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coastalmanagement

Lake Brunton 2009

Synoptic Survey, Macrophyte Mapping and Vulnerability Assessment

Prepared for

Environment Southland

June 2009

Cover Photo: Lake Brunton. Photo next page: ***Ruppia*** **beds exposed when Lake Brunton was low in March 2008.**

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By

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All photos by Wriggle except where noted otherwise.

EXECUTIVE SUMMARY

Maintaining an understanding of the condition and risks to coastal and estuarine habitats is critical to Environment Southland (ES) in their resource management role for Southland. In the late 1990's, ES initiated a long term coastal monitoring programme which targets vulnerable coastal habitats throughout Southland. In 2008, Lake Brunton, an 800m wide, shallow, brackish coastal lagoon (75ha) in Waipapa Bay, was identified as being vulnerable to various problems and in need of synoptic monitoring and risk assessment (Robertson and Stevens 2008). The current report presents the results of the February 2009 synoptic survey of the lagoon, identifies issues and makes monitoring and management recommendations.

RESULTS

Results of the 2009 synoptic survey (undertaken when the lagoon was closed to the sea and the water level was high) showed that the lagoon was shallow (mean depth 1.5m), unstratified and poorly-flushed. In an earlier survey (March 2008) undertaken when the lagoon was open to the sea (which is expected to occur for a short period once approximately every 100 days), the lagoon was well-flushed and water level was low (mean depth 0.5m). Aquatic macrophytes (mainly native species dominated by *Ruppia polycarpa*) covered 50% of the lagoon area and the lagoon sediments were predominantly a thin layer of fine mud and organic ooze overlaying sand and gravels. A thin layer of black, sulphide-rich sediment was sometimes present near the surface under rotting organic detritus but in general the sediments were well-oxygenated. Salinity was relatively constant at approximately 4ppt when closed and 24ppt when open, while dissolved oxygen levels were relatively high (>95% saturation).

ISSUES

The report identified two key issues, or vulnerable components of Lake Brunton, as important for monitoring and management. The two key vulnerabilities were;

1. Aquatic Macrophyte Community. Shallow, brackish, poorly flushed lagoons, like Lake Brunton, are typically in one of two contrasting states; a clear state with submerged macrophytes (either native or introduced communities), or a more eutrophic, turbid state dominated by phytoplankton and macroalgae. The synoptic survey confirmed that Lake Brunton was in a relatively pristine state dominated by native macrophytes and very vulnerable to further degradation. The major threats were identified as:

a. Reduced flushing, from further freshwater abstraction or mouth changes
b. Catchment landuse intensification and increased nutrient runoff
c. Invasive weeds or pests
d. Sea level rise
e. Loss of saltmarsh

2. Saltmarsh and Terrestrial Margin. Estuaries function best with a large area of saltmarsh and a healthy natural vegetated terrestrial margin. Recent broad scale mapping showed there was a relatively large area of saltmarsh remaining around the lagoon and the terrestrial margin included some natural vegetation but was generally highly modified. Because saltmarsh assimilates and filters excess nutrients and sediment, the presence of such a large area in Lake Brunton acts to minimise nutrient and sediment concentrations in the lagoon and thereby helps maintain the high value submerged macrophyte community. The major threats to further deterioration in saltmarsh and terrestrial margin communities were; increased stock access to the lagoon margin, drainage and invasion by plant pests.

MONITORING AND MANAGEMENT

Key Threats	Monitoring Recommendations	Management Recommendations
Risk of Eutrophication and Loss of *Ruppia* Beds	**Water Quality.** Monitor nutrients, clarity, salinity, chlor. a, temp, and DO annually. **Macrophyte Mapping and Sediment Quality**. Map macrophyte beds and sediment quality every 5 years. **Monitor Catchment Landuse, FW Abstractions, Mouth Openings**.	Ensure Adequate Freshwater Input Flushing Flows. Develop Nutrient and Sediment Input Guidelines. Encourage Landuse Practices to Meet Guidelines.
Risk of Invasive Aquatic Weeds	**Macrophyte Mapping.** Map macrophyte beds every 5 years.	Develop Plan for Control of Invasive Weeds.
Risk of Loss of Saltmarsh	**Broad Scale Habitat Mapping.** Map saltmarsh every 5 years.	Maintain Natural Opening Regime. Develop Plan to Minimise Ecological Impacts of Sea Level Rise. Saltmarsh and Terrestrial Margin Restoration.

1. INTRODUCTION

Maintaining an understanding of the condition and risks to coastal and estuarine habitats is critical to Environment Southland (ES) in their resource management role for Southland.

Lake Brunton (25ha) and associated wetland (50ha), centred at Waipapa Beach in Eastern Southland (Figure 1), is a small, intermittently open/closed, shallow, "coastal lake" estuary separated from the sea by a barrier beach. It is fed by three small streams and drains to the sea through an unmanaged opening which is closed most of the time. The lake is bordered by extensive areas of saltmarsh (jointed wire rush and flax) and its bed has a high value submerged aquatic plant community (*Ruppia*-dominated). The catchment (24 km^2) is dominated by farmland (sheep, beef and dairying) and drainage is expected to have elevated nutrient concentrations. The lagoon water has a characteristic brown humic stain, likely natural low nutrient status, and low pH.

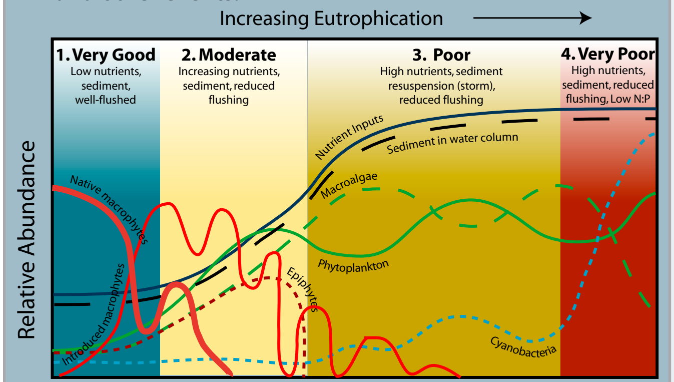
Figure 1. Aerial photo of Lake Brunton.

A recent broad scale study (Robertson and Stevens 2008) identified the lake as being very susceptible to having water quality problems that would adversely affect the high value *Ruppia* community if the relevant stressors were present (e.g. terrestrial runoff, climate change, saltmarsh loss, invasive weeds). Available information indicates that landuse has intensified and may already be adversely affecting existing conditions, primarily through increased dairying and terrestrial margin modification.

In addition, the effect of the mouth geomorphology on the existing *Ruppia* communities is unknown - in particular, exposure of *Ruppia* beds to the atmosphere and elevated salinities when the lagoon is open to the sea. Apart from sea level rise, eutrophication has been highlighted as the greatest risk for this lagoon. The likely pattern of increasing eutrophication that such lagoons follow in response to increased nutrients (particularly nitrogen and phosphorus) is presented in Figure 2.

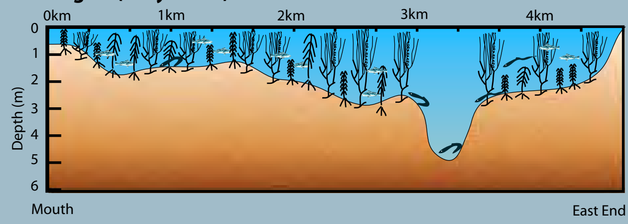
1. Introduction (Continued)

Figure 2. Intermittently open/closed, shallow, "coastal lake" estuary - Response to increasing eutrophication and other events.

