Macrophyte monitoring in Waituna Lagoon - summer 2017

Prepared for Department of Conservation, Murihiku Area Office, Southland

November 2017

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NIWA CLIENT REPORT No: 2017381HN
Report date: November 2017
NIWA Project: DOC16206

Quality Assurance Statement		
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Cover photo: Ruppia sample being retrieved to the surface at Waituna Lagoon. [Aleki Taumoepeau, NIWA]

Contents

Tables

Figures

1 Introduction

Waituna Lagoon, located in Southland, is a highly valued coastal lagoon due to its high aesthetic, biological and recreational values and is one of the best remaining examples of a coastal lagoon in New Zealand. The diverse range of habitat in Waituna Lagoon is important 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 the lagoon is an important safe moulting area for large numbers of these waterfowl. The Waituna catchment contains marine, estuarine and freshwater fish species, as well as being a national stronghold for the threatened giant kokopu, inanga, short fin eels and the threatened long fin eel (Atkinson 2008). The lagoon is a place of great significance to Ngāi Tahu, and was traditionally an important mahinga kai area.

In 1976 Waituna lagoon was New Zealand's first wetland to gain Ramsar registration. The Ramsar Convention is an intergovernmental treaty aimed to halt and, where possible, reverse damage to wetlands. Wetlands accepted for registration need to meet very high standards and participating governments agree to accept their obligation to protect and manage them. The Department of Conservation administers the Convention in New Zealand, but needs support as it has no control over land use practices in much of the catchment.

As the lagoon has no permanent natural outlet to the sea, it is a freshwater environment for much of the time, becoming estuarine when opened. The lagoon is fed by three lowland streams that flow through agricultural pastures. As a result of increased land-use intensification in the catchment, there has been an increase in contaminant loads entering the lagoon, in particular ammonium and phosphorus (Lagoon Technical Group 2013). This has resulted in degradation of water quality and the lagoon is now described as being in a eutrophic state, meaning that the lagoon has high nutrients, high phytoplankton biomass and poor water quality (Lagoon Technical Group 2013).

The lagoon is artificially opened when the water level exceeds 2.0 meters above sea level (m.a.s.l.) and sea conditions are suitable, while closure occurs naturally. While artificial openings have been of benefit to low lying farmland areas, they also provide a mechanism to mitigate against eutrophication in the lagoon. When opened, the lagoon exchanges water with the lower nutrient sea and high nutrient concentrations in the lagoon are diluted.

Historically, Waituna Lagoon was in a macrophyte dominated state with dense beds of *Ruppia megacarpa* (horse's mane weed), along with *Myriophyllum triphyllum* (milfoil), present throughout the lagoon, particularly in deeper water (Johnson and Partridge 1998). However, in recent years, there has been a decline in macrophyte abundance, in particular *Ruppia* spp. beds. Macrophyte surveys carried out over the last seven years suggests that the macrophyte community is responsive to the status of the lagoon opening during the growing period (defined as 1 August to 31 March). When the lagoon is open during the growing period, beds are lost, either through desiccation, through wave action or by birds grazing. In contrast, when the lagoon is closed during the growing period, macrophyte beds flourish but so too does algal (both benthic and free-floating) communities.

Continued eutrophication of the lagoon, together with loss of macrophyte beds during summer-time lagoon openings, 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 considered to be the desired state. In contrast, an algal dominated state can often lead to decreased values and increased risk of toxic algal 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 or impossible to reverse, so it enters a new stable state – an algal dominated lagoon without submerged macrophytes. Understanding the trade-off between improved water quality during lagoon opening and protecting the *Ruppia* spp. habitat is pivotal in management decisions regarding the likely impact of opening events on the ecological character of Waituna Lagoon (Robertson and Funnell 2012).

As part of their responsibility for managing Waituna lagoon, under their biodiversity conservation role, Department of Conservation (DOC) initiated macrophyte surveys in the 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 2017 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) and to provide an inter-annual comparison of its condition. This report summarises the results of the 2017 annual summer-time survey.

2 Methods

The methodology used during these surveys was initially developed by Robertson and Stevens (2009) and Stevens and Robertson (2010) and has remained consistent over the course of the annual surveys to date. The methodology is summarised below and the reader is directed to both Robertson and Stevens (2009) and Stevens and Robertson (2010) reports for full background to the methodology used.

2.1 Survey sites

A total of forty seven[1] sites situated on ten transects (orientated north-south) were surveyed across Waituna Lagoon in 2016 (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 the 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 15cm and 6cm deep were cut from the sediment, using a flat based garden hoe, and carefully lifted to the surface. Each replicate sample was then assessed for:

[1] Site 8-9 is now located within the barrier spit following migration of sediment during the lagoon closure in 2015 and is no longer included in the survey.

- Macrophyte and / or macroalgae species present.
- Cover score[2] of each species present.
- Mean height of each species present.
- Life stage[3] 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 10m diameter by snorkel / SCUBA 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, as well as sediment parameters were measured at each site (Appendix D and E). 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 macrophyte survey was carried out between 19 and 22 February 2017.

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, Sutherland et al. 2014, Sutherland and Taumoepeau 2015, Sutherland et al. 2016).

[2] 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%.

[3] Life stage categories were V = vegetative, F = flowering, PF = post flowering.

Water quality for the 2016/2017 year was summarised across the key growing season for macrophytes (1 August to 31 March) as defined by Robertson and Funnell (2012). Source data was obtained from Environment Southland from both a long-term monitoring site, and from the automated 'monitoring platform'. However, data for the latter site only existed up until 23 February 2017 (Environment Southland comments on continuous data).

3 Results

3.1 Macrophyte and macroalgae

Full measurements of the macrophyte and macroalgal communities recorded at each site are listed in Appendices B and C.

There was a slight reduction in the overall frequency of occurrence of *Ruppia* spp. in 2017 (74%) since 2016 (87%), with a return to similar frequencies recorded in 2015 (70%). Years that have had *Ruppia* spp. recorded at over 50% of surveyed sites included 2009 (73%) and 2012 (60%).

Ruppia polycarpa was recorded at 72% of surveyed sites, similar to its frequency of occurrence in 2015 and 2016 (Figure 3-1). *Ruppia megacarpa* remained infrequent (6% of sites) and was recorded together with *R. polycarpa,* except where it alone dominated at Site 1.1 (Figure 2-1). The charophyte *Lamprothamnium macropogon* was recorded at 17% of sites, with plants comprising germlings <5 cm in height.

In summer 2017, the greatest proportion of sites recorded covers for *R. polycarpa* in the 1-25% class (Figure 3-2), whilst *R. megacarpa* was not recorded at the majority of sites. There was a reduction in the proportion of sites recording higher covers (>50%) for *R. polycarpa* compared to 2016 and 2015. The number of sites recording dense covers (>75%) for *R. megacarpa* have also decreased since 2016 (Figure 3-2). Only two sites retained high covers of *Ruppia* spp. (average >50%), with both sites (1.1 and 4.3) being the eastern side of the Lagoon (Figure 2-1). *Ruppia* spp. were unrecorded in the west and along the south-west shorelines (Sites 10.2, 10.3, 9.2, 9.3, 9.4, 8.6, 8.7, 7.7, 7.1, 6.5).

Lamprothamnium macropogon also decreased in cover overall, recording 1-5% cover at most sites where it was present in 2017 (71% frequency), compared with 2016 where *L. macropogon* had covers >5% at the majority of sites (63% frequency) where it was recorded.

Macrophyte heights in 2017 were similar to 2016, ranging from 0.5 – 220 cm and a mean height of 27 (± 45) cm (see Appendix B). The height of *R. megacarpa* at site 1.1, at over 200 cm, exceeded all previous measurements.

Ruppia spp. were not flowering during the 2017 survey, although *R. megacarpa* was post-flowering at Site 1.1 (see Appendix B). This is a major difference from 2016 when plants were flowering at 70% of the sites.

Extended observations (10m diameter circle) showed the hoe method was less likely to detect *R. polycarpa* presence at a site (Figure 3-3), as has been found in previous years. Plants were detected at 83% of sites based on extended observations and 72% of sites using the hoe method. Accordingly, occurrences of *R. polycarpa* at all covers classes were greater for the extended observations method than the hoe method.

Macroalgal composition and abundance in 2017 was highly variable across the lagoon. Macroalgae were dominated by *Ulva intestinalis* and filamentous green algae including *Cladophora* sp. and *Spirogyra* sp. *Ulva intestinalis* was recorded from 23% of sites and conspicuous filamentous green algae were present at 36% of sites. The frequency of occurrence of *U. intestinalis* has decreased 3-fold since 2016, at which time it had the highest occurrence since surveys commenced in 2009 (Figure 3-1). Other, filamentous green algae remained at a similar occurrence to 2016, and at a lower frequency than 2015. The marine species *Bachelotia antillarum* was not observed in the lagoon during the summer 2017 survey.

