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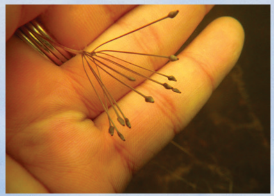

Technical Report on Vegetation Status in Waituna Lagoon: 2009–2019

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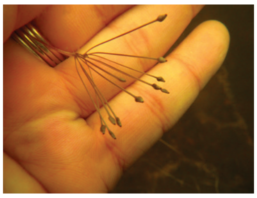


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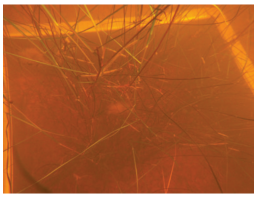
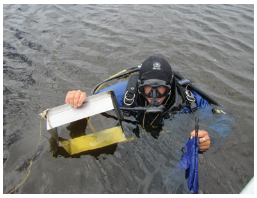


Introduction

This technical report accompanies the summary report on vegetation status in Waituna Lagoon in 2019 (de Winton 2019). We review the lagoon conditions over the period of vegetation monitoring from 2009 to 2019 and update current vegetation status according to findings in 2019.

As background to the summary report, this technical report describes water level, mouth status and duration (Section 1). The report also provides descriptions of monitoring methods and presents summaries of data and analyses (Sections 2, 3 and 4). We briefly conclude what the findings mean for lagoon management.





1. Water Level Regime

Methods

Water level data supplied by Environment Southland from the gauge at Waghorns Road was examined to identify lagoon openings by the onset of a sudden, substantial reduction in water level. Lagoon closure was estimated from timing of subsequent, sustained increases in level. The total time period for openings was calculated, the mouth status was confirmed and the duration of that status before each vegetation monitoring event was calculated as months (one month is 30 days).

Results

When monitored in 2019, Waituna lagoon had been closed to the sea for just over three months (Figure 1). At this time water level was similar to previous closed lagoon conditions (2009–10, 2012, 2015–17), but higher than closed conditions in 2018 when Southland had experienced a drought (Figure 2). Water level during monitoring in 2019 was higher than the previous monitoring occasions when the Lagoon was open to the sea (2011, 2013–14).

Prior to 2019, periods of closure in Waituna Lagoon have ranged from 1 to 13.7 months before monitoring (Figure 1). The lagoon has also been open for 3.9 to 6.2 months prior to three monitoring occasions (Figure 1, negative axis). The years that exceeded three months of lagoon closure before a monitoring event were 2009, 2010, 2012, 2015, 2016, 2018 and 2019.

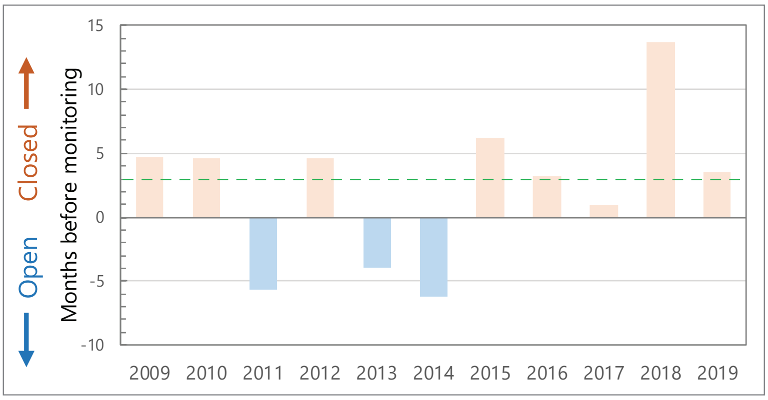


Figure 1: Diverging bar plot showing the number of months for which Waituna Lagoon was open or closed prior to monitoring (as indicated by the y axis). The dotted line indicates the ecological target of three months of lagoon closure before monitoring.