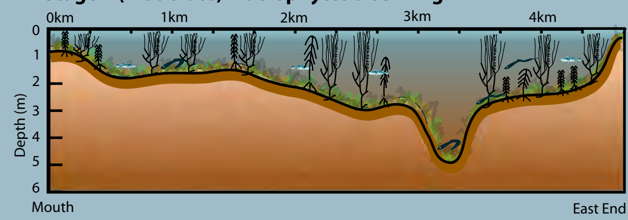


Conceptual representation of response of aquatic vegetation to increased nurients in coastal lagoons (modified from de Wit et al. 2001, Viaroli et al. 2004, Zaldivar et al. 2008 and information on NZ coastal lagoons - Mitchell 1971, Gibbs 1973, Gerbeaux and Ward 1991, Gibbs 2002, Edwards and Clayton 2002, Stevens and Robertson 2007 and 2007a, Ward 2008)

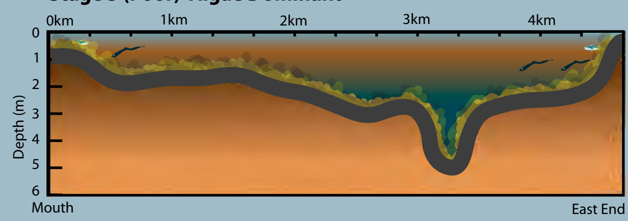
Stage 1 (Very Good) Pristine



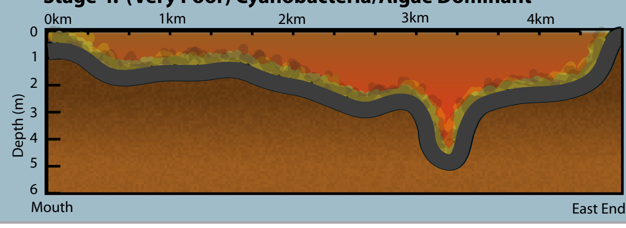
Stage 2 (Moderate) Macrophytes Declining



Stage 3 (Poor) Algae Dominant



Stage 4. (Very Poor) Cyanobacteria/Algae Dominant



The response to increased nutrients/eutrophication can be divided into four main stages as follows (Figure 2):

Stage 1 (Very Good) Pristine

In their pristine state, these lagoons are well flushed with river and marine tidal waters. Nutrient and sediment inputs are low and their brackish, clear, shallow waters are dominated by extensive meadows of native macrophytes (e.g. *Ruppia*, *Potamogeton*) and possibly some non-aggressive invasive species which take advantage of nutrient supply from the sediment. Sediment quality and biodiversity are high.

Stage 2 (Moderate) Macrophytes Declining

As nutrient and sediment concentrations increase, nuisance macroalgae (e.g. *Enteromorpha, Bachelotia, Cladophora*), phytoplankton and epiphyte growth increases, while native macrophyte growth, sediment oxygenation and water clarity declines. In addition, introduced and often aggressive macrophytes can become dominant and the sediment bed becomes muddier. A surface sulphide layer is common. If inflows of marine and river waters are reduced (due to freshwater abstraction or constriction of the mouth) then the susceptibility to eutrophication is enhanced and biodiversity declines. During this stage, the dominant aquatic vegetation can alternate in cycles depending on conditions. Generally shallow water (<2m) and good clarity (e.g. secchi disc visible on bottom) tends to favour the presence of macrophytes. Once light becomes limiting (due to excessive nutrients causing phytoplankton blooms, elevated fine sediment inputs, or storms acting to resuspend sediment), then phytoplankton dominate. Storm and waterfowl damage to macrophyte beds can also cause a shift to phytoplankton dominance, especially in situations where the lagoon bed consists of muds rather than sands or gravel.

Stage 3 (Poor) Algae Dominant

At the third stage, nutrient inputs are high and the lagoon reaches a threshold where macrophytes are lost from the lagoon and replaced with nuisance short-lived macroalgae and phytoplankton. Water clarity is low, sediments are muddy, anoxic, and sulphide-rich close to the surface, and sediment macrofauna are dominated by high numbers of a few tolerant species only.

Stage 4 (Very Poor) Cyanobacteria/Algae Dominant

At the fourth stage, the nitrogen to phosphorus ratio declines to low levels and results in nuisance cyanobacteria and toxic bloom events. Sediment macrofauna are often absent, but nuisance short-lived macroalgae (e.g. *Bachelotia* and *Enteromorpha*) and phytoplankton are still present. Water clarity is low and sediment quality poor (increasing mud content, anoxic, and sulphide-rich).

1. Introduction (Continued)

A primary aim of the present survey was to assess the trophic status of Lake Brunton, particularly its current macrophyte status, as it provides a useful indicator of the lagoon condition. The main parameters assessed in the survey were water clarity, salinity, water depth, sediment oxygenation, muddiness, and presence of macrophytes and nuisance macroalgae. A previous survey (Stevens and Robertson 2008) assessed the condition of the intertidal and terrestrial margin habitats of the lagoon.

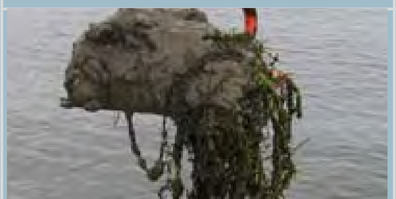
This report identifies the Lake Brunton and catchment characteristics to provide an overview of the primary ecological issues, to enable further monitoring and management recommendations.

2. SYNOPTIC SURVEY METHODS

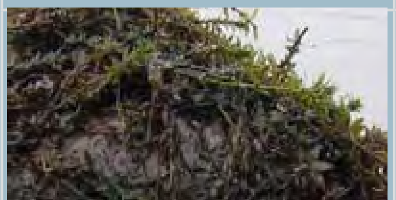
Percent Cover 0-5%

Percent Cover 5-10%

Percent Cover 10-20%



Percent Cover 20-50%



Percent Cover 50-80%

Percent Cover 80-100%

In order to assess the condition of Lake Brunton, various key indicators of coastal lake condition were monitored on 23 February 2009. The methodology involved sampling 38 georeferenced sites along transects which, through future repeat sampling (and replication), can be used as a rapid and robust technique to indicate change.

Details of the 2009 sampling methodology are as follows: field sampling (carried out by 3 scientists using a dinghy and outboard motor) was undertaken at sites located along 7 transects designed to represent conditions throughout much of the lake (Figure 3).

Once the boat was positioned above each site, a sediment sample was collected by digging up a 5-6cm deep layer of the surface sediments with a garden hoe (area 15 x 15cm) and carefully bringing the contents to the surface. At the surface, the sample was photographed and records taken of;

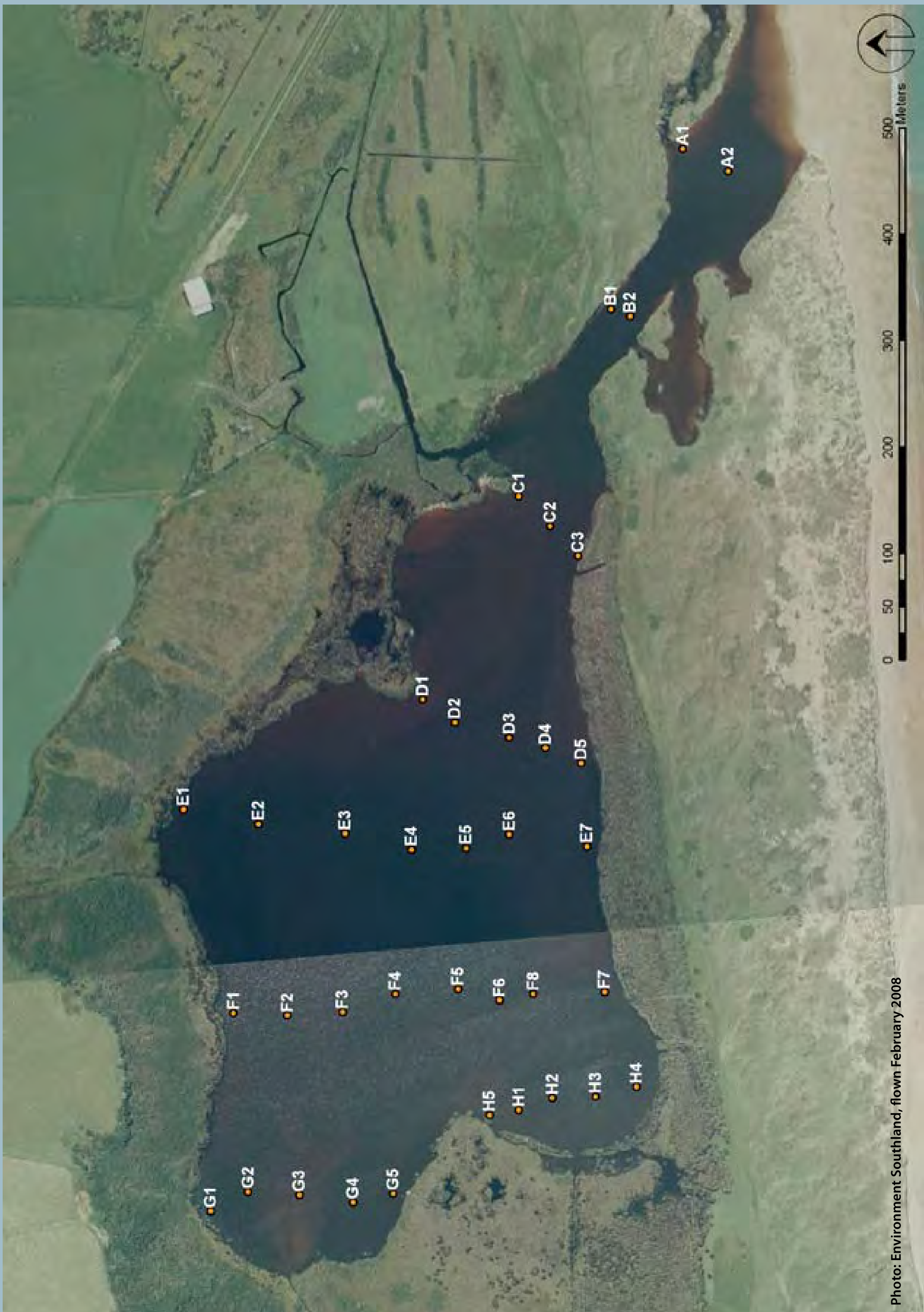
- the aquatic vegetation (taxa, height, percentage cover and life stage),
- the sediment type and depth to the blackened sulphide rich layer (redox potential discontinuity layer - RPD). Examples of percentage cover estimates for macrophytes are shown in the margin figure.

