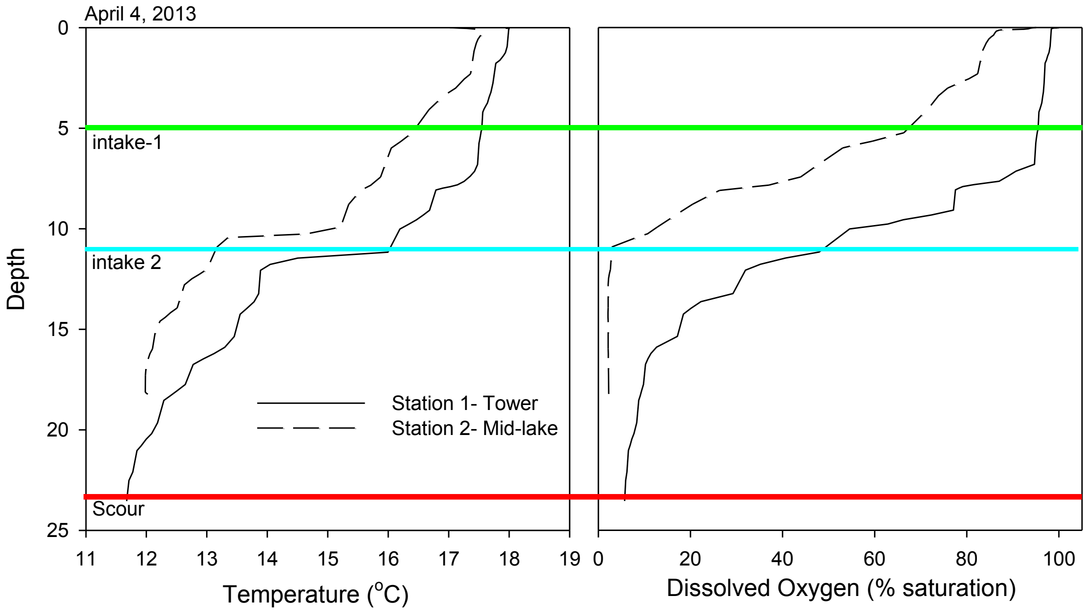

Figure 9. Depth profiles of temperature and dissolved oxygen (DO) in the Maitai Reservoir at two stations on 4 April 2013. Lines on the graph show the water intake levels on the intake tower backfeed to the Maitai River South Branch.

A number of other water quality parameters were measured in the Maitai Reservoir including nutrient concentrations, chlorophyll-*a* concentration, light attenuation, secchi disk depth, pH, and various cation concentrations (Table 8). Note that this data is from a one-off sampling event, and so provides only an indication of the physico-chemical conditions in the reservoir to support biological monitoring results. Protocols for evaluating water quality generally recommend calculating averages from a minimum of six samples over a period of a year to provide a more robust assessment of water quality and account for seasonal variation (Hamill & Verburg 2010). However, this was not possible for the purpose of this investigation. Data from the one-off survey is compared against water quality data sets collected for three other small lowland lakes in the Tasman region as well as a 20-lake dataset for the South Island (Drake *et al.* 2009) to provide context for the water quality conditions in the Maitai Reservoir.

Water chemistry of the reservoir is clearly influenced by limestone geology of the Dun Mountain (Wooded Peak Limestone) and Stephen's argillite (limestone outcrops) rock formations in the catchment (DSIR 1964). In particular, both pH (8.1 in mixed surface layer) and calcium cation concentrations (18.5 g/m^3) were high (Table 8). Nutrient concentrations were low, characteristic of the highly undisturbed native forest catchment drainage upstream, predominantly in the North Branch. Concentrations of total nitrogen (0.193 g/m^3) and total phosphorus (< 0.004 g/m^3) were indicative of oligotrophic conditions, with an overall trophic level Index (TLI) score of 2.0 near the bottom of the oligotrophic range (Table 9). These were all in the lower 10th percentile range of the South Island 20-lake dataset. Somewhat unusual was that nitrate concentrations (mean 0.032 g/m^3) were a significant portion of the total nitrogen fraction, suggestive of excess soluble nitrogen in the water column. This could be related to very low phosphorus concentrations and thus highly phosphorus limited algal production and nutrient uptake in the Maitai Reservoir. This was supported by a high DIN:TP ratio of > 9, with ratios over 4 indicating strong phosphorus limitation (Schallenberg *et al.* 2011). Chlorophyll-*a* concentrations were at the oligotrophic-mesotrophic boundary, at 0.003 g/m^3, suggesting that phytoplankton production was low to moderate.

Water clarity of the reservoir was relatively high, with a Secchi depth of 4.2 m, and an estimated euphotic depth (using light profiling data) of 6.1 m. Clarity of the water column appeared to be predominantly controlled by coloured dissolved humic compounds, rather than turbidity or algal biomass, which were both low. A surrogate measure for humic staining is dissolved organic carbon (DOC), which was 4.2 mg/l and is considered to be a moderate concentration for New Zealand lakes. This concentration of DOC also suggests dystrophic lake processes.

Overall, surface water quality in the Maitai Reservoir in comparison with other small lakes in the region and on the South Island was high. This would be a key aim for the Nelson District Council in managing a waterbody for drinking-water quality purposes. Several of the lakes in the comparison set had catchments dominated by agricultural land use. Water quality in the Maitai Reservoir was comparable or better than other pristine lakes on the South Island, such as Lake Otuhie and the Kaihoka lakes. Nutrients, trophic status, and visual clarity; three of the key aspects in considering water quality were all indicative of high water quality and oligotrophic conditions.

Table 8. Water quality in the Maitai Reservoir in comparison to other small lakes in the Nelson/Tasman region from a dataset of twenty lakes (Drake *et al.* 2010). Measurements of water quality variables were averaged from the surface water (0 - 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 (20 lakes). Rankings below the 10^{th} percentile and above the 90^{th} percentile are highlighted in red. Rankings between the 10^{th} and 25^{th} percentiles and above the 75^{th} and 90^{th} percentiles are highlighted in blue.

