coastalmanagement

Lake Murihiku - Broad Scale Habitat Mapping 2013

Prepared for

Environment Southland

June 2013

Cover Photo: Lake Murihiku, February 2013.

Niggerheads *(Carex secta)* growing in muddy sediments around edge of Lake Murihiku.

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By

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LAKE MURIHIKU - EXECUTIVE SUMMARY

This report summarises the results of the 2013 broad scale habitat mapping of Lake Murihiku, a small (5.3ha) shallow coastal freshwater lake in central Southland. It is one of several shallow lakes in Environment Southland's long-term monitoring programme. The following sections summarise the broad scale monitoring results, macrophyte condition ratings, overall lake condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Mud dominated the lake sediments, with a low incidence of sulphide-rich anoxic muds.
- Very low water clarity (0.4m depth). No data available for nutrients or chlorophyll a.
- Submerged macrophyte cover was estimated at <5% of the total lake area, but emergent macrophyte cover around the shallow margins occupied 27%.
- Maximum depth of macrophyte cover (MCD) was very low at 0.4m (emergents mainly).
- Macrophyte cover consisted mostly of natives, with dominant species being emergent species; the sedge *Eleocharis sphacelata* (13% of lake), the reed *Typha orientalis* (raupo) (9% of lake), and *Carex secta* (niggerhead) (3% of lake).
- Introduced macrophyte cover was present but limited to the emergent *Solanum dulcamara* (bittersweet).
- Turf species (0-0.2m depth zone) were sparse (1.5% of lake) and dominated by *Glossostigma elatinoides*.
- In the 0.4-0.8m depth zone, there were no macrophytes, i.e. the bed was unvegetated.
- The terrestrial margin was dominated by grazed pasture (82% of area), native and exotic scrub/forest and flaxes (7% of area), and residential and industrial (9% of the area).

LAKE CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sedimentation, eutrophication, and habitat modification), the 2013 results indicate that the lake was in a likely tentative mesotrophic/eutrophic state. Within the lake, submerged macrophyte cover was virtually absent, but dense cover of emergent vegetation was present in the shallow waters around the lake margin. Overall, it was estimated that the submerged macrophytes were at <20% of their maximum potential. This poor score reflected the presence of emergent species only, the absence of submerged species, low cover of invasive species, and the fact that macrophyte growth extended to only half of the lake depth. Clearly, submerged macrophytes were under some stress, with the potential causes being a combination of wind resuspension of the muddy sediments, elevated phytoplankton levels and the dark natural brown humic staining. Given the lack of data for nutrients, chlorophyll a, colour and wind resuspended sediment, the dominant cause could not be clearly identified. In order to address these issues, further work is recommended.

RECOMMENDED MONITORING AND MANAGEMENT

Multiple shallow lake studies from overseas indicate that submerged macrophyte cover needs to be >50% to ensure a clear water state. Because macrophyte cover in Lake Murihiku was well less than this guideline, i.e. <5%, it is recommended that broad scale habitat mapping of macrophyte diversity and abundance be undertaken at 5 yearly intervals, but only if interim investigations (see below) confirm that non-natural causes are responsible for the low submerged macrophyte cover. If broad scale monitoring is repeated it is recommended that water quality data (DO, conductivity, temperature, secchi disc, total nitrogen and total phosphorus) also be measured at one central site and that broad scale mapping includes identification of sediment substrate type and presence of visible sulphides throughout the lake.

Interim investigations should be undertaken to determine concentrations of nutrients, chlorophyll a, water colour, and sediment resuspension and their likely relative influence on submerged macrophyte growth. Further macrophyte monitoring is recommended only if some factor other than water colour is found likely to be driving macrophyte presence/absence (e.g. excessive phytoplankton chlorophyll a bought about by elevated nutrients, or excessive wind resuspension of bed sediments).

To maintain the lake macrophyte cover at a level that ensures a clear water state with good water clarity (if interim investigations indicate that this is achievable), the following management actions, undertaken in a step-wise fashion, are recommended:

- determine appropriate nutrient and sediment load guidelines for the lake.
- determine current nutrient and sediment loads.
- reduce input nutrient and sediment loads to meet guidelines (if required).
- manage invasive aquatic plants.

All photos by Wriggle except where noted otherwise.

1. INTRODUCTION

Figure 1. Location of the coastal freshwater lake, Lake Murihiku, and its catchment (shown as red line).

OBJECTIVES

The Southland region has a number of coastal freshwater lakes in developed catchments that are relatively shallow and poorly flushed. Determining the condition of these shallow lakes is important to Environment Southland (ES) in fulfilling its resource management role for the region.

In early 2013, Environment Southland contracted Wriggle Coastal Management to undertake broad scale habitat mapping of four shallow freshwater coastal lakes in their region, Reservoir, Vincent, Murihiku and George.

The aim of these assessments was threefold:

1. To provide an overview of the major habitats, in particular the spatial distribution of the major sediment substrate types, plant species, and water column characteristics.
2. To determine the general condition of the lake, particularly in relation to sedimentation and eutrophication, in order to determine if the lakes are currently impacted from agricultural developments in their catchments.
3. To enable the design of appropriate long term, fine-scale monitoring programmes for each of the lakes.

This approach follows a similar procedure to that used for the Environment Southland estuary and coastal lagoon monitoring programmes, and is specifically designed to provide defensible, cost effective monitoring of shallow waterbodies. This report summarises the results of the Lake Murihiku (Figure 1) survey undertaken on 21-23 February 2013.

SETTING

Lake Murihiku is a small shallow coastal lake (5.3ha) situated 3.7km from Oreti Beach near Invercargill. The lake has a small surface catchment (31ha), which drains predominantly pastoral land, and the outlet is situated at the northern end. Given that the lake has maintained its water level over recent dry summers, it is likely that it also receives water from groundwater sources. The lake is bordered by rushes and flax and is known to support a variety of fishlife.

1. Introduction (Continued)

BACKGROUND

Shallow lakes are defined as generally:

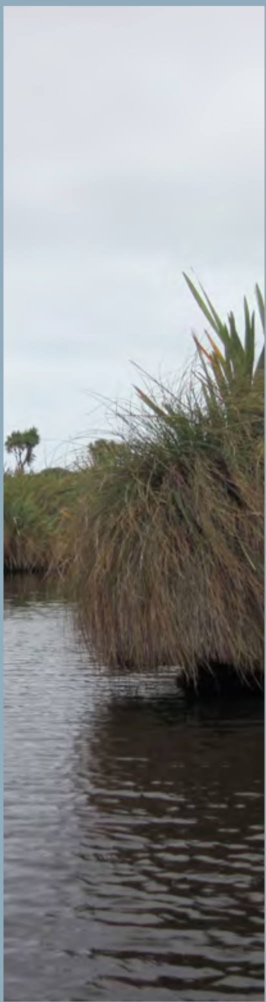
- having an average depth of less than three metres and therefore interactions between the sediment, water phase and biological components are closely interrelated.
- being able to support large aquatic plant life.
- not being stratified - their shallow depth means the lake's water is stirred up regularly due to wind and wave action.

Key Threats

The key shallow lake threats are identified as eutrophication, sedimentation, disease risk, toxicity and habitat loss (Table 1). Because excessive nutrient and fine sediment inputs are the major risk to the four Southland coastal lakes surveyed, a more comprehensive discussion on the eutrophication process in shallow lakes, and the methodologies used for its assessment, particularly in relation to macrophytes, is presented in the following section.

Table 1. Summary of the major issues affecting most NZ shallow lakes.

Major Shallow Lake Issues	
Sedimentation	Because shallow lakes are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, many NZ shallow lakes have begun to infill rapidly. Today, average sedimentation rates in our shallow lakes are typically 10 times or more higher than before humans arrived.
Eutrophication (Nutrients)	Excessive nutrient enrichment of shallow lake ecosystems, particularly with phosphorus, stimulates the production and abundance of fast-growing algae, such as phytoplankton and short-lived macroalgae, at the expense of rooted aquatic macrophytes. Maintenance of a healthy aquatic macrophyte community in shallow lakes is beneficial to overall ecosystem health as their loss negatively affects macro-invertebrate diversity, fisheries, bird populations, filtering of water pollutants, and the ability of shorelines and benthic habitat to resist sediment resuspension. The presence of macrophytes has been shown to be important for modifying nutrient concentrations and reducing the potential for algal blooms. However, at high nutrient concentrations, submersed macrophytes are absent and the lakes are algal-dominated. Target nutrient concentrations to maintain macrophyte growth in shallow lakes are difficult to predict, as a lake's response is often dependent on a number of site-specific variables (e.g. depth, substrate type (particularly mud content), humic content, wind exposure, residence time, mixing).
Disease Risk	Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the shallow lake environment, can survive for some time. Every time humans come into contact with lake water that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Diseases linked to pathogens include gastroenteritis, salmonellosis, hepatitis A, and noroviruses.
Toxic Contamination	In the last 60 years, New Zealand has seen a huge range of synthetic chemicals introduced to lakes through urban and agricultural stormwater runoff, industrial discharges and air pollution. Many of them are toxic in minute concentrations. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), and pesticides. These chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to humans and freshwater life.
Habitat Loss	Shallow lakes have many different types of habitats including shellfish beds, macrophyte beds, marshes (rushlands, herbfields, reedlands etc.), forested wetlands, shores, river deltas, and rocky shores. The continued health and biodiversity of shallow lake systems depends on the maintenance of high-quality habitat. Loss of habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is commonplace with the major causes cited as population pressures on margins, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges.



Eutrophication

In relation to eutrophication, shallow lakes have the potential to exist in two states – a more pristine state with clear water and aquatic plants, or a more enriched state with turbid water and suspended algae. As these lakes undergo phosphorus enrichment and/or increased muddiness, they can reach a point where they switch from clear to turbid. Whether this switch happens abruptly when a threshold level of phosphorus is reached (Scheffer et al. 1993) or gradually over many years (James et al. 2005) is somewhat controversial, yet there is no debate that when a lake switches to a turbid state, the dense algae in the water shade out the submerged plants.

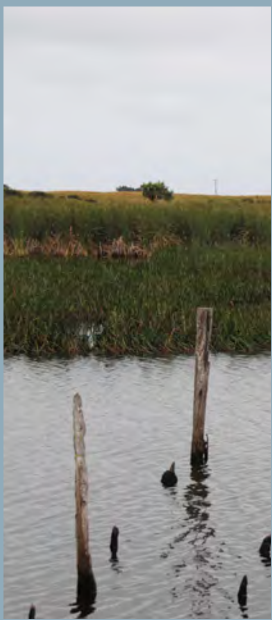
When these rooted submerged plants die, they cannot provide the benefits that reduce the impacts of phosphorus (e.g. they no longer stabilise sediments with their roots, support attached algae which take up phosphorus from the water, or provide daytime cover for zooplankton which emerge at night to feed on suspended algae). This means that shallow lakes without macrophytes are more prone to algal blooms and water quality deterioration (i.e. eutrophication) than lakes with macrophytes. They also require a greater nutrient load reduction to switch back to a clear macrophyte dominated state.

Consequently, there is now a strong emphasis on macrophyte abundance and diversity monitoring as a tool for assessing the ecology and trophic status of shallow lakes (e.g. Ecological Status Macrophyte Index).

Summarised below are a list of the important findings related to using macrophytes for trophic state assessment in shallow lakes <3m mean deep.