In addition, the water column at each site was sampled for the following;

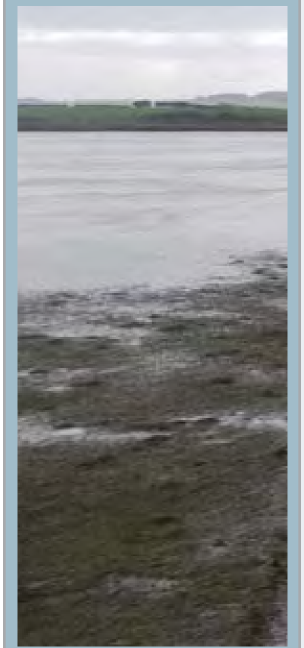
- secchi disc clarity,
- depth,
- temperature and
- salinity (at surface and bottom).

Geo-referenced sampling positions and photographs, and field measurements were recorded and are presented in Appendix 1. The data are also available as an ArcMap GIS layer containing georeferenced digital field photos (GPS- Photolink).

Figure 3. Lake Brunton transects and sampling sites.



3. RESULTS



Lake Brunton when water level was low - March 2008.

The detailed results for the 23 February 2009 synoptic survey of Lake Brunton are presented in Appendix 1. Sampling of aquatic vegetation, sediment type, sediment oxygenation, and water quality (secchi disc clarity, dissolved oxygen, salinity and temperature) was undertaken when the lagoon was closed to the sea and water level was high. A summary of the key findings is presented below, along with other relevant information (including that collected when the lagoon level was low and open to the sea on 23 March 2008), and the results of the 2008 vulnerability assessment (Robertson and Stevens 2008).

Aquatic Macrophyte and Macroalgal Cover

The results of the dominant macrophyte and macroalgal survey (Figures 4, 5 and 6) indicated that rooted aquatic macrophytes covered approximately 50% of the lagoon area. The dominant species was *Ruppia polycarpa* (horse's mane weed). This high ecological value NZ native was virtually the only plant present. At one site (E1), scattered specimens of the native water milfoil, *Myriophyllum triphyllum*, were also present. Such macrophytes are common inhabitants of relatively pristine freshwater and brackish waterbodies.

Ruppia was growing in the 0-1.6m depth range and reached a height of up to 0.5m. Most plants showed no sign of reproductive structures. The densest patches were found in shallow waters less than 1.2m deep (Figure 6). Also present on the sediment surface, and as epiphytic growth in many places, was an unidentified brown filamentous macroalgal layer, and accompanying black, anoxic, sulphide-rich surface sediments. Beneath this shallow layer, however, the sediments were well-oxygenated.

Figure 4. Percentage cover and dominant aquatic vegetation type, Lake Brunton 23 February 2009.

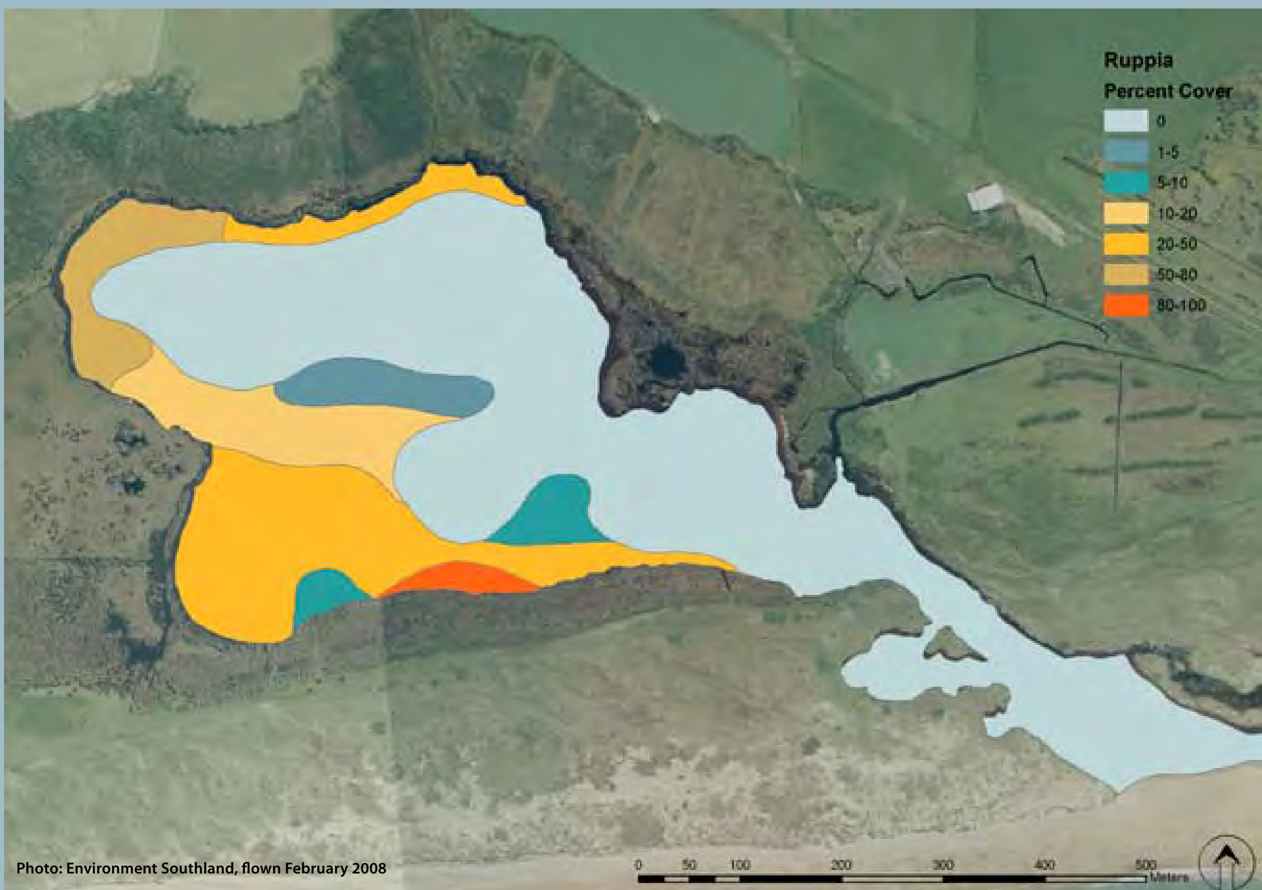


Figure 5. Dominant macrophytes and macroalgae, Lake Brunton, February 2009

***Ruppia polycarpa* (Horse's mane weed)**

R. 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 0-1.5 depth range (depending on water clarity). Germination has a high tolerance to salinity (*R. polycarpa* from Westenport Bay (Australia) begins at salinities of 40ppt), while soaking seeds in 2.25 and 4.5 x seawater for 14 days did not inhibit germination when seeds were transferred to distilled water. Optimal germination under laboratory conditions is at 20°C in freshwater (Vollebergh and Congdon 1986, Ungar 1991).

Myriophyllum triphyllum (Water milfoil)

Myriophyllum triphyllum is a native submerged perennial that commonly grows in lowland to subalpine lakes, rivers and streams and in brackish coastal lagoons. Can grow in water up to several meters deep depending on water clarity.