			CDRP Data (Drake *et al.* 2010)			
Variable	**Unit**	**Maitai Reservoir**	**Kaihoka Lake 1**	**Kaihoka Lake 2**	**Lake Otuhie**	**Percentile rank 20 South Island lakes (%)**
Conductivity	µS/cm	151	107	142	30	63
pH		8.2	6.9	7.1	6.0	100
Turbidity	NTU	1.8	0.7 1.4	2.2	67	
Secchi depth	m	4.6	3.8	2.8	0.7	100
Cl-	g/m^3	3.4	33.4	34.0	12.1	0
Ca++	g/m^3	18.5	2.0	4.0	1.3	100
Mg+	g/m^3	3.8	2.5	2.6	0.8	56
DOC	g/m^3	4.2	3.2	5.2	13.8	29
Euphotic depth	m	6.1	8.9	5.7	1.3	88
Chl. *a*	g/m^3	0.003	0.0016	0.011	0.001	53
TN	g/m^3	0.193	0.151	0.325	0.235	6
TP	g/m^3	< 0.004	0.0066	0.019	0.007	6
NO3	g/m^3	0.032	0.0013	0.001	0.010	100
NH4	g/m^3	0.006	0.0157	0.015	0.020	0
DON	g/m^3	< 0.011	0.231	0.191	0.274	40
DRP	g/m^3	< 0.002	< 0.0001	0.0001	0.0007	12
DIN:TP		> 10	3.9	0.9	4.2	100
TLI		2.0	3.00	4.18	3.38	12

Table 9. Ranges of total nitrogen, total phosphorus, and chlorophyll-*a* concentrations for trophic level states of New Zealand lakes according to Burns *et al.* (2000).

Trophic state	**TLI**	**Chl-*a* (mg/m^3)**	**TN (mg/m^3)**	**TP (mg/m^3)**
Ultra -microtrophic	0–1	0.13–0.33	16–34	0.84–1.8
Microtrophic	1–2	0.33–0.82	34–73	1.8–4.1
Oligotrophic	2–3	0.82–2.0	73–157	4.1–9.0
Mesotrophic	3–4	2.0–5.0	157–337	9.0–20
Eutrophic	4–5	5.0–12	337–725	20–43
Supertrophic	5–6	12–31	725–1558	43–96
Hypertrophic	6+	> 31	> 1558	> 96

Surface waters in the Maitai Reservoir were of high pH in comparison to bottom waters (Figure 10). Alkaline lakes that are influenced by natural sources of calcium carbonate can affect the alkalinity and buffering capacity of lakes (Wetzel 1983).

Some alkaline lakes can have a tendency for diurnal swings in pH as phytoplankton take up carbon dioxide for photosynthesis, which tends to increase pH over mid-day periods when photosynthetic rates are greatest. Water chemistry sampling during this survey was conducted during mid-day periods between 12:00–14:00, so could have been influenced by this. Lower pH observed in the hypolimnion (between 7.1–7.3) compared with surface waters could have resulted from either surface waters being affected by photosynthetic induced pH increases. Further physiochemical investigation would be required to better understand reservoir pH dynamics.

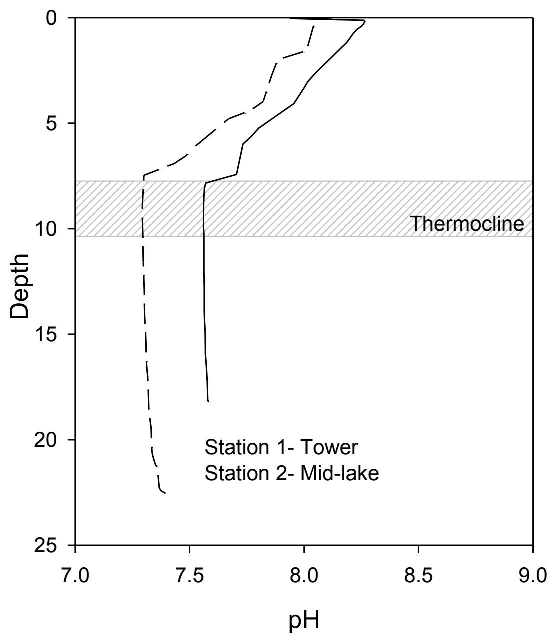

Figure 10. Water column pH profiles in the Maitai Reservoir 3 April 2013 at two monitoring stations.

Near-anoxic conditions in the hypolimnion of the reservoir are of concern for aquatic communities in the Maitai Reservoir, as well as riverine communities downstream from the dam. However, such conditions in bottom waters of deeper lakes in New Zealand are not uncommon as shown by Hamill and Verburg (2010) who collated DO and temperature profiles for 63 lakes nationally. During periods of stratification, 81% of lakes in this dataset had average bottom-water DO concentrations of less than 5 mg per litre, suggesting that low DO may have limited the potential fish habitat. Furthermore, during periods of stratification 45% of the lakes in this dataset had average bottom-water DO concentrations of less than 1 mg per litre, or near anoxic. The depletion rate of oxygen in the bottom waters of lakes is positively correlated to the phytoplankton biomass and relatively uncommon in oligotrophic lakes (Burns 1995; Schallenberg & Burns 1999). Thus anoxia in the Maitai Reservoir, which is relatively unproductive, is harder to explain and as previously discussed potentially linked to degradation of organic material flooded during the formation of the reservoir or washed into the reservoir in subsequent floods. Interestingly Moore *et al.* (1963), who reported temperature and oxygen profiles for the Kaihoka Lakes showed that Kaihoka 1 was thermally stratified with oxygen reading declines from 8.8 mg/l in the upper mixed layer to 1.4 mg/l in bottom water. These findings are important because they indicate that even relatively pristine natural lakes in the region may be prone to deoxygenation. Further work around understanding deoxygenation and managing the effects of this on the downstream Maitai River are recommended.

4.2.3. Phytoplankton

Of greatest concern in drinking water, contact recreation and food gathering is that some species or strains of cyanobacteria produce highly potent neurotoxins, hepatotoxins or dermatotoxins ('cyanotoxins'). Commencing in around the year 2000, there has been an apparent rapid increase in the incidence of potentially toxic cyanobacterial blooms in New Zealand (*e.g.* Wood *et al.* 2006). Eutrophication due to increasing nutrient inputs appears to be a major driver of increasing dominance of cyanobacteria in lakes (*e.g.* lowland lakes in Waikato). Hamilton *et al.* 2010) and Paul *et al.* (2012) demonstrated a positive correlation between cyanobacterial densities in lakes and the percentage of a lake's catchment that is in pasture. Regional and district councils in New Zealand have statutory obligations to protect the health and wellbeing of their constituent populations and so, when cyanobacteria biovolumes in a lake exceed defined threshold levels (MfE 2009), the lake (or the area within a lake where the threshold biovolume exceedance occurs) may be closed to contact recreation. Similarly, alternate drinking water supplies or specific additional treatment may be required when thresholds of potentially toxic cyanobacteria in drinking water are exceeded (Kouzminov *et al.* 2007).

Phytoplankton species and biomass can be highly dynamic in lakes, changing over a daily or weekly time scales (*e.g.* Marshall & Peters 1986). Therefore, one must be prudent in interpreting phytoplankton data from one-off samplings. However, some phytoplankton species are of interest due to their ability to develop into nuisance blooms (*e.g.* some cyanobacteria, dinoflagellates, green algae, *etc*.), due to their potential toxicity to wildlife and humans (*e.g.* some cyanobacteria), due to their edibility (*e.g.* small green algae and diatoms) or inedibility (*e.g.* colonial algae) by herbivore grazers such as zooplankton.