The mean cover for *U. intestinalis* where it was recorded was 34%. *U. intestinalis* and/or filamentous green algae formed >75% average cover at five sites (4.5, 6.2, 9.1, 10.1, 10.3). High covers (>75%) of a fine, low-growing alga were additionally recorded at Site 5.1. This level of algal dominance appeared similar to 2016 (4 sites >75% cover).

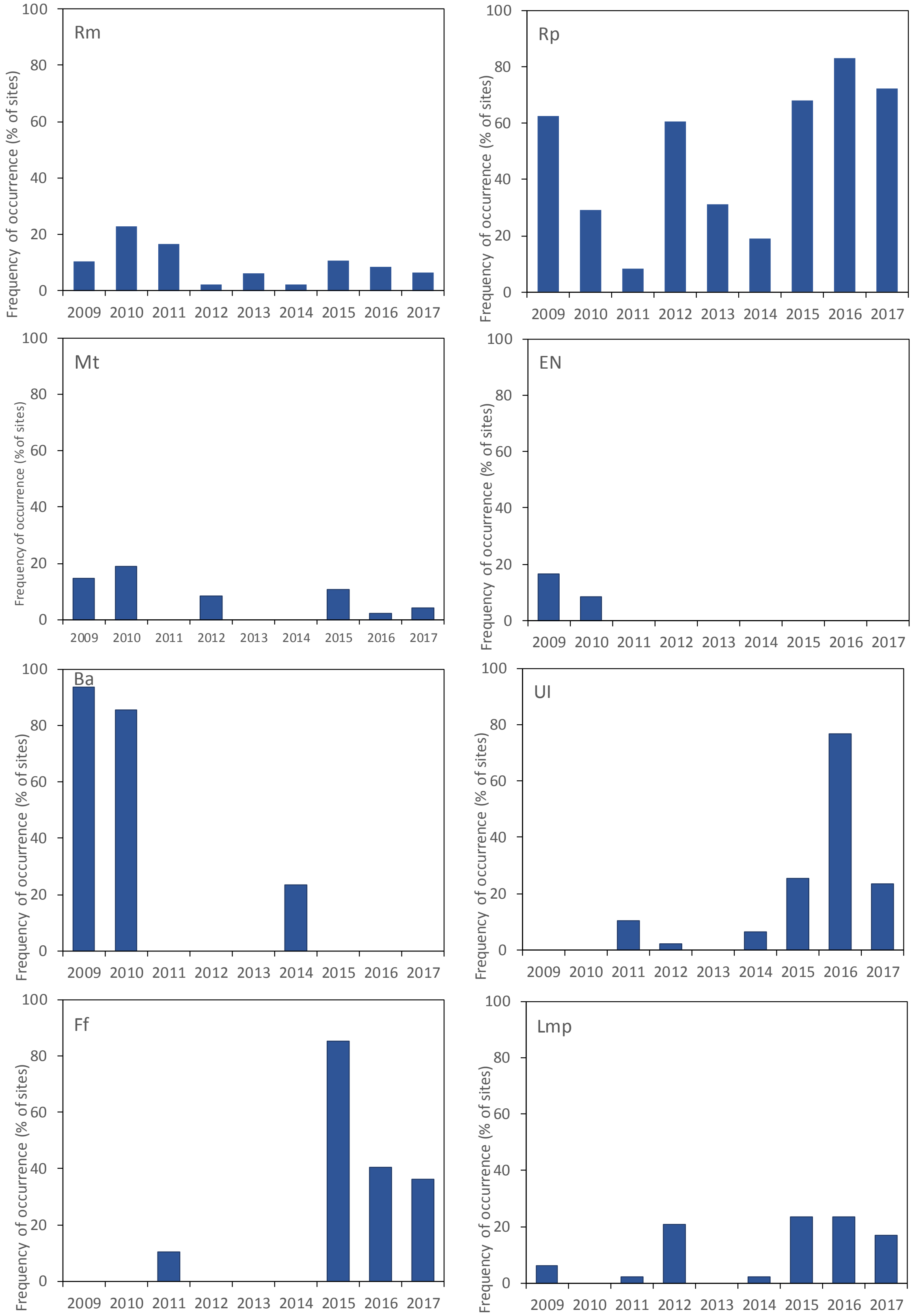

Figure 3-1: Frequency of occurrence of macrophytes and macroalgae in Waituna Lagoon between 2009 and 2017. Rm= *Ruppia megacarpa*, Rp = *Ruppia polycarpa*, Mt= *Myriophyllum triphyllum*, EN = *Entromorpha* sp., Ba= *Bachelotia antillarum*, Ul = *Ulva intestinales*, Ff = Filamentous green algae, Lmp = *Lamprothamnium macropogon*.

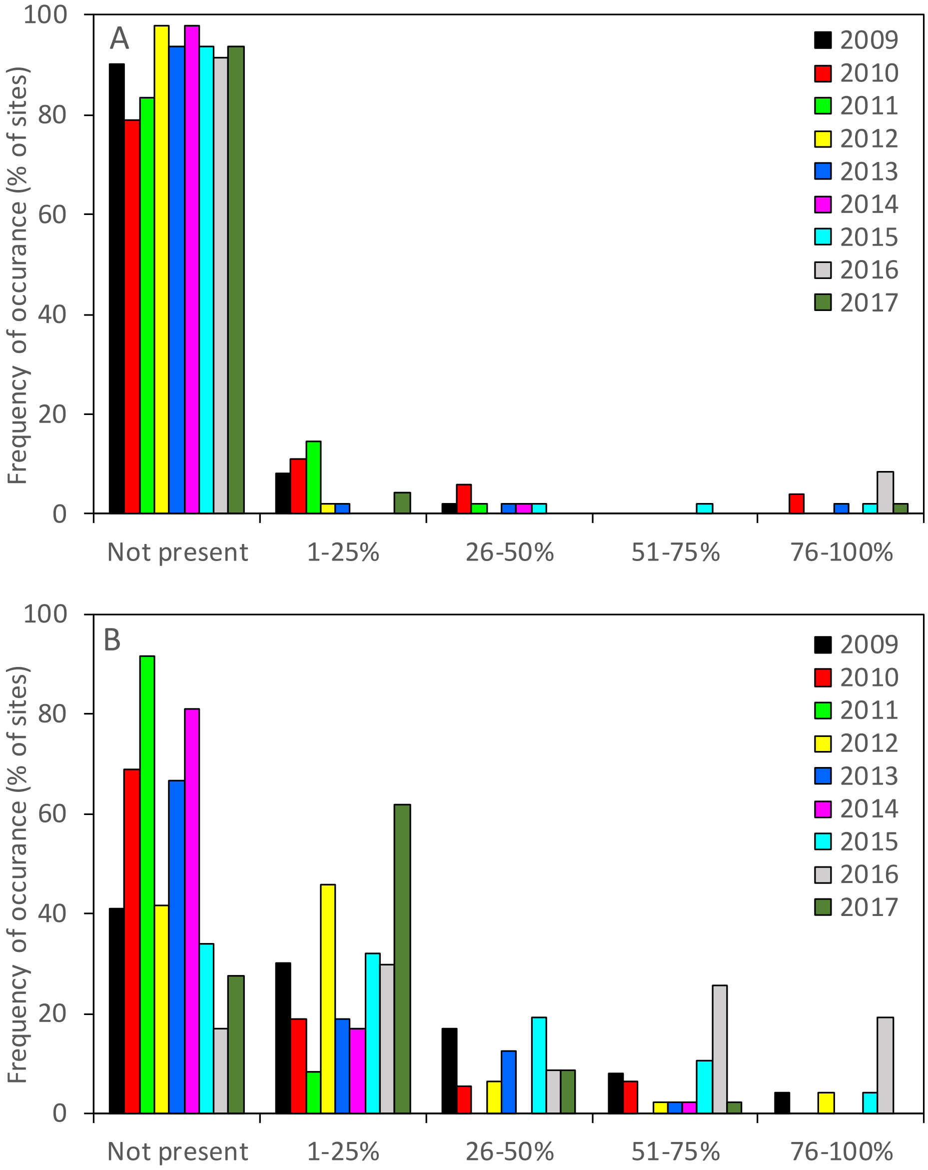

Figure 3-2: Frequency of occurrence of A) *Ruppia megacarpa* and B) *Ruppia polycarpa* across the cover abundance classes from 2009 to 2017.

