Macrophyte monitoring in Waituna Lagoon - Summer 2014

Prepared for Department of Conservation, Murihiku Area Office, Southland

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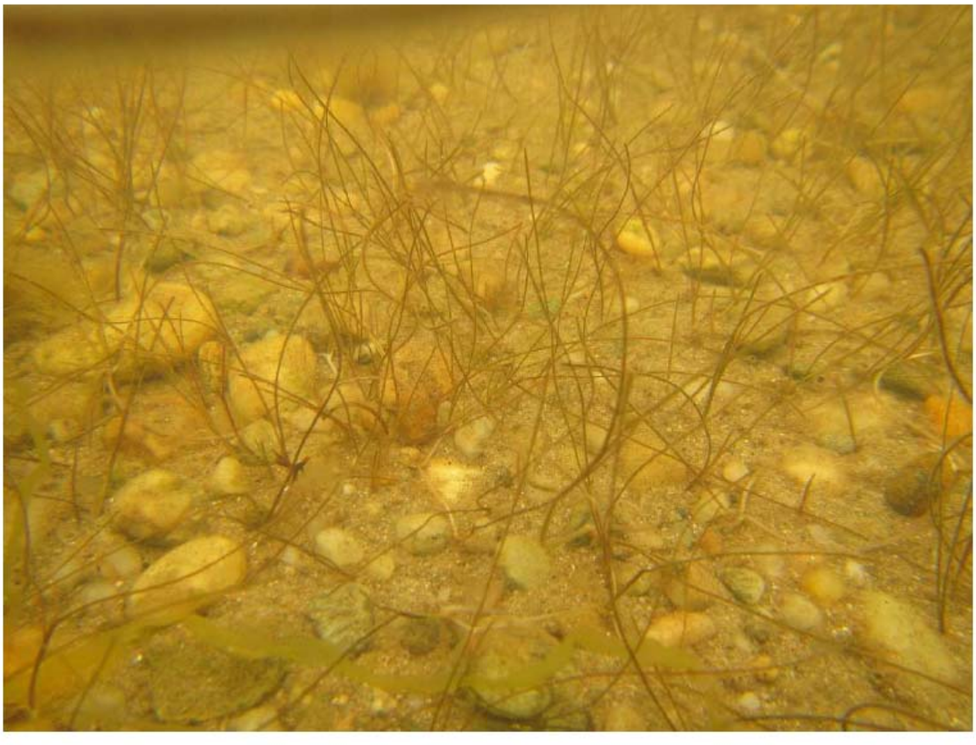

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Photo: Ruppia *growing in Waituna Lagoon. [Aleki Taumoepeau, NIWA]*

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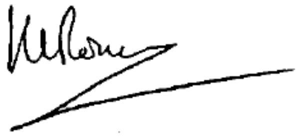

Helen Rouse

1 Introduction

Waituna Lagoon is a highly valued coastal lagoon. It forms part of the Awarua complex and is recognised as a wetland of international importance under the Ramsar Convention on wetlands. It is significant because of the important diverse habitats in the area that support a wide range of fauna. It is a nationally significant natural feature and landscape. Waituna lagoon provides important habitat for waterfowl, migratory birds, coastal birds and native fish. Over 81 species of birds have been recorded in the area, including paradise shelduck, grey duck, black swan and shoveler, and is an important safe moulting area for large numbers of these waterfowl. The Waituna catchment contains marine, estuarine and freshwater fish species. These include a national stronghold for the threatened giant kokopu as well as inanga, short fin eels and the threatened long fin eel (Atkinson 2008).

It is a place of great significance to Ngai Tahu and was traditionally an important mahika kai area. The lagoon has high aesthetic and recreational values, including fishing and duck hunting.

The lagoon is fed by three lowland streams that flow through agricultural pastures and has no permanent natural outlet to the sea. Openings now occur artificially when the lagoon level is above 2.2 meters above sea level (m.a.s.l.) and sea conditions are suitable, however, closing occurs naturally. The lagoon is a freshwater environment when closed and becomes estuarine when open. Increased land-use intensification in the catchment has resulted in a decline in water quality, in particular increased ammonium and phosphorus concentrations entering the lagoon (LTG 2011). Waituna Lagoon is described as meso-eutrophic on the Trophic Level Index, a measure of the life supporting capacity of a lake or lagoon (Schallenberg et al. 2010). This means that the lagoon has high nutrients, high phytoplankton biomass and poor water quality. Increased nutrient run-off has been linked to increased phytoplankton biomass and turbidity in the lagoon, which poses a threat to the macrophyte beds.

Waituna Lagoon has historically been a macrophyte dominated system. Dense beds of *Ruppia* were present in the lagoon in the 1960's (Johnson and Partridge 1998). Dominant beds of *Ruppia megacarpa* (horse's mane weed) along with *Myriophyllum triphyllum* (milfoil) were present throughout the lagoon, particularly in deeper water as late as 1995 (Johnson and Partridge 1998).

The current trophic level of the lagoon coupled with increased land-use intensification in the catchment has raised concern over the potential for the lagoon to switch from a macrophyte dominated to an algal dominated state. A macrophyte dominated state typically has high values for biodiversity; aesthetic, recreational and tourist values and is usually the desired state. In contrast, an algal dominated state can often lead to decreased values and increased risk of toxic blooms. The process by which a lagoon moves from one state to the next can be quite rapid and is termed "flipping". Once a lagoon flips from macrophyte dominated to algal dominated it is often difficult to reverse and it becomes its new stable state.

Department of Conservation (DOC), as part of their responsibility for managing the lagoon under their biodiversity conservation role, initiated macrophyte surveys in Waituna Lagoon in 2007. The purpose of these surveys is to better understand the dynamics of the macrophyte community in relation to present day water quality and to assess changes in the community over time. The surveys have been undertaken at least annually since 2009. DOC commissioned NIWA to undertake the 2014 summer-time macrophyte survey to document the status of the lagoon vegetation using the methodology used by Robertson and Stevens (2009) and Stevens and Robertson (2010) to provide an inter-annual comparison of its condition. This report summarises the results of the 2014 annual summer-time survey.

2 Methods

The methodology used during these surveys was developed by Robertson and Stevens (2009) and Stevens and Robertson (2010) and has remained consistent over the course of the annual surveys to date. As the methodology is not entire in either report, the reader is directed to both reports for background to the methodology used.

2.1 Survey sites

A total of forty eight sites situated on ten transects (orientated north-south) were surveyed across Waituna Lagoon (Figure 2-1). The sites were established in 2009 by Robertson and Stevens (2009) and are positioned in locations designed to represent both the shallow and deeper water habitats of the lagoon, with additional sites established on longer transects to improve spatial cover.

Easting and Northing co-ordinates (NZ map grid) of the survey sites are in Appendix A.

Figure 2-1: Geo-referenced survey sites located in Waituna Lagoon. Transects are numbered 1 to 10 from East to West and numbered on each transect in ascending order from North to South.