The dominant taxon detected in the Maitai Reservoir during the April 2013 was a colonial cyanobacteria species of the genera *Cyanodictyon* (Table 10). This genera, for which 11 species have been reported, is not known to have any species with known toxin or flavour tainting properties. At the intake tower site, another cyanobacteria species, *Aphanocapsa sp.*, was also relatively abundant at 890 cells/ml. Some strains of this cyanobacteria genus have been linked with cyanotoxin production (Microcystin), although this would not mean that cyanotoxin risk is necessarily an issue in the Maitai Reservoir. Toxin production can depend on a range of properties including the particular species, strain, its density, and conditions that would favour toxin production (Wood *et al.* 2012). *Aphanocapsa* is a very small celled species (approximately 1 µm diameter) thus although counts were somewhat high, by biovolume the species was relatively less abundant (Wood *et al.* 2012). As a precautionary measure we tested the sample for any known toxin producing genes, and there were no positive tests for this, indicating very low likelihood for cyanotoxin risk (pers. comm. Susie Wood, Cawthron Institute, 11 June 2013).

The majority of other taxa that were abundant in the reservoir included species characteristic of oligotrophic New Zealand lakes, including colonial green algal taxa (*Sphaerocystis*, *Oocystis*, *Monorahidium*), *Cryptomonas*, and a number of diatom taxa (*Nitzschia*, *Cyclotella*). The dinoflagellate *Certatium*, which can cause flavour tainting if present in high numbers, was present in very low abundances (< 4 cells/ml). Overall the composition of phytoplankton in the Maitai Reservoir was quite typical of oligotrophic lakes. The presence of *Aphanocapsa* sp. would likely only be of concern if obvious blooms were to form, and this is unlikely in an oligotrophic system such as Maitai. Should significant internal nutrient flux of nutrients, particularly phosphorus, occur in the reservoir during times of hypolimnetic anoxia this could facilitate greater biomass of phytoplankton in spring following the winter mixing period. Further monitoring of chlorophyll concentrations over the seasonal mixing cycle could be pursued to better understand these dynamics.

Table 10. Mean cell counts of phytoplankton by order of abundance from sampling through the mixed layer (0-5m) in the Maitai Reservoir on 4 April 2013.

Species	**Group**	**Mid-lake (cells/ml)**	**Tower (cells/ml)**
Cyanodictyon sp.	Cyanobacteria	2000	6900
Aphanocapsa sp. *	Cyanobacteria	0	890
Sphaerocystis sp.	Chlorophyta	810	0
Monoraphidium sp.	Chlorophyta	110	130
Oocystis sp.	Chlorophyta	88	330
Cryptomonas sp	Cryptophyta	65	77
Small unicells *(< 5 µm)*	Assorted	64	0
Peridinium sp.	Dinoflagellates	63	6
Small flagellates *(< 5 µm)*	Assorted	23	10
Crucigeniella sp.	Chlorophyta	21	0
Elakatothrix sp.	Chlorophyta	9	4
*Cyclotella sp.***	Diatoms	8	2
Ceratium sp.	Dinoflagellates	4	2
Encyonema sp.	Diatoms	3	0
Coelastrum sp.	Chlorophyta	1	0
Gomphonema sp.	Diatoms	1	0
Navicula sp.	Diatoms	1	0
Nitschia sp.	Diatoms	0	12

* Potential toxin forming species ** Potential taste/odour species

4.2.4. Zooplankton

Metazooplankton (zooplankton > 150 µm) in the Maitai Reservoir was comprised of four native zooplankton taxa, with the dominants being two Crustacean species, *Daphnia carinata* and *Ceriodaphnia dubia* (Table 11). Exotic species of Daphnia, predominantly the North American *Daphnia pulex,* are spreading through lakes in New Zealand (Duggan *et al.* 2012). Reservoirs are often sites for incursion by invasive species because they offer a new lentic habitat that are largely devoid of lake species when they are formed and thus are colonised over time lake species (Henriques 1987). Because many exotic species are often highly adapted for spread, they often out-compete native fauna in colonising new sites. The presence of an entirely native zooplankton community in the Maitai Reservoir is thus encouraging. Larger bodied daphnid taxa such as *Daphnia carinata* are known to be effective phytoplankton grazers (Burns & Schallenberg 2001). Thus the presence of this species could indicate that zooplankton would be effective at cropping phytoplankton should spring phytoplankton production increase following the winter mixed period.

As with discussions on the previous section for phytoplankton, zooplankton community dynamics are highly temporally dynamic. Thus one-off sampling events are difficult to interpret in terms of their influence on the ecology lake system. This sampling has provided a snapshot picture to document the presence of zooplankton in the reservoir, dominant species, and any potential invasive species.

Table 11. Mean zooplankton densities in the Maitai Reservoir over the 0–10 m mixed layer collected 4 April 2013.

Group	Taxa	Mean density (m^{-3})
Crustacea	*Daphnia carinata*	2.99
	Ceriodaphnia dubia	1.17
	Larval un-ID Crustacea	0.15
Copepoda	*Boeckella triarticulata*	0.16
	Microcyclops sp.	0.29
	Nauplii	0.24

4.2.5. Aquatic macrophytes

Aquatic macrophytes play many important roles in the ecology of lakes (Kelly & McDowall 2004). They provide habitat for zooplankton, invertebrates and fish, by providing a refuge to these animals from predators (Kelly & Hawes 2005). They can also provide food source to aquatic birds. 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 (Howard-Williams *et al.* 1987). Reservoirs can often be cites of exotic plant invasions due to conditions of greater water level fluctuations favouring tall exotic weeds, and because reservoirs are often very accessible and often attract recreational boating access.

The only species observed to be present in the Maitai Reservoir was the emergent species, *Typha orientalis* (Table 12), which occurred along the reservoir margin, and was above the water table at the time of sampling. The lack of macrophytes in the reservoir was somewhat unexpected, as the reservoir has now been present for over two decades, thus colonisation would be expected to occur over this time frame (Henriques 1987, Closs *et al.* 2004). Other lakes in the region have diverse aquatic macrophyte communities and this would be expected to enhance their ecological functioning, uptake soluble nutrients and provide habitat for fish. Reasons behind the lack of macrophytes in the reservoir are unknown, the magnitude and frequency of water level fluctuations would unlikely be a major factor in preventing macrophytes from growing between the depth of normal draw-down levels to the light extinction depth, or between 1.5–6 m (discussed in previous Section 4.2.1). It is possible colonist sources of aquatic macrophytes to the reservoir have been lacking, as there are no macrophytes present in upstream inflow streams which are steep and 'bouldery', and the reservoir has minimal access for boating or recreation which would also reduce the potential for introducing aquatic plant fragments, seeds, and spores. The only remaining transfer vectors would be aquatic birds (Champion & Clayton 2000, Closs *et al.* 2004). Importantly, this lack of colonist sources minimises risk of introduced aquatic weeds that could negatively impact the reservoir for its intended water uses.