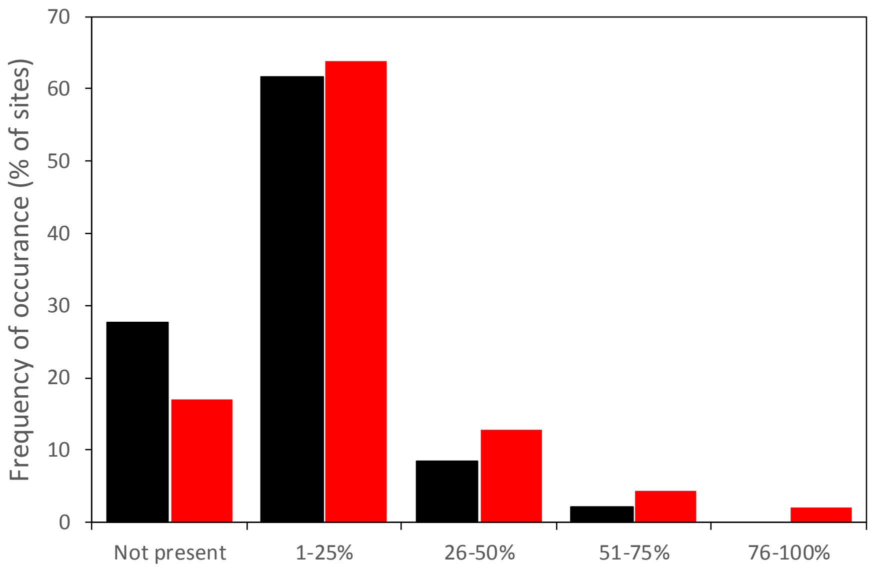

Figure 3-3: Frequency of occurrence of *Ruppia polycarpa* in each cover abundance class as recorded by spot sampling and extended observations (10m diameter). Spot sampling indicated by black bars, and extended observations average cover indicated by red bars.

3.2 Water quality

3.2.1 Water depth

During the 2016-17 growing season (defined as 1 August to 31 March; Robertson and Funnell 2012) the median water level recorded at the Environment Southland Waghorn Road gauge was 0.72 m a.s.l, or 0.48 m below normal level (1.20 m a.s.l.). Median water level over the growing season in 2016-17 was substantially lower than in 2015-16 (1.29 m a.s.l.), in 2014-15 (1.39 m a.s.l.) or 2011-12 year (1.29 m a.s.l.) and is closer to the 2013-14 year (0.60 m a.s.l.) and 2012-13 year 0.73 m a.s.l.).

3.2.2 Substrate type

Substrate types and distribution were similar to previous surveys. Sand and gravel remained the dominant substrate types across the Waituna Lagoon. Sites on the western side of the lagoon were typically characterised by sand / mud while sites on the eastern side were characterised by gravel / sand.

[See Appendix E for substrate type categories recorded at 47 sites during the summer 2017 survey].

3.2.3 Sediment health

No visible blackened layer was observed in samples taken for 21% of the sites (i.e., beyond 4 cm depth), and at another 10% of sites this layer was observed in only one of the four samples. Nevertheless, compared to the 2016 sampling, there was a higher proportion of samples that had the visible blackened layer in the top 2 cm of sediment depth.

In previous years where the lagoon was open at the time of survey (2011, 2013, 2014), numerous sites were dry and 'not recorded'. It also appears that a greater proportion of samples had the blackened layer at the substrate surface or positioned within the top 2 cm in 2009 and 2010 than in later years. No obvious other pattern occurs with time or mouth status of the lagoon.

[See Appendix E for depth of blackened sediment layer recorded at 47 sites during the summer 2017 survey].

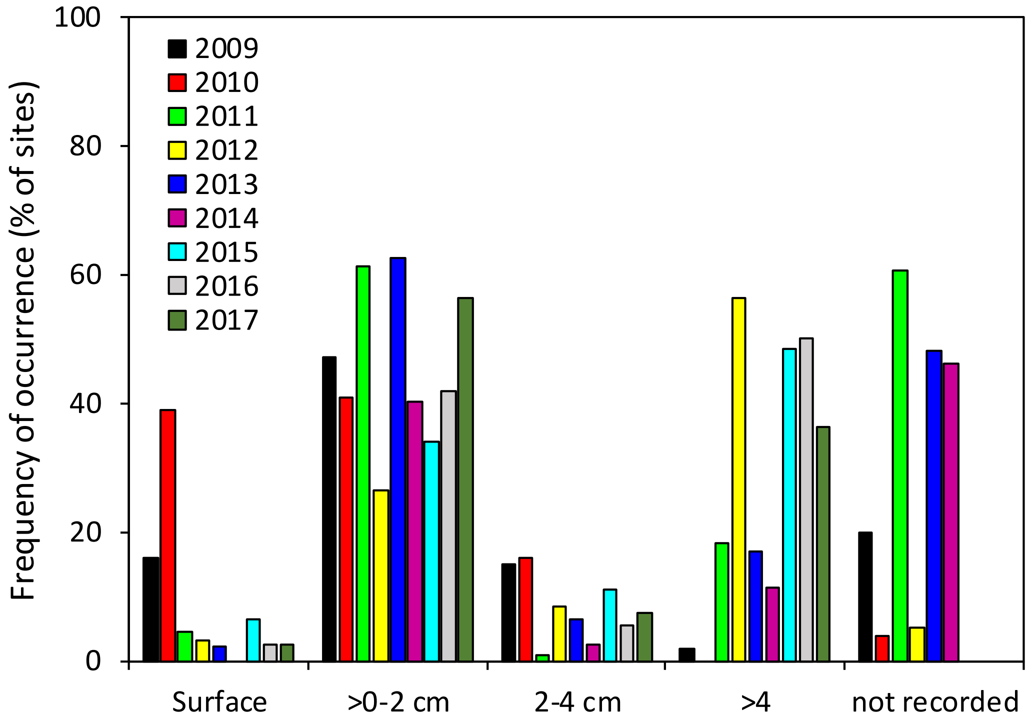

Figure 3-4: Frequency of occurrence of blackened sediment on all submerged sites between 2009 and 2017 using depth classes.

3.2.4 Dissolved oxygen

During the February 2017 survey, surface DO concentrations ranged from 64.9 – 122.1%, with a median value of 81.7%. For the bottom waters, DO concentrations ranged from 27.6 – 99.3%, with a median value of 73.1%. Differences in DO concentration between surface and bottom waters exceeded 10% at seventeen sites, and bottom waters generally had lower DO concentrations (39 sites).

According to draft National Objectives Framework attributes for dissolved oxygen[4] in rivers and streams (Davies-Colley et al. 2013), DO concentrations in surface waters at three sites fell below the suggested 7 day mean critical threshold for ecosystem health (6.5mg L^{-1}). Note, however, that these critical values are a guide only as DO measurements are spot records not continuous data. DO concentrations in bottom waters at 18 sites fell below 6.5mg L^{-1} suggested as a 7 day mean critical threshold for ecosystem health. Two sites fell below the 1 day critical threshold for ecosystem health. These latter two sites varied by c. 50% DO concentration between surface and bottom waters and had the greatest temperature differential (Section 3.2.8).

[4] *Risk of significant degradation of ecosystem health if 7-day mean value <6.5 mg L^{-1}, the 7-day mean minimum <5 mg L^{-1} or the 1-day minimum < 4 mg L^{-1} during summer monitoring data for discrete specified periods*

[See Appendix D for dissolved oxygen concentrations recorded in surface and bottom waters at 47 sites during the February 2017 survey].

During the growing period that the lagoon was open to the sea (171 days) dissolved oxygen (DO) concentrations in the surface water measured at the monitoring station ranged from 81 – 157%, with a median value of 97% (± 8%). During the same period DO concentrations in the bottom water ranged from 82 – 136%, with a median value of 97% (± 7).

During the growing period that the lagoon was closed to the sea (71 days) DO concentrations in the surface water measured at the monitoring station ranged from 77 – 125%, with a median value of 95% (± 6%), and in the bottom water ranged from 73 – 117%, with a median value of 93% (± 6).

3.2.5 Water clarity

Black disc measurements ranged from 0.3 to 1.9m across the lagoon, giving an equivalent Secchi depth (SD) range of 0.3 to 2.5 m, with a median SD of 1.7m ± 0.4m (as per conversion protocol in Davis-Colley 1994). This median SD value was similar to the summer 2016 survey (1.65m) and 2015 survey (1.67m), and approximately 0.5m higher than that recorded during the 2013 and 2014 summer surveys.

SD was greater than the depth of the water column at 34 out of the 47 sites surveys. There was no relationship between water depth (a proxy to wave action effects) and water clarity, although shallower sites <1 m depth had greater variablity in SD values and possessed the lower values (SD <1.25 m).