- **Oligotrophic and mesotrophic shallow lakes** are likely to have the entire lake sediment surface covered by macrophytes (O'Sullivan and Reynolds 2004). Often they will be covered with charophytes in the more oligotrophic state, and change to a more diverse and productive community as the level of enrichment rises, including native charophytes, milfoils, pondweeds, turf plants, emergents and *Isoetes*. A shift to include dense growths of invasive plants such as *Potamogeton crispus*, elodeids (i.e. *Elodea canadensis* and the more nuisance-prone *Lagarosiphon major*) and epiphytic macroalgae can occur in their more enriched state (e.g. Waiau lagoon - Stevens and Robertson 2011). In the stable state, phytoplankton levels, and therefore chlorophyll-a concentrations, are consistently low (<0.010-0.015mg/l chlorophyll-a) (Sayer et al. 2010).
- **Eutrophic shallow lakes** are characterised by a reduction in species diversity, the development of bare areas, an eventual decline in macrophyte growth to low levels or a complete absence (De Nie 1987), and an accompanying increase in phytoplankton (chlorophyll a concentrations consistently >0.015mg/l) and phosphorus (TP >0.04-0.05mg/l) (Sayer et al. 2010). At TP concentrations above approximately 0.15 mg/l, the likelihood of low macrophyte growth is very high. For example, in a 13-year study of 11 Dutch lakes, Coops et al. (2007) found that submerged vegetation cover >20% never occurred when TP was >0.15 mg $P.l^{-1}$, while coverage was always higher than 20% with TP <0.08 mg $P.l^{-1}$. Bachmann et al. (2002) studied macrophyte abundance and water quality in 319 mostly shallow, fully mixed, Florida lakes and showed that if TP >0.16 mg/l, TN >3.75mg/l and chlorophyll a >0.18mg/l, then submersed macrophytes would be predictably absent and the lakes algal dominated. Below these levels, macrophyte abundance could be high or low. Søndergaard et al. (2010), in a study of 300 mostly shallow Danish lakes, showed that plant cover varied according to TP range as follows; TP 0.03-0.07 mg/l macrophyte coverage ranged from nearly 0 to 100%; TP 0.10-0.20 mg/l only 29% of the lakes had coverage >10%. The surveys of Danish shallow lakes indicates that the shift from macrophytes to phytoplankton takes place at TP concentrations in the range 0.05-0.125mg/l.

1. Introduction (Continued)



Such findings are important considerations in the design of long term monitoring programmes for shallow freshwater lakes. Clearly, monitoring the key trophic state indicators of TN, TP, chlorophyll a and secchi disc alone to describe a lake's condition in relation to eutrophication, as often occurs in New Zealand (i.e. using Carlson's TSI or Burns (1999) trophic state indicators - Table 2), is likely to be very limited in determining which of the two trophic states it is in - a more pristine state with clear water and aquatic plants, or a more enriched state with turbid water and suspended algae. At best, they can provide guidance on nutrient concentrations targets for lakes where macrophyte cover and diversity is not reaching its full potential (e.g. if macrophyte cover was only 50% of full potential for that lake and P was identified as the likely cause, then reducing P to meet the mesotrophic guidelines should ensure a macrophyte recovery).

Table 2. Values of variables defining the boundaries of different trophic levels for NZ lakes (Burns et al., 1999).

Nutrient Enrichment Category	Trophic State	Trophic Level	Chlor. a (mg/m3)	Secchi Disc (m)	TP (mg/m3)	TN (mg/m3)
Low	Oligotrophic	2-3	< 2	> 7	< 10	< 200
Medium	Mesotrophic	3-4	2–5	3-7	10–20	200–300
High	Eutrophic	4-5	5–15	1–3	20–50	300–500
Very high	Supertrophic	5-6	15-30	0.5–1	50–100	500–1500
Extremely high	Hypertrophic	6-7	> 30	< 0.5	> 100	> 1500

- **Maximum Depth of Submerged Plant Colonisation (MCD).** Maximum colonisation depth (MCD) is widely recognised as a simple proxy measure of macrophyte abundance in deeper lakes, but it is not as useful in shallow lakes unless the MCD is less than the bottom depth. It is sensitive to eutrophication (Søndergaard 2007) and climate change (Birks 2000).
- **Macrophyte Cover Required to Ensure a Clear State.** Various overseas studies have shown that submerged macrophyte cover needs to be >30-60% to ensure a clear water state. For example, it has been suggested that coverage should be >30% to ensure maintenance of a clear water state in shallow lakes (Jeppesen et al. 1994, Kosten et al. 2009), but coverage of 50% (Tatrai et al. 2009) or 60% (Blindow et al. 2002) has also been reported. In a recent review, 50% coverage has been used as a conservative level to ensure a clear water state.
- **Charophyte Dominance.** Charophyte dominated vegetation represents the optimum state for most shallow lakes because it enhances water clarity and reduces phytoplankton growth. This effect is caused by enhanced sedimentation and reduced sediment resuspension within charophyte meadows (Van den Berg et al. 1998), efficient nutrient immobilisation (Blindow 1992, Kufel and Kufel, 2002) and possibly the production of allelopathic substances (Hootsmans and Blindow 1994, Wium-Andersen et al. 1982). Many charophyte species are green in winter and therefore possibly cause less oxygen depletion in the lake during winter than annual submerged plants. In contrast to many submerged angiosperms, charophytes rarely grow to the water surface in lakes deeper than 1m and therefore they seldom interfere with boating and swimming activities in the lake. Many charophytes are heavily calcified. Therefore, in contrast to most submerged angiosperms, charophyte fragments sink to the lake bottom and do not bother swimmers.

1. Introduction (Continued)

- **Macrophyte Cover and Diversity Expressed as Percentage of Maximum Macrophyte Potential.** Measuring a lake's macrophyte abundance and diversity (including information on native and invasive species) can be used to develop a score that can be compared with maximum potential scores for that particular lake type. The recently developed LakeSPI (Lake Submerged Plants Indicators - Clayton and Edwards 2006) provides a useful tool and defensible means of trophic state assessment for deep lakes, but is not particularly suited for shallow lakes. This is because the indices are based on measuring macrophyte abundance and diversity on up to 5 transects per lake, rather than the recommended method for shallow lakes (<3m mean depth) of measuring abundance over the whole lake (e.g. Søndergaard et al. 2010). Only measuring plant cover along transects out to the MCD, as in the unmodified LakeSPI approach, overlooks the significance of the extent of the unvegetated area and therefore trophic status, in shallow lakes. As a result, one shallow lake with 80% macrophyte cover can score the same as another lake with only 35% macrophyte cover (e.g. Reservoir and Lake Vincent, see results in Section 3).

  In order to improve the predictive abilities of the LakeSPI for shallow lakes, the approach was modified by adding an additional indicator to the methods (see Table 3) called the Lake Macrophyte Cover Indice, adjusted for density. The results using both methods are presented and discussed later in the report for each of the four lakes surveyed. By monitoring trends in this score, information is provided that indicates the lakes general trophic states, and identifies management priorities.

- **Water Colour.** Another factor that strongly influences macrophyte cover is water colour. In a study of 700 European lakes (Sondergaard et al. 2012) found that at colours above 100 PCU, the maximum depth of plant colonisation rarely exceeded 2m, but the maximum depth could still reach up to 5m at 60–70 PCU. Bachmann et al. (2002) shows that Florida lakes with <50 PCU can have as much as 100 percent of the lake bottom covered in plants. However, once the true colour exceeds 50 PCU, the percentage of the bottom that is covered seldom exceeds 40%. This is most likely due to reductions in light penetration caused by the stained water.

In summary, it is apparent that regular monitoring of macrophyte cover is the preferred method for assessing the trophic status of a shallow lake, rather than physical, chemical and chlorophyll a variables alone (Søndergaard et al. 2010). In addition, available information indicates that there are sufficient methods and indices available to interpret the monitoring data and identify appropriate management approaches.

Previous Surveys

Limited scientific studies of three of the 2013 surveyed lakes, George, Vincent and Reservoir, have been previously undertaken as follows:

- Historical Environment Southland data collected during a 2004 survey of New Zealand shallow coastal lakes (Drake et al. 2009, 2010).
- Data collected in 2012 for Environment Southland of six shallow coastal lakes in Southland (Schallenberg and Kelly 2012). It examines the ecological condition of the lakes as represented by preliminary studies of water quality, phytoplankton, zooplankton, macrophytes, benthic invertebrates, and fish.

A summary of the findings is presented in Table 4.

Table 3. Modified LakeSPI - Scoring Approach for Shallow Lakes

Native Index	Lake SPI	Invasive Index
	Vegetation Maximum	Invasive Ratio
	Invasive Species Impact	Invasive Species Impact
Native Maximum Depth		
	Invasive Depth Impact	Invasive Depth Impact
Native Diversity	Native Diversity	
	Nature of Invasive Cover	Nature of Invasive Cover
Max. Charophyte Depth	Max. Charophyte Depth	
	Invasive Maximum	Invasive Maximum
Native Distribution	Native Distribution	
Native Ratio	Native Ratio	
	Macrophyte Cover	
Native Score	**Lake SPI**	**Invasive Score**

1. Vegetation Max. Height

LakeSPI Depth (m)	Score	
	Native	Invasive
no plants	0	0
0 – 2.9	1	1
3 – 4.9	2	2
5 – 6.9	3	3
7 – 8.9	4	4
9 – 10.9	5	5
11 – 12.9	6	
13 – 14.9	7	
15 – 16.9	8	
17 – 18.9	9	
19 m +	10	

2. Native Maximum Depth

LakeSPI Depth (m)	Score
no plants	0
0 – 2.9	1
3 – 4.9	2
5 – 6.9	3
7 – 8.9	4
9 – 10.9	5
11 – 12.9	6
13 – 14.9	7
15 – 16.9	8
17 – 18.9	9
19 m +	10

3. Native Diversity

Native Diversity	Points
Charophytes	1
Pondweeds	1
Milfoils	1
Isoetes	1
Turf Plants	1
Emergents	

4. Max. Charophyte Depth

LakeSPI Depth (m)	Score
No charophytes	0
0-4.9m	1
5-9.9m	2
10-14.9m	3
15-19.9m	4
20m +	5

5. Native Distribution

Present at >5m)	Points
Milfoils	1
Pondweeds	1
Isoetes	1

6. Native Ratio

Native Ratio (%)	Score
No Natives	0
<5%	1
5-25%	2
25-50%	3
50-75%	4
75-95%	5
>95%	6
100% native	7

7. Invasive Ratio

Invasive ratio (%)	Score
No Invasives	0
<5%	1
5-25%	2
25-50%	3
50-75%	4
75-95%	5
>95%	6
100% Invasives	7

8. Invasive Species Impact

Invasive Species	Score	SPI Score
No invasives	0	7
Juncus bulbosus	1	6
Ranunculus trichophyllus	1	6
Potamogeton crispus	2	5
Utricularia gibba	2	5
Elodea canadensis	3	4
Vallisneria species	4	3
Lagarosiphon major	4	3
Egeria densa	5	2
Hydrilla verticillata	6	1
Ceratophyllum demersum	7	0

9. Invasive Depth Impact

LakeSPI Impact Depth	Score	SPI Score
No Invasives	0	5
>8m	1	4
4-7.9m	2	3
2-3.9m	3	2
0-1.9m	4	1
No Natives	5	0

10. Nature of Invasive Cover

Invasive Cover	Score	SPI Score
No invasives	0	5
Plants occasional	1	4
Plants common	2	3
Open canopy	3	2
Partly closed canopy	4	1
Closed canopy	5	0

11. Invasive Max. Height

Invasive Height (m)	Score	SPI Score
No Invasives	0	3
<1m	1	2
1-3m	2	1
>3m	3	0

12. Lake Macrophyte Cover

% of lake area	Score
No macrophytes	0
1-10%	1
10-40%	3
40-70%	5
70-100%	8
>100%	10

New criterion to account for overall macrophyte cover in shallow lakes. The lake is divided into 6 macrophyte density classes (0%, 1-10%, 10-40%, 40-70%, 70-100%, >100%). Overall cover is the sum of each macrophyte density class multiplied by its median value (i.e. 0%, 5%, 25%, 65%, 85%, 100%) based on the portion of the lake area in each class.