2.2 Survey methodology

2.2.1 Macrophyte and macroalgae

At each site, 4 replicate samples 15 x 15 cm and 6 cm deep were cut from the sediment, using a flat based garden hoe, and carefully lifted to the surface. Each replicate was then assessed for:

- Macrophyte and / or macroalgae species present.

- Cover score[1] of each species present.
- Mean height of each species present.
- Life stage[2] of *Ruppia* spp. (where applicable).

In addition to the spot surveys, at each of the survey sites extended macrophyte observations were made within a circular area of 10 m diameter by snorkel diver where the bottom could not be viewed from the surface. The maximum and average cover scores and the average height were recorded for each macrophyte species present. Full results are detailed in Appendices B and C.

2.2.2 Water quality and sediment parameters

Water quality and clarity and well as sediment parameters were measured at each site (Appendix D). Water quality parameters were measured using a calibrated Horiba multi-sensor meter. The parameters measured were:

- Temperature
- Dissolved oxygen
- Salinity
- Turbidity
- Black disc measurements (as a proxy for Secchi depth)
- Sediment type
- Depth to blackened sulphide layer

2.3 Timing

The annual survey was carried out between 27 and 29 January 2014.

2.4 Analysis

Data analysis follows Robertson and Funnell (2012). Frequency of occurrence of key macrophytes and macroalgae was compared based on data from previous surveys (Robertson and Stevens 2009, Stevens and Robertson 2010, Sutherland and Taumoepeau 2011, Sutherland and Taumoepeau 2012, Sutherland et al. 2013).

Water quality for the 2013/14 year was summarised across the key growing season for macrophytes (1 August to 31st March) as defined by Robertson and Funnell (2012). Source data was obtained from Environment Southland from a long term monitoring site, and also a recently installed (mid 2012) 'monitoring platform'.

[1] The cover scores are based on the categories established by Robertson and Stevens (2009). These cover scores were 1 = 1-5%, 2 = 5-10%, 3 = 10-20%, 4 = 20-50%, 5 = 50=80%, 6 = 80-100%.
[2] Life stage categories were V = vegetative, F = flowering, PF = post flowering.

3 Results

3.1 Macrophyte and macroalgae

The species present, plant bed height, percent cover of vegetation and vegetative stage of the macrophytes as well as the species and percent cover of macroalgae, recorded for each site are listed in Appendix B.

Macrophyte beds were recorded at a total of nine out of forty eight sites sampled in the lagoon in January 2014. This was half the number of sites recorded in February 2013. *Ruppia polycarpa* was recorded at all nine sites, while *Ruppia magacarpa* and *Lamprothamnium macropogon* were recorded at one site each. The frequency of occurrence of *R. polycarpa* throughout the lagoon was 19%, while *R. megacarpa* and *L. macropogon* only occupied 2% of the sites surveyed (Figure 3-1). Where present, the percent cover of *R. polycarpa* was typically low, with most cover recorded in the 1-25% cover class (Figure 3-2). During the 2014 survey, both the frequency of occurrence and the cover of macrophytes recorded in Waituna Lagoon was the second lowest since monitoring began (see Figures 3-1 and 3-2). This is a result of the lagoon being open and water levels being low during the entire summer growth period. Therefore a number of sites were exposed and devegetated during this period. Low lagoon levels could have also exacerbated wave action effects on plants growing in the lagoon. Previous prolonged opening of the lagoon during the 2012-13 growth season may have also contributed to low frequency of occurrence and cover of macrophytes in the lagoon in the present growth season due to sustained loss of biomass over prolonged period of time.

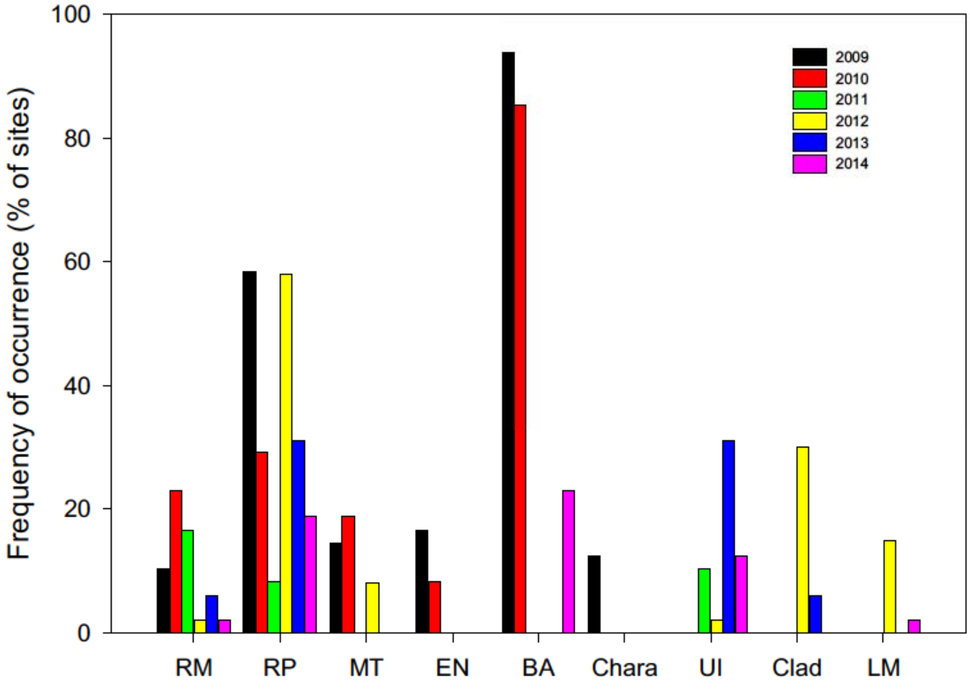

Figure 3-1: Frequency of occurrence of macrophytes and macroalgae in Waituna lagoon between 2009 and 2014. RM= *Ruppia megacarpa*, RP = *Ruppia polycarpa*, MT= *Myriophyllum triphyllum*, EN = *Entromorpha* sp., BA = *Bachelotia antillarum*, Chara = Charophyte undefined, UI = *Ulva intestinales*, Clad = *Cladophora* sp., LM = *Lamprothamnium macropogon*.