Light attenuation (K_d) through tannin stained water columns can be approximated from SD by the equation (Davis-Colley 1994):

$$K_d = \frac{3}{SD}$$

K_d allows the depth to which a specific proportion of surface irradiance penetrates to be estimated and consequences for macrophyte 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* spp. (Congdon and McComb 1979). The median depth of the water column where light is ~10% of surface irradiance was estimated to be 1.33m, meaning that at the time of the survey 28 out of 47 sites were more shallow than the 10% irradiance depth limit.

[See Appendix D for black disc measurements recorded at 47 sites during the summer 2017 survey].

3.2.6 Turbidity

Water column turbidity was low across the lagoon, ranging from 1.5 – 28.2 NTU in the surface waters and 1.5 - 32.6 NTU in the bottom waters. The highest measurements were from a single site (Site 10.1) and results were otherwise similar to those measured during the summer of 2016 and 2015.

Most sites (35 sites) had similar levels of turbidity in surface and bottom waters, but 12 sites showed differences of >1 NTU – 7.1 NTU between the two water strata.

Over the growing season (1 August – 31 March), turbidity (as measured as part of the State of the Environment monitoring undertaken by Environment Southland) ranged from 1.6 – 9.4 NTU, with a median value of 3.8 (± 0.7) NTU during the closed period and a median value of 4.1 (± 2.2) NTU during the open period.

[See Appendix D for turbidity measurements recorded at 47 sites during the summer 2017 survey].

3.2.7 Salinity

Salinity during the *Ruppia* survey (February 2017) was moderate across the lagoon with surface water salinity ranging from 5 to 12 ppt and bottom water salinity ranging from 5 to 20 ppt, with a lagoon-wide median salinity of 10.4 ppt. This is consistent with the lagoon being recently closed to the sea (c. mid-January 2017) and receiving recent water inputs from freshwater sources. Salinity in the lagoon was higher than that recorded in 2016 (6.3 ppt) and 2015 (2.1 ppt) but is still much lower than values recorded during 2013 (36.3 ppt) and 2014 (39.3 ppt) when the lagoon was open to the sea.

[See Appendix D for salinity measurements recorded at 47 sites during the summer 2017 survey].

3.2.8 Temperature

At the time of the 2017 summer survey temperature across the lagoon ranged from 18.1 – 21.6°C (median = 19.5°C ± 0.8) in the surface waters and from 8.7 – 21.3°C (median = 19.1°C ± 1.8) in the bottom waters. Of the 47 sites, 42 showed <1°C difference in temperature between the surface and bottom waters (ranging from 0.0 – 0.76°C), with 53% of these being < 0.1°C difference. Five sites showed >1°C difference in temperature, with the greatest being 4.0°C recorded at site 1.1, where surface temperature was 20.3°C and bottom temperature amongst dense *Ruppia* was 16.3°C.

[See Appendix D for temperature measurements recorded at 47 sites during the summer 2017 survey].

3.3 Water quality over the key growing period of macrophytes

The lagoon was open for the majority (171) of the 2016-2017 growing period. This contrasts with the previous two reporting years (2014/15 and 2015/16) where the lagoon was closed for more than 200 days of the growing period (Table 3-1 and 3-2).

A rapid increase in salinity occurred when the lagoon was opened to the sea, while higher water levels and lower salinity were associated with periods where the lagoon was closed to the sea (Figure 3-6).

In general, there is a tendency for nutrient concentrations in the lagoon to be higher when the lagoon is closed, with decreases in both total nitrogen (TN) and total phosphorus (TP) occurring when the lagoon is opened and flushed by seawater with lower nutrient concentrations (Table 3-2). Although TN and TP were slightly higher when the lagoon was closed in 2017 based on limited sampling events, this difference in nutrient status is not pronounced.

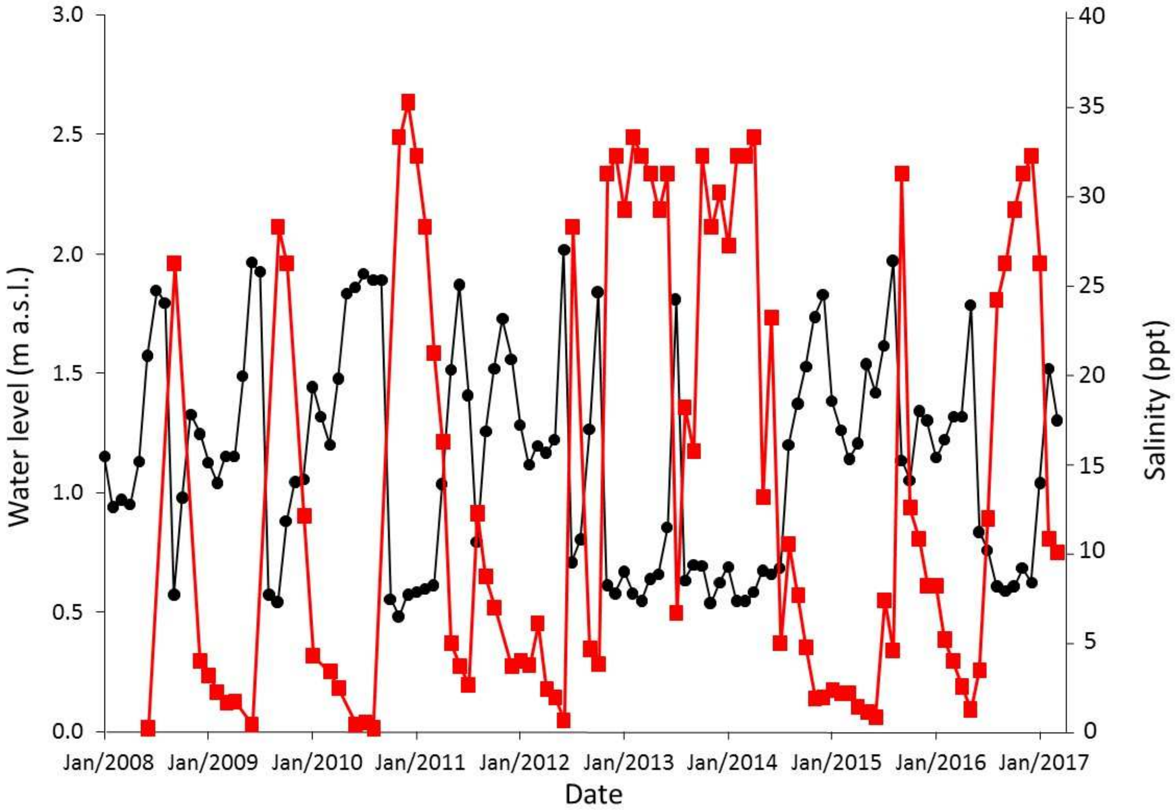

Figure 3-5: Variation in salinity (red line) in Waituna Lagoon between 2008 and 2017 relative to changes in water level (black line). Periodic increases in salinity correspond to lagoon opening events and intrusion of sea water.

Table 3-1: Summary of physical water quality (mean ± s.d.) in Waituna Lagoon during open and closed periods for the key macrophyte growing season (2008 - 2016). This is defined as the period between 1 August and 31 March. * data collected from Environment Southland's monitoring platform. n.p = data not provided. † Data drawn from SOE monitoring sites as monitoring data was not complete.

Year	Status	Measurements	Duration open / closed	% Growing season	Salinity (ppt)*	Turbidity (NTU)*	pH	Temperature (°C)*
2008-2009	Open	(n=1)	(43 d)	18%	28	5.8	8	9.6
	Closed	(n=6)	(200 d)	82%	2.8 (0.5)	10.1 (2.0)	7.5 (0.2)	14.7 (0.8)
2009-2010	Open	(n=2)	(64 d)	26%	29.5 (3.5)	13.8 (10.2)	7.85 (0.05)	10.7 (0.8)
	Closed	(n=4)	(179 d)	74%	7.9 (2.4)	5.4 (1.0)	7.8 (0.1)	15.0 (1.3)
2010-2011	Open	(n=6)	(181 d)	74%	30.2 (2.1)	4.6 (1.3)	8.0 (0.1)	15.8 (0.8)
	Closed	(n=3)	(62 d)	26%	0.4 (0.1)	8.3 (2.7)	7.5 (0.1)	7.43 (0.6)
2011-2012	Open	(n=1)	(15 d)	6%	16.6	3.7	7.5	6.3
	Closed	(n=1)	(228 d)	94%	5.3	3.7	8.1	14.4
2012-2013	Open	(n=2)	(182 d)	75%	36.3 (6.8)	3.3 (2.1)	8.0 (0.1)	14.1 (3.7)
	Closed	(n=1)	(61 d)	25%	11.3	7.7	7.5	10
2013-2014	Open	(n=1)	(243 d)	100%	39.3 (6.9)	7.5 (9.1)	8.0 (0.1)	13.8 (3.2)
	Closed	(n=0)	(0 d)	0%	-	-	-	-
2014-2015	Open	(n=0)	(0 d)	0%	-	-	-	-
	Closed	(n=1)	(243 d)	100%	4.7 (3.9)	7.5 (12.3)	7.7 (0.1)	12.2 (3.3)
2015-2016	Open	(n=0)	(33 d)	14%	35.8 (8.7)	6.8 (1.4)	n.p	10.6 (1.6)
	Closed	(n=1)	(210 d)	86%	9.8 (4.7)	4.6 (2.7)	n.p	13.4 (4.3)
2016-2017	Open	(n=6)	(171 d)	71%	27.9 (4.0)†	4.0 (2.2)†	n.p	11.9 (3.1)
	Closed	(n=2)	(71 d)	29%	10.4 (0.5)†	3.8 (0.7)†	n.p	15.6 (2.1)

Table 3-2: Summary of biological water quality (mean ± s.d.) in Waituna Lagoon during open and closed periods for the key macrophyte growing season (2008 - 2016). This is defined as the period between 1 August and 31 March.