Overall the lack of any significant aquatic plants reduces value of the Maitai Reservoir as habitat to fish and invertebrate communities in the reservoir. Aquatic plants, if present, could also sequester nutrients in the reservoir water column, and buffer the lake from nutrient inputs from tributaries. Reasoning behind their lack of occurrence in the reservoir is unknown, but possibly due to its geographic isolation from colonist sources. From a positive perspective, the lack of any significant aquatic macrophytes would deter large abundances of waterfowl from using reservoir thereby minimising sources of animal faecal contamination to reservoir which is predominantly sourced for drinking water.

Table 12. Aquatic macrophytes observed in the Maitai Reservoir in April 2013, and plants reported in historical surveys of three other lakes in the region, the Kaihoka Lakes and Lake Otuhie.

Survey	**Maitai Reservoir**	**Kaihoka Lake 1**	**Kaihoka Lake 2**	**Lake Otuhie**
April 2013	*Typha orientalis*			
Drake *et al.* (2009) and R. Wells (pers. comm.) — sampled in July 1997.		*Typha orientalis* *Lilaeopsis sp.* *Glossostigma submersum* *Nitella pseudoflabellata* *Nitella hookeri*	*Typha orientalis* *Glossostigma submersum* *Lilaeopsis sp.* *"pratia-like species"* *Chara sp.* *Nitella sp.*	*Jointed wire rush* *Flax (emergent)* *Eliocharis sp. (emergent)* *Typha orientalis (emergent)* *Lilaeopsis sp.*

4.2.6. Macroinvertebrate communities

Macroinvertebrates were comprised of a moderately diverse range of taxa, with 14 taxa observed over the three sites (Table 13). Numerically, the community was dominated by molluscs including *Potamopyrgus* and unidentified species of fingernail clams, which together comprised 76% of the total invertebrate abundance. Both of these taxonomic groups could potentially have colonised the reservoir from the upstream river, as both taxa occur in the rivers and were found in the North Branch upstream of the reservoir. There were several more lentic specialists' taxa, including insects from the orders Odonata (dragonflies/damselflies), Trichoptera (caddis flies) and Diptera (mainly chironomids). All of these insect species have flying adult stages, and thus would likely have colonised the reservoir from small ponds or wetlands in the area.

Table 13. Mean macroinvertebrate density (and standard errors) at littoral sites in the Maitai Reservoir on 4 April 2013.

Group	Taxa	Mean density (m^{-2})	SE of Density
Crustacea	Chydoridae	43.6	43.6
	Cyclopoida	82.8	42.9
	Ostracoda	7969	990
Diptera	Ceratopogonidae	34.9	23.1
	Chironominae	1825	1214
	Chironomus sp. "a"	222.2	125.6
	Cryptochironomus	662.3	457.2
	Tanypodinae	710.2	253.3
Mollusca	*Gyraulus*	17.4	17.4
	Potamopyrgus	15089	6851
	Sphaeriidae	4662	4389
Nematoda	Nematoda	169.9	94.6
Odonata	*Procordulia grayi*	17.4	17.4
	Xanthocnemis	8.7	8.7
Oligochaeta	Oligochaeta	6827	1753
Trichoptera	*Oecetis unicolor*	719.0	399.6
	Triplectides cephalotes	113.3	74.5
	Total density	39176	14818

Comparatively speaking the Maitai Reservoir had intermediate (between 30-75th percentile) invertebrate scores for invertebrate metrics which quantify the richness, diversity, and evenness of the invertebrate community in comparison to other South Island small lakes (Table 14). However, other lakes in the Tasman region such as Kaihoka Lake 1 and Lake Otuhie did tend to have substantially more abundant and diverse invertebrate communities than the Maitai Reservoir. This could be related to two factors, firstly the greater range of habitats within these natural lakes which had rich aquatic plant communities. Secondly, the Maitai Reservoir could very well still be in the process of being colonised by new species, with the reservoir being relatively young (25 years old) by comparison to natural lakes that would have been formed centuries ago during the process of dune migrations and stream blockages along the Tasman coast (Leathwick *et al.* 2010).

An MDS ordination plot that graphically represents the similarity of the macroinvertebrate community composition of the 18 South Island lakes in relation to each other is shown in Figure 11. From this cluster analysis, it can be seen that lakes with similar physic-chemical properties in terms of nutrient status, presence of macrophytes, and tannin staining form distinctive groupings of lakes. The Maitai Reservoir clusters together with a group of lakes that are characterised by low nutrients, but have low dominance by aquatic macrophytes mostly linked with dissolved tannin staining of their waters. Lakes that were most similar in their invertebrate community composition to the Maitai Reservoir included Lake Otuhie (Tasman), Lake Wilkie (Catlins) and the Maori Lakes (South Westland).

Overall the macroinvertebrate community of the Maitai Reservoir was of an intermediate diversity and abundance, with a combination of aquatic generalist (species that can inhabit both rivers and lakes) and lentic specialist species present in the reservoir. The relatively lesser community diversity and abundance in comparison to other lakes in the Tasman region was most likely related to a lack of habitat complexity in the Maitai Reservoir, which contains no aquatic macrophytes. Macroinvertebrate communities were mostly characteristic of other lakes with low nutrients, few aquatic plants, and moderate to high tannin staining.

Table 14. Macroinvertebrate metrics for the Maitai Reservoir, three other lakes in the region, and a percentile rank of the Maitai Reservoir against 18 South Island small lakes from Drake *et al.* (2009).