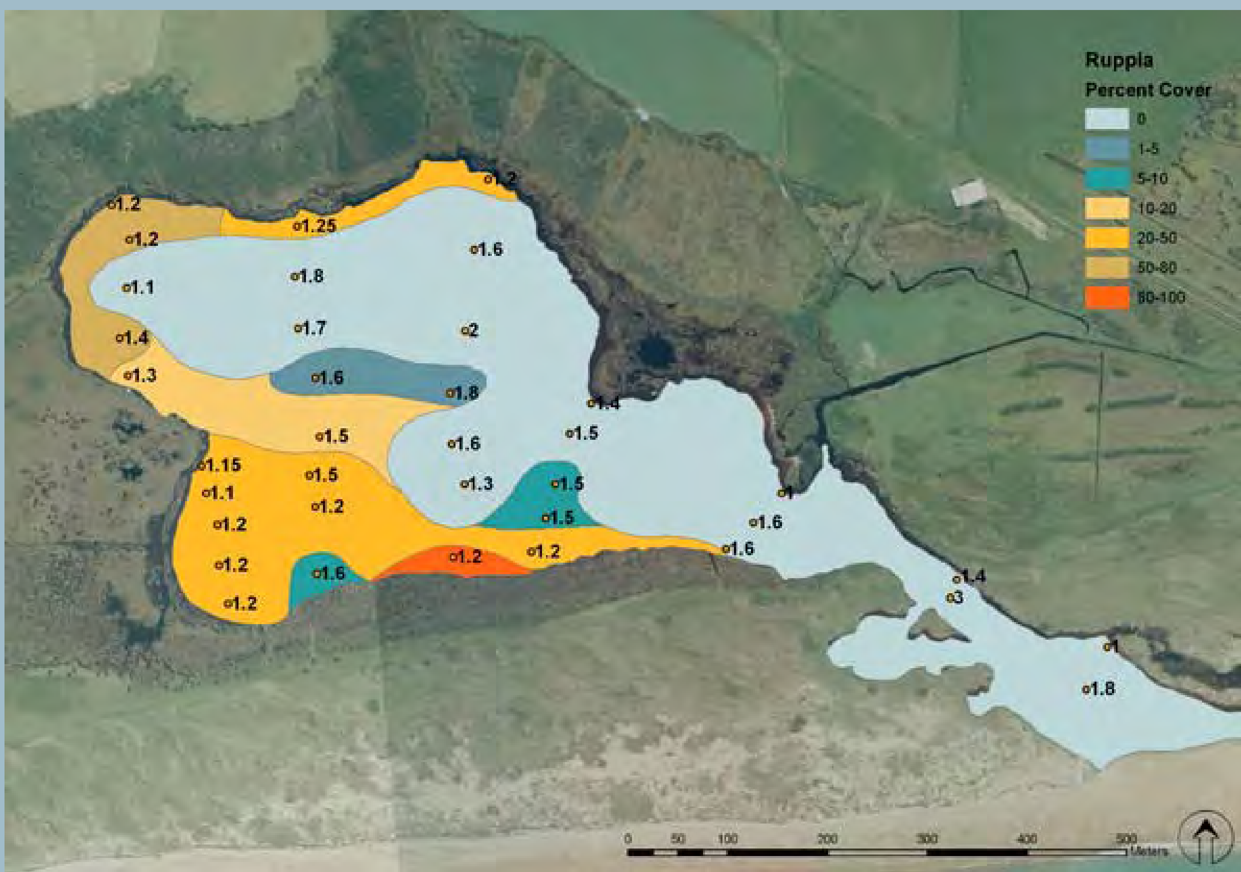
Within New Zealand, many high residence time coastal lakes/lagoons have populations of *Ruppia* (e.g. Tukituki and Waitangi Estuaries in Hawkes Bay, and Waituna Lagoon in Southland). Other poorly flushed, shallow lakes/lagoons in New Zealand have lost *Ruppia* populations following excessive sedimentation and eutrophication, and the introduction of exotic macrophytes.

Lake Waahi (522ha and max. depth 5m) had a predominantly native macrophyte population including *R. polycarpa*, which became dominated by exotic macrophytes prior to 1978 and in 1978-79 the macrophyte populations crashed. This was attributed to low lake levels due to low rainfall, high nutrient concentrations and continued sediment input from mining (Dell et al. 1988). Currently Lake Waahi is super-eutrophic, remains unvegetated and is extremely turbid, which renders it undesirable for recreational activities.

Lake Ellesmere (20,000ha and average depth 1.5m) once had extensive macrophyte beds dominated by *R. megacarpa* and *Potamogeton pectinatus* (Ward 2008). Loss of these beds has been attributed to a major storm in 1967, as well as excessive nitrogen loads and swan damage (Gerbeaux and Ward 1991). The lake is now super-eutrophic (mean TN 1.5-2mg/l, TP 0.2mg/l, chlorophyll a 80mg.m^{-3}), highly turbid (Kelly and Jellyman 2007) and remains unvegetated. Studies indicate that the lake is light-limited for 51% of the year, phosphorus-limited for 12% of the year and nitrogen-limited for the remaining 37% of year (Hamilton 2005).

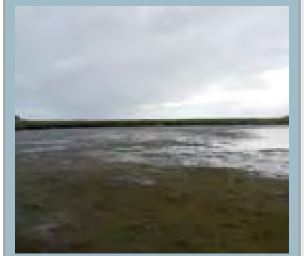
Waituna Lagoon (1,350ha and average depth 1m) has extensive beds of both *R. megacarpa*, and *R. polycarpa*. In addition, it has extensive nuisance macroalgal cover, is close to being eutrophic (mean TN 0.6mg/l and TP 0.04mg/l, chlorophyll a 1-15mg.m^{-3}), with low water clarity (secchi 0.5 to 0.8m) (Stevens and Robertson 2007, Robertson and Stevens 2009).

Figure 6. Water depth at sample sites (m) in relation to *Ruppia* % cover Lake Brunton, 23 February 2009.



3. Results (Continued)

Lake Brunton, high water level, mouth closed to sea, 23 February 2009.



Lake Brunton, low water level, mouth open to sea, *Ruppia* beds exposed, 23 March 2008.

Typical sediments with muddy organic ooze near surface.

Water Depth and Level

On 23 February 2009, the lagoon was closed to the sea and the water level was close to the maximum above which the lagoon mouth reopens through the sand barrier between the sea and lagoon. On this date the lagoon water depth was predominantly 1-2m, except for the deeper area (3m) in the channel at the east end (Figure 6). On an earlier visit (23 March 2008), the lagoon water level was 1.2m shallower, and large areas of the lagoon bed were exposed.

Salinity, Temperature and Dissolved Oxygen

Salinity measurements during high water levels indicate that the lagoon was unstratified; salinity was similar throughout the lagoon at 3.8-4.5ppt (Appendix 1). Water temperature varied from 11.7 to 12.8 degrees C and there was little difference between the surface and bottom. Dissolved oxygen concentrations in the water column were relatively high at 92 to 101% saturation. During low water levels, when the lagoon was open on 23 March 2008, salinity in the lagoon was 24ppt.

Sediment Type and Anoxic Layer

The substrate type on the bed of the lagoon was predominantly sands and gravels with a significant mud and organic ooze component near the surface. At the eastern end, near the sea, the sediments were mainly clean sands. A thin layer of black, sulphide rich sediment was sometimes present near the surface under rotting organic detritus. An anoxic layer was also present at most sites but was relatively deep at 3->10cm.

Water Clarity (Secchi Disc)

In general, the lagoon has a brown humic stain that reduces visual clarity, and during high water level water clarity was relatively poor at 0.78-1m (Appendix 1). Such water clarity is typical of muddy bed shallow lakes under relatively calm conditions. During windy conditions, water clarity is known to decline further.

Terrestrial and Saltmarsh Vegetation

The extent of terrestrial margin vegetation, saltmarsh and water in Lake Brunton was mapped in 2008 (Robertson and Stevens 2008). The results showed a high incidence of saltmarsh (66% of estuary area), a highly modified terrestrial margin and a small intertidal area (Table 1). Nuisance macrophyte growth on the intertidal area was absent.

Table 1. Terrestrial margin vegetation and saltmarsh in Lake Brunton 2008.

Habitat	**Area (ha)**	**% of Estuary**
Saltmarsh (flax, oioi)	50	66%
Water	25	34%
Total Estuary Area	**75**	**100.0**

Terrestrial Margin	**% of margin**
• Duneland (Marram)	15%
• Grassland (pasture)	85%
• Scrub/Forest	0

3. Results (Continued)

Vulnerability Assessment 2008

The 2008 vulnerability assessment (Robertson and Stevens 2008) of the Southland coast from Te Waewae Bay to Waiparau Head in the Catlins identified the following in relation to Lake Brunton (background data is provided in Table 2).

LAKE BRUNTON RATING		
Human Use		Low
Ecological Value		High
Existing Condition		Fair
Susceptibility		High
Stressors		High
OVERALL VULNERABILITY		High

Summary Information from 2008 Vulnerability Assessment

Uses and Values.
Low use. It is valued for its aesthetic appeal, biodiversity, duck shooting, and scientific appeal.

Ecological Values.
Ecologically, habitat diversity is high, it has a relatively pristine native aquatic plant community (*Ruppia*-dominated), internationally important birdlife, and large areas of relatively unmodified wetland and modified terrestrial vegetation.

Existing Condition.
Condition was assessed as fair given the possibility of problems such as eutrophication, sedimentation, disease risk - generated when the lake is closed and poorly flushed.