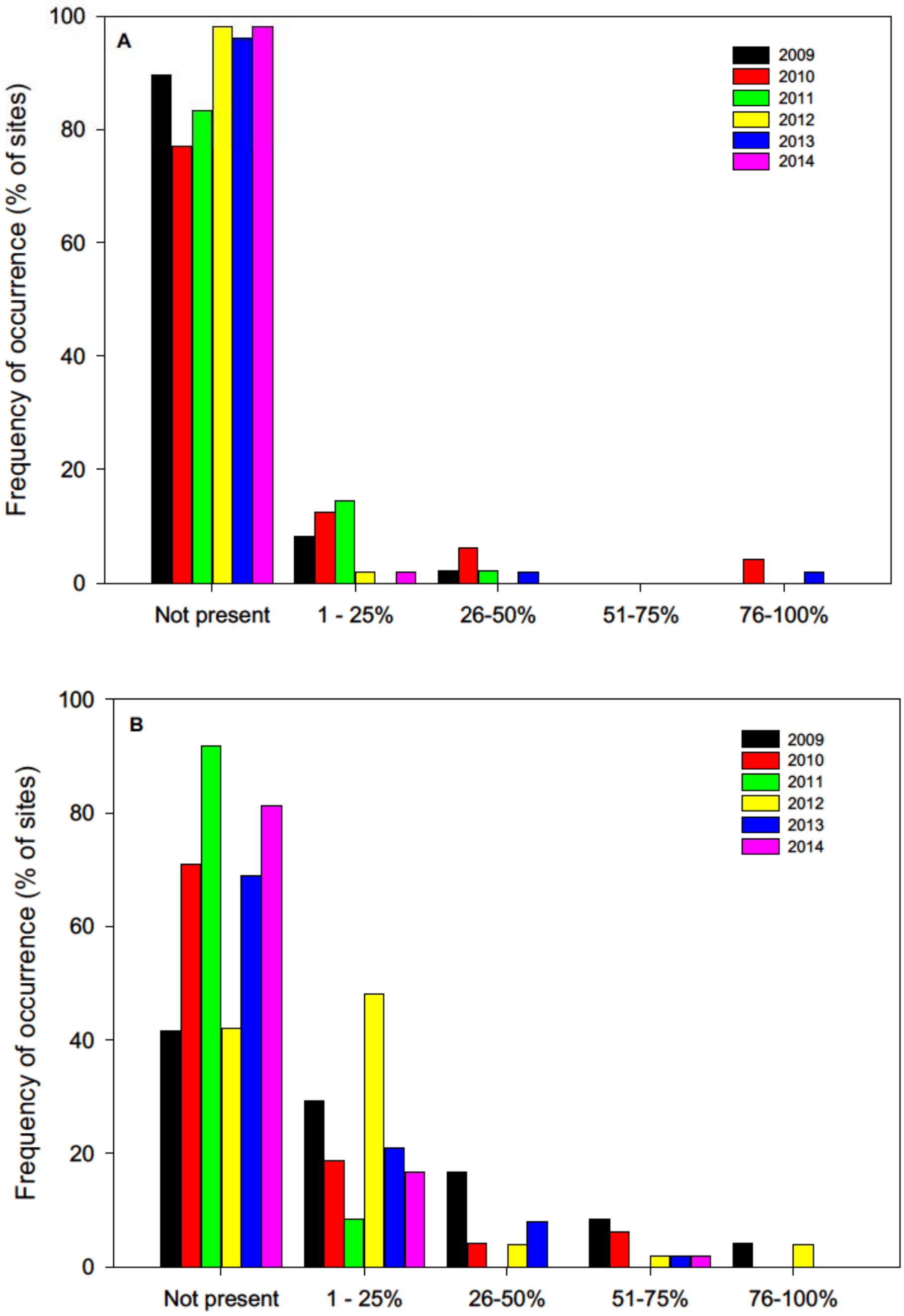

Figure 3-2: Frequency of occurrence of A) *Ruppia megacarpa* and B*) Ruppia polycarpa* across the cover abundance classes from 2009 to 2014.

The frequency of occurrence of macrophyte beds observed in a 10 m diameter circle was similar to that recorded during spot sampling (Figure 3-3). The maximum percent cover observed in the 10 m area was higher for two sites, compared to spot sampling (Figure 3-3).

[Results for the individual sites are detailed in Appendix C: Macrophyte and macroalgae cover in the 10m diameter circles].

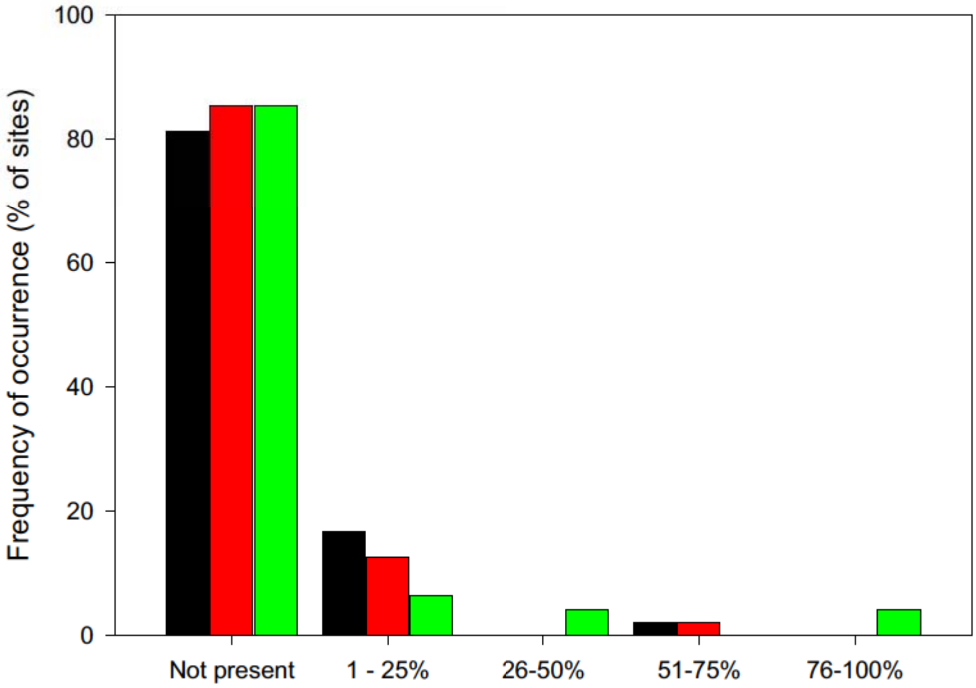

Figure 3-3: Frequency of occurrence of *Ruppia polycarpa* in each cover abundance class as recorded by spot sampling (black) and extended observations average cover (red) and maximum cover (green).

The frequency of occurrence of macroalgae was also low across the lagoon with only 27% of sites occupied by macroalgae (Figure 3-1). Only two species were recorded during the 2014 survey, the marine species *Bachelotia antillarum* and *Ulva intestinales*. The percent cover of *B. antillarum* ranged from < 1 – 100%, with an average cover of 20% and a median cover of 5% (Appendix B). The filamentous growth form of *B. antillarum* means that it is often found smothering plants in intertidal habitats (Figure 3-4). The percentage frequency and cover of *B. antillarum* has been variable since monitoring began. In 2009, it was considered to be widespread throughout the lagoon but had begun to decline in 2010 (see Robertson and Stevens 2009, Stevens and Robertson 2010 for details). *B. antillarum* was not recorded during the 2011 – 2013 surveys. The cover of *U. intestinales* recorded on the spot survey sites was typically < 5%, however, it was noted that cover was higher throughout the lagoon and large accumulations were present on the shoreline (Figure 3-5).