Year	Status	Measurements	Duration open / closed	% Growing season	Chl *a* (mg/L)	TN (mg/L)	TP (mg/L)	NO_3 (mg/L)	DRP (mg/L)	TN:TP
2008-2009	Open	(n=1)	(43 d)	18%	<0.01	0.33	0.03	0.03	<0.01	17:1
	Closed	(n=6)	(200 d)	82%	0.01 (<0.01)	1.08 (0.21)	0.26 (0.21)	0.05 (0.01)	<0.01 (<0.01)	22:1
2009-2010	Open	(n=2)	(64 d)	26%	<0.01 (<0.01)	0.49 (0.14)	0.07 (0.07)	0.06 (0.04)	<0.01 (<0.01)	8:1
	Closed	(n=4)	(179 d)	74%	<0.01 (<0.01)	0.64 (0.18)	0.05 (0.05)	0.03 (<0.01)	<0.01 (<0.01)	21:1
2010-2011	Open	(n=6)	(181 d)	74%	<0.01 (<0.01)	0.37 (0.09)	0.06 (0.06)	0.02 (<0.01)	<0.01 (<0.01)	19:1
	Closed	(n=3)	(62 d)	26%	<0.01 (<0.01)	1.76 (0.01)	0.91 (0.04)	0.06 (0.02)	0.01 (<0.01)	29:1
2011-2012	Open	(n=1)	(15 d)	6%	<0.01	1.23	0.02	0.9	<0.01	62:1
	Closed	(n=1)	(228 d)	94%	<0.01	0.77	0.03	0.11	<0.01	26:1
2012-2013	Open	(n=2)	(182 d)	75%	<0.01 (<0.01)	0.43 (0.3)	0.03 (0.01)	0.08 (0.16)	0.01 (0.01)	14:1
	Closed	(n=1)	(61 d)	25%	<0.01	1.52	0.05	0.75	0.01	30:1
2013-2014	Open	(n=1)	(243 d)	100%	0.0025 (0.0034)	0.43 (0.3)	0.01 (0.005)	0.10 (0.26)	0.004 (0.003)	43:1
	Closed	(n=0)	(0 d)	0%	-	-	-	-	-	-
2014-2015	Open	(n=0)	(0 d)	0%	-	-	-	-	-	-
	Closed	(n=1)	(243 d)	100%	0.0053 (0.0046)	1.13 (0.31)	0.04 (0.02)	0.47 (0.41)	0.007 (0.01)	28:1
2015-2016	Open	(n=0)	(33 d)	14%	0.0031 (0.0011)	0.92 (0.38)	0.04 (0.01)	n.p	n.p	24:1
	Closed	(n=1)	(210 d)	86%	0.0047 (0.0066)	0.83 (0.33)	0.03 (0.01)	n.p	n.p	32:1
2016-2017	Open	(n=6)	(171 d)	71%	0.0016 (0.0018)	0.37 (0.14)	0.02 (0.01)	n.p	n.p	20:1
	Closed	(n=2)	(71 d)	29%	0.0015 (0.0007)	0.72 (0.09)	0.03 (0.01)	n.p	n.p	29:1

4 Discussion

An ecological health objective for Waituna Lagoon includes the target of > 30-60% cover for macrophytes dominated by the *Ruppia* community (Lagoon Technical Group 2013). In 2017, the frequency of occurrence for *Ruppia* sp. remained high at 74% of surveyed sites, although the average lagoon-wide cover for *Ruppia* sp. was only 16%. We note that the time elapsed between the closure of the lagoon following an extended (171 day) lagoon opening and the 2017 survey was only 31 days, an insufficient time to allow plant covers to recover substantially. However, although the abundance of the *Ruppia* community had been reduced there remained a widely distributed inoculum of plants to fuel ongoing plant expansion.

The management guidelines to safeguard ecology of the lagoon recommend a winter opening regime that will allow a high chance of the mouth closing before summer (Lagoon Technical Group 2013). Results from the annual *Ruppia* surveys support this recommendation, with both the frequency of occurrence and the percent cover of *Ruppia* beds shown to be responsive to lagoon openings. Summer surveys in 2015 and 2016 were within an extended period of lagoon closure with a short winter opening. Consequently, both a high frequency of occurrence and average lagoon-wide cover for *Ruppia* were recorded in 2015 (70% of sites and average 39% cover) and 2016 (87% of sites and average 56% cover). In contrast, lower occurrence and average covers were recorded for periods with extended lake openings over 2013 (31% of sites and average 25% cover) and 2014 (19% of sites and average 29% cover).

The observations of *Ruppia* spp. declines under extended lagoon openings are likely to result from a combination of increased disturbance, desiccation and possibly salinity stress. Declines are not innate seasonal responses to the onset of winter. For instance, temporal monitoring of 16 of the annual sites in late May 2016 (before the June 2016 lake opening) recorded an average *Ruppia* spp. cover of 70% and flowering plants (data not shown).

A winter time opening of the lagoon is recommended to allow for the “flushing” and reductions in nutrient concentrations at the onset of the growing period (Lagoon Technical Group 2013). Macroalgae status was high in 2016, possibly as a result of a long closure and short opening duration. Macroalgae status had decreased in 2017, following a 171 day opening and closure just 31 days prior to the summer survey.

The 2017 *Ruppia* survey has followed a prolonged opening similar to 2011 and 2013. While there has been a reduction in the cover values of plants, frequency of plant occurrence remains high. In the absence of a further prolonged opening, it is expected that rapid recovery of the *Ruppia* community will attain the ecological health objective target of > 30-60% macrophyte cover within 2017.

5 Acknowledgements

Chris Owen is thanked for his skilled boat skipper duties and assistance in the field. Charlie Bedford provided diver attendant duties and field assistance.

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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 percent cover, height and growth stage of spot samples in Waituna Lagoon.

Rp = *Ruppia polycarpa*, Rm = *Ruppia megacarpa*, Lmp = *Lamprothamnium macropogon*, Ui – Ulva intestinalis, Ff = freshwater filamentous green algae (predominantly *Cladophora* sp. and *Spirogyra* sp), Algae = unidentified spp., Lnz = *Lilaeopsis novae-zelandiae*, Mt = *Myriophyllum triphyllum*, Pp= *Stuckenia pectinata*, Sm = *Samolus repens*. f= flowering, p= post flowering, v = vegetative.

Transect	Rep	Species	% Cover	Height (cm)	Stage
1.1	1	Rm	100	210	PF
1.1	2	Rm	100	180	PF
1.1	3	Rm	100	220	v
1.1	4	Rm	100	220	v
2.1	1	Rp	5	16	v
2.1	2	Rp	15	12	v
2.1	3	Rp	5	13	v
2.1	4	Rp	20	18	v
2.2	1	Rp	2	12	
2.2	2	Rp	2	10	
2.2	3	Rp	5	14	
2.2	4	Rp	1	14	
2.3	1	Ul	1		
2.3	2	Ul	1		
2.3	3	Ul	1		
2.3	4	Ul	1		
3.1	1	Ul	100		
3.1	1	Algae	10		
3.1	1	Rp	1	16	
3.1	2	Algae	1		
3.1	2	Rp	1	16	
3.1	3	Ul	5		
3.1	3	Ul	2		
3.1	4	Algae	1		
3.1	4	Algae	70		
3.2	1		0		
3.2	2	Rp	1	2	
3.2	3		0		
3.2	4		0		
3.3	1	Rp	15	22	
3.3	2	Rp	5	22	
3.3	3	Ff	1		