Presence of Stressors.
The major threats are: catchment runoff, sea level rise, salinity shifts from variable lagoon opening regimes and less importantly, drainage of margin areas, and invasive weeds.

Susceptibility to Stressors.
Because Lake Brunton is shallow, poorly flushed, has a long residence time, and experiences cycles of open and closed regimes, it is very susceptible to having water quality problems. If the relevant stressors (e.g. terrestrial runoff, climate change, invasive weeds) were present, they would adversely affect the unique community in the lake. Available information indicates that these stressors are likely to be present and may already be adversely affecting existing conditions. In particular, the catchment has increasing intensive agriculture, and there may be pressure to drain saltmarsh margins further. In addition, current high salinity and shallow depth conditions may be causing stress to existing *Ruppia* communities.
When the lake was visited in March 2008, the mouth was open, salinity was 24 ppt and many *Ruppia* beds were exposed. Sea level rise is expected to increase the extent of the lake area and cause habitat migration, but also threaten the *Ruppia* community with an increased salinity regime.

3. Results (Continued)

Table 2. Summary of key Lake Brunton characteristics (from 2008 Vulnerability Assessment).

General	Type	Coastal Lake (intermittently closed and open lake or lagoon - ICOLL)
	Mouth Closure	Opens and closes. Open on 23 Feb 2009 and closed on 23 March 2008
	Mean depth (m) and Volume (m^3)	1.5m
	Depth of central basin (m)	1.5m
	Estuary Area (ha)	75ha (25ha water, 50ha saltmarsh)
	Salinity regime	24ppt when open and water level low (23 March 2008), 4ppt when closed and water level high (23 February 2009)
	Length of salinity intrusion	Throughout whole lagoon
	Residence Time	Long when closed - expected to be greater than 90 days. Based on 200l/s freshwater inflow and lagoon volume 3.75 million m^3
	Slope of Catchment	Low
	Lagoon Wind Exposure	Mod-High
	Mean Tidal Range (m)	Varies depending on whether lagoon is open or closed
	Mean Freshwater Inflow (l/s) estimated	200
	Catchment Area (km2)	24
	Limiting Nutrient (N or P)	Uncertain but likely to be both N and P
Habitat Diversity	Sheltered fringe areas	Low
	Saltmarsh/Dune Area (ha)	Approx 50ha saltmarsh and 25ha of dunes
	Seagrass/Macrophyte Abundance	High (*Ruppia*) - 50% of water area, no seagrass (*Zostera*)
	Tidal Flats present	Yes when lagoon is open to sea
	Sediments in Estuary	Predominantly sands and gravels with a significant mud and organic ooze component near the surface
	Margin buffer	Pasture and dune
Stressors	Catchment Rock Type	Sandstone/siltstone, peat, sand, gravel
	Landuse	4% native forest/scrub, 85% high producing pasture, 4% low producing pasture, 2% exotic forest/ scrub, 2.2% sand-gravel-rock
	Number Dairy Cows	780
	Catchment SS yield (t/km2/yr)	Low 46 (WRENZ Model output from NIWA website)
	Catchment TN yield (kg/ha/yr)	Mod 14 (WRENZ Model output from NIWA website)
	Point Source Inputs	U/S dairy effluent?
	Input Water Quality	No Data
	Sea Level Rise Impact	More frequent openings, lagoon shift, saltmarsh migration
	Other Stressors	Saltmarsh and wetland drainage
Existing Condition	Macroalgal Blooms	Possible
	Phyto blooms	Possible
	DO depletion	Possible
	HABs offshore	Low
	Anoxic sediments	Low
	Sediment Quality	No data
	Water Quality	No data
Potential	Potential for Improvement and Maintenance of Current Values	Improve natural terrestrial margin Ensure low nutrients and sediments in freshwater inflows Maintain existing saltmarsh

4. DISCUSSION AND CONCLUSIONS

The combined results of the 2009 synoptic monitoring, the 2008 broad scale habitat mapping, and the 2008 vulnerability assessment provide a relatively comprehensive framework to identify issues and appropriate monitoring and management recommendations for Lake Brunton. The results show that two key issues, or vulnerable components of Lake Brunton, can be identified as important for ongoing management of this high value lagoon; the aquatic macrophyte community, and the saltmarsh and terrestrial margin habitat. These habitat components have been shown as vital for the overall health of the lagoon and if these are maintained in good condition, other important parts of the ecosystem (e.g. macroinvertebrates, fish and birdlife) would thrive. A discussion of each of these issues or vulnerabilities and their main causes of decline follows.

1. Aquatic Macrophyte Community

Shallow brackish lagoons, like Lake Brunton, typically are in one of two contrasting states:

a. a clear state with submerged macrophytes (either native or introduced communities) (i.e. Stages 1 and 2 in Figure 7) or
b. a turbid state dominated by phytoplankton and macroalgae (i.e. Stages 3 and 4 in Figure 7).

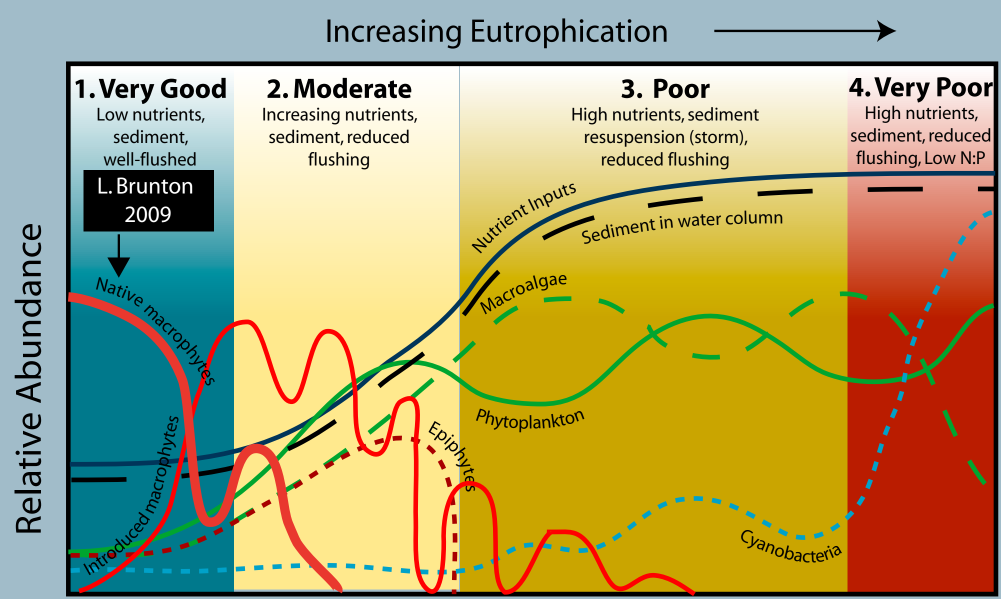
The synoptic survey confirmed that Lake Brunton is currently in state (a) and fits the Stage 1 "very good" rating, because of the domination by high value native species and moderate clarity (Figure 7).

This rating was based on the following findings.

- high incidence of native macrophytes (*Ruppia polycarpa* dominated)
- absence of introduced species and highly invasive species (e.g. *Elodea*)
- low incidence of nuisance macroalgae and oxygen-poor sediments
- predominantly sand and gravel sediments overlain by a thin layer of muds and organic ooze
- absence of shallow water unvegetated habitat
- macrophytes restricted to shallow depths (<1.8m) by low water clarity

In addition, it is likely that the lagoon has a moderate input loading of nutrients.

Figure 7. Lake Brunton - condition rating and current trophic state.



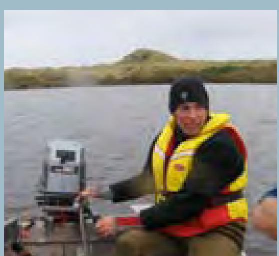
Conceptual representation of response of aquatic vegetation to increased nurients in coastal lagoons (modified from de Wit et al. 2001, Viaroli et al. 2004, Zaldivar et al. 2008 and information on NZ coastal lagoons - Mitchell 1971, Gibbs 1973, Gerbeaux and Ward 1992, Gibbs 2002, Edwards and Clayton 2002, Stevens and Robertson 2007 and 2007a, Ward 2008)

4. Discussion and Conclusions (Continued)

Near mouth of Lake Brunton.

Lagoon Filling & Draining

Catchment rainfall and runoff results in increasing water levels until levels reach the crest of the entrance sand barrier or berm (Figure 8). Once the sand berm becomes overtopped, high velocity outflows cause scour and rapid channelisation. Discharge from the lagoon continues to enlarge the entrance channel until the lagoon attains a comparable water level to the adjacent ocean. This can be further exacerbated by storm wave erosion cutting into the entrance berm on the ocean side. The resulting 'open' entrance allows tidal exchange between the ocean and the lagoon until marine sands, reworked under the action of tides and waves, once again infill the channel (Haines et al. 2006).