3.2 Water quality

3.2.1 Water depth

During the 2013-14 growth season (defined as 1 August to 31 March; Robertson and Funnell 2012) the median water depth recorded at the Environment Southland monitoring station in Waituna Lagoon was 0.52 m.a.s.l. On average, this was 1/3 lower than the 2012-13 growth season and half the water depth of the 2010-11 and 2011-12 growing seasons.

Figure 3-4: The marine macroalga *Bachelotia antillarum* smothering *Ruppia polycarpa*.

Figure 3-5: *Ulva intestinales* stranded on the shoreline of Waituna Lagoon.

At the time of the January 2014 survey, only 28 sites were submerged, compared to 31 sites in 2013, 46 in 2012 and 28 in 2011. Water depth at the sampling sites ranged from 0.1 – 1.4 m, with an average depth of 0.55 m across all submerged sites (refer to Appendix D for water depths recorded at 48 sites in January 2014).

3.2.2 Substrate type

Sand and gravel were the two dominant substrates across all sites in Waituna Lagoon. A gradient was present across the lagoon with the western side dominated by sand/mud and the eastern side dominated by gravel/sand. This gradient across the lagoon is similar to previous surveys.

[See Appendix D for substrate type categories recorded at 48 sites during the January 2014 survey].

3.2.3 Sediment health

Of the 54% of sites where a layer of blackened sediment was observed, the depth to this layer from the surface varied from 0.5 - > 4 cm, with a mean depth of 1.4 cm. The depth of the blackened layer occurred in the >0-2 cm depth class for half of sites where a layer was recorded (Figure 3-6). This is consistent with previous years, with the highest frequency of occurrence in the >0 -2 cm class for all sites with a blackened sediment layer, in all survey years (Figure 3-6).

[See Appendix D for depth of blackened sediment layer recorded at 48 sites during the January 2014 survey].

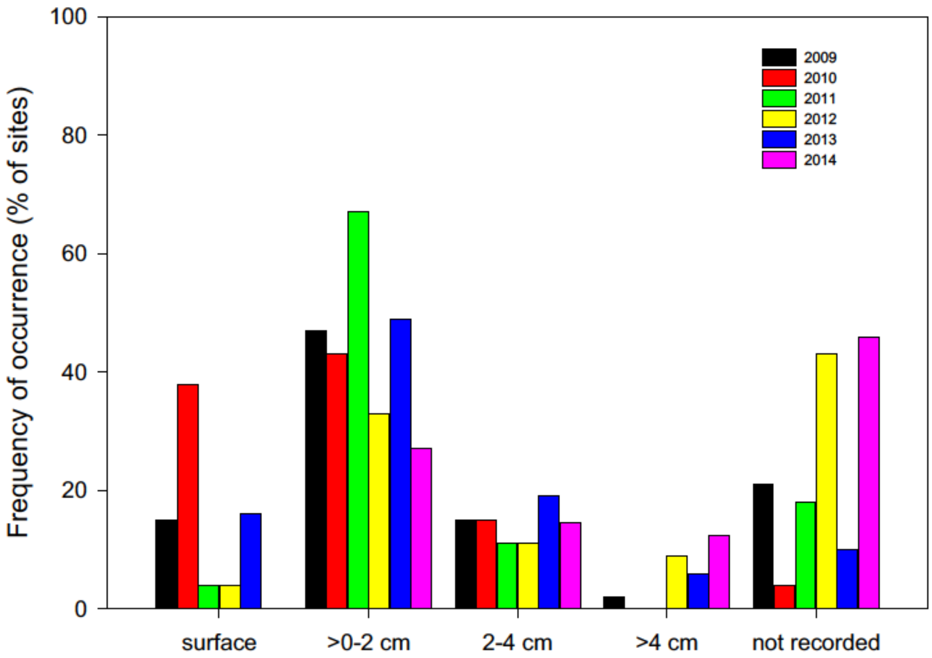

Figure 3-6: Frequency of occurrence of blackened sediment on all submerged sites between 2009 and 2014 using depth classes.

3.2.4 Dissolved oxygen

Dissolved oxygen concentrations in the surface water ranged from 77 – 111%, with a median value of 97%, while for the bottom waters dissolved oxygen ranged from 83 – 110%, with a median value of 99%. Of the 25 sites where dissolved oxygen measurements were taken, only 3 surface water values and 3 bottom water values were below the 90% threshold adopted by management agencies for many New Zealand waterbodies (range 77 – 89%). The high daytime dissolved oxygen concentrations across the lagoon and a lack of stratification reflect a well-mixed, aerated water column.

[See Appendix D for percent dissolved oxygen recorded in surface and bottom waters at 48 sites during the January 2014 survey].

3.2.5 Water clarity

Black disc measurements ranged from 0.1 to 1.36 m across the 25 sites surveyed in the lagoon. This gave a Secchi depth range of 0.13 – 1.81 m, with a median Secchi depth of 1.1 m. Median Secchi depth was similar to the median depth recorded during the 2013 survey. Secchi depth was greater than the water column depth at 22 of the 25 sites surveyed in 2014.

Light attenuation (K_d) through the water column can be approximated from Secchi depth (SD) by the equation $K_d = \frac{3}{SD}$ (Davis-Colley 1994). K_d allows the depth to which a specific proportion of surface irradiance penetrates to be estimated and consequences for plant growth to be considered. In the case of *Ruppia* sp., a 10% light threshold has been shown to affect productivity, i.e. light levels in the water column that are < 10% will negatively affect the productivity of *Ruppia* sp. (Congdon and McComb 1979). The median depth of the water column where light is ~10% of surface irradiance was estimated to be 0.85 m in Waituna Lagoon. This is 0.33 m deeper than the median water level at the monitoring platform through the growth season. This estimate is conservative as the contribution of tannin water to the seawater in the lagoon is unknown. While depth varies at a number of sites throughout the lagoon, light, for the most part, would not be considered to be the major limiting factor for *Ruppia* growth in Waituna Lagoon.

[See Appendix D for black disc measurements recorded at 48 sites during the January 2014 survey].

3.2.6 Turbidity

Turbidity of the water column ranged from 6 – 142 NTU in the surface water and 6 – 32 NTU in the bottom waters. Two surface water sites had high turbidity with 61 NTU recorded at Site 3.2 and 142 NTU at Site 2.2. In the case of Site 2.2, the high turbidity reading may be a result of wave action in the very shallow water column (0.12 m). For Site 3.2, there is no obvious explanation for the high turbidity reading as the bottom water was < 20 NTU. With the exception of the two high readings, turbidity across the lagoon was moderately low and there was no significant difference between surface and bottom water turbidity.

[See Appendix D for turbidity measurements recorded at 48 sites during the January 2014 survey].

3.2.7 Salinity

Salinity was high across the lagoon ranging from 16.5 to 33.7 ppt with a median salinity of 28.3 ppt. This is consistent with the lagoon being open to the sea and typical low freshwater inflows during this period. Salinity values are similar to those recorded during the 2013 survey, when the lagoon was also open, and considerably higher than those recorded during the 2012 survey when the lagoon was closed.