Transect	Rep	Species	% Cover	Height (cm)	Stage
3.3	3	Rp	15	22	
3.3	4	Rp	5	16	
4.1	1	Ul	20		
4.1	1	Algae	1		
4.1	1	Lmp	10	2	
4.1	1	Rp	1	8	v
4.1	2	Lmp	1	1	
4.1	3	Ul	15		
4.1	3	Algae	1		
4.1	3	Rp	1	10	v
4.1	4	Ul	20		
4.1	4	Algae	70		
4.1	4	Algae	20		
4.1	4	Lmp	10	2	
4.2	1	Lmp	5	2	
4.2	1	Rp	8	20	v
4.2	2	Lmp	8	4	
4.2	2	Rp	5	20	v
4.2	3	Ff	20		
4.2	3	Lmp	5	2	
4.2	3	Rp	8	20	v
4.2	4	Lmp	2	2.5	
4.2	4	Rp	15	18	v
4.3	1	Ff	100		
4.3	1	Rp	10	130	
4.3	2		0		
4.3	3	Ff	50		
4.3	3	Rp	60	40	
4.3	4	Ff	20		
4.3	4	Rp	100	200	
4.4	1	Rp	10	15	v
4.4	2	Algae	4		
4.4	2	Algae	1		
4.4	2	Rp	1	11	v
4.4	3	Algae	1		
4.4	3	Rp	40	20	
4.4	4	Algae	5		
4.4	4	Rp	40	21	

Transect	Rep	Species	% Cover	Height (cm)	Stage
4.5	1	Ff	100		
4.5	1	Rm	5	160	v
4.5	1	Rp	1	30	
4.5	2	Ff	100		
4.5	2	Pp	5	150	
4.5	2	Rp	1	10	v
4.5	3	Ff	100		
4.5	3	Rm	5	160	v
4.5	4	Rp	30	40	
5.1	1	Algae	75		
5.1	1	Lmp	1	1.5	
5.1	1	Rp	1	6	v
5.1	2	Algae	80		
5.1	2	Algae	1		
5.1	2	Lmp	1	1	
5.1	3	Algae	70		
5.1	3	Lmp	1	1	
5.1	4	Algae	70		
5.1	4	UI	70		
5.1	4	Algae	1		
5.1	4	Lmp	1	1	
5.2	1	Rp	50	29	
5.2	2	Rp	25	23	
5.2	3	UI	10		
5.2	3	Rp	40	18	
5.2	4	UI	25		
5.2	4	Rp	50	29	
5.3	1		0		
5.3	2		0		
5.3	3		0		
5.3	4	Rp	1	4.5	
5.4	1	Rp	20	27	v
5.4	2	Rp	5	27	v
5.4	3	Rp	20	24	v
5.4	4	Rp	40	24	v
5.5	1	UI	5		
5.5	1	Algae	2		
5.5	1	Rm	1	30	v

Transect	Rep	Species	% Cover	Height (cm)	Stage
5.5	1	Rp	5	20	v
5.5	2	Ul	5		
5.5	2	Rp	10	24	v
5.5	3	Rp	15	17	v
5.5	4	Lmp	1	2.5	
5.5	4	Rp	1	18	v
6.1	1	Rp	2	25	
6.1	2	Rp	3	24	
6.1	3	Rp	1	19	
6.1	4	Mt	1	12	
6.1	4	Rp	2	10	
6.2	1	Ff	95		
6.2	1	Algae	5		
6.2	1	Lmp	15	4	
6.2	1	Rp	2	32	
6.2	2	Ff	100		
6.2	2	Lmp	10	2	
6.2	2	Rp	3	26	
6.2	3	Ff	100		
6.2	3	Lmp	30	4.5	
6.2	3	Rp	1	6	
6.2	4	Ff	100		
6.2	4	Algae	5		
6.2	4	Algae	2		
6.2	4	Lmp	10	3	
6.3	1	Rp	15	17	
6.3	2	Rp	40	23	v
6.3	3	Rp	40	24	v
6.3	4	Rp	25	16	v
6.4	1	Rp	30	25	v
6.4	2	Rp	30	20	v
6.4	3		0		
6.4	4	Algae	5		
6.5	1	Lmp	5	0.5	
6.5	2	Ff	2		
6.5	2	Lmp	5	1	
6.5	3	Ff	2		
6.5	3	Lmp	5	1	

Transect	Rep	Species	% Cover	Height (cm)	Stage
6.5	4	Ff	1		
6.5	4	Lmp	5	1	
7.1	1		0		
7.1	2		0		
7.1	3		0		
7.1	4		0		
7.2	1		0		
7.2	2	Ff	1		
7.2	2	Rp	2	11	
7.2	3		0		
7.2	4		0		
7.3	1	Rp	35	15	v
7.3	2	Rp	40	15	v
7.3	3		0		
7.3	4	Rp	5	20	v
7.4	1	Ff	5		
7.4	1	Rp	7	24	v
7.4	2	Rp	30	30	v
7.4	3	Rp	10	24	v
7.4	4	Rp	15	36	v
7.5	1		0		
7.5	2	Ff	1		
7.5	2	Rp	1	13	v
7.5	3	Rp	1	12	v
7.5	4	Rp	1	19	v
7.6	1		0		
7.6	2	Rp	1	5	v
7.6	3		0		
7.6	4		0		
7.7	1		0		
7.7	2		0		
7.7	3		0		
7.7	4		0		
8.1	1	Rp	1	5	v
8.1	2	Algae	5		
8.1	2	Algae	10		
8.1	3		0		
8.1	4	Algae	5		

Transect	Rep	Species	% Cover	Height (cm)	Stage
8.1	4	Algae	20		
8.2	1	Rp	1	13	v
8.2	2	Rp	1	28	v
8.2	3	Rp	2	23	v
8.2	4		0		
8.3	1		0		
8.3	2	Rp	2	17	v
8.3	3	Rp	15	20	v
8.3	4		0		
8.4	1	Rp	1	15	v
8.4	2	Ul	25		
8.4	3	Ff			
8.4	4		0		
8.5	1	Ff	5		
8.5	1	Algae	5		
8.5	1	Algae	5		
8.5	2		0		
8.5	3		0		
8.5	4		0		
8.6	1		0		
8.6	2		0		
8.6	3		0		
8.6	4		0		
8.7	1	Algae	20	1	
8.7	2		0		
8.7	3	Ff	5		
8.7	3	Algae	60		
8.7	4		0		
8.8	1	Ul	10		
8.8	1	Rp	2	22	v
8.8	2	Ul	5		
8.8	2	Rp	1	11	v
8.8	3	Ul	5		
8.8	3	Rp	5	20	v
8.8	4	Ul	5		
8.8	4	Algae	2		
9.1	1	Ul	80		
9.1	1	Ff	90		

Transect	Rep	Species	% Cover	Height (cm)	Stage
9.1	1	Rp	1	6	v
9.1	2	Ul	80		
9.1	2	Ff	95		
9.1	2	Algae	5		
9.1	3	Ff	5		
9.1	4	Ul	100		
9.1	4	Ff	70		
9.1	4	Algae	5		
9.2	1		0		
9.2	2		0		
9.2	3		0		
9.2	4		0		
9.3	1	Algae	30		
9.3	1	Algae	20		
9.3	2	Algae	2		
9.3	2	Algae	5		
9.3	3	Algae	50		
9.3	3	Algae	10		
9.3	4	Algae	30		
9.3	4	Algae	20		
9.4	1		0		
9.4	2		0		
9.4	3		0		
9.4	4		0		
9.5	1	Ff	10		
9.5	1	Lmp	1	2	
9.5	1	Rp	10	22	v
9.5	2	Rp	15	25	v
9.5	3	Rp	10	19	v
9.5	4	Lmp	1	2	
9.5	4	Rp	20	15	v
9.6	1	Lmp	1	2	
9.6	1	Rp	5	23	v
9.6	2	Lmp	1	0.5	
9.6	2	Rp	50	11	v
9.6	3	Ff	10		
9.6	3	Rp	10	15	v
9.6	4	Rp	20	17	v

Transect	Rep	Species	% Cover	Height (cm)	Stage
9.7	1		0		
9.7	2	Rp	2	13	v
9.7	3		0		
9.7	4	Algae	30		
9.7	4	Algae	1		
9.7	4	Rp	2	14	v
10.1	1	Algae	5		
10.1	1	Ff	50		
10.1	1	Lnz	50		
10.1	1	Mt	5		
10.1	2	Ul	90		
10.1	2	Ff	100		
10.1	3	Ul	45		
10.1	3	Ff	60		
10.1	3	Lnz	5		
10.1	3	Mt	2		
10.1	4	Ul	80		
10.1	4	Ff	40		
10.1	4	Lnz	5		
10.2	1	Algae	15		
10.2	1	Rp	1	4	v
10.2	2	Algae	10		
10.2	2	Rp	1	13	v
10.2	3	Algae	20		
10.2	4		0		
10.3	1	Ul	60		
10.3	2	Ul	100		
10.3	2	Ff	5		
10.3	2	Sm	1		
10.3	2	Lnz	20		
10.3	3	Ul	50		
10.3	4	Ff	90		
10.3	4	Ul	5		
10.3	4	Lnz	5		

Appendix C Macrophyte cover in 10m diameter.