		CDRP Data (Drake *et al.* 2010)			
Variable	**Maitai Reservoir**	**Kaihoka 1**	**Kaihoka 2**	**Otuhie**	**Maitai Rank 18 SI lakes (%)**
Species richness (N)	17	26	28	28	33.3
Total density (m^{-2})	39176	122014	95051	52918	39.9
Shannon diversity	1.71	1.78	2.02	2.10	73.3
Pielou evenness	0.60	0.55	0.61	0.63	60

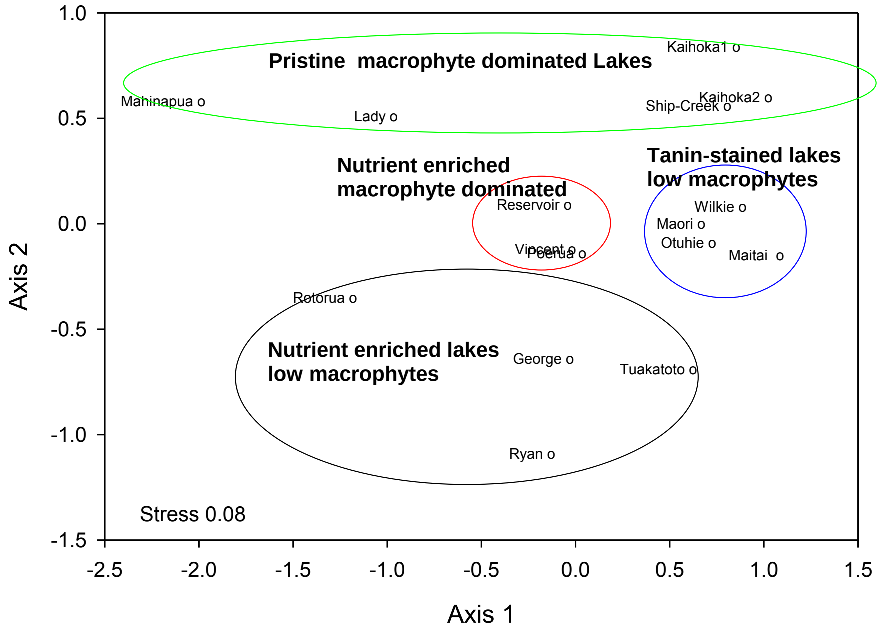

Figure 11. Multi-dimensional scaling (MDS) ordination plot of the Bray Curtis similarity of macroinvertebrate community from 18 South Island small lakes. Also shown are ellipses around clusters of lakes with hypothesised environmental habitat parameters characterising each cluster.

4.3. Fisheries

Fish populations in the Maitai Reservoir were surveyed on a single occasion to provide an understanding of the species inhabiting the reservoir, their relative dominance, and main habitats utilised. This data is compared against fisheries survey data collected in the same manner (same fishing effort and season) from 18 small lowland lakes on the South Island (Drake *et al.* 2009). Four species were present in the reservoir, which included longfin eel, upland bully, common bully, and brown trout. Common bully was the most numerically dominant in the reservoir, followed by upland bully, and longfin eel (Table 15). With respect to biomass, longfin eel would have been the largest component. Trout were not caught as part of this survey but have been reported in the reservoir from gillnet surveys (pers. comm. M. Rutledge, Department of Conservation). Catches in minnow traps, which extended through the littoral zone between 0 and 25 m, suggested fish were very rare or absent beyond 5 m depth in the reservoir. The greatest catches were from traps closest to lake shore margins in depths less than 30 cm (Figure 12).

Table 15. Fish species and catch per unit effort (CPUE) from overnight fish surveys in the Maitai Reservoir in April 2013, and those from three Tasman district lakes in 2009 (Kaihoka lakes and Lake Otuhie). Also shown is the percentile rank of the Maitai Reservoir fish metrics in relation to 18 South Island small lowland lakes.

		CDRP Data (Drake *et al.* 2010)			
Variable	**Maitai Reservoir**	**Kaihoka1**	**Kaihoka2**	**Lake Otuhie**	**Rank 18 SI lakes (%)**
Fish richness (N)	4	2	1	4	14
Species	Common Bully Upland Bully Longfin eel Brown trout	Banded kokopu Longfin eel	Banded kokopu	Common bully Inanga Longfin eel Shortfin eel	n/a
CPUE (fish/trap or net)	18.8	1.75	29.1	27.5	50
#Exotic fish sp.	1	0	0	0	50

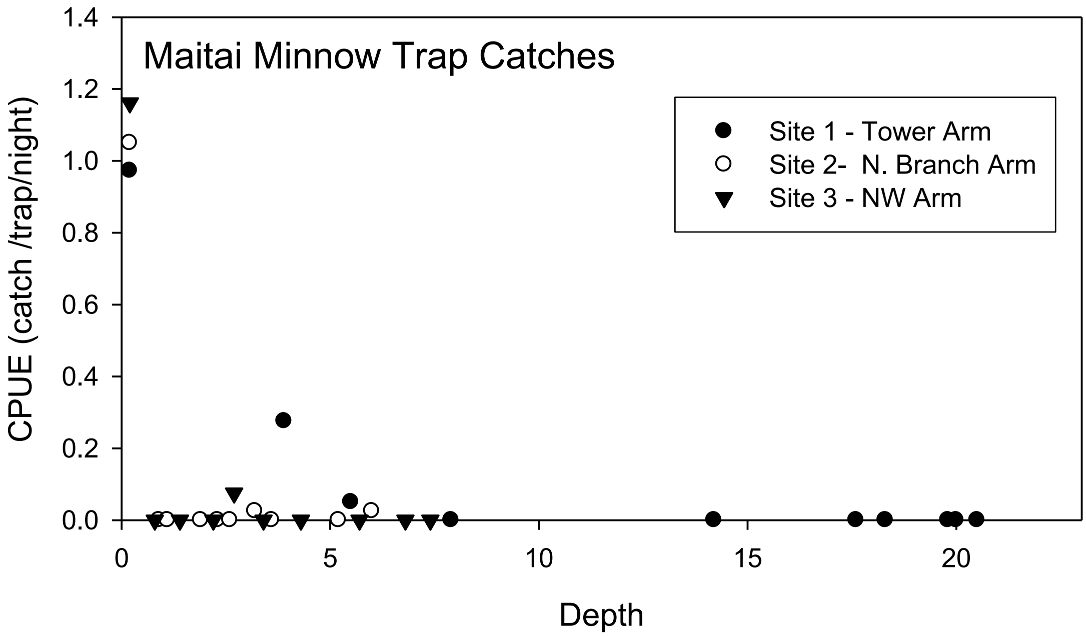

Figure 12. Overnight catch per unit effort (CPUE) of common and upland bullies in gee-minnow traps situated at varying depths in the Maitai Reservoir on 3-4 April 2013.

The fish community richness and overall catch abundances were intermediate to low in comparison to other South Island lakes. The trend for no fish to be present at deeper depths due to near anoxic conditions below the thermocline would have contributed to this. The fact that no other exotic fish other than brown trout were detected in the Maitai Reservoir was a positive aspect for fisheries populations. Many lakes in the 18-lake South Island dataset had populations of other exotic species such as European perch and goldfish. The lack of access to the Maitai Reservoir has probably minimised this risk. Most of the species presently occurring in the Reservoir are likely to have colonised the waterbody from upstream tributary reaches, as passage over the 20 m dam would be less likely. There were populations of koaro observed the North Branch of the Maitai River during this survey; however these were not detected in the reservoir despite koaro known to inhabit lakes (Kelly & McDowall 2004). Juvenile koaro, which drift downstream following their emergence from eggs, could colonise the reservoir but none were detected using the methods employed.