Table 4. Key characteristics of three Southland shallow coastal freshwater lakes (based Schallenberg and Kelly 2012, Drake et al. 2009).

Characteristic	**The Reservoir**		**Lake Vincent**		**Lake George**	
Lake Area (ha)	35.5ha (Note: 48ha recorded in the present survey)		17.2ha (Note: 18ha recorded in the present survey)		90.8ha (Note: 105ha (recorded in the present survey, +45ha emergent rushland)	
Catchment Area (km2)	5.73km^2 (Note: 5.6km^2 recorded in the present survey)		3.14km^2 (Note: 3.4km^2 recorded in the present survey)		29km^2 (Note: 11.1km^2 recorded in the present survey)	
Mean (Max) depth (m)	5.0 (Note: 5.5m recorded in the present survey)		5.0 (Note: 6.0m recorded in the present survey)		2m (Note: 0.8m recorded in the present survey)	
Landuse (%)	66% pasture, 34% natural		91% pasture, 6% natural		50% pasture, 43% natural	
	2004	2012	2004	2012	2004	2012
Conductivity (uS/cm)	248	284	282	333	182	186
Colour (abs@440nm/10cm)	0.267	0.180	0.154	0.090	0.192	0.225
Colour (PtCo Units)	48	32	27	16	34	40
Total Phosphorus (mg/m3)	20.7	36	14.7	19	26.7	33
Total Nitrogen (mg/m3)	615	630	563	670	434	460
Chlorophyll a (mg/m3)	10.3	20	1.0	<1.5	6.2	4.0
Secchi Depth (m)	1.0		1.4		0.3	
Euphotic Depth (m)	2.6	3.27	3.5	3.95	0.7	1.26
Trophic Status (based on TP, TN, SD, Chlor a- Burns et al 2000)	**Eutrophic**		**Mesotrophic**		**Eutrophic**	
Macrophytes (3 x 50m transects - grab samples 2012, SCUBA 2004)	10% cover *Potamogeton ochreatus* *Myriophyllum triphyllum* *Ranunculus triphylis* *Elodea canadensis* *Limosella lineata* *Elatine gratioloides* *Glossostigma elatinoides*	16% cover *Potamogeton ochreatus* (locally abundant) *Chara corralina* (locally abundant) *Ranunculus triphylis* (locally abundant) *Elodea canadensis* (sparse)	86% cover *Potamogeton ochreatus* *Nitella hookeri* *Chara corralina* *Lilaeopsis ruthiana* *Limosella lineata* *Glossostigma elatinoides* *Ranunculus triphylis* *Elodea canadensis*	66% cover *Potamogeton ochreatus* (locally abundant) *Nitella hookeri* (locally abundant) *Chara corralina* ((locally abundant) *Lilaeopsis ruthiana* (sparse) *Elodea canadensis* (sparse)	0.5% cover *Lilaeopsis ruthiana* (locally abundant) *Nitella hookeri* (locally abundant) *Myriophyllum triphyllum*(locally abundant)	36% cover *Lilaeopsis ruthiana* (locally abundant) *Nitella hookeri* (locally abundant) *Myriophyllum triphyllum*(locally abundant)

2. METHODS

The 2013 broad scale habitat survey was undertaken in February 2013 by three experienced scientists, when submerged aquatic vegetation (SAV) exhibited maximum biomass. The methodology included the following:

- **Delineation of Lake Surveys** - Since most of the lakes have never been depth sounded in detail, and this particular survey did not require high detail, an intermediate approach was taken that would provide sufficient information to map broad habitat types and depth zones. Due to the logistics of boat speed, access for boat launching, shallow depth, time limitations and weather constraints, we established a series of priority regions for the surveys based upon gathering information on all depth zones and habitat types. In general, data were collected along transects that zig-zagged backwards and forwards from shore to shore along the length of each lake. Transect spacing was approximately 50 metres, with lake sampling tracks shown in Appendix Figure 1. Terrestrial margin and emergent vegetation was additionally mapped from the shoreline and aerial photographs.

- **Method of Transport -** In order to survey a large portion of each of the lakes using rapid techniques, an efficient method was needed that would work well in shallow water (0-0.5m), near shore, as well as offshore in water up to 5m depth. We used a combination of techniques as follows: wading, a dinghy and outboard motor, canoes and by or snorkelling.

- **Instrumentation** - The equipment needed to record depth, identify SAV species and heights, and sample bed substrate. We decided to use a combination of techniques as follows:
    - **Depth Sounder.** A Garmin Fishfinder 90 dual-beam transducer, which provides excellent shallow-water performance, was used to record depths along georeferenced transects. This unit also provided a record of depth and presence of SAV in areas where the beds did not extend to the surface or were emergent.
    - **Underwater Videography.** The equipment and configuration used in this project needed to be portable on a small vessel/canoe, while ensuring acquisition of high quality video images and limiting sources of variation in acquiring and classifying SAV habitat. To overcome expected limitations due to underwater visibility, we used a lightweight compact 420TVL CCD underwater camera with 30m cable, built-in white LED lighting for illumination in darker waters (5m in pitch black), and an adjustable ballast enabling it to be tilted slightly up or down. This camera provided clear underwater video images through its attached surface viewing monitor, even during periods of high turbidity and low light conditions (Secchi depths < 0.5 m), which were occasionally encountered.

      For field deployment, the camera was lowered overboard on a cable or pole, angled slightly downwards, until the bed sediments and/or SAV came into focus on the viewer.

2. Methods (Continued)

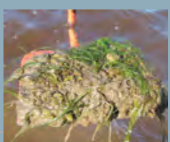
- **SAV/Substrate Sampler.** In order to sample the benthic substrate (usually mud/sand and gravel), a purpose built sediment sampler mounted on the end of a telescopic 4-5m pole was used. The sampler has a 20cm square flat bottom, two 20cm high enclosed sides and a supported open back. The front section, which digs into the sediments, is pointed. In addition, in shallow areas where sediment overflow from the sampler was not an issue, a garden hoe was used.
- **Bathyscope.** A bathyscope is a cone-shaped device (in our case 48cm high) with an 11.5cm open-ended viewing hole at the top and a 31.0cm diameter perspex transparent cover at the bottom. This device allows non-destructive viewing of the lake bed and the associated macrophyte community. The bathyscope was lowered over the side of a boat to allow assessment of the macrophyte community composition at each site where it was used.

Percent Cover 0-5%

Percent Cover 5-10%

Percent Cover 10-20%

Percent Cover 20-50%



Percent Cover 50-80%

Percent Cover 80-100%

Within the priority regions, the boat, canoe or wading person was positioned, and the substrate sampler used to carefully dig and bring up a 5-6cm deep layer of surface sediment to the surface. Representative photographs were taken, and the submerged aquatic vegetation (taxa, height, percentage cover, life stage), the sediment type, and the depth to any blackened sulphide rich layer (Redox Potential Discontinuity layer - RPD) recorded as summary information on laminated aerial photos which are subsequently used to create validated ArcMap GIS shapefiles of key broad scale habitat features throughout the lake. Examples of percentage cover classes used are shown in the margin figure. Three replicate samples were collected at each site, and sites were added until the priority region could be reliably characterised. Emphasis was placed on delineating boundaries between dominant plant species and substrate types, and changes in plant densities. Features present between sites were assessed using underwater video or direct observation. The water column at representative sites was also sampled for secchi disc clarity, dissolved oxygen, conductivity, temperature, and salinity (at surface and bottom), with summary measurements presented in Appendix 1.

The approach was based on the broad scale habitat methods described in the National Estuary Monitoring Protocol (Robertson et al. 2002), and previously applied to coastal lagoons (e.g. Stevens and Robertson 2011). Broad scale mapping summary data are presented in Section 3 and Appendix 1.

Clean muddy sediments Lake Murihiku, February 2013 - note absence of macrophyte growth.

2. Methods (Continued)

Table 5. Dominant underwater plants recorded in the four Southland shallow lakes - February 2013.

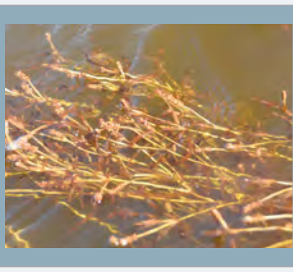
Taller Growing Native Macrophytes

These are the dominant visible species of macrophytes and they include two main genera *Potamogeton* (pondweeds) and *Myriophyllum* (milfoils). These species often form a canopy above smaller turf species and charophytes, and are often dotted amongst them without seriously impacting on their density.

Ruppia polycarpa **and** ***R. megacarpa*** **(Horse's mane weed). Photo - R. polycarpa, The Reservoir Feb 2013**

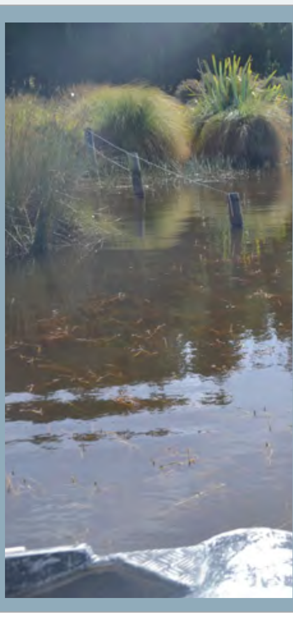
Ruppia polycarpa is a native surface-flowering submerged aquatic annual or perennial; stems to 50cm long, with the longer stems formed in deeper water; vegetative buds (turions) can be formed in some ephemeral habitats. Grows in fresh to hypersaline coastal lakes, lagoons and estuaries and is relatively common in the 0-1.5m depth range (depending on water clarity). Prefers sandy sediments.

R. megacarpa is a surface-flowering, large, robust perennial with long, much branched stems, thread-like long narrow leaves, and distinctive small flowers that are terminal on white stalks. Common in relatively shallow (~2m) permanent water (salinity range 5-46 PSS), although seeds require salinities in the lower end of range to germinate. Grows slowly and matures later, producing fewer, larger seeds than *R. polycarpa*. Seeds germinate and form seedlings in spring , with flowering and fruiting occur in summer and autumn.



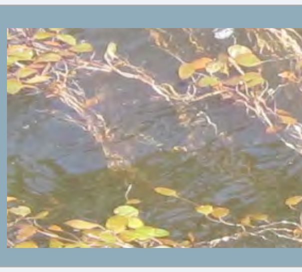
Potamogeton ochreatus **(Blunt pondweed). Photo - Lake Vincent Feb 2013**

Potamogeton ochreatus is a common native pondweed species, tolerant of slightly brackish as well as fresh water. Survives low light and temperatures, and prefers high nutrient water. It forms dense mats of vegetation up to the water surface. Germinates in autumn, grows vigorously in spring, and dies off in the late summer. Decaying plant matter can make the water enriched and encourage nuisance algal mats near the sediment surface. Common in The Reservoir and Lake Vincent.