See Appendix B for species codes.

Site	Species	Percent cover	
		Average	Maximum
1.1	Rm	100	85
2.1	Algae	5	1
2.1	Rp	40	5
2.2	Algae	5	1
2.2	Rp	10	2
2.3	Ul	40	5
3.1	Algae	100	60
3.1	Algae	100	45
3.1	Rp	1	1
3.2	Algae	1	1
3.2	Rp	1	1
3.3	Ul	30	10
3.3	Ff	20	5
3.3	Mt	1	1
3.3	Rp	20	10
4.1	Ul	100	40
4.1	Algae	100	10
4.1	Rp	1	1
4.2	Ul	80	20
4.2	Ff	10	5
4.2	Rp	28	10
4.3	Ul	100	50
4.3	Rm	100	65
4.4	Ul	30	10
4.4	Rp	40	10
4.5	Ff	100	80
4.5	Pp	60	10
4.5	Rm	5	1
4.5	Rp	2	1
5.1	Ul	90	65
5.1	Algae	10	5
5.1	Sm	85	1
5.1	Rp	1	1
5.2	Ul	80	40

Site	Species	Percent cover	
		Average	Maximum
5.2	Algae	20	5
5.2	Algae	20	5
5.2	Rp	50	35
5.3	Ul	100	50
5.3	Rm	1	1
5.3	Rp	1	1
5.4	Ul	50	5
5.4	Algae	5	1
5.4	Algae	5	1
5.4	Rp	40	10
5.5	Algae	80	35
5.5	Rm	5	1
5.5	Rp	70	35
6.1	Ff	10	2
6.1	Algae	5	1
6.1	Algae	3	1
6.1	Mt	2	1
6.1	Rp	10	5
6.2	Ff	100	90
6.2	Algae	100	75
6.2	Rp	15	10
6.3	Ul		
6.3	Algae		
6.3	Rp	70	45
6.4	Algae	5	2
6.4	Algae	30	5
6.4	Rp	75	45
6.5	Ul	50	5
6.5	Ff	100	50
6.5	Algae	5	1
6.5	LMP		5
7.1	Ff	10	5
7.1	Algae	10	1
7.1	Ul	5	1
7.2	Ff	5	1
7.2	Algae	5	1
7.2	Algae	5	1

Site	Species	Percent cover	
		Average	Maximum
7.2	Rp	15	1
7.3	Algae	1	1
7.3	Rp	75	40
7.4	Ff	30	5
7.4	Ul	5	1
7.4	Algae	5	1
7.4	Rp	70	60
7.5	Ff	75	10
7.5	Algae	1	1
7.5	Algae	30	5
7.5	Rp	5	1
7.6	Algae	1	1
7.6	Rp	1	1
7.7	Algae	1	1
7.7	Ui	3	1
8.1	Ul	20	5
8.1	FF	20	5
8.1	Algae	80	40
8.1	LR	5	1
8.2	Algae	1	1
8.2	Algae	1	1
8.2	Rp	5	1
8.3	Ui	90	20
8.3	Rp	65	30
8.4	Ui	85	50
8.4	Rp	45	2
8.5	Ff	100	60
8.5	Rp	1	1
8.6	Ul	60	50
8.6	Algae	1	1
8.6	Algae		
8.6	Algae	60	50
8.7	Ff	100	25
8.7	Algae	15	15
8.7	Algae	5	1
8.7	Algae	5	1
8.8	Ul	1	1

Site	Species	Percent cover	
		Average	Maximum
8.8	Algae	5	5
8.8	Algae	50	1
8.8	Rp	40	10
9.1	Ul	100	40
9.1	Ff	100	50
9.1	Algae	60	40
9.1	Rp	1	1
9.2	Algae	100	5
9.2	Algae	2	1
9.2	Rp	2	1
9.3	Ff	100	60
9.3	Algae	60	30
9.4	Ui	100	95
9.4	Pp	1	1
9.5	Ff	90	45
9.5	Ul	30	10
9.5	Algae	20	5
9.5	LMP	1	1
9.5	Rp	20	15
9.6	Ff	100	65
9.6	LMP		
9.6	Mt	1	1
9.6	Rp	35	5
9.7	Ul	100	60
9.7	Algae	40	10
9.7	Algae	10	5
9.7	Algae	10	10
9.7	Rp	5	2
10.1	Ul		
10.1	Ff		
10.2	Algae	20	5

Appendix D Water quality and sediment parameters in Waituna Lagoon.

Parameters measured at each site including at the surface and bottom of the water column.

	Surface					Bottom				
Site	Depth (m)	Temperature (°C)	DO (mg/l)	Turbidity (NTU)	Salinity (ppt)	Temperature (°C)	DO (mg/l)	Turbidity (NTU)	Salinity (ppt)	Black disk (m)
1.1	1.9	20.3	8.7	2.6	10.4	16.34	3.8	2.1	11.1	1.12
2.1	0.8	20.1	7.1	4.7	9.7	20.07	6.53	11.8	19.9	0.8
2.2	1.5	19.5	6.9	3.5	10.8	19.16	5.73	6.1	10.9	1.15
2.3	0.9	19.0	6.7	3.2	11	18.56	5.2	3.2	11	1.15
3.1	0.9	19.9	7.8	3.3	10.2	19.67	7.4	4.4	10.5	1.38
3.2	2.6	20.1	7.3	3.5	10.2	17.5	2.65	3.9	11.2	1.05
3.3	1.4	20.3	7.2	3.8	10.2	19.24	7.34	5.5	10.7	1.05
4.1	0.8	18.7	7.0	1.8	10.4	18.69	6.39	4.6	10.4	1.55
4.2	1.2	18.5	6.8	1.5	10.5	18.52	6.44	1.5	10.5	1.4
4.3	1.9	19.5	6.9	2.8	11	19.02	5.35	7.6	11	1.45
4.4	1.3	19.0	7.4	3.1	11	19.05	7.3	3	11	1.4
4.5	1.6	18.7	7.6	2.3	11	18.3	9.23	2.4	11	1.41
5.1	0.8	20.1	6.5	1.7	10.5	19.94	5.62	3.2	10.5	1.51
5.2	1.3	20.2	6.9	1.8	10.7	19.73	6.95	2.3	10.7	1.6
5.3	2.1	19.0	9.3	2.8	10.8	18.86	7.66	3	10.9	1.37
5.4	1.3	18.8	7.1	3.1	10.9	18.73	6.62	3.2	10.9	1.35
5.5	1.0	18.4	7.1	2.9	11.1	18.37	5.94	5.3	11.1	1.45
6.1	0.9	20.8	7.0	4.2	11	20.75	6.75	5.2	11	1.39
6.2	0.9	20.2	8.4	3.2	11	20.2	7.97	3.3	11	1.35
6.3	1.4	18.8	7.3	4.6	10.4	18.65	5.85	4.5	10.6	1.3
6.4	1.8	18.8	7.2	4.6	10.3	18.58	6.41	3.7	10.8	1.25
6.5	0.7	19.6	8.1	3.8	10.6	19.64	8.13	4.9	10.5	1.25