Most of the freshwater fish fauna present in rivers of the South Island Northern regions are obligate migrants. Obligate migrants periodically utilise inland freshwater habitats (McDowall 2006) and coastal and estuarine resources at certain times and/or at particular periods of their life cycle. Some species complete essential portions of their lifecycles (*e.g.* reproduction) well inland while others achieve this far away at sea (*e.g.* eels). Species habitat preferences and climbing ability usually determine the distance inland they travel. Some species such as koaro and longfin eels can migrate

> 100 km inland while others such as giant bully, smelt and inanga are rarely found beyond the lower reaches of rivers/streams.

Some fish species (longfin eel, probably koaro) presently residing in the reservoir are diadromous, however these populations likely have been derived from populations upstream of the dam. In particular, it was evident from the size structure of the reservoir eel population that limited or no recruitment by juvenile upstream migrants has occurred, possibly since the dam was put in place (Figure 13). We observed no longfin eels of less than 600 mm fork length in the Maitai Reservoir. In contrast, the dataset for all other South Island lakes showed a much more normally distributed size distribution. Given the slow growth rates for this species in lakes (Jellyman 2001, Kelly & Jellyman 2007), these individuals could likely have been present in the North Branch Maitai system prior to the dam's construction. Although anecdotally there has been some transfer of longfin eels of various size classes upstream of the dam via trap and transfer, these transfer efforts have not necessarily targeted juvenile elvers migrating upstream, and thus it has not maintained a normal age/size population structure. In the case of koaro, no adults were detected in the reservoir, possibly indicating that the species has also not been unable to climb the dam face, and only low densities of large adult fish were observed in the North Branch tributary.

The size of the dam (20 m) and slope of the dam face would not entirely rule out that fish with good climbing ability, as longfin eel and koaro possess, could bypass the structure during times when flow was overtopping the spillway. Flows over the dam are quite regular, particularly during the periods of peak eel migration in spring (McDowall 1990). Thus it is probable that attributes of the dam face surface are preventing these species from climbing over the dam. It is recommended that fisheries passage options, which could potentially consist of relatively inexpensive modifications to the dam face (*e.g.* PVC tubes fixed with brushes), are pursued to enable native fish passage.

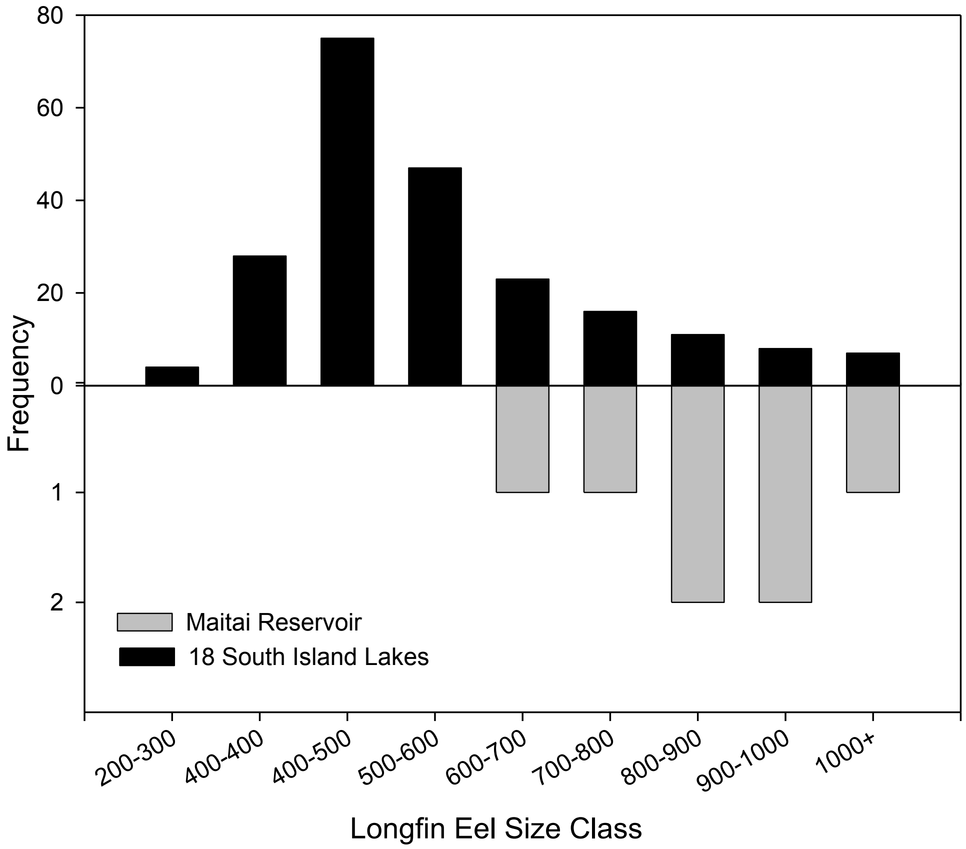

Figure 13. Size distribution histogram of longfin eels in the Maitai Reservoir (grey bars) compared against the size distribution of longfin eels caught in a pooled dataset from 18 lakes on the South Island.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Key findings

North Branch

- Manganese (Mn) and iron (Fe) in the North Branch were found at concentrations well below those detected in backfeed water of up to 1.2 g/m^3 for Mn. Thus, although other chemical parameters such as calcium concentration and pH of the North Branch appear to be affected by geological formations in the Dun Mountain mineral belt, Mn and Fe were at normal levels based on the single sampling event. As soluble Mn and Fe are known to be by-products of chemical reduction processes in anoxic hypolimnia of reservoirs, it is anticipated these contaminants are sourced from reservoir sediments.

- Results from the one-off survey suggest that water quality (dissolved oxygen, conductivity, temperature and pH), was high and periphyton and macroinvertebrate communities were similar to those at the upstream control biomonitoring site in the South Branch.
- There was no indication that degraded biological conditions downstream of the backfeed discharge were the results of the follow through impacts of water quality in the North Branch.
- Upstream fish passage appears to be an issue for longfin eels and koaro populations accessing the North Branch system. Longfin eels were not found in the North Branch, and koaro were found only in very low densities in the North Branch. Landlocked lake populations of this species can occur, but any koaro in the North Branch would historically have been from a sea-run population. Koaro can live quite long periods with individuals of 16+ years found in this region. Thus the finding of only few very large individual koaro in the North Branch suggests uncertainty regarding whether migrants are regularly bypassing the dam face to access the upper catchment.