Myriophyllum triphyllum**. Photo - Lake Vincent Feb 2013**

Myriophyllum triphyllum is a widespread native water milfoil species. Plants grow to 3m tall, have emergent and submerged leaves. Emergent stem apices (mid summer) often reddish, flowers male and female together. Emergent leaves 4-11mm long and 4mm wide. Submerged leaves pinnately divided 1.5 - 3.0cm long. Patches in Lakes George and Vincent.



Potamogeton cheesemanii **(Red pondweed). Photo - The Reservoir Feb 2013**

Potamogeton cheesemanii is a widespread native pondweed species that is tolerant of slightly brackish as well as fresh water. Submerged or floating, rhizomatous sparsely branched perennial herb. Rhizomes rooting at nodes and producing mostly simple leafy branches; these ultimately emerge at water surface. A common plant of ponds, lake margins and slowly flowing streams. Flowering Nov-March and fruiting Dec-March.

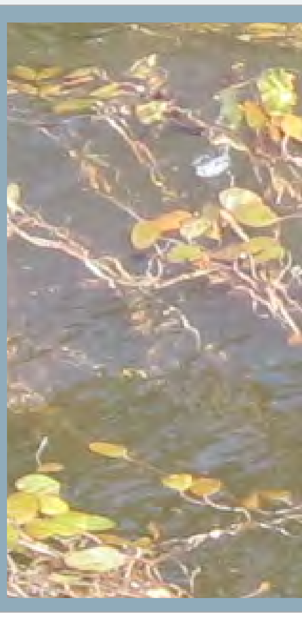
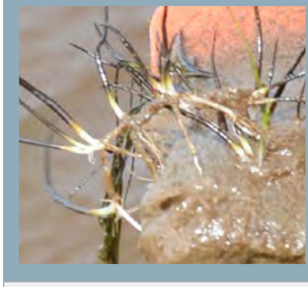


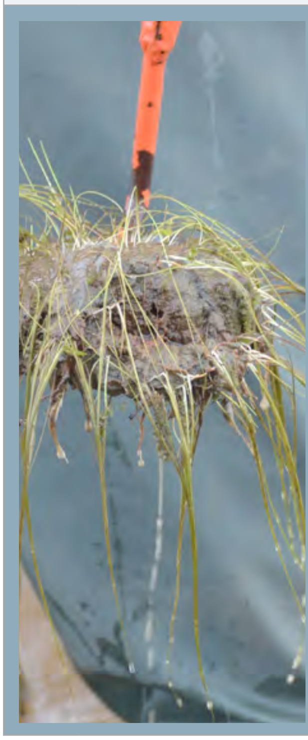
Table 5. Dominant underwater plants recorded in the four Southland shallow lakes - February 2013.

Turf Species of Native Macrophytes

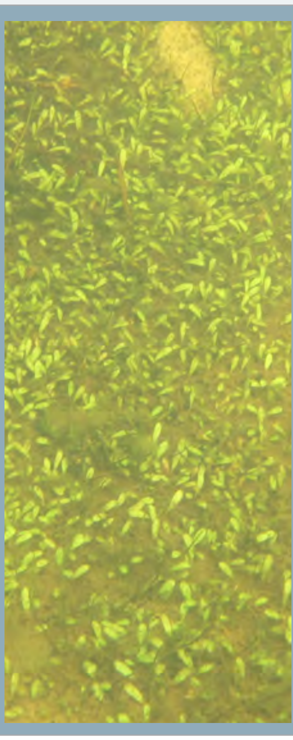
These short species grow in shallow water (up to 2m depth) along the lake shorelines that have a moderate degree of exposure. They tend to be absent on sheltered shorelines and their position is occupied by emergent macrophytes. They may also mix with the adjacent emerging plants in deeper water. *Isoetes* is often quoted as being of special value, since it can grow to greater depths (up to 6m in large clear lakes) than other turf species.

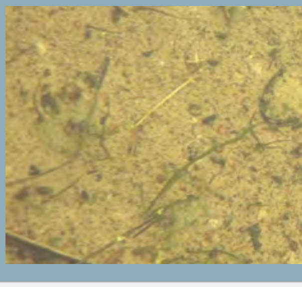


***Lilaeopsis ruthiana*. Photo - Lake George Feb 2013**
Native, submerged vascular macrophyte, rooted in substrate. Creeping herb with cylindrical septate leaves (2-5cm long). Vegetatively similar to *L. novae-zelandiae,* but leaves are often finer with paler septa. Rhizome creeping like *Ruppia*. Widespread in damp margins of waterways.



***Glossostigma elatinoides*. Photo - The Reservoir Feb 2013**
Native, submerged vascular turf macrophyte, rooted in substrate. Spatulate leaves, loose mats with leaves in pairs not tufts like *Limosella*. Widespread in North and South Islands. Common in Lakes George, Vincent and The Reservoir.





Limosella lineata.
Native, submerged vascular turf macrophyte, rooted in substrate. Loose mats with leaves in tufts. Widespread in North and South Islands. Common in Lakes George, Vincent and The Reservoir.

Ranunculus amphitrichus (Waoriki). **Photo - The Reservoir Feb 2013**
Native, submerged vascular turf macrophyte, rooted in substrate. Coastal to montane. Often partially submerged in shallow water, wet grassland and lake, pond or tarn marginal turf communities. Sometimes in moist clearings within forest or tussock grassland. Flowers in Oct-Jan (yellow flower).

2. Methods (Continued)

Table 5. Dominant underwater plants recorded in the four Southland shallow lakes - February 2013.

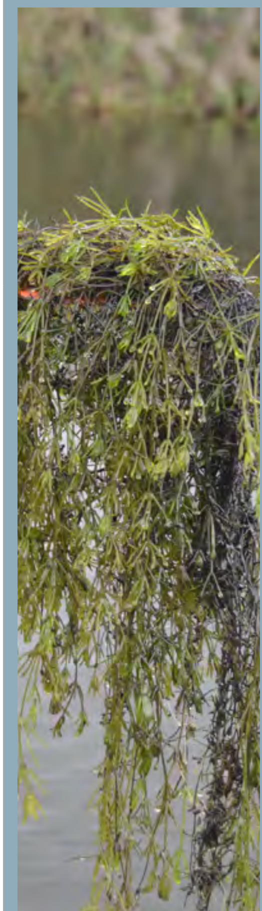
Charophytes (large green algae)

Charophytes are highly-developed green macro-algae that grow in mainly alkaline, freshwater lakes and ponds. They are a native species and were the dominant submerged macrophyte species in New Zealand prior to European arrival (Wood and Mason, 1977). They are sensitive to mechanical damage by bottom dwelling fish (Blindow, 1992), wind turbulence, and water clarity (Casanova and Brock, 1999). Their growth rates can be affected by more competitive plants (Wade, 1990), variable light and nutrient treatments, water depth, P concentration, and substratum particle size. Consequently, they are often absent from highly eutrophic lakes (Forsberg, 1964).

Besides aquatic mosses, charophytes are the deepest macrophytic colonists in lakes. Charophytes are a common component of the littoral zone in oligo- to moderately eutrophic water bodies. Along with increasing eutrophication, charophytes are known to give way to angiosperms, mainly to *Potamogeton* species (Ozimek and Kowalczewski 1984, Pieczy´nska et al. 1988, Blindow, 1992a), to disappear finally from extremely turbid lakes.

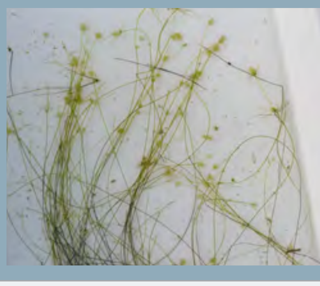
Charophytes have poorly developed root systems and most nutrient uptake is via the shoots (Kufel and Kufel 2002).

Charophytes tend to dominate in deeper water at low light intensities, particularly where the water has a high pH value. They are usually at a competitive disadvantage in shallow, moderately productive habitats. Charophytes live in all types of freshwater environments and are considered an ecologically significant component of aquatic ecosystems due to their ability to clarify the water column (Blindow et al. 2002). Charophytes prefer relatively calm waters (Garcı´a 1994), and there is evidence that windy weather destabilises *Chara* spp. beds in shallow lakes (Garcı´a 1994, Havens 2004). Wind-driven uprooting and sediment re-suspension may partly account for this observation (Blindow et al. 2002); however, disappearance of *Chara* spp. or long-term difficulties of recovery, even without uprooting, are among the adverse effects of wind-driven turbulence (Blindow et al. 2002).



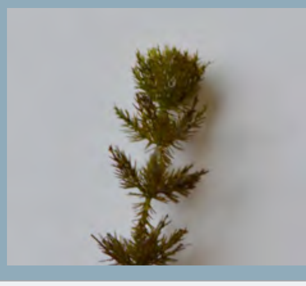
***Chara corallina*. Photo - Lake George Feb 2013**

Chara corallina is a widespread native submerged bottom-dwelling green charophyte algal species, that superficially resembles flowering aquatic plants. Plants are stout and crisp with turgid segments and pinched nodes, pale to bright green. The conspicuous antheridia (male sex organs) are spherical and bright orange or yellow when mature. No stem divisions in *Chara corallina*. Widespread in North and South Islands. Common in Lakes Vincent, George and The Reservoir.



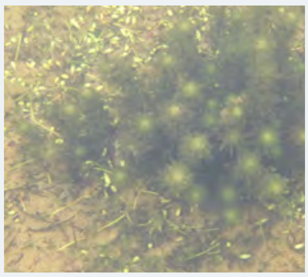
***Nitella* sp. Photo - Lake George Feb 2013**

Nitella is a widespread native bottom-dwelling, green charophyte algal species that superficially resembles flowering aquatic plants. *Nitella* sometimes creates dense carpets on freshwater or slightly saline lagoon beds, reaching depths of 30m in some clear lakes (Johnson and Brooke 1989). It is a long stringy looking plant without leaves. Stems "pop" if squeezed. Photo shows *Nitella* flowering in Lake George (February 2013). Moderate abundance in Lakes Vincent, George and The Reservoir.



***Chara fibrosa*. Photo - Lake George Feb 2013**

Chara fibrosa is a relatively common native bottom dwelling, grey-green charophyte algal species. Many small spines grow from a central stem (generally <0.5m) with reproductive organs found near the stem, surrounded by spines. Oospores black. Most common in shallows <2m.

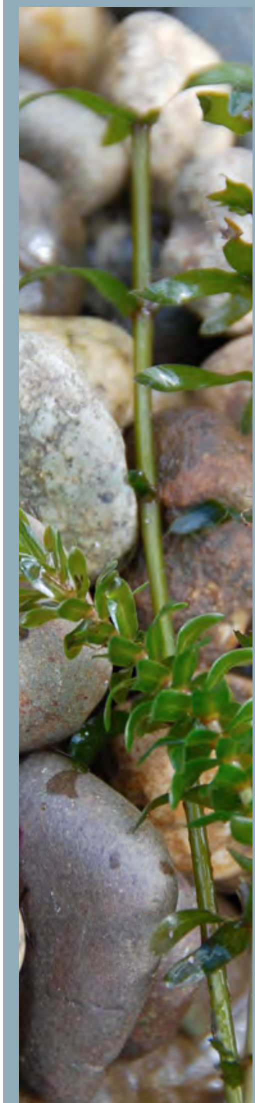


2. Methods (Continued)

Table 5. Dominant underwater plants recorded in the four Southland shallow lakes - February 2013.