[See Appendix D for salinity measurements taken at surface and bottom waters during the January 2014 survey].

3.2.8 Temperature

The temperature ranged from 14.1 – 20.8ºC in the surface waters and from 15.6 – 18.3 ºC in bottom waters, with a median temperature of 16.5 ºC across the lagoon. The difference between surface and bottom waters was due to sites where the water depth was too shallow to take a bottom measurement and not a result of thermal stratification.

[See Appendix D for temperature recorded at 48 sites in January 2014].

3.3 Water quality over the key growing period of macrophytes

During the 2013 – 2014 growing season (defined as period between1 August and 31 March – Robertson and Funnell 2012), the lagoon was open the entire period (243 days). This is in contrast to previous surveys when there has been at least 60 days, or 25%, of the growth period when the lagoon has remained closed (Table 3-1).

As a result of the lagoon being open for the entire growth period, mean salinity levels were the highest, while water levels were the lowest since monitoring began (Table 3-1, Figure 3-7). Salinity in the lagoon is driven by the status of the lagoon mouth, with low salinity when the mouth is closed and the water inputs are predominantly derived from freshwater sources, and high salinity when the mouth is open to the sea. Salinity rapidly rises immediately following the opening of the mouth (Figure 3-7).

Nutrient concentrations during the 2013-14 growth season are comparable to the open period of the 2012-13 growth season. Nitrogen, both nitrate-nitrogen (NO_3-N) and total nitrogen (TN) concentrations when the lagoon was open did not differ significantly between the two years (Table 3-1). Dissolved reactive phosphorus (DRP) was considerably lower in 2013-14 growth period compared to the open growth period in 2012-13, while total phosphorus (TP) did not differ significantly. Sutherland et al. (2013) noted that the nutrient concentrations in the lagoon were responsive to the status of the lagoon mouth. Both TN and TP decrease significantly when the lagoon is open to the sea. This is the result of the dilution of higher nutrient freshwater in the lagoon by the lower nutrient seawater.

The mean chlorophyll *a* value, a measure of the phytoplankton, or free-floating algae, biomass, was 2.5 μgL^{-1} during the growth season (Table-3-1). A comparison could not be made with previous years' as chlorophyll *a* values were often reported as below detection limits. Using the mean chlorophyll *a*, TN and TP values the trophic level index for the 2013-14 growth season is calculated as TLI = 3.6, meaning that Waituna Lagoon is classified as mesotrophic, according to Burns et al. (1999).

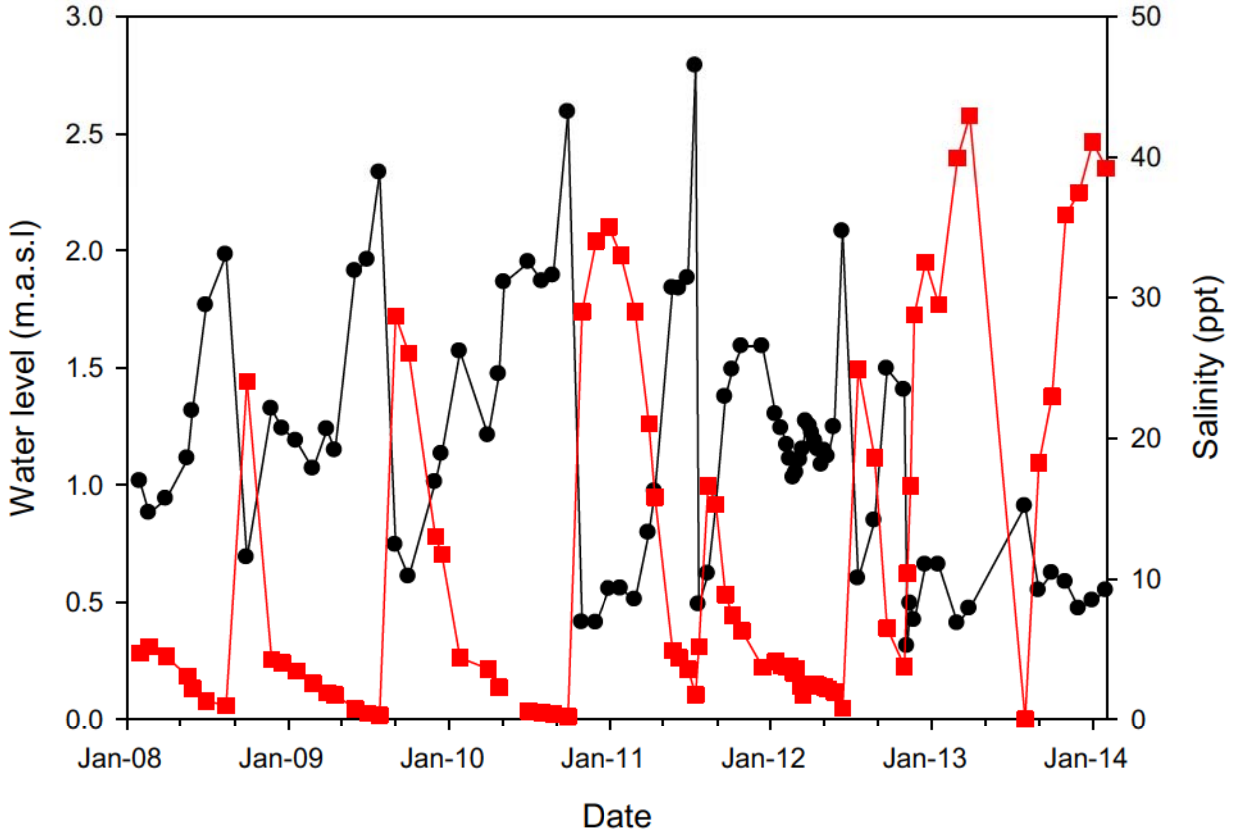

Figure 3-7: Variation in salinity (red line) in Waituna Lagoon between 2008 and 2014 relative to changes in water level (black line). Periodic increases in salinity correspond to lagoon opening events and intrusion of sea water.

Table 3-1: Summary of water quality (mean ± s.d.) in Waituna Lagoon during open and closed periods for the key growing season (1 August – 31 March) of macrophytes from 2008 to 2014.