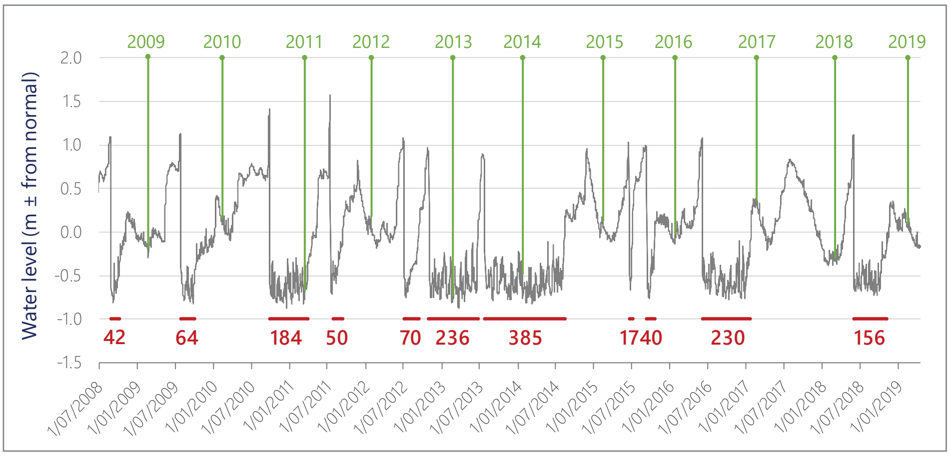


Figure 2: Plot showing the continuous water level time series for Waituna Lagoon, measured at Waghorns Road. Periods of lagoon opening are indicated by horizontal red lines. The number of days during which the lagoon was open correspond to the red numbers. Finally, the annual summer vegetation monitoring events are indicated by green vertical lines.

Discussion

Status and timing of lagoon openings have previously been shown to be a major driver of physico-chemical conditions in the lagoon (Schallenberg and Tyrell 2005, Schallenberg et al. 2010, Hodson 2017, de Winton and Mouton 2018). In turn, physico-chemical conditions have been linked to the spatio-temporal patterns of the vegetation in Waituna Lagoon (Robertson and Funnell 2012, Lagoon Technical Group 2013, de Winton and Mouton 2018).

The sustained closed lagoon conditions prior to the 2019 monitoring event would likely be associated with lowered salinity and total suspended solids, but increased temperature and nutrients. A closed lagoon would have a higher eutrophication risk (Hodson 2017, Schallenberg and Tyrell 2005, Schallenberg et al. 2010) and higher temperature (Schallenberg and Tyrell 2005) than when it is open. Eutrophication is in turn linked to blooms of macroalgae or phytoplankton. In the following section (Section 2) we describe the physico-chemical conditions at the time of monitoring in 2019 and compare with previous annual monitoring over a range of mouth status.

2. Annual Physico-chemical Monitoring

Methods

The location of 47-48 monitoring sites is given in Figure 3. (One site could not be sampled due to the migration of the coastal spit in 2014).

At each monitoring site, measurements were made from 2009 to 2019 of:

- Water depth (m).
- Visual clarity as black disk distance (m).

A calibrated multi-sensor meter (Horiba or YSI Exo 1) measured parameters at the water surface and bottom (where depth allowed) that included:

- Temperature (°C).
- Dissolved oxygen (DO, mg l^{-1}).
- Salinity (PSU).
- Turbidity (NTU).

Black disk, DO and turbidity were measured from 2011 to 2019 only.

Figure 3: Monitoring sites in Waituna Lagoon. Transects are numbered from 1 to 10 from East to West. The numbers of each transect were allocated on ascending order from North to South.

Results

Waituna Lagoon was closed for 3.5 months prior to the 2019 monitoring. Salinity levels in 2019 were moderately low (average 5.5 PSU), especially compared to open lagoon conditions in 2011 (average 17.7 PSU) and 2014 (average 29.1 PSU) that had lasted approximately six months (Figure 4). Salinity was also high in 2017, probably as the lagoon had only been closed for a month before monitoring. Highest salinity levels in 2019 were recorded from sites in close proximity to the lagoon opening site.

Water depth at monitoring sites in 2019 was higher than recorded when the lagoon was open in 2011, 2013 and 2014 (Figure 4). It was also higher than the previous year of 2018, despite the lagoon being closed, when there were drought conditions in Southland (Figure 2). Water temperature in 2019 (average 16.5°C) was a little cooler than the previous six years but was higher than values recorded over 2009 to 2012 (Figure 4). In 2019, DO averaged 10.0 mg l^{-1} (Figure 5) and all sites were over 85% DO saturated indicating the lagoon to be well oxygenated.

Turbidity in 2019 averaged 8.4 NTU and was similar to the previous six years (Figure 5). Values >30 NTU were only recorded in bottom waters at three sites in 2019. A common feature across years are the upper outliers that may represent wind-wave disturbance of sediment at some shorelines (Figure 5). Water clarity indicated by black disk measurements in 2019 was variable but generally better than all previous years (Figure 5).