Maitai Reservoir

- Water levels in the reservoir are operated over a reasonably narrow range by comparison to operations of most reservoirs (mean drawdown 1.4 m between 2004 and 2013), and are anticipated to maintain healthy ecological conditions in the lake-edge littoral community, which extends to the euphotic depth of around 6 m.
- Water quality in the reservoir can be characterised as a low productivity dystrophic system (Trophic Level Index score of 2.0), and water clarity was relatively high (Secchi of 4.2) by comparison to other small South Island lakes. The pH in the reservoir was somewhat unusually high, and likely influenced by limestone geology of several rock formations (principally Dun Mountain, Stephen's argillite) in its catchment.
- Thermal stratification in the reservoir over spring-summer contributes to deoxygenaton in its hypolimnon, which was near-anoxic between 10 and 25 m depth at the time of this field surveys during April 2013. This is not entirely uncharacteristic of deep lakes in the region, however it does present ecological issues associated with the supply of backfeed water to the South Branch during stratified periods.
- Phytoplankton communities present in the reservoir are mostly characteristic of low productivity systems, dominated by small-celled cyanobacteria, colonial greens and diatoms. Although one of the dominant species (*Aphanocapsa sp.*) is known to be linked with cyanotoxin production, further testing suggested there were no genetic markers for toxin producing strains present, and the overall biovolume for *Aphanocapsa* was low at the time of sampling.

- The zooplankton community was comprised predominantly of the native daphnids *Daphnia carinata* and *Ceriodaphnia dubia*. These species would be effective phytoplankton grazers and could promote good water quality in the reservoir should phytoplankton increase in spring following the winter mixed period.
- Submerged macrophyte species were absent from the reservoir, despite suitable substrata and a moderate reservoir water-level operating regime. Possibly a lack of localised colonist sources along with the reservoirs isolated access have meant that no macrophyte species have yet colonised the system. The absence of macrophytes does result in poorer quality habitats for aquatic biota, but would minimise its use by aquatic waterfowl that could contribute to faecal bacteria loads unfavourable to human drinking water uses of the reservoir.
- The littoral macroinvertebrate community was of intermediate abundance and relatively low diversity by comparison to other South Island lakes, most likely related to the limited diversity of habitats and lack of submerged macrophytes.
- Fish populations consisted of four species, numerically dominated by common bullies, followed by upland bullies and longfin eels. Koaro were found in the river and juveniles may inhabit the reservoir, but were not detected during this survey, possibly due to the autumn timing. Brown trout are also known to be present in the reservoir but were not observed in the present survey principally due to survey methods used (fyke nets, gee-minnow traps).
- Near-anoxic conditions in the hypolimnion limited fish to the shallow portions of the reservoir, and no fish were caught below 5 m depth. The heavily skewed size class structure of longfin eels towards large (>600 mm) adult individuals indicates that limited or possibly no recruitment is occurring to the reservoir from upstream juvenile migrants.

5.2. Recommendations

- More detailed work conducted around the development of anoxia in the hypolimnion of the reservoir, and in association with organic matter decomposition, and nutrient and contaminant cycling from reservoir sediments during periods of anoxia. This would be important to further understand biological and/or biochemical sources of oxygen demand in the reservoir bottom waters and determine possible options to reduce the extent or rates of oxygen depletion. Better understanding of nutrient cycling from sediments is key for both the Maitai Reservoir and South Branch systems.
- More detailed work around stratification development and progression to provide the council better informed options on suitable reservoir layers for sourcing backfeed water discharged to the South Branch. It would appear that the mid-intake for the backfeed, at 12 m depth, is below the thermocline over most of the anoxic period. If this was potentially modified to another level through an engineering solution, it could enable cooler but less toxic water to be put through

the backfeed. This work would form the baseline study for the development of a backfeed discharge management strategy to improve water quality in the South Branch, with an engineering assessment on tower intake modification done in conjunction. The present practice of discharging hypolimnetic water during anoxic periods through the backfeed is a less appealing option.

- Phytoplankton composition and biomass measured as part of the wider water quality study in the reservoir to better document if potentially toxin producing cyanobacteria can proliferate during periods of maximum production following winter mixed conditions. Phytoplankton dynamics are presently unknown in regards to their possible links with drinking water quality.
- More detailed investigations conducted into facilitating upstream fish passage for diadromous species in the North Branch. Both koaro and longfin eel are highly effective climbers, thus a relatively non-technical option to allow fish to climb over the dam face may be available.
- Consideration of a possible macrophyte establishment programme for the Maitai Reservoir to potentially enhance habitats for invertebrate and fish populations: This could provide more control over the types of species that may colonise the reservoir, and limit any unoccupied habitats for potential weeds should they be accidentally or naturally be introduced. This would need to be weighed against risk of increased waterfowl use and possible animal faecal contaminant sources.

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8. APPENDICES

Appendix 1. Hills Laboratory and Cawthron Institute Analytical Services reports.

Appendix 2. Macroinvertebrates collected in Surber samples from the North Branch of the Maitai River, 18 April 2013: number of taxa, densities, percent EPT_{taxa}, Macroinvertebrate Community Index (MCI) and Quantitative Macroinvertebrate Community Index (QMCI) scores. The samples were collected in riffle and cascade habitats.