Variable	2008-2009		2009-2010		2010-2011		2011-2012		2012-2013		2013-2014	
	Open (n=1)	Closed (n=6)	Open (n=2)	Closed (n=4)	Open (n=6)	Closed (n=3)	Open (n=1)	Closed (n=1)	Open (n=2)	Closed (n=1)	Open (n=1)	Closed (n=0)
Duration open / closed (% growing season)	18% (43 days)	82% (200 days)	26% (64 days)	74% (179 days)	74% (181 days)	26% (62 days)	6% (15 days)	94% (228 days)	75% (182 days)	25% (61 days)	100% (243 days)	0% (0 days)
Salinity (ppt)*	28.0	2.8 (0.5)	29.5 (3.5)	7.9 (2.4)	30.2 (2.1)	0.4 (0.1)	16.6	5.3	36.3 (6.8)	11.3	39.3 (6.9)	-
Turbidity (NTU)*	5.8	10.1 (2.0)	13.8 (10.2)	5.4 (1.0)	4.6 (1.3)	8.3 (2.7)	3.7	3.7	3.3 (2.1)	7.7	7.5 (9.1)	-
pH	8.0	7.5 (0.2)	7.85 (0.05)	7.8 (0.1)	8.0 (0.1)	7.5 (0.1)	7.5	8.1	8.0 (0.1)	7.5	8.0 (0.1)	-
Temperature (°C)*	9.6	14.7 (0.8)	10.7 (0.8)	15.0 (1.3)	15.8 (0.8)	7.43 (0.6)	6.3	14.4	14.1 (3.7)	10.0	13.8 (3.2)	-
Chl *a* (mg/l)*	<0.01	0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01	<0.01	<0.01 (<0.01)	<0.01	0.0025 (0.0034)	-
TN (mg/L)	0.33	1.08 (0.21)	0.49 (0.14)	0.64 (0.18)	0.37 (0.09)	1.76 (0.01)	1.23	0.77	0.43 (0.3)	1.52	0.43 (0.3)	-
TP (mg/L)	0.03	0.26 (0.21)	0.07 (0.07)	0.05 (0.05)	0.06 (0.06)	0.91 (0.04)	0.02	0.03	0.03 (0.01)	0.05	0.01 (0.005)	-
NO_3 (mg/L)	0.03	0.05 (0.01)	0.06 (0.04)	0.03 (<0.01)	0.02 (<0.01)	0.06 (0.02)	0.9	0.11	0.08 (0.16)	0.75	0.10 (0.26)	-
DRP (mg/L)	<0.01	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	<0.01 (<0.01)	0.01 (<0.01)	<0.01	<0.01	0.01 (0.01)	0.01	0.004 (0.003)	-
TN:TP	17:1	22.1	8:1	21:1	19:1	29:1	62:1	26:1	14:1	30:1	43:1	-

4 Discussion

Waituna Lagoon provides a variable, and likely challenging, environment for macrophyte growth due to temporally variable conditions of salinity, water depth, clarity and competing macroalgal development. Currently, a snapshot survey of *Ruppia* status during the growing season is used to compare inter-annual variability.

Based on the results from the annual surveys over the past few years, *Ruppia* dynamics in Waituna Lagoon appear to be very responsive to the status of the lagoon mouth. When the lagoon remains open, *Ruppia* spp. beds are lost, either through desiccation of sites, or through reduction in water levels and therefore possible increased wave damage effects or waterfowl grazing. 2014 was the second consecutive growth period the lagoon mouth was open for an extended timeframe. This has resulted in a reduction in the total number of sites containing *Ruppia* spp. beds, as well as a reduction in the overall cover of plants compared to previous years, particularly years when the mouth is closed for much of the growth season.

In addition to desiccation, the presence of marine macroalgae in the lagoon during open periods may negatively impact on *Ruppia* beds. The two macroalgal species recorded present during the 2014 survey are capable of smothering the *Ruppia* spp. beds as well as occupying habitat that would otherwise be available for *Ruppia* spp. growth. While this is likely to negatively impact on the growth of the *Ruppia* beds it is difficult to ascertain the degree of this effect as other major stressors, such as low water levels, increased salinity, increased wave action and desiccation, occur at the same time.

Water quality in Waituna Lagoon is considerably improved during periods that the lagoon is open as the seawater intrusion allows for the dilution of nutrients from the freshwater inputs. During the 2013-14 growth season, the lagoon was considered to be mesotrophic, meaning moderate nutrients and moderate phytoplankton growth. Mesotrophic conditions in the lagoon are not likely to negatively impact on the macrophyte beds, however, as nutrient loads increase and dilution effects decrease (during closed periods) then the macrophyte beds are more likely to be negatively impacted by degraded water quality.

Elsewhere, temporal *Ruppia* dynamics have been driven more by environmental fluctuations rather than by innate seasonality (e.g. Vollebergh and Congdon 1986), however, distinguishing natural changes in macrophyte population trends from those due to anthropogenic impact can be a major challenge (e.g. Cho and Poirrier 2005). For instance, *R. polycarpa* is reported to behave as an annual or perennial plant (Jacobs and Brock 1982) so that natural seasonal changes may be difficult to distinguish from major community perturbations. An increased understanding of spatio-temporal dynamics of *Ruppia* in relation to drivers would better inform management of such systems (Rogers and Paton 2009).

The ability of the *Ruppia* beds to reproduce, disperse and recolonize after perturbation associated with mouth openings would be of vital importance to ensure the future of these communities. It seems likely that a propagule bank plays a significant role in population dynamics for *Ruppia* in Waituna Lagoon, but subsequent cover and biomass development is likely be reliant on rhizome expansion and vegetative growth. Determining the presence and responsiveness of the propagules bank at Waituna Lagoon may provide an insight into recovery potential. For instance, loss of the propagule bank was seen as a major factor restricting colonisation for an Australian *Ruppia* species (Frahn et al. 2012).Little is known about the ability of *Ruppia* in the Waituna system to recover from perturbations such as extended mouth openings. We note recovery has taken place after low biomass years previously, but 2013-14 was the first time that the lagoon has been open during two consecutive growth seasons. What impact this has had on the ability of the beds to recover is unclear. While the annual monitoring of the macrophyte beds in Waituna Lagoon since 2009 has provided a robust dataset on which to assess future changes in macrophyte beds, understanding how the beds recover and the impacts of repeat lagoon openings on the ability to recover, requires a different scientific strategy.

5 Recommendations

We recommend the continuation of at least annual summer-time surveys of the macrophyte beds in Waituna Lagoon. This will further enhance the current dataset in order to better predict and mitigate any negative impacts on the macrophyte beds in the future, such as timing of lagoon openings and artificial closing.

In 2012, we recommended the inclusion of sentinel sites for more frequent monitoring to better understand the temporal variation in the *Ruppia* beds and we continue to recommend this. The purpose of this is to better understand the growth of *Ruppia* in the Waituna lagoon during the defined growing season and the impact of the stressors on the *Ruppia* beds. This information would be important in order to inform on the best practices for managing the beds, in relation to lagoon openings as well as catchment nutrient management.

In order to understand the impacts of, and frequency of, perturbation events on the recovery of *Ruppia* beds we recommend a two stage approach. 1) Assess seed and turion bank deposits across environmental and plant biomass gradients within the lagoon, 2) Assess the effects of various stressors, and repeat stressors on the availability and germinability of seeds and / or turions.

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Appendix A Easting and Northing (NZMG) for sampling sites in Waituna Lagoon.