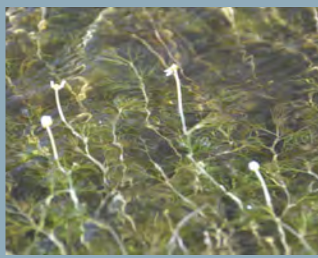
Taller Growing Introduced Macrophytes

These are the dominant visible species of macrophytes and they include two main genera *Potamogeton* (pondweeds) and *Myriophyllum* (milfoils). These species often form a canopy above smaller turf species, and charophytes and are often dotted amongst them without seriously impacting on their density.



***Elodea canadensis* (Canadian pondweed). Photo - The Reservoir Feb 2013**

Elodea, an introduced oxygen weed, is an aquatic perennial which can grow easily from fragments and spread via vegetative growth and cause major infestations in many freshwater and slightly saline waterbodies. Classified in "The Lake Managers Handbook - Alien Invaders" (Champion et al. 2002) as a member of the most problematic submerged aquatic weed plant families i.e. Hydrocharitaceae (genera: *Elodea, Egeria* and *Lagarosiphon*) and Ceratophyllaceae (genus: *Ceratophyllum*). Patchy distribution, The Reservoir, Lake Vincent.

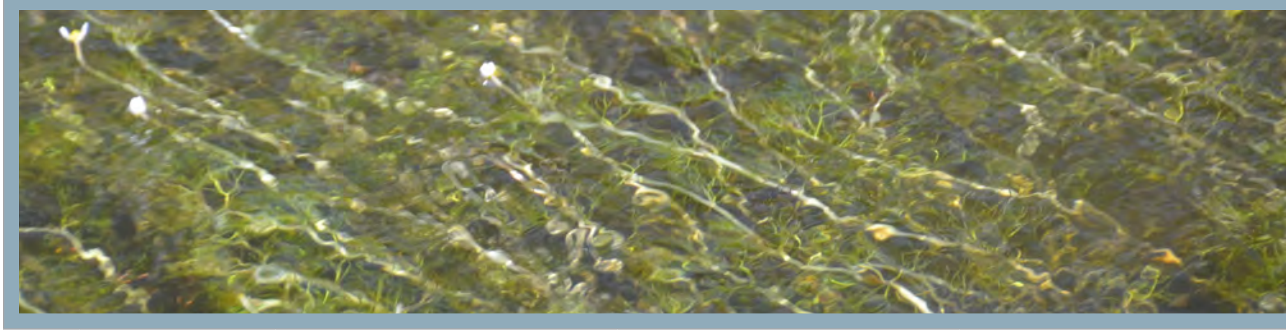


***Ranunculus trichophyllus* (Water buttercup). Photo - The Reservoir Feb 2013**

Ranunculus trichophyllus (water buttercup) is an introduced species common in freshwater and slightly saline waterbodies. Stems are up to 2m long, leaves are narrow and bright green. Flowers are white with a yellow centre. These mats inhibit the growth of native aquatics, and can interfere with boating and other water recreation. These plants germinate in autumn, grow vigorously in spring, and die off in the summer. The decaying plant matter can make the water extremely enriched and encourage nuisance algal mats near the sediment surface. Isolated patches in The Reservoir near the ocean. Common in Waiau Lagoon.

***Potamogeton crispus* (Curly pondweed). Photo - Waiau Lagoon 2011**

Potamogeton crispus is an introduced species that is tolerant of slightly brackish as well as freshwater. It can survive in low light and low temperatures, and prefers high nutrient water. It spreads mostly by means of vegetative buds (turions) that germinate in autumn. It forms dense mats of vegetation to the surface of the water. These mats inhibit the growth of native aquatics, and can interfere with boating and other water recreation. These plants germinate in autumn, grow vigorously in spring, and die off in the summer. The decaying plant matter can make the water extremely enriched and encourage nuisance algal mats near the sediment surface. Very common in Waiau Lagoon.



2. Methods (Continued)

Table 5. Dominant underwater plants recorded in the four Southland shallow lakes - February 2013.

Emergent Shoreline Plants

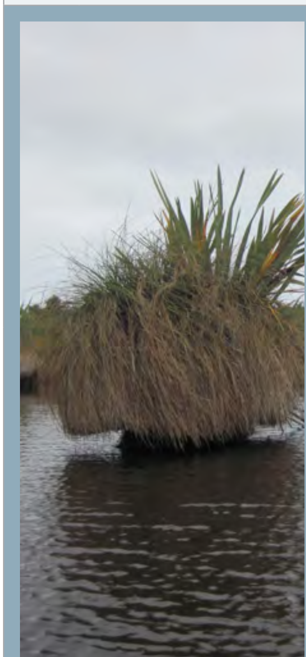
These are the dominant visible species of emergent shoreline macrophytes and they include a variety of wetland species that tend to be tall-growing, erect and occupy the lake margin from just above the water line and can extend out into the water to a depth of around 2m. This community is generally only found in sheltered shores such as around the margins in small lakes and is not found in wave-exposed areas.

***Typha orientalis* - raupo. Photo - L. Murihiku Feb 2013.**
A vigorous erect clump-forming native plant with spreading rhizomes. Found throughout NZ in shallow fertile waters of sheltered lakes and swamps. Leaves are pale green and large, furry brown, cylindrical seed heads, the lower female part and the narrower upper male part. The seedheads are fluffy when ripe. Raupo dies down in the winter.

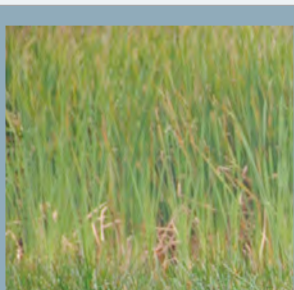
***Juncus edgeriae* - wiwi or Edgars rush. Photo - The Reservoir Feb 2013.**
This is the most common indigenous species. Coastal to alpine (1600 m.a.s.l.) but mainly coastal to montane. Usually in open shrubland, fringing wetlands, and in seasonally damp sites. Often found invading pasture and in urban areas. Flowering Oct-Dec and fruiting Nov-April.

***Carex secta* - purei or nigger-head. Photo - The Reservoir Feb 2013.**
An endemic tussock-forming sedge. Found throughout the North, South and Stewart Islands. Widespread in suitable wetlands from coastal to montane wetlands. Flowering Oct-Nov and fruiting Oct-Dec.

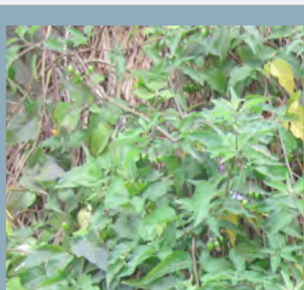
***Apodasmia similis* - *oioi* or jointed wire rush. Photo - L. George Feb 2013.**
Formerly *Leptocarpus similis*. A rush with dark-banded wire-like slightly zigzagging stems. An endemic coastal rush but is also found around peat bogs and hot springs. It flowers from October to December and bears fruit from December to March.



***Carex secta* - L. Murihiku.**



***Eleocharis sphacelata* - bamboo spike sedge. Photo - Murihiku Feb. 2013.**
A common native - mainly in lowland areas. Preferring sunny situations where it usually grows in still deep water such as along lake and pond margins, often amongst Raupo. Rarely bordering slowly flowing streams and rivers, bogs.



***Solanum dulcamara* - bitter-sweet or deadly nightshade. Photo - Murihiku Feb. 2013.**
An introduced perennial climber growing to 2.5m by 2.5m at a medium rate. All parts of the plant, including the fruit, are poisonous.

Lake Murihiku Feb 2013

3. RESULTS AND DISCUSSION

Lake Muruhiku, a small, freshwater shallow lake near Oreti Beach in Southland, was sampled on 21-23 February 2013. Weather on the days of sampling was partly cloudy with a light westerly wind. Detailed results and discussion are presented below, along with other relevant information.

WATER DEPTH AND MORPHOMETRY

The survey of lake water depth (see Appendix 1 for details on the path followed to collect depth and other information) and morphometry showed a 400m long, oval-shaped lake with a maximum depth of 0.8m (Figure 2). The most extensive shallow areas were located around the margins of the lake. The deepest sections were located in the main basin of the lagoon. In general, although the lake was situated within very gently rolling farmland that offered little shelter, it had limited wind fetch because of its small size.

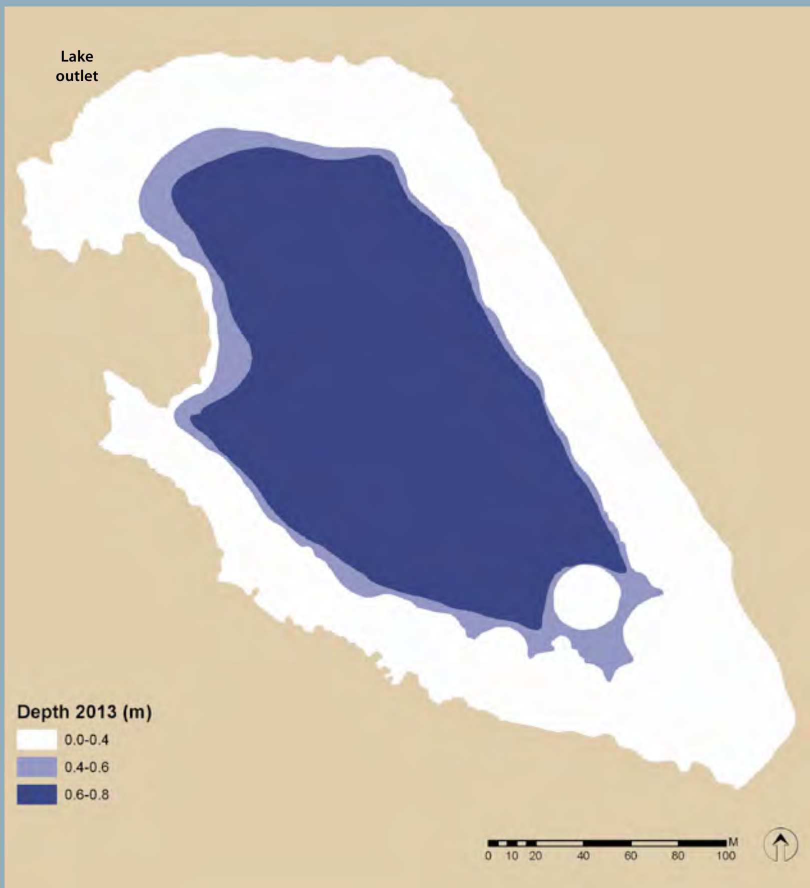


Figure 2. Lake Murihiku, water depth on 21 February 2013 (detailed transect measurements in Appendix 1).

WATER CLARITY AND COLOUR

Secchi disc clarity was very low and similar throughout the lagoon (0.3-0.4m). These values meant that the majority of the bed of the lagoon on 21-23 February 2013 was not receiving sufficient light for plant growth. The lake had a natural brown stain from elevated dissolved organic carbon but as yet no colour readings have been taken. Once these readings have been collected, the results can be used to assess the extent to which the brown stain affects water clarity and macrophyte growth.