Greg Larkin (ES) undertaking monitoring on Lake Brunton.

The primary threat to the aquatic macrophyte community in Lake Brunton is a switch to either of the following:

- a low clarity, algal (phytoplankton and macroalgae) dominated system or
- a community dominated by introduced species.

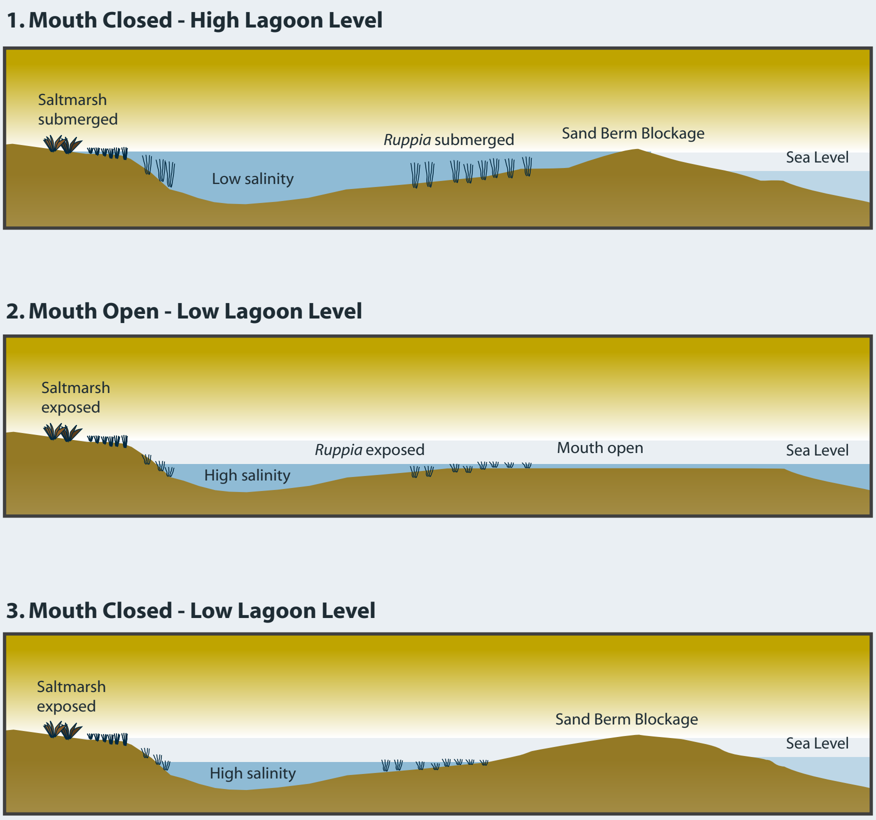
Identifying the variables that control the current native macrophyte dominated community is therefore considered important for ongoing lagoon management. Studies have shown that these variables are; (a) water residence time, (b) wind fetch, (c) nutrient concentrations, (d) substrate type, (e) extent of saltmarsh, and (f) water depth (Janse 2005). Because these vary between lagoons, and within lagoons over time, there is no simple, stand-alone guideline (for say nutrients or substrate type) that could be used for the management of all lagoons. Instead, equations or models are used to identify likely lagoon response to a shift in any of these variables. Unfortunately, such tools do not exist for NZ lagoons and shallow lakes, and consequently identification of switch-point guidelines for Lake Brunton is currently difficult. In this situation, a review of the major switch-point drivers, as they relate to Lake Brunton, can be helpful in identifying priorities for monitoring and management of this coastal lagoon.

(a) Residence Time

In relation to the long term maintenance of aquatic macrophytes, the shorter the residence time (i.e. the better it is flushed) the less likelihood of a switch to algal dominance.

For lagoons like Lake Brunton, that are mostly closed to the ocean, the residence time is often long (in the case of Brunton it is >90 days, Table 2) and therefore they are poorly flushed. The process of filling and draining and the mouth opening closing sequence is explained in the margin inset and Figure 8.

Figure 8. Mouth opening and closing sequence Lake Brunton.



4. Discussion and Conclusions (Continued)

Mouth of Lake Brunton when open on 23 March 2008.

There are two main threats to flushing or residence time in Lake Brunton:

- Changes to freshwater inflows and
- Changes to mouth opening dynamics.

Changes to the freshwater inflows can either increase the residence time (e.g. through increased freshwater abstraction), or decrease it (e.g. from increased catchment rainfall and runoff). Both these scenarios are considered likely possibilities (Table 3). Climate change also has the potential to impact on residence time of coastal lagoons through predicted increases in sea level and changes in wave climate (Haines and Thom 2007), (Table 3).

Table 3. Lake Brunton - summary of likely reasons for changes to lagoon flushing.

Impacts	Reason
Decreased residence time through increased rainfall and runoff (i.e. better flushing).	NIWA (see website; http://www.niwa.cri.nz/ncc/clivar/scenarios) currently predict a 1.9 deg C change in annual average air temperature and a 7% increase in the annual average rainfall for Southland by 2090. Increased catchment rainfall and runoff will lead to greater flushing of Lake Brunton as it will take less time to fill and breakout to the sea.
Increased residence time through increased freshwater abstraction (i.e. poorer flushing).	Pressure for increased freshwater abstraction in the catchment is likely to arise as landuse intensifies in the area (primarily from dairy conversions).
Increase in residence time through increase in the lagoon high water level.	In the past century, sea level rise has averaged approximately 2.1mm/year, but this is predicted to increase up to 7mm/year or more in the next 100 years (Ministry Environment 2008). The entrance berm height of Lake Brunton is likely to increase as sea level increases.
Increase in residence time through increase in the lagoon volume.	In the past century, sea level rise has averaged approximately 2.1mm/year, but this is predicted to increase up to 7mm/year or more in the next 100 years (Ministry Environment 2008). When the lagoon is open it will reflect the current increased sea level.
Increase in lagoon residence time through lengthening of time to build up entrance sand berm or blockage	With the predicted increased frequency of heavy swells from the southwest, it can be expected that south-to-north sediment transport will increase within the Waipapa embayment area until the alignment of the shoreline adjusts to the altered wave climate. The outcome is likely to be an increase in erosion at the southern end and accretion at the northern end, resulting in significant landward migration of the beach profile. Removal of significant quantities of sediment from the lagoon entrance will mean that the berm will take longer to build up and therefore will lead to decreased lagoon residence times. However, long-shore drift of eroded beach sands from further south, may increase the frequency of mouth blockages and thereby increasing the residence time. In addition, the entrance channel is likely to shorten.

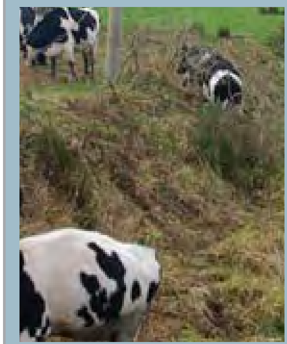
Overall, the response to climate change for Lake Brunton will reflect the relative influence of various controlling factors (i.e. increased freshwater inflows, and increased wave climate and erosion). More detail is required for each of these variables in order to predict the likely outcome.

(b) Wind Fetch
Fetch is the maximum length of open water over which the wind can blow. In relation to the long term maintenance of aquatic macrophytes, the lower the wind fetch the less likelihood of a switch to algal dominance. Currently wind fetch in Lake Brunton is relatively low (approximately 800-1000m), and is most significant in the southeast direction.

4. Discussion and Conclusions (Continued)

(c) Substrate Type

Substrate type (muds, sands or gravels) influences the likely water clarity of a lagoon, the stability of macrophytes under extreme wind events, the sediment quality, and hence macrophyte quality. As a consequence, the finer the sediment type the greater the risk of a switch to algal dominance. Currently, Lake Brunton is dominated by sands and gravels (but with a significant mud and organic ooze component near the surface). Such conditions indicate a low-moderate risk of the lagoon changing to low water clarity and algal dominance. Ensuring low inputs of fine sediment to the lagoon in conjunction with adequate flushing or natural removal of existing fine sediments from the bed of the lagoon, would enhance long-term lagoon condition.



Landuse intensification in Lake Brunton catchment through increase in dairy conversions.

(d) Nutrient Concentrations

Excessive nutrient concentrations (mainly nitrogen and phosphorus) encourage nuisance algal growth, low water clarity and loss of macrophytes. As a consequence, the higher the nutrient concentration the greater the risk of a switch to algal dominance.