Transect	Site	Easting (NZMG)	Northing (NZMG)
1	1	2177865	5395520
2	1	2177014	5395517
2	2	2177033	5395373
2	3	2177067	5395234
3	1	2176005	5395562
3	2	2176009	5395432
3	3	2176048	5395245
4	1	2175050	5396183
4	2	2175047	5396001
4	3	2175050	5395363
4	4	2174994	5394989
4	5	2175035	5394643
5	1	2174118	5395889
5	2	2174129	5395817
5	3	2174104	5395284
5	4	2174060	5394866
5	5	2174017	5394771
6	1	2173090	5396803
6	2	2173085	5396617
6	3	2173087	5396013
6	4	2173102	5395536
6	5	2173134	5395398
7	1	2172004	5397069
7	2	2172017	5396657
7	3	2172050	5395872
7	4	2172047	5395297
7	5	2172012	5394838
7	6	2172010	5394041
7	7	2172000	5393900
8	1	2171028	5396501
8	2	2171042	5396368
8	3	2171049	5396071
8	4	2171048	5395470
8	5	2171120	5394893
8	6	2171195	5394495
8	7	2170958	5393126
8	8	2170989	5393047
8	9	2171015	5392974
9	1	2170021	5396268
9	2	2169973	5395831
9	3	2169946	5395338
9	4	2169832	5395189
9	5	2169946	5394950
9	6	2170245	5394350
9	7	2170280	5392766
10	1	2169042	5396141
10	2	2169028	5395949
10	3	2169050	5395759

Appendix B Macrophyte and macroalgae cover in Waituna Lagoon on spot samples.

Rp = *Ruppia polycarpa*, Rm = *Ruppia megacarpa*, Lm = Lamprothamnium macropogon, Ba = *Bachelotia antillarum*, Ui = *Ulva intestinales.* f= fruiting, v = vegetative.

Transect	Site	Rep	Macrophyte	Height (cm)	Stage	% cover	Macroalgae	% cover
1	1	1	-				-	
		2	Rp, Rm	80	f	40	Ba	30
		3	-				-	
		4	Rp	7	v	3	-	
2	1	dry	-				-	
2	2	1	Rp	3	v	10	-	
		2	Rp	3	v	10	-	
		3	Rp	3	v	10	-	
		4	Rp	4	v	10	-	
2	3	dry	-				-	
3	1	dry	-				-	
3	2	1	-				Ba	<1
		2	-				-	
		3	-				Ba	1
		4	-				-	
3	3	dry	-				-	
4	1	dry	-				-	
4	2	1	-				Ba	50
		2	-				Ba	50
		3	-				Ba	50
		4	-				Ba	50
4	3	1	Rp	60	f	90	Ba	10
		2	Rp	60	f	90	Ba	10
		3	Rp	30	v	15	Ba	60
		4	Rp	40	v	85	Ba	100
4	4	1	Rp	3	v	10	Ui	<5
		2	Rp	3	v	5	Ui	<5
		3	Rp	3	v	35	-	
		4	Rp	3	v	1	Ba	<5
4	5	1	Rp	15	v	<5	Ba/Ui	<5
		2	Rp	60	v	35	Ba	40
		3	-				-	
		4	Rp	40	v	20	Ba	50
5	1	dry	-				-	
5	2	1	Rp	4	v	15	Ba	5
		2	Rp	4	v	20	Ba	<5
		3	Rp	3	v	15	Ba	<5
		4	Rp	3	v	20	Ba	<5
5	3	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
5	4	1	Rp	5	v	5	Ba	1

Transect	Site	Rep	Macrophyte	Height (cm)	Stage	% cover	Macroalgae	% cover
		2	Rp	5	v	<5	Ba/Ui	5
		3	Rp	4	v	<5	Ba	5
		4	Rp	6	v	10	Ba	5
5	5	dry						
6	1	dry						
6	2	dry						
6	3	1	-				-	
		2	Rp	4	v	10	Ba	10
		3	-				Ba	10
		4	-				Ba/Ui	70/10
6	4	1	-				unknown	<5
		2	-				unknown	<5
		3	-				unknown	10
		4	-				unknown	10
6	5	dry	-				-	
7	1	dry	-				-	
7	2	1	-				-	
		2	-				-	
		3	-				Ba	<5
		4	-				Ba/Ui	<5
7	3	1	-				Ba	<5
		2	-				Ba/Ui	<5
		3	-				Ba	100
		4	-				Ba	<5
7	4	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
7	5	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
7	6	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
7	7	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	1	dry					-	
8	2	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	3	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	

Transect	Site	Rep	Macrophyte	Height (cm)	Stage	% cover	Macroalgae	% cover
8	4	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	5	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	6	dry	-				-	
8	7	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	8	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
8	9	dry	-				-	
9	1	dry	-				-	
9	2	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
9	3	dry	-				-	
9	4	1	-				-	
		2	-				-	
		3	-				Ui	<5
		4	-				unknown	<5
9	5	1	Rp, Lm	3, <1	v	5, <1	-	
		2	Rp, Lm	3, <1	v	5, <1	-	
		3	Lm	<1		<1	-	
		4	Rp, Lm	3, <1	v	5, <1	-	
9	6	dry	-				-	
9	7	1	-				-	
		2	-				-	
		3	-				-	
		4	-				-	
10	1	dry	-				-	
10	2	dry	-				-	
10	3	dry	-				-	

Appendix C Macrophyte and macroalgae cover in 10m diameter.

Transect	Site	Species	Percent cover	
			Average	maximum
1	1	*Ruppia polycarpa*	20	100
		Ruppia megacarpa	20	60
		Bachelotia antillarum		
2	1	Dry		
2	2	*Ruppia polycarpa*	10	10
		Bachelotia antillarum	5	10
2	3	Dry		
3	1	Dry		
3	2	unknown macroalga	1	1
3	3	Dry		
4	1	Dry		
4	2	-		
4	3	*Ruppia polycarpa*	70	100
4	4	*Ruppia polycarpa*	20	30
		Bachelotia antillarum	5	5
		Ulva intestinales	5	5
4	5	*Bachelotia antillarum*		
		Ulva intestinales		
5	1	Dry		
5	2	*Ruppia polycarpa*	10	30
		Bachelotia antillarum	20	40
5	3	*Bachelotia antillarum*	10	100
5	4	*Bachelotia antillarum*	10	30
5	5	Dry		
6	1	Dry		
6	2	Dry		
6	3	*Ruppia polycarpa*	5	10
		Bachelotia antillarum	20	60
		Ulva intestinales	20	60
6	4	*Bachelotia antillarum*	30	50
		Ulva intestinales	30	50
		unknown macroalga	5	10
6	5	Dry		
7	1	Dry		
7	2	*Ulva intestinales*	20	60
7	3	*Bachelotia antillarum*	40	70
7	4	*Gracilaria chilensis*	5	5

Transect	Site	Species	Percent cover	
			Average	maximum
7	5	*Bachelotia antillarum*	<5	<5
7	6	bare		
7	7	Dry		
8	1	Dry		
8	2	*Bachelotia antillarum*	10	20
8	3	*Bachelotia antillarum*	10	20
		Ulva intestinales	10	20
8	4	*Ulva intestinales*	<5	<5
8	5	*Bachelotia antillarum*	10	20
8	6	Dry		
8	7	*Ulva intestinales*	<5	<5
8	8	*Ulva intestinales*	<5	<5
8	9	Dry		
9	1	Dry		
9	2	*Ulva intestinales*	<5	10
9	3	Dry		
9	4	Bare		
9	5	*Ruppia polycarpa*	1	1
		Lamprothamnium macropogon	1	1
9	6	Dry		
9	7	Bare		
10	1	Dry		
10	2	Dry		
10	3	Dry		

Appendix D Water quality and sediment parameters in Waituna Lagoon.