WATER SALINITY/CONDUCTIVITY

Although Lake Murihiku is a coastal lake located within 3.8km of the sea, it consisted primarily of freshwater. Survey results showed a conductivity of 279-282uS/cm, which equates to a salinity of approximately 0.17ppt (c.f. full strength seawater has salinity of 34-36ppt). Such readings indicate a relatively low influence of the sea on the lake chemistry. The data shows little difference between surface and bottom salinities, indicating that the lake waters were well-mixed.

WATER DISSOLVED OXYGEN

The dissolved oxygen concentrations were in the range 93-103% saturation throughout the lake in both surface and bottom waters on 21 February 2013. These results confirmed the well-mixed nature of the lake.

SUBSTRATE TYPE, REDOX STATUS

The bottom sediments of the lake were dominated by very soft muds over the whole of the lake bed (Figure 3). Such sediment types are typical of shallow coastal lakes in New Zealand where the catchments have been developed, thus exacerbating inputs of fine sediment. The survey also showed a presence of black, sulphide-rich anoxic sediments, but at a low incidence, with visible black staining only being present in some locations. The presence of a visible anoxic layer, as well as implications for phosphorus (P) availability, is further elaborated on in the next section.

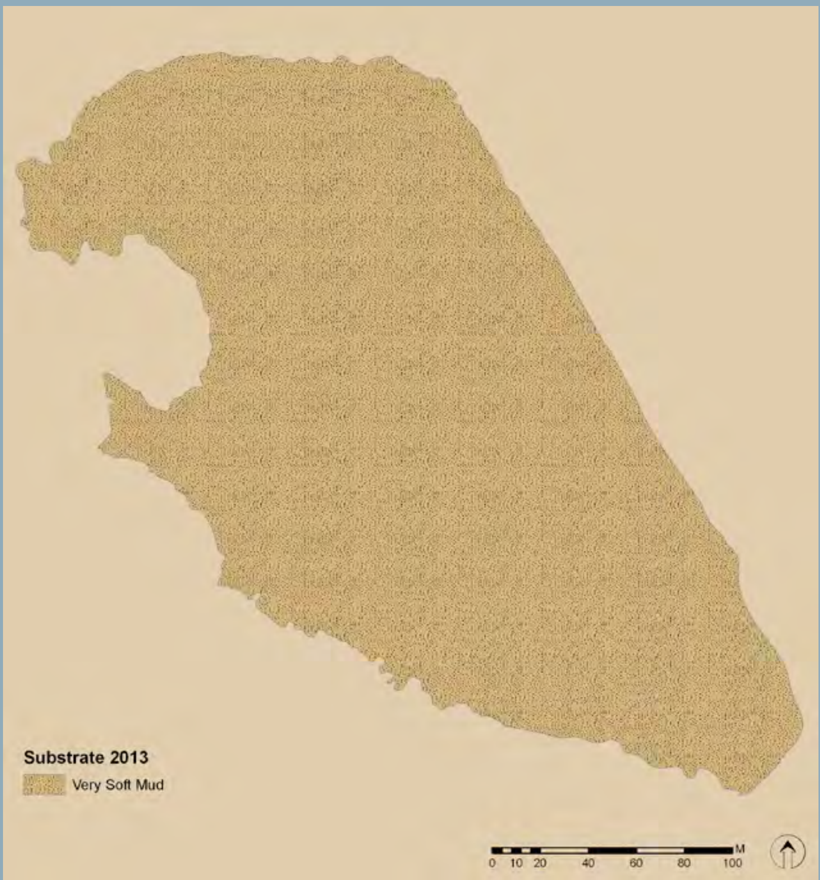


Figure 3. Lake Murihiku, substrate type, 21 February 2013.

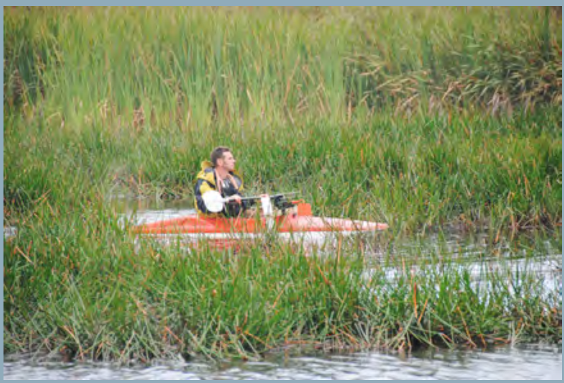
3. Results (Continued)

- **Visibility of RPD Layer.** In estuaries and the ocean, the use of the depth of the Redox Potential Discontinuity (RPD) layer as an indicator of the extent of eutrophication is well understood as a recognizable division zone between oxidised (sub-oxic) and reduced chemical conditions in the sediment (Fenchel 1970, Lyle 1983, Santschi et al. 1990). The oxidised part appears as rust-brown, and the reduced layer below is generally grey or black. Monitoring results indicate that the RPD should be deeper than 2cm to allow the existence of a normal macrobenthic community (Grizzle and Penniman 1991, Tett et al. 2007). This vertical zonation results from the oxidation of organic matter being coupled to a succession of increasingly less energetically-favorable terminal electron acceptors. Oxygen (O_2) is used first; then nitrate (NO_3^{-1}), then manganese Mn(IV), then iron Fe(III), and then sulphate ($SO4^{-2}$). The oxidation of sulphates to sulphides is the only one of these redox reactions that produces a strong change in colour marking the presence of the anoxic or reduced zone. Unfortunately, in shallow lakes, sediment sulphate concentrations are often low, so the strong colour marker does not occur and the sediments remain brownish even though they may be strongly anoxic.
- **Influence on Phosphorus Availability.** The low sulphate concentrations in lakes also have an important bearing on which nutrients are in short supply. In lakes, phosphorus (P) is generally the limiting nutrient while in marine waters it is nitrogen (N). To a large extent, this is because in estuaries, and the ocean, dissolved sulphate is elevated which acts to increase P release from the sediments, primarily by the dissolution of P bearing phases (particularly iron-bound P) by hydrogen sulfide generated in the process of microbial sulfate reduction. Because freshwaters have comparatively low dissolved sulphate concentrations, their potential for iron sequestration by sulphides is very limited and consequently explains the higher availability of P in marine and estuarine areas (and with it higher nitrogen limitation) (Blomqvist et al. 2004). In addition, in shallow, well-mixed lakes like those surveyed, the water column is generally always oxic, and allows oxygen to diffuse down into the sediment and keep the redox potential sufficiently high to maintain iron in an oxidised state (i.e. keeps the lid on the sediment P pool). In deeper eutrophic lakes with bottom water anoxia, sediment P release is favoured because iron converts to a dissolved form (FeII) which means adsorbed P dissolves and is transferred to the water phase.

Muddy sediments with sulphides present, Lake Murihiku.

Muddy sediments, Lake Murihiku.

Muddy sediments plus decaying vegetation.



***Eleocharis* and *Typha* beds, Lake Murihiku.**

3. Results (Continued)

Table 6. Area of major aquatic vegetation classes.

Vegetation Class	Area (ha)	% of lake
Tussockland	0.2	3.4
Reedland	0.5	8.9
Sedgeland	0.7	13.4
Turf Plant	0.1	1.5
Unvegetated	3.9	72.8
Total	**5.3**	**100**

MACROPHYTE AND MACROALGAL COVER

The results of the broad scale survey of dominant macrophyte and macroalgal cover (Figures 4 and 5) indicated the following (full list of species in Appendix 1 and major vegetation classes in Table 6):

- Macrophyte cover was estimated at 27% of the total lake area, and where present was at a high density (>70% cover).
- Maximum depth of macrophyte cover (MCD) was 0.4m.
- Macrophyte cover consisted mostly of natives, with the dominant cover being the emergent species *Eleocharis sphacelata* (bamboo spike sedge), the reed *Typha orientalis* (raupo), and sedge *Carex secta* (niggerhead).
- Introduced cover was limited to the emergent *Solanum dulcamara* (bitter-sweet or deadly nightshade) growing as a sub-dominant around the lake margins primarily among reeds and sedges.
- The shallow edge emergent zone (0-0.4m) was dominated by the emergent sedge *Eleocharis sphacelata* (13% of lake), the reed *Typha orientalis* (raupo) (9% of lake), and *Carex secta* (niggerhead) (3% of lake).
- Turf species (in the 0-0.2m depth zone) were dominated by *Glossostigma elatinoides* (1.5% of lake).
- In the 0.4-0.8m depth zone, there were no macrophytes, i.e. the bed was unvegetated.

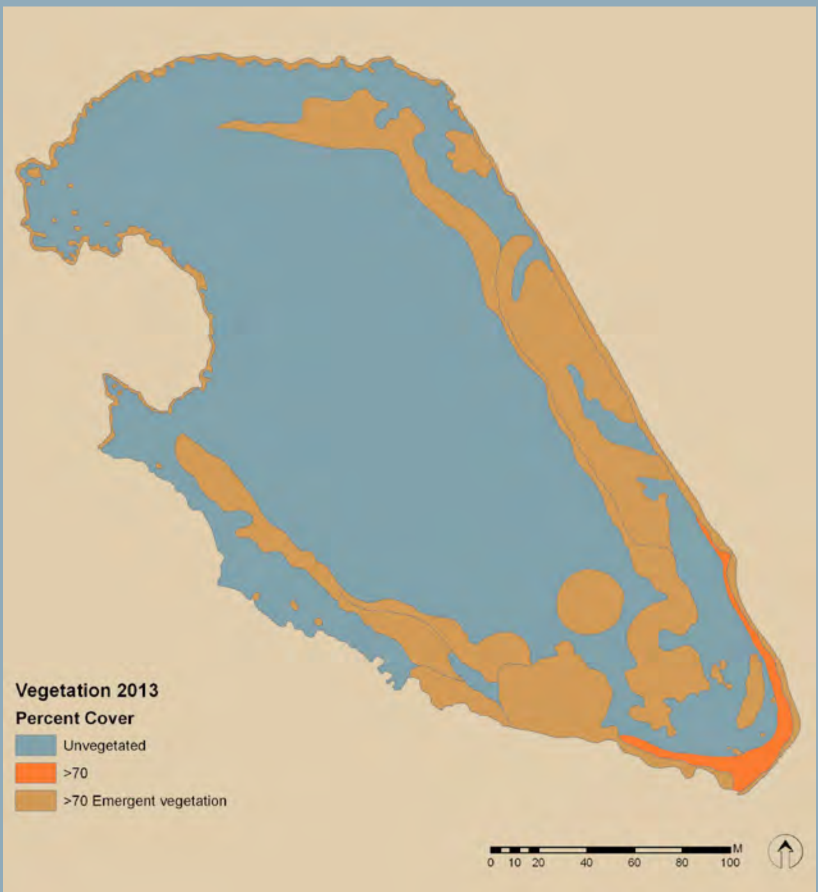


Figure 4. Lake Murihiku, aquatic macrophyte percentage cover, 21 February 2013.

TROPHIC STATUS

As explained in Section 1, in terms of trophic status, shallow lakes (<3m mean depth) are in best condition when macrophytes cover the entire lake bed. However, as they become more nutrient enriched and eutrophic, gaps may occur in the macrophyte cover either temporally (seasonally or between years) or spatially (macrophyte-free areas). In addition, a shift towards more invasive introduced species can accompany this increase in bare areas. When macrophyte cover is low or absent, then phytoplankton often dominate (Sayer et al. 2010).

The results of the 2013 broad scale survey of Lake Murihiku identify three key features that indicate that the lake is likely to be in a mesotrophic/eutrophic state.