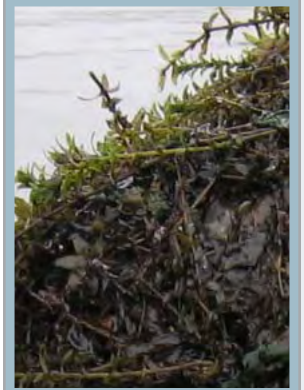
Currently, nutrient concentrations in Lake Brunton have not been measured. Given the dominance of stream inputs over seawater inputs, concentrations are likely to be similar to freshwater inflows. Stream inflows of nitrogen are expected to be elevated given the moderate estimated nitrogen loads (14 kgN/ha/yr) from the catchment (Table 2). Nutrient release from the sediments during wind resuspension events is also likely to be a contributing factor at times. Lagoon nutrient concentrations may already be elevated or are at risk of becoming elevated because of increasing intensive catchment landuse (primarily from dairying) combined with the long residence time of the lagoon. As such, it is a high priority to monitor the existing lagoon and freshwater input nutrient levels, plus the current extent of dairying in the catchment. Ensuring on-going low nutrient inputs to the lagoon would also enhance long-term lagoon condition.

(e) Saltmarsh

Saltmarsh acts to increase the ability of an estuary to assimilate fine sediment and nutrients and thereby decreases the risk of a switch to algal dominance. Currently, the area of saltmarsh in Lake Brunton is high (50ha or 66% of the estuary area). Hence the risk of a shift to algal dominance from a low saltmarsh area is low. Encouraging maintenance of the existing saltmarsh within the lagoon is therefore a high priority for long-term management of lagoon condition. The issue of saltmarsh loss is also considered in more detail on page 14.

(f) Water Depth

As water depth increases, the light available for macrophyte growth declines. In situations like Lake Brunton, where secchi disc water clarity is relatively poor (range 0.78-1m), aquatic macrophyte growth is restricted to areas less than 1.5m deep. Because only 40% of the lagoon is in this shallow depth range, such growth currently occupies only 40% of the lagoon. Ensuring low fine sediment inputs to the lagoon and/or flushing or removal of existing fine sediments from the bed of the lagoon would act to improve water clarity and limit the risk of a switch to algal dominance.



Highly invasive *Elodea canadensis*

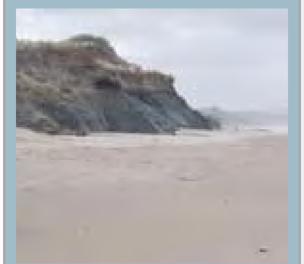
(g) Invasion of Weeds

Another factor affecting the aquatic macrophyte community is invasion by introduced weed species. Invasive species can have severe impacts on biodiversity, the economy and human health. The low stature and vigour of most native aquatic species compared to many of the introduced species can lead to either a complete elimination of native species from a water body, or (more commonly) exclusion from more favourable sites (to either the deeper more light-limited or shallower more exposed sites).

Long term maintenance of the existing high value aquatic macrophyte community to ensure no invasion of introduced species is therefore a high priority. Given the low human use, the major risk of spread of invasive species from other areas is likely to come from waterfowl. Regular, broad scale mapping/monitoring of macroalgal weed cover during low water periods, and subsequent elimination of any introduced species, is recommended for the management of this potential issue.

2. Modified Saltmarsh Vegetation and Terrestrial Margin

Saltmarsh provides for important wildlife, recreational and aesthetic values, plus has a primary role in flood and erosion protection, contaminant mitigation, sediment stabilisation, and nutrient cycling. Estuaries function best with a large area of rooted vegetation, i.e. aquatic macrophytes, saltmarsh and seagrass, as well as a healthy vegetated terrestrial margin. Recent broad scale mapping showed there was a large area of saltmarsh around the lagoon, bordered by a terrestrial margin of predominantly grazed pasture and dune (predominantly marram grass) (Robertson and Stevens 2008).



Waipapa Beach. Erosion of dunes between sea and Lake Brunton.

The major threats to deterioration in saltmarsh and terrestrial margin communities are as follows:

Sea Level Rise

- In the past century, sea level rise has averaged approximately 2.1mm/year, but this is predicted to increase up to 7mm/year or more in the next 100 years (Ministry for the Environment 2008). The most vulnerable coastal areas are like Lake Brunton; low lying, soft-shore areas, with high erosion, a large predicted rise in sea level, high wave energy, and a low tidal range. The likely response is increased erosion of the dune barrier spit and entrance berm, and greater inundation of the lagoon with sea water. This inundation will alter the saltmarsh and aquatic macrophyte community and other parts of the ecosystem. Currently, information on erosion and inundation scenarios for the lagoon due to accelerated sea level rise over the next 100 years is very limited.

Increased Stock Access to the Lagoon Margin

- The most significant factor in degrading the lagoon saltmarsh and terrestrial margin vegetation is grazing and trampling by cattle and to a lesser extent sheep. The current situation in relation to stock access to the lagoon margin is poorly known.

Plant Pests

- A variety of plant pests, particularly gorse, blackberry, and tall fescue, can degrade the saltmarsh community and terrestrial margin. These are present in some areas around the lagoon, but not to a large extent.

Restoration and maintenance opportunities for the saltmarsh and terrestrial margin communities around the lagoon are currently limited to such actions as encouraging:

- stock access exclusion of wetland and terrestrial margin habitat, and
- weed eradication.

5. MONITORING

Maintenance of Lake Brunton in its semi-pristine state, is considered important if the relatively high ecological status of the lagoon is to be maintained. This survey has identified a need for regular targeted monitoring, as well as intensive studies, for effective ongoing management of this lagoon as follows:

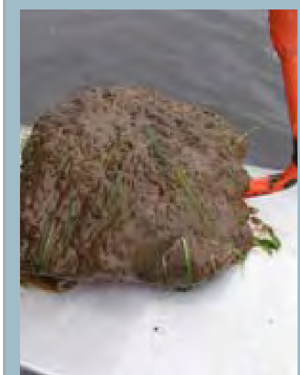
Water Quality
To assess trophic status, and the likelihood of a switch from macrophyte to phytoplankton dominance, undertake monitoring for nutrients, water clarity, salinity, chlorophyll a, temperature, and dissolved oxygen near the middle of the lagoon (0.5m deep measurements) annually for 3 years to establish a baseline and subsequently every 5 years (when the lagoon water level is high).

Macrophyte Mapping
To assess condition of macrophyte beds and sediment quality, undertake monitoring (every 5 years) of the following:

- Map aquatic macrophytes and nuisance macroalgae presence, location, % cover and life stage on fixed transects (include salinity, depth and clarity at each site).
- Sediment quality - broadscale (depth to RPD layer, sediment type) and fine scale (grain size, total nitrogen, total phosphorus and total organic carbon) at three sites.

Catchment Landuse, Freshwater Abstractions, Mouth Openings/Constrictions
To assess the potential for excessive nutrients and sediment entering the lagoon and for reduced flushing, monitor the following: intensive catchment landuse, freshwater abstractions, mouth opening/constrictions and water level. Because of the susceptibility of the lagoon, any changes in the key stressors should trigger an evaluation of the likely impact on the lagoon.

6. MANAGEMENT



Ensure Adequate Freshwater Input Flushing Flows
Ensure the lagoon is well-flushed by maintaining or improving existing freshwater inflow volumes.

Maintain Natural Opening Regime
Many coastal lagoons in NZ and Australia are artificially opened from time to time, usually to avoid flooding of adjacent lands. However, a recent assessment of such lagoons (Haines et al. 2006), recommended against artificially opening a lagoon at a level lower than the natural breakout range without a thorough environmental risk assessment, as this may lead to more frequent openings, increased shoaling at the entrance, drying out, terrestrialisation of fringing wetlands and changes to macrophyte and benthic communities.

Develop Nutrient and Sediment Input Guidelines
Undertake studies to develop appropriate nutrient and sediment input guidelines for the lagoon.

Develop Plans to Control Invasive Aquatic Macrophytes

Saltmarsh and Terrestrial Margin Restoration
Because of the importance of the current saltmarsh and natural vegetated terrestrial margin to ecological values of the lagoon, it is recommended that a plan be developed to encourage its long-term survival.

Plan to Minimise Ecological Impacts of Sea Level Rise
Develop a plan to minimise the loss of ecosystem services of Lake Brunton that are vulnerable to climate change effects, particularly sea level rise. A preliminary requirement is a detailed vulnerability assessment.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from Greg Larkin (Coastal Scientist, Environment Southland) who skippered the boat, and provided heaps of information, enthusiasm and support. Thanks also to Jules Blair who allowed access across his land to the lake and provided invaluable local knowledge, and to Maz Robertson for editing.