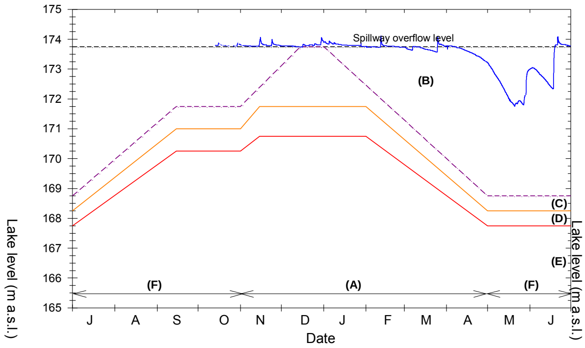
	MCI	**Bottom - Riffle**		**Middle - Cascade**		**Upper - Cascade**	
Site	**Taxon**	**A**	**B**	**A**	**B**	**A**	**B**
Replicate	**Score**	18-Apr-13	18-Apr-13	18-Apr-13	18-Apr-13	18-Apr-13	18-Apr-13
Ephemeroptera (mayflies)							
Coloburiscus humeralis	**9**	-	1	-	8	1	-
Deleatidium spp.	**8**	62	53	22	262	68	91
Neozephlebia scita	**7**	-	-	-	-	1	-
Plecoptera (stoneflies)							
Austroperla cyrene	**9**	-	-	-	1	-	-
Spaniocerca sp.	**8**	-	1	1	1	4	-
Stenoperla prasina	**10**	-	2	-	5	1	-
Zelandobius sp.	**5**	1	1	1	9	1	-
Zelandoperla sp.	**10**	3	2	7	-	-	
Megaloptera (dobsonflies)							
Archichauliodes diversus	**7**	1	-	-	-	5	4
Coleoptera (beetles)							
Elmidae	**6**	4	-	1	11	-	5
Hydraenidae	**8**	-	3	-	13	-	-
Ptilodactylidae	**8**	-	-	-	-	1	-
Diptera (true flies)							
Anthomyiidae	**3**	-	-	-	-	-	1
Aphrophila neozelandica	**5**	10	6	1	28	5	4
Austrosimulium spp.	**3**	2	5	1	11	2	-
Blepharceridae	**7**	-	1	-	-	1	-
Chironomidae	**2**	1	1	-	-	1	-
Empididae	**3**	-	2	1	1	-	-
Eriopterini	**9**	-	-	-	1	-	-
Maoridiamesa spp.	**3**	6	-	-	6	1	1
Neocurupira hudsoni group	**7**	-	-	2	-	-	-
Orthocladiinae	**2**	24	7	3	15	1	4
Polypedilum sp.	**3**	-	-	-	1	-	-
Tanytarsus vespertinus	**3**	39	10	4	26	1	6
Trichoptera (caddis flies)							
Aoteapsyche spp.	**4**	26	15	3	82	13	5
Beraeoptera roria	**8**	-	-	-	3	-	-
Confluens olingoides	**5**	4	6	6	15	2	6
Costachorema xanthopterum	**7**	-	-	1	-	-	-
Helicopsyche sp.	**10**	2	-	1	6	-	2
Hydrobiosella stenocerca	**9**	2	6	1	3	2	-
Hydrobiosis parumbripennis	**5**	-	1	-	1	-	-
Hydrobiosis spp.	**5**	1	3	1	3	1	1
Olinga feredayi	**9**	1	1	3	27	9	3
Oxyethira albiceps	**2**	-	-	-	1	-	-
Paroxyethira sp.	**2**	2	2	1	1	-	-
Polyplectropus puerilis	**8**	-	1	-	-	-	-
Psilochorema macropharpax	**8**	-	-	-	-	-	1
Psilochorema sp.	**8**	-	-	-	1	-	1
Pycnocentrodes sp.	**5**	1	-	-	1	-	-
Zelolessica cheira	**10**	2	-	1	-	-	-
Nematoda (roundworms)	**3**	-	1	-	-	1	-
Oligochaeta (worms)	**1**	-	3	1	7	1	-
Mollusca (snails)							
Potamopyrgus antipodarum	**4**	-	-	-	2	-	-
Acarina (mites)	**5**	1	-	-	-	-	-
Taxa Richness		21	24	21	30	22	15
Density (no.m^2)		1950	1340	630	5520	1230	1350
% EPT_{taxa}		57.1	58.3	61.9	60.0	50.0	53.3
% $EPT_{abundance}$		54.9	70.9	77.8	77.9	83.7	81.5
MCI		112	112	116	114	112	111
QMCI		5.19	6.01	6.68	6.47	7.06	7.08

Appendix 3. Fish collected by electric-fishing in the North Branch of the Maitai River, 18 April 2013: abundance, habitat type, densities. A total area of $70m^2$ was fished.

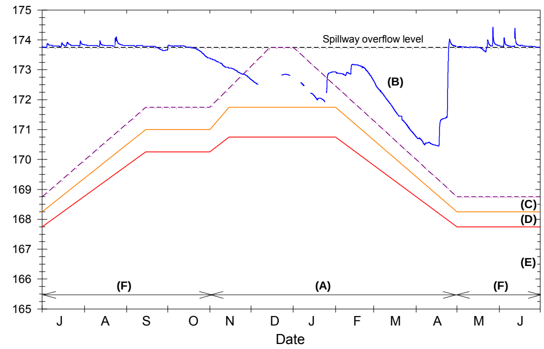
	Cascade	Run	Riffle	Pool	Density (No/m^2)	Size (mm)
Brown trout (*Salmo trutta*)	3	0	1	0	0.06	112, 118, plus 2 seen and not caught ~118 mm
Upland bully (*Gobiomorphus breviceps*)	0	19	18	0	0.53	24, 25, 25, 26, 26, 27, 29, 29, 30, 30, 31, 32, 32, 34, 34, 34, 34, 36, 36, 37, 38, 38, 38, 39, 41, 41, 41, 41, 42, 42, 43, 44, 45, 47, 57, 61 plus one bully caught then lost
Koaro (*Galaxias brevipinnis*)	1	0	0	0	0.01	144
Area fished (m^2)	18	24	20	8		

Appen

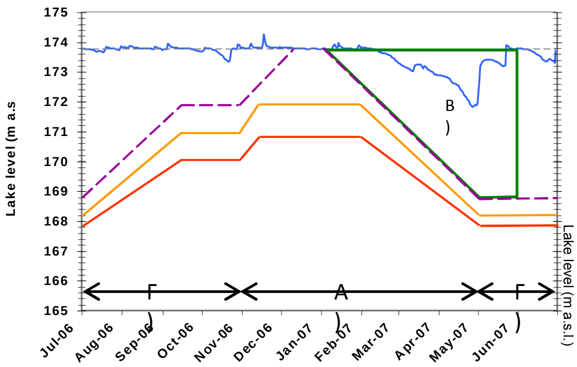
a) 2004-05



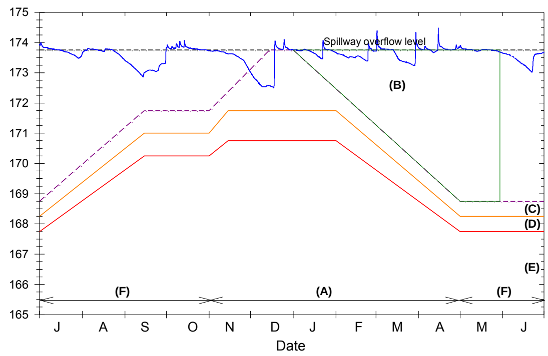
b) 2005-06



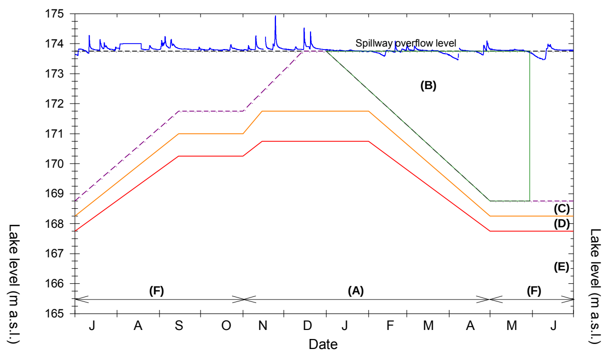
c) 2006-07



d) 2007-08



e) 2008-09



f) 2009-10