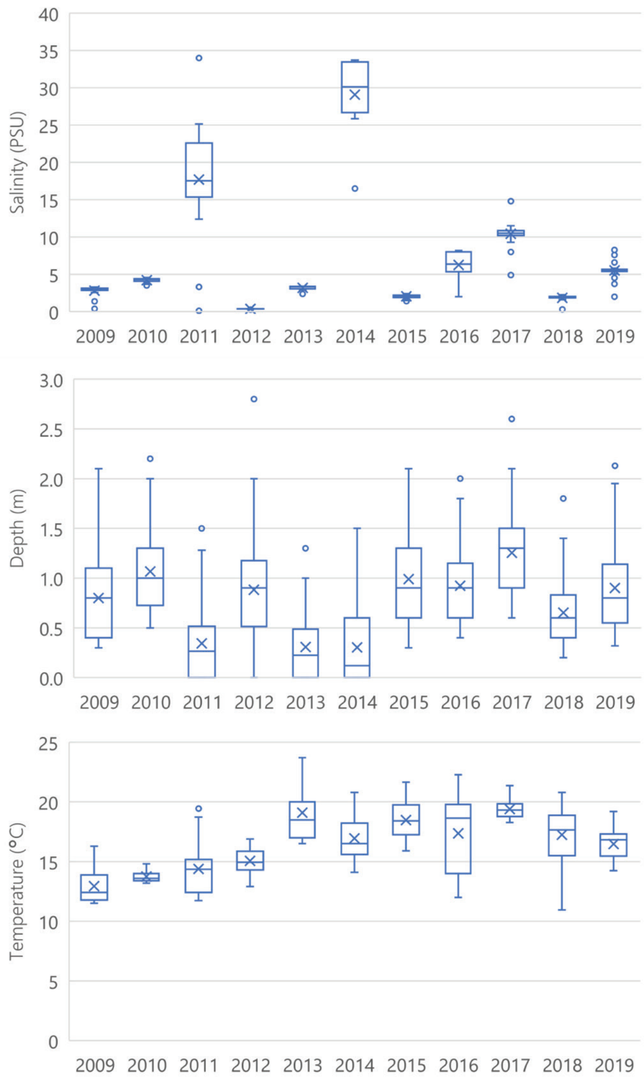


Figure 4: Box and whisker plots of salinity (top), depth (middle) and temperature (bottom) over all monitoring years. (n= 48 or 47).

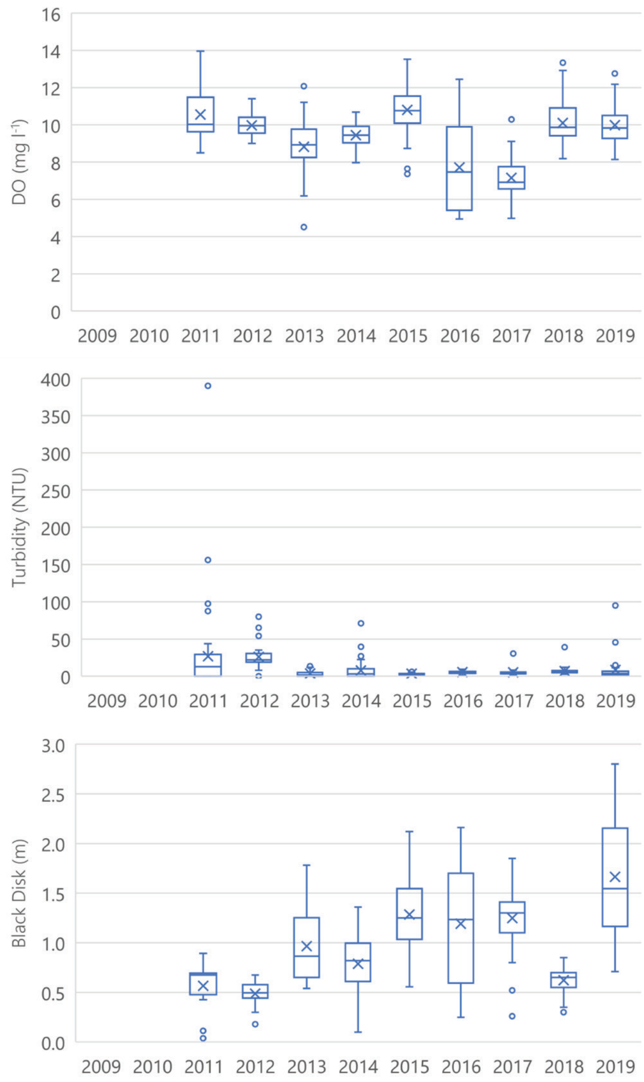
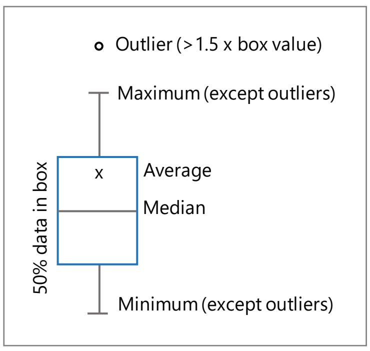


Figure 5: Box and whisker plots of DO (top), turbidity (middle) and black disk (bottom) at the monitoring sites (n= 48 or 47), from 2011 to 2019.



The legend shows features that are plotted on the graphs above.

Discussion

Physico-chemical conditions at the time of the annual vegetation monitoring reflect whether the lagoon was open or closed at the time of monitoring and recent mouth status. Low salinity and turbidity recorded in 2019 is in keeping with the closed lagoon status. However, in 2019 