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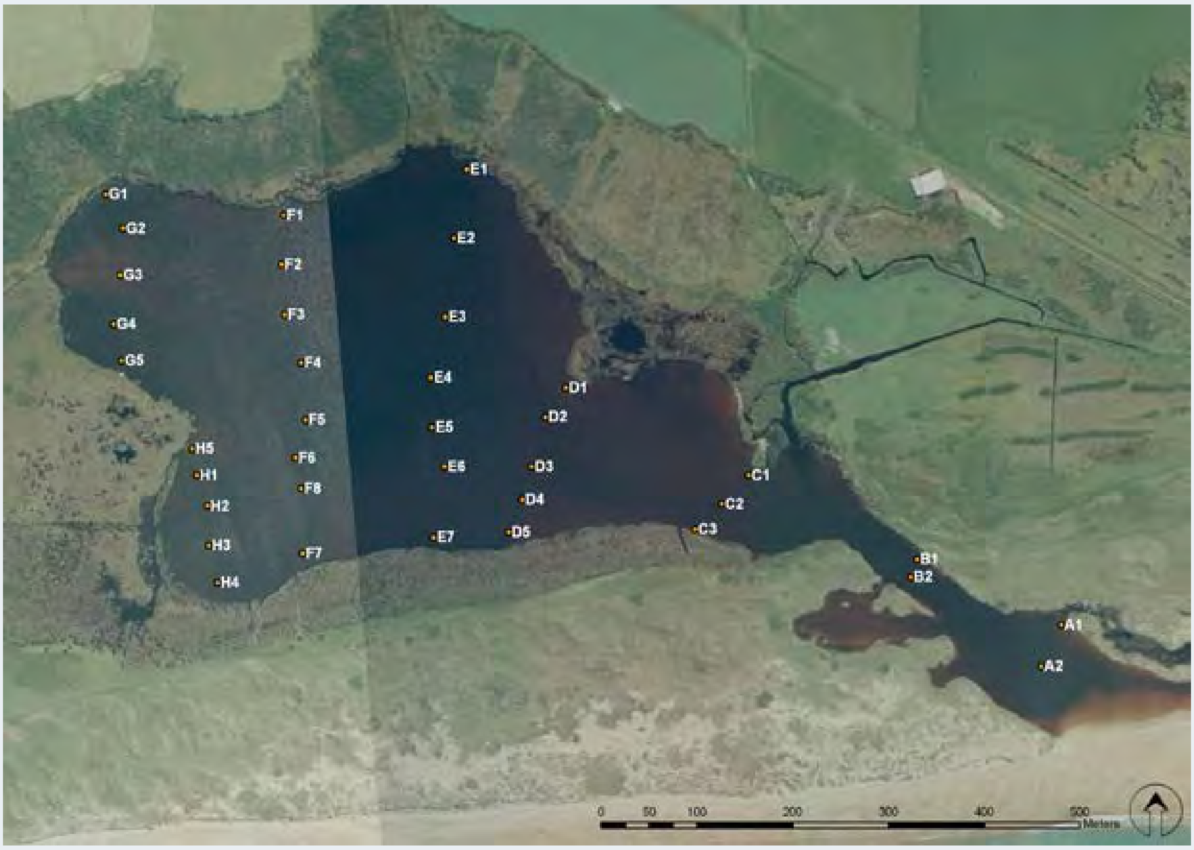
APPENDIX 1

Lake Brunton: Aquatic Vegetation and Site Details, 23 February 2009

Map of Lake Brunton with transects and site locations.



Lake Brunton: Aquatic Vegetation and Site Details, 23 February 2009

Station	Depth	Secchi	Temp	Salinity	DO	NZMG	NZMG	Sed Type	RPD	Macrophyte/Algae	Height	% cover
	(m)	(m)	(ºC)	(ppt)	(%sat)	East	North		(cm)		(cm)	
A1	1.0	bottom	12.25	4.43	99.50	2195567	5386962	3cm mud over clean sand	Surface anoxia			
A2	1.8	0.9	11.89	4.42	99.10	2195546	5386920	3cm mud over clean sand	Surface anoxia			
B1	1.4	0.9	12.11	4.43	99.60	2195416	5387030	3cm mud over clean sand	Surface anoxia			
B2	3.0	0.9	11.70	4.38	97.80	2195410	5387011	3cm mud over clean sand	Surface anoxia			
C1	1.0	0.9	11.92	4.08	93.60	2195240	5387116	clean sandy MUD	>10			
C2	1.6	0.95	11.92	4.25	93.50	2195212	5387087	clean sandy MUD	>10			
C3	1.6	0.8	12.06	4.14	94.30	2195185	5387060	clean sandy MUD	>10	*Ruppia polycarpa*	40	10-20
D1	1.4	0.9	12.12	4.11	92.40	2195050	5387206	clean sandy MUD	>10			
D2	1.5	0.9	12.09	4.14	93.00	2195028	5387176	clean sandy MUD	>10	Microalgae		
D3	1.5	0.85	12.11	4.08	95.10	2195014	5387125	clean sandy MUD	>10	*Ruppia polycarpa*	5	1-5
D4	1.5	0.9	12.11	4.06	95.40	2195004	5387091	clean sandy MUD	>10	*Ruppia polycarpa*	20	5-10
D5	1.2	0.9	12.11	4.27	95.70	2194990	5387057	clean sandy MUD	>10	*Ruppia polycarpa*	50	20-50
E1	1.2	0.9	12.14	4.44	98.20	2194946	5387431	clean sandy MUD	>10	*Ruppia polycarpa* *Myriophyllum triphyllum*	10 20	20-50 20-50
E2	1.6	0.9	11.94	4.39	98.80	2194933	5387361	clean sandy MUD	3			
E3	2.0	0.9	11.98	4.35	98.00	2194924	5387279	sandy MUD	3			
E4	1.8	0.9	12.02	4.24	96.90	2194908	5387217	clean sandy MUD	>10	*Ruppia polycarpa*	5	1-5
E5	1.6	0.9	12.05	4.17	96.40	2194910	5387166	clean sandy MUD	6			
E6	1.3	0.9	12.08	4.10	94.90	2194923	5387125	clean sandy MUD	>10			
E7	1.2	0.85	12.21	4.26	97.00	2194911	5387052	clean sandy MUD	>10	*Ruppia polycarpa*	50	80-100
F1	1.3	0.9	12.08	4.40	99.20	2194755	5387384	clean sandy MUD	>10	*Ruppia polycarpa*	10	20-50
F2	1.8	0.9	12.09	4.43	99.70	2194753	5387333	clean sandy MUD	3			
F3	1.7	0.9	12.09	4.39	98.20	2194756	5387282	clean sandy MUD	3			
F4	1.6	0.9	12.05	4.38	98.80	2194773	5387232	clean sandy MUD	>10	*Ruppia polycarpa*	5	1-5
F5	1.5	0.9	12.04	4.34	98.40	2194778	5387173	clean sandy MUD	4	*Ruppia polycarpa*	30	10-20
F6	1.5	0.9	12.06	4.27	97.80	2194767	5387134	clean sandy MUD	5	*Ruppia polycarpa*	40	20-50
F7	1.6	0.9	12.10	4.22	97.30	2194775	5387036	clean sandy MUD	6	*Ruppia polycarpa*	20	5-10
F8	1.2	0.9	12.17	4.26	95.70	2194773	5387102	clean sandy MUD	>10	*Ruppia polycarpa*	20	10-20
G1	1.2	0.78	11.89	3.79	99.70	2194569	5387406	clean sandy MUD	3	*Ruppia polycarpa*	60	50-80
G2	1.2	0.8	12.20	4.15	100.10	2194587	5387370	clean sandy MUD	>10	*Ruppia polycarpa*	20	50-80
G3	1.1	0.8	12.17	4.39	99.40	2194584	5387322	clean sandy MUD	>10			
G4	1.4	0.8	12.60	4.40	100.50	2194577	5387272	clean sandy MUD	4	*Ruppia polycarpa*	30	50-80
G5	1.3	0.8	12.23	4.30	100.20	2194586	5387234	clean sandy MUD	3	*Ruppia polycarpa*	5	10-20
H1	1.1	0.8	12.30	4.32	100.40	2194664	5387116	clean sandy MUD	3	*Ruppia polycarpa*	10	10-20
H2	1.2	0.8	12.26	4.29	101.10	2194675	5387084	clean sandy MUD	4	*Ruppia polycarpa*	40	20-50
H3	1.2	0.8	12.24	4.29	100.40	2194677	5387044	clean sandy MUD	3	*Ruppia polycarpa*	40	20-50
H4	1.2	0.8	12.24	4.28	100.00	2194686	5387005	clean sandy MUD	3	*Ruppia polycarpa*	30	20-50
H5	1.2	0.85	12.35	4.34	99.40	2194659	5387144	clean sandy MUD	3	*Ruppia polycarpa*	30	20-50