		Surface				Bottom				
Site	Depth (m)	Temperature (°C)	DO (mg/l)	Turbidity (NTU)	Salinity (ppt)	Temperature (°C)	DO (mg/l)	Turbidity (NTU)	Salinity (ppt)	Black disk (m)
7.1	0.9	19.4	6.0	4.4	10.7	19.37	5.4	3.7	10.8	1.17
7.2	1.5	20.0	7.3	4.3	10.7	19.99	7.5	4.3	10.7	1.4
7.3	1.5	18.9	7.7	4.1	10.7	19.3	7.46	4.4	11	1.39
7.4	1.4	18.1	7.5	4.5	10.4	18.47	6.17	4.3	10.4	1.3
7.5	1.6	19.3	7.8	5.7	10.3	19.13	7.71	5.2	10.3	1.02
7.6	1.3	19.3	6.6	6.6	10.4	19.16	5.53	6.7	10.4	1.01
7.7	0.9	19.5	7.0	6.2	10.5	19.53	6.8	6.2	10.5	1.03
8.1	0.7	18.2	6.9	6.6	10.1	19.24	6.66	6.9	10.1	0.95
8.2	1.5	18.9	11.4	3.7	10.2	18.93	9.16	3.6	10.2	1.2
8.3	1.5	19.0	7.5	4	10.3	18.92	6.53	4.2	10.3	1.25
8.4	1.8	18.6	8.7	4.4	10.3	19	8.04	4	10.5	1.22
8.5	1.7	19.7	7.3	5.01	10.2	19.43	5.86	6.1	10.6	1.02
8.6	0.7	19.8	6.6	5.8	10.2	19.85	6.51	5.4	10.2	1.1
8.7	1.0	21.6	9.4	5.5	10.7	20.5	8.09	6.8	10.8	1.25
8.8	1.3	20.8	8.6	6	11	20.04	7.48	7.7	11.3	1.56
9.1	1.8	19.8	7.5	5.5	9.3	19.84	7.36	5.9	9.3	1.4
9.2	1.4	19.4	7.0	4.7	9.6	19.37	6.3	4.5	9.6	1.57
9.3	1.1	19.2	6.1	4.3	9.5	19.22	5.76	4.6	9.5	1.11
9.4	1.0	19.7	8.2	2.8	9.8	19.8	7.2	3.5	9.9	1.59
9.5	1.1	19.5	7.6	2.3	10.1	19.53	6.79	2.3	10.1	1.85
9.6	1.0	19.2	6.4	2.9	10.1	19.26	5.84	2.7	10.1	1.49
9.7	1.2	21.4	8.2	5.3	11.5	21.33	7.66	5.2	11.5	1.46
10.1	0.7	19.6	8.1	28.2	4.9	19.55	8.31	32.6	4.9	0.26
10.2	0.8	20.1	7.3	11.9	8	20.14	7.49	12.6	8	0.52
10.3	0.6	20.2	9.2	8.7	9.6	20.24	9.03	9.7	9.6	0.84

Appendix E Sediment conditions

Substrate codes are FS = firm sand, Gr = gravel, Gr/S= gravel and sand, Gr/SM = gravel and soft mud, P/S = peat and sand, S/Gr = sand and gravel, SM = soft mud, SM/S = soft mud and sand, SM/S/G = soft mud, sand and gravel. Sulphide depth is distance (cm) to any visible blackened layer.

Site	Rep	Substrate	Sulphide depth (cm)
1.1	1	SM	none
1.1	2	SM	none
1.1	3	SM	none
1.1	4	SM	none
2.1	1	Gr/S	1
2.1	2	Gr/S	none
2.1	3	Gr/S	none
2.1	4	Gr/S	2
2.2	1	Gr/S	1.5
2.2	2	Gr/S	1
2.2	3	Gr/S	1
2.2	4	Gr/S	1
2.3	1	Gr	none
2.3	2	Gr	none
2.3	3	Gr	none
2.3	4	Gr	none
3.1	1	Gr/S	none
3.1	2	SM/S	0.5
3.1	3	Gr/S	none
3.1	4	Gr/S	none
3.2	1	SM/S	1.5
3.2	2	SM/S	1.5
3.2	3	SM/S	1.5
3.2	4	SM/S	1.5
3.3	1	SM/S/G	none
3.3	2	SM/S/G	2
3.3	3	Gr/S	2
3.3	4	Gr/S	2
4.1	1	S/Gr	none
4.1	2	Gr	1
4.1	3	Gr/S	none
4.1	4	Gr/S	none
4.2	1	S/Gr	none

Site	Rep	Substrate	Sulphide depth (cm)
4.2	2	S/Gr	none
4.2	3	S/Gr	none
4.2	4	FS	none
4.3	1	SM/S	none
4.3	2	S/Gr	none
4.3	3	SM/S	none
4.3	4	SM/S	none
4.4	1	S/Gr	none
4.4	2	S/Gr	none
4.4	3	Gr/S	none
4.4	4	Gr/S	1.5
4.5	1	SM/S	none
4.5	2	SM/S	none
4.5	3	SM/S	none
4.5	4	SM/S	none
5.1	1	S/Gr	0.5
5.1	2	S/Gr	none
5.1	3	S/Gr	none
5.1	4	S/Gr	none
5.2	1	S/Gr	1.5
5.2	3	S/Gr	1
5.2	3	S/Gr	1
5.2	4	S/Gr	1.5
5.3	1	SM	1
5.3	2	SM	1
5.3	3	SM	1
5.3	4	SM	1.5
5.4	1	SM/S	none
5.4	2	SM/S	1
5.4	3	SM/S	1.5
5.4	4	SM/S	1.5
5.5	1	SM/S/G	0.5
5.5	2	SM/S/G	0.5
5.5	3	SM/S/G	0.5
5.5	4	SM/S/G	0.5
6.1	1	FS	1
6.1	2	FS	2
6.1	3	FS	1.5
6.1	4	FS	none

Site	Rep	Substrate	Sulphide depth (cm)
6.2	1	SM/S/G	none
6.2	2	SM/S/G	1
6.2	3	SM/S/G	1
6.2	4	SM/S/G	1
6.3	1	SM/S	2
6.3	2	SM/S/G	1.5
6.3	3	SM/S/G	1
6.3	4	SM/S/G	1
6.4	1	Gr/S	1.5
6.4	2	Gr/S	1.5
6.4	3	SM/S/G	1
6.4	4	SM/S/G	1
6.5	1	S/Gr	none
6.5	2	S/Gr	none
6.5	3	S/Gr	none
6.5	4	S/Gr	none
7.1	1	S/Gr	2
7.1	2	S/Gr	2
7.1	3	S/Gr	2
7.1	4	S/Gr	2
7.2	1	S/Gr	1.5
7.2	2	S/Gr	1.5
7.2	3	S/Gr	2
7.2	4	S/Gr	1
7.3	1	S/Gr	1.5
7.3	2	S/Gr	1
7.3	3	S/Gr	2
7.3	4	S/Gr	2
7.4	1	FS	0.5
7.4	2	FS	0.5
7.4	3	FS	1.5
7.4	4	FS	1
7.5	1	SM/S	3
7.5	2	SM/S	3
7.5	3	SM/S	3
7.5	4	SM/S	2.5
7.6	1	FS	3.5
7.6	2	FS	3.5
7.6	3	FS	3.5

Site	Rep	Substrate	Sulphide depth (cm)
7.6	4	FS	3.5
7.7	1	SM/S	2
7.7	2	SM/S	2
7.7	3	SM/S	1.5
7.7	4	SM/S	1.5
8.1	1	S/Gr	2
8.1	2	S/Gr	none
8.1	3	S/Gr	none
8.1	4	S/Gr	none
8.2	1	FS	1
8.2	2	S/Gr	1.5
8.2	3	S/Gr	1
8.2	4	S/Gr	2
8.3	1	FS	0.5
8.3	2	FS	1
8.3	3	FS	0.5
8.3	4	FS	1
8.4	1	FS	2
8.4	2	FS	2
8.4	3	FS	2
8.4	4	FS	3
8.5	1	SM/S	4
8.5	2	SM/S	3.5
8.5	3	SM/S	2.5
8.5	4	SM/S	3.5
8.6	1	S/Gr	1
8.6	2	S/Gr	1
8.6	3	P/S	0.1
8.6	4	P/S	0.1
8.7	1	Gr	none
8.7	2	SM	1
8.7	3	Gr	1
8.7	4	Gr/SM	0.7
8.8	1	SM	none
8.8	2	SM	1.5
8.8	3	SM	none
8.8	4	SM	2
9.1	1	S/Gr	none
9.1	2	S/Gr	none

Site	Rep	Substrate	Sulphide depth (cm)
9.1	3	S/Gr	none
9.1	4	S/Gr	none
9.2	1	FS	1
9.2	2	FS	1.5
9.2	3	FS	1.5
9.2	4	FS	0.5
9.3	1	SM/S/G	0.5
9.3	2	SM/S/G	0.5
9.3	3	SM/S/G	none
9.3	4	SM/S/G	1
9.4	1	SM	none
9.4	2	SM	none
9.4	3	SM	none
9.4	4	SM	none
9.5	1	SM/S	3
9.5	2	SM/S	1.5
9.5	3	SM/S	none
9.5	4	SM/S	1
9.6	1	FS	none
9.6	2	FS	none
9.6	3	FS	none
9.6	4	FS	none
9.7	1	SM	1.5
9.7	2	SM/S	1
9.7	3	SM/S	1
9.7	4	SM/S	1
10.1	1	SM/S/G	none
10.1	2	SM/S/G	none
10.1	3	SM/S/G	none
10.1	4	SM/S/G	none
10.2	1	S/Gr	1.5
10.2	2	S/Gr	1.5
10.2	3	S/Gr	2
10.2	4	S/Gr	2
10.3	1	SM/S	0.5
10.3	2	S/Gr	none
10.3	3	S/Gr	none
10.3	4	SM/S/G	1