1. Macrophyte Cover.

- **As % of Total Lake Area.** Overall lake macrophyte cover occupied only 25% of the lakebed, of which the majority were shallow water emergents. As indicated in Section 1, macrophyte cover should be greater than 50% coverage to ensure a clear water state.
- **As % of Maximum Potential.** The submerged plant indicators (SPI) management tool, LakeSPI - unmodified (Table 7) shows that this particular tool was not able to be applied to Lake Murihiku because "any lake with emergent species around the lake margins must also have submerged vegetation present for scoring purposes" (Clayton and Edwards 2006). However, the absence of submerged vegetation, clearly places the lake in a state that is far from its maximum potential, with a rough guess at 10-20%.

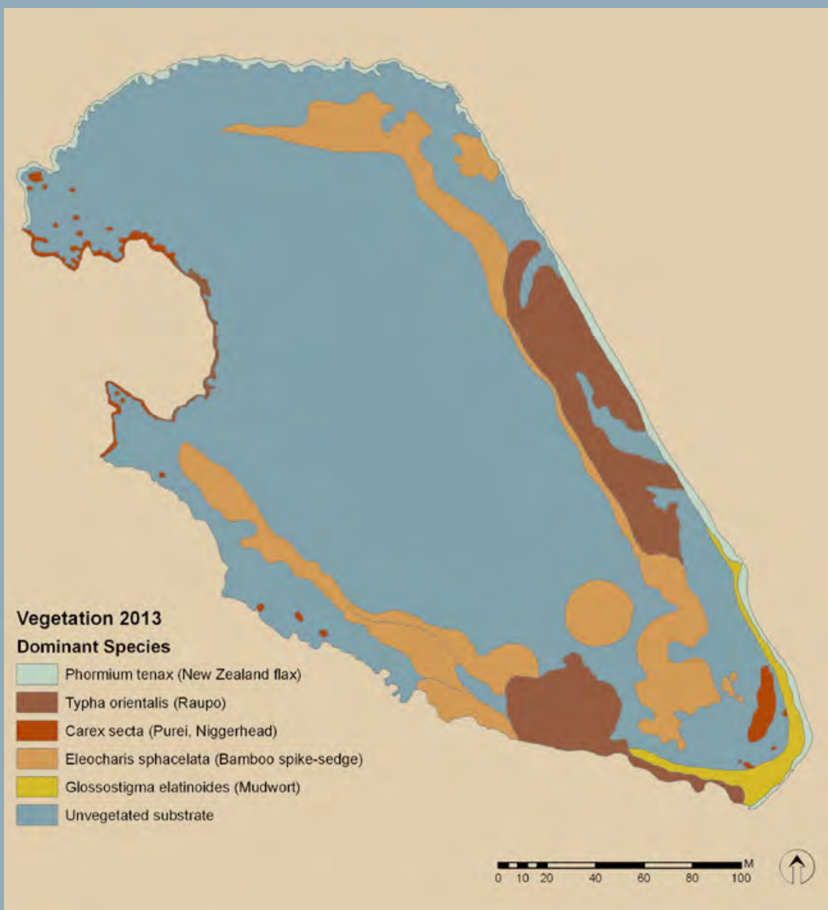


Figure 5. Lake Murihiku, dominant aquatic macrophyte species, 21 February 2013.

Table 7. LakeSPI Scores for 4 shallow lakes using unmodified and the recommended modified approaches (modifications explained on p.4).

	The Reservoir			Lake Vincent			Lake Murihiku			Lake George		
	Points	LakeSPI	Modified LakeSPI	Points	LakeSPI	Modified LakeSPI	Points	LakeSPI	Modified LakeSPI	Points	LakeSPI	Modified LakeSPI
a. Vegetation Max. Depth	1	1	1	2	2	2	1	1	1	1	1	1
b. Native Max Depth	1	-	-	2	-	-	1	-	-	1	-	-
c. Native Diversity	4	4	4	4	4	4	1	1	1	4	4	4
d. Charophyte Meadows	1	1	1	1	1	1	0	0	0	1	1	1
e. Native Distribution	0	0	0	0	0	0	0	0	0	0	0	0
f. Native Ratio	6	6	6	6	6	6	6	6	6	7	7	7
g. Invasive Ratio	1	-	-	1	-	-	1	-	-	0	-	-
h. Invasive Species Impact	3	4	4	3	4	4	0	7	7	0	7	7
i. Invasive Depth Impact	3	2	2	3	2	2	0	5	5	0	5	5
j. Nature of Invasive Cover	2	3	3	2	3	3	1	4	4	0	5	5
k. Invasive Max. Height	1	2	2	2	1	1	1	2	2	0	3	3
l. Macrophyte Overall Cover	3	-	3	8	-	8	0	-	0	5	-	5
TOTAL LakeSPI SCORE	-	**23**	**26**	-	**23**	**31**	Not appropriate to score due to low submerged cover			-	**33**	**38**
Max Potential Score	-	**40**	**50**	-	**40**	**50**				-	**34**	**44**
Final LakeSPI Index (% of max potential)		**58%**	**52%**		**58%**	**62%**					**97%**	**86%**

Note: Scores are based on whole lake broad scale vegetation mapping rather than a limited number of transects.
LakeSPI = LakeSPI Score a+c+d+e+f+h+i+j+k,
Modified LakeSPI = Modified LakeSPI a+c+d+e+f+h+i+j+k+l,
Native Condition Index = Points b+c+d+e+f,
Invasive Condition Index = Points g+h+i+j+k.

- **Maximum Depth of Plant Colonisation (MCD).** The MCD was only 0.4 m (and these were emergents) despite the lake depth extending to 0.8m, which indicates low water clarity (secchi disc depth 0.4m) brought about by one or all of the following; wind resuspension of the muddy sediments, elevated phytoplankton levels, and the dark natural brown humic staining. In March Lake Murihiku was 100PtCo units, therefore colour was likely to be one of the main factors limiting macrophyte growth on the lake bed. However, wind resuspension of sediments also sits very high on the list of likely limiting factors given the shallowness, exposure and low secchi disc depth.

2. Nutrient Enrichment.

- As yet, concentrations of nutrients and chlorophyll have not been measured in the lake, so the importance of phytoplankton in reducing light levels is unknown. Further work is recommended to provide this. Once such information is available, then nutrient and chlorophyll a concentrations will be able to be used to help explain the absence of submerged macrophytes. For example, P concentrations need to be consistently above 0.05-0.125mg/l for a shift to a phytoplankton dominated state and chlorphyll a concentrations need to be consistently greater than 10ug/l.

Taken in combination, the macrophyte cover results place Lake Murihiku in the tentative mesotrophic/eutrophic category. The key factors influencing this trophic state rating are the very low macrophyte cover, high margin emergent cover, muddy sediments, the low abundance of invasive species, the absence of nuisance macroalgae and epiphytes, and the low water clarity.

Clearly, this rating needs to be better substantiated by additional studies that identify the cause of the lakes very low submerged macrophyte cover.

The key issues that could turn Lake Murihiku towards a more degraded trophic state are excessive nutrients and fine sediments. It is recommended that management actions to minimise nutrient and fine sediment loads be undertaken.

3. Results (Continued)

Terrestrial margin, Lake Murihiku.

Terrestrial and Rushland Vegetation

The broad scale mapping of the vegetation (Figure 6) in the 200m terrestrial margin (ignoring rushland as it was included in the emergent aquatic vegetation) surrounding the lake in 2013 showed a highly modified terrestrial margin, dominated by grazed pasture (82% of area), native and exotic scrub/forest and flaxes (7% of area), and residential and industrial (9% of the area) (Table 8). The industrial area included a small quarry.

Table 8. 200m terrestrial margin vegetation 2013.

Terrestrial Margin	Area (ha)	% of margin
• Grassland	26.46	82%
• Industrial/Residential	2.82	9%
• Tussockland	1.45	4%
• Scrub/forest	0.93	3%
• Forest	0.72	2%
TOTAL	**32.4ha**	**100**

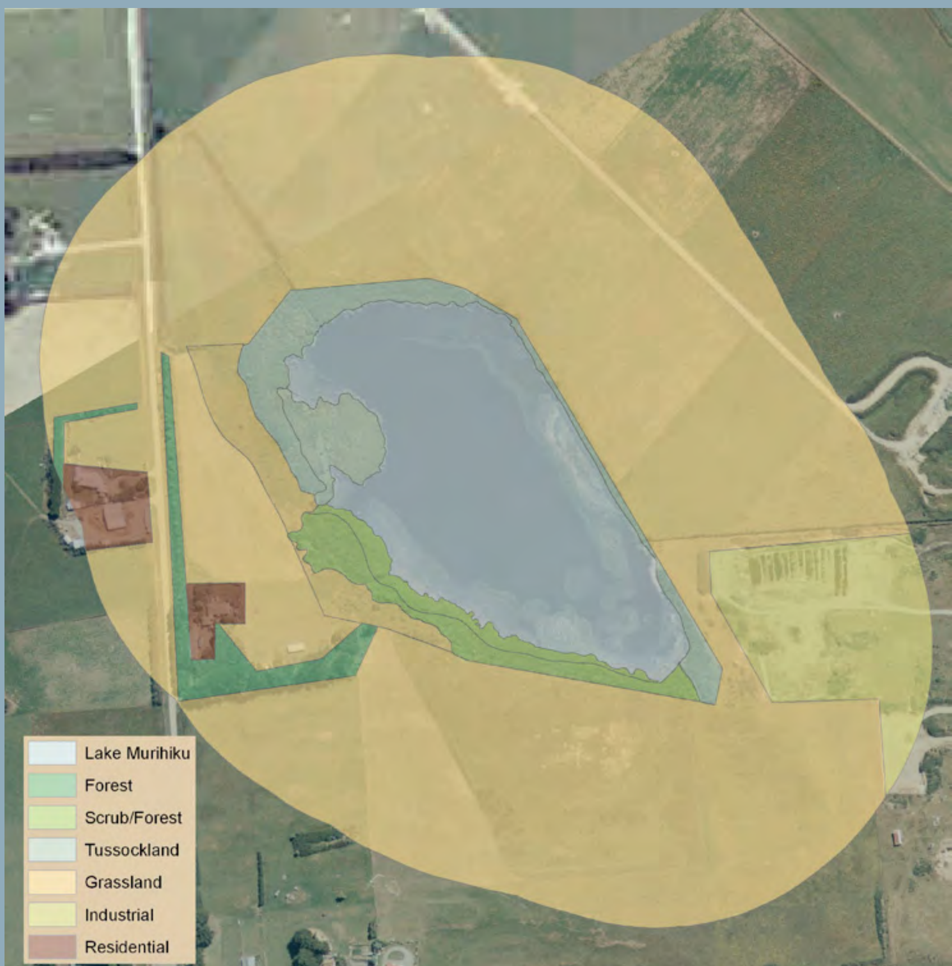


Figure 6. Lake Murihiku, dominant 200m terrestrial margin vegetation, 21 February 2013.

4. SUMMARY

The results of the 2013 broad scale habitat mapping and macrophyte survey of Lake Murihiku identified it as a very shallow, semi-sheltered, moderately flushed freshwater coastal lake (maximum depth 0.8m). The lake is situated near the lower Oreti River and drains a very small 31ha catchment consisting of mainly pasture (Figure 1). As is typical for such small shallow coastal lakes, the water was well mixed, oxygenated, and had a strong natural brown dissolved organic matter (DOM) stain. The lake bottom was dominated by very soft muds.