T = transect, S= site, (top) and (bot) = top and bottom of water column, Temp = temperature, Sal = salinity, DO = dissolved oxygen, Turb = turbidity, Sed = sediment. Sediment codes are s = sand, gr = gravel, m = mud, sm = soft mud.

T	S	Depth (m)	Temp (°C) (top)	Temp (°C) (bot)	Sal ppt (top)	Sal ppt (bot)	DO (mg/l) (top)	DO (mg/l) (bot)	Turb NTU (top)	Turb NTU (bot)	Black disk (cm)	Sed Rep 1	Sed Rep 2	Sed Rep 3	Sed Rep 4	Sulphide depth 1 (cm)	Sulphide depth 2 (cm)	Sulphide depth 3 (cm)	Sulphide depth 4 (cm)
1	1	0.6	18.1	18.1	16.5	16.5	103.2	103.3	8	12	0.67	Gr/SM	Gr/SM	SM/S/G	Gr/Sm	> 4	1	> 4	> 4
2	1	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
2	2	0.12	14.1		18.3		77.1		142		0.47	SM/S/G	SM/S/G	SM/S/G	SM/S/G	2	2	2	2
2	3	Dry										Gr	Gr	Gr	Gr				
3	1	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
3	2	1.4	15.6	15.6	25.7	26.0	91.2	82.9	61	18	1.13	SM	SM	SM	SM	1	1	1	1
3	3	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
4	1	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
4	2	Dry																	
4	3	0.9	15.5	15.7	26.5	26.6	90.1	92.3	7	12	1	SM	SM	SM	SM	1	1	1	<1
4	4	0.1	15.6		27.7		96.1		18		0.88	FS	S/Gr	S/Gr	S/Gr	2	> 4	> 4	> 4
4	5	0.7	15.6		26.6		86.3		6		0.66	SM/S	SM/S	SM/S	SM/S	2	<1	> 4	<1
5	1	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
5	2	0.18	16.5		28.1		103.6		15		0.63	SM/S/G	SM/S/G	SM/S/G	S/Gr	1	1	<1	<1
5	3	1	15.8	15.8	27.1	27.1	97.9	99.6	7	9	0.88	SM	SM/Gr	SM	SM	1	1	1	1
5	4	0.3	15.4		28.6		98.2		32		0.22	S/Gr	S/Gr	S/Gr	S/Gr	<1	<1	<1	<1
5	5	Dry																	
6	1	Dry										FS	FS	FS	FS				
6	2	Dry										FS	FS	FS	FS				
6	3	0.4	19.2		28.3		109.5		9		0.1	SM/S/G	SM/S/G	SM/S/G	SM/S/G	1	3	1	<1
6	4	0.7	16.6	16.4	30.6	31.8	107.4	110.2	18	15	0.72	S/Gr	S/Gr	SM/S/G	SM/S	2	1	1	2
6	5	Dry										S/Gr	S/Gr	S/Gr	S/Gr				
7	1	Dry										S/Gr/SM	S/Gr/SM	S/Gr/SM	S/Gr/SM				
7	2	0.5	17.3	17.3	27.2	27.2	102.9	105.9	23	22	0.59	S/Gr	S/Gr	S/Gr	S/Gr	<1	<1	<1	<1
7	3	0.4	16.8		29.5		99.2		9		1.21	S/Gr	S/Gr	Gr/SM/S	S/Gr	1	<1	1	<1

T	S	Depth (m)	Temp (°C) (top)	Temp (°C) (bot)	Sal ppt (top)	Sal ppt (bot)	DO (mg/l) (top)	DO (mg/l) (bot)	Turb NTU (top)	Turb NTU (bot)	Black disk (cm)	Sed Rep 1	Sed Rep 2	Sed Rep 3	Sed Rep 4	Sulphide depth 1 (cm)	Sulphide depth 2 (cm)	Sulphide depth 3 (cm)	Sulphide depth 4 (cm)
7	4	0.35	17.8	17.8	33.6	33.6	96.6	98.3	22	32	0.83	FS	FS	FS	FS	2	1	2	2
7	5	0.7	18.4	18.3	33.7	33.7	101.4	98.5	15	9	0.65	FS	FS	FS	FS	2	2	2	1
7	6	0.3	18.8		33.7		96.1		20		0.82	FS	FS	FS	FS	> 4	> 4	> 4	> 4
7	7	Dry										S/GR	S/GR	S/GR	S/GR				
8	1	Dry										S/GR	S/GR	S/GR	S/GR				
8	2	0.2	16.2		32.5		93.1		6		1.36	SM	SM	SM	SM	2	2	2	2
8	3	0.6	15.7	15.6	29.0	32.9	92.5	89	10	11	0.87	SM/S	SM/S	SM/S	SM/S	3	1	2	2
8	4	0.6	15.7	15.7	28.4	30.2	92.7	88.9	9	10	0.75	FS	SM/S	SM/S	SM/S	3	> 4	> 4	> 4
8	5	0.6	15.6		26.5		88.8		7		0.93	SM/S/G	SM/S/G	SM/S/G	SM/S/G	> 4	> 4	> 4	> 4
8	6	Dry										Gr	Gr	Gr	Gr				
8	7	0.3	19.6		33.6		95.9		18		0.99	Gr/SM/S	SM/S/G	SM/S/G	SM/S/G	2	2	2	2
8	8	1	16.5	16.6	33.5	33.4	96.7	101	12	6	1.28	FS	SM	SM	FS	> 4	> 4	> 4	> 4
8	9	Dry																	
9	1	Dry																	
9	2	0.3	19.1		25.7		99.4		43		0.5	FS	FS	FS	FS	<1	1	1	1
9	3	Dry										Gr/S	Gr/S	Gr/S	Gr/S				
9	4	0.1										SM	SM	SM	SM	2	2	1	1
9	5	1.5	20.8		23.1		110.8		22		0.43	SM	SM	SM/S	SM/S	2	2	3	3
9	6	Dry			33.5	33.4													
9	7	0.45	17.3	17.2			101.6	105.4	12	11	1.12	FS	FS	FS	FS	2	2	2	2
10	1	Dry										S/Gr/SM	S/Gr/SM	S/Gr/SM	S/Gr/SM				
10	2	Dry										SM/S	SM/S	SM/S	SM/S				
10	3	Dry			16.5	16.5						S/Gr/SM	S/Gr/SM	S/Gr/SM	S/Gr/SM				