Within the lake, submerged macrophyte cover was virtually absent, but dense cover of emergent vegetation was present in the shallow waters around the lake margin. Overall, it was crudely estimated that the submerged macrophyte vegetation and diversity were at <10-20% of their maximum potential. This poor score reflected the presence of emergent species only, the absence of submerged species, presence of invasive species, and the fact that macrophyte growth extended to only half of the lake depth. Clearly, submerged macrophytes were under some stress, with the potential causes being a combination of the following:

- wind resuspension of the muddy sediments,
- elevated phytoplankton levels, and
- the dark natural brown humic staining.

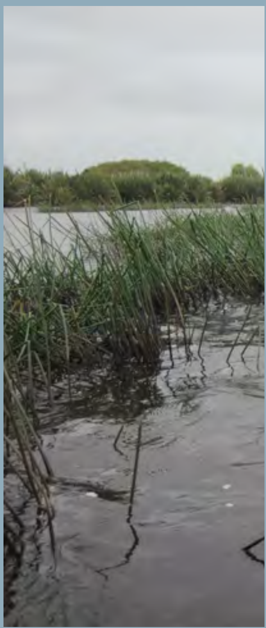
Given the lack of data for nutrients, chlorophyll a, colour, and wind resuspended sediment, the actual cause could not be clearly identified. In order to address these issues, further work is recommended.

Taken in combination, these results indicate that the lake is currently in a tentative "mesotrophic/eutrophic" condition, with a poor community of submerged aquatic macrophytes. As such, it is recommended that further short-term, targeted investigative monitoring be undertaken, guidelines for nutrient and fine sediment loads to the lake be derived, and current loads be reduced to meet these guidelines.

A brief summary guide of recommended targets and actions for improving macrophyte condition is presented in the following table.

Indicators	Existing Condition	Target Condition	Action
Poor Macrophyte Cover	<5% submerged macrophyte cover. Macrophytes at <20% of maximum potential.	Maintain at existing level or improve.	Monitor macrophyte diversity and cover at 5 yearly intervals to assess trends, but only if interim investigations confirm that non-natural causes are responsible for the low submerged macrophyte cover.
Presence of Invasive Macrophytes	0% of lake occupied by invasive macrophytes.	Maintain at existing level.	Monitor macrophyte diversity and cover at 5 yearly intervals to measure any trends of increasing invasive cover and/or new incursions.
Nutrients, Colour, Wind Resuspension	Unknown.	Ensure TP loads to the lake keep a mean TP lake concentration of <20ug/l. Chlor a <10 ug/l. Ensure SS loads to the lake are low to ensure lake infills slowly and sediment resuspension is minimised.	Undertake desktop model calculations (e.g. PCLake) to calculate appropriate nutrient and sediment load guidelines for the lake. Undertake water colour, and sediment resuspension measurements to assess whether submerged macrophytes are limited by water colour and sediment resuspension.

5. MONITORING RECOMMENDATIONS



The key indicator of the ecological condition of shallow lakes is the presence of a healthy cover of primarily native macrophytes. Multiple shallow lake studies from overseas indicate that submerged macrophyte cover needs to be >50% to ensure a clear water state. Because macrophyte cover in Lake Murihiku was less than this guideline, i.e. <5%, it is recommended that broad scale habitat mapping of macrophyte diversity and abundance be undertaken at 5 yearly intervals, but only if interim investigations (see below) confirm that non-natural causes are responsible for the low submerged macrophyte cover. Such a survey will provide sufficient data to establish lake trophic condition trends using macrophyte based tools and guidelines such as modified LakeSPI, and the results of similar type lake studies. In addition, on each sampling occasion, it is recommended that water quality data (DO, conductivity, temperature, secchi disc, total nitrogen and total phosphorus) also be measured at one central site, and that broad scale mapping includes identification of sediment substrate type and presence of visible sulphides throughout the lake.

Interim investigations should be undertaken to determine concentrations of nutrients, chlorophyll a, water colour, and sediment resuspension and their likely relative influence on submerged macrophyte growth. Further macrophyte monitoring is recommended only if some factor other than water colour is found likely to be driving macrophyte presence/absence (e.g. excessive phytoplankton chlorophyll a bought about by elevated nutrients, or excessive wind resuspension of bed sediments).

6. MANAGEMENT RECOMMENDATIONS

To improve the lake macrophyte cover to a level that ensures a clear water state (if interim investigations indicate that this is achievable) with improved water clarity, the following management actions, undertaken in a step-wise fashion, are recommended.

- **Step 1. Determine Appropriate Nutrient Load Guidelines.** Develop appropriate nutrient load guidelines for the lake that will maintain the lake at close to maximum macrophyte potential and hence ensure a clear water state.
- **Step 2. Determine Current Nutrient Loads.** Identify current nutrient loads to the lake through landuse yield estimates, augmented with validation monitoring of the main input stream.
- **Step 3. Match Nutrient Loads to Meet Guidelines.** If nutrient load guidelines are not currently being met, undertake investigations to identify primary sources and develop plans to reduce loads from these sources to a level that meets guidelines.
- **Manage Invasive Aquatic Plants.** Fortunately, no invasives were found in Lake Murihiku apart from emergents. The recommended approach to ensure a low risk of invasives becoming prevalent in Lake Murihiku is to monitor macrophyte diversity and cover regularly to measure any trends in existing cover, and to detect any new incursions. This is because the options for containment and eradication are both increased, and have a greater chance of success with minimal damage to other components of the aquatic biota, if new incursions can be detected early.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from various people including Andy Hicks (Aquatic Ecologist, Environment Southland), and local landowners who provided access and valuable local information.

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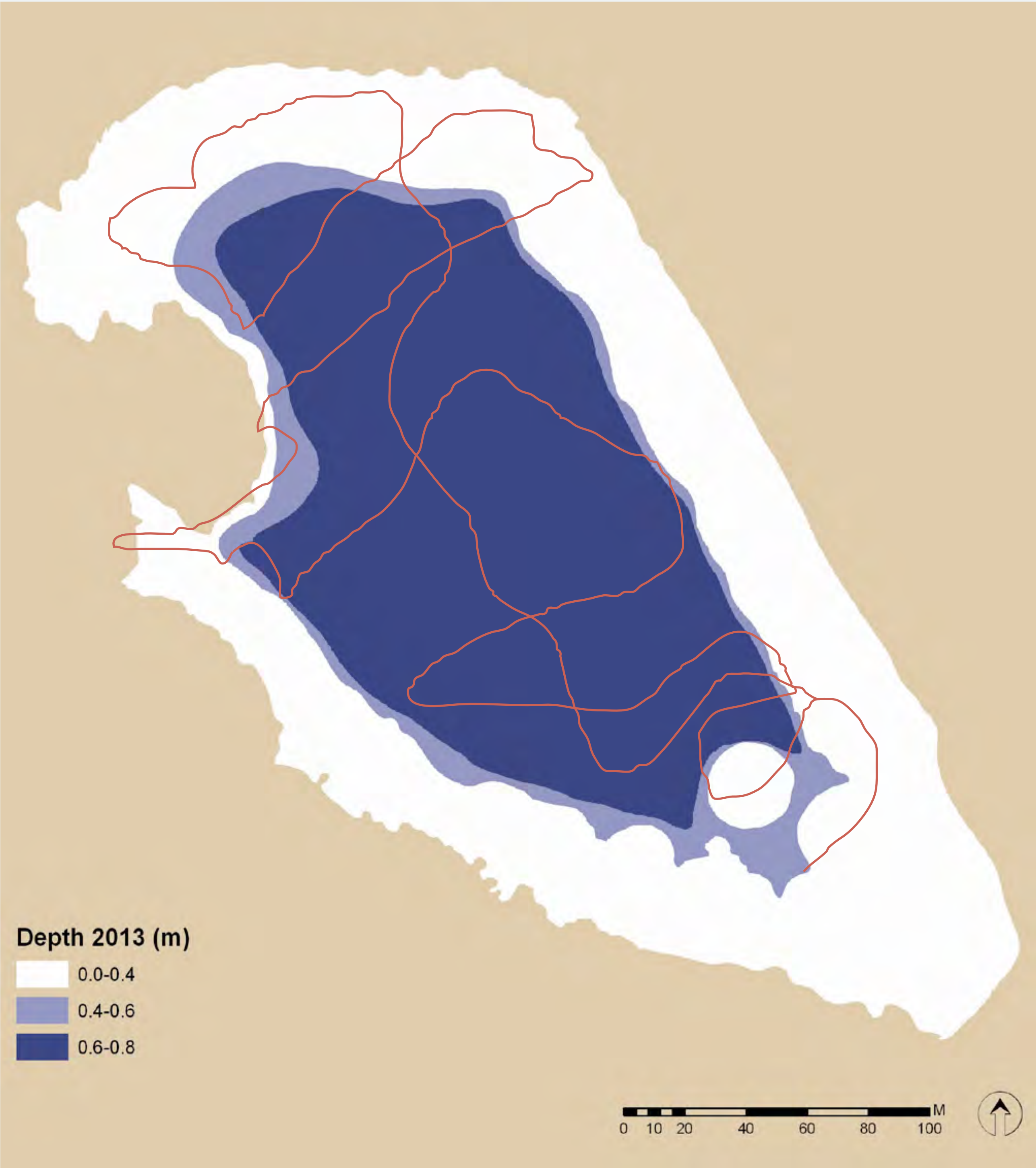
APPENDIX 1

Appendix Figure 1. Transect path used in broad scale assessments of sediment, vegetation, depth, and water quality, Lake Murihiku, 21-23 February 2013.



Appendix 1 (Continued)

Summary of water chemistry results, Lake Murihiku, 21-23 February 2013.

	Central Basin Northern End		Central Basin Southern End	
	Surface	Bottom	Surface	Bottom
Secchi Depth (m)	-	0.3	-	0.4
DO (mg/l)	10	9.07	10.1	9.91
DO (%sat)	104.3	93.8	103	98.2
Temp (degC)	17.1	17.1	17.1	17.1
Conductivity (uS/cm)	282.6	282.6	279.4	279.4
Sed Type	very soft mud		very soft mud	
Sulphides	some visible >5cm		some visible >5cm	

Summary results for invasive species found in Lake Murihiku, 21-23 February 2013.

Invasive Species	40-70% Cover	10-40% Cover	0-10% Cover	No Invasives	Grand Total (ha)
Solanum dulcamara - Bittersweet	0.02	0.01	0	5.2	
Mixed weeds	-	-	0.13	-	
Grand Total (ha)	**0.02ha**	**0.01ha**	**0.13ha**	**5.2ha**	**5.3ha**
Area of Invasives (ha)	0.03 ha of invasives spread over 3% (0.2ha) of lake				

Summary results for dominant native species found in Lake Murihiku, 21-23 February 2013.

Dominant Class	Dominant Species	Species % Cover	Depth (m)	Area (ha)
Tussockland	*Carex secta*	>70%	emergent	0.06
	Phormium tenax	>70%	emergent	0.13
Reedland	*Typha orientalis*	>70%	<0.2	0.47
Sedgeland	*Eleocharis sphacelata*	>70%	<0.2	0.71
Turf Plant	*Glossostigma elatinoides*	>70%	<0.2	0.08
Unvegetated	Unvegetated substrate	-	0-0.8	3.86

1.2ha of native vegetative cover within the 5.3ha (mean density of cover in lake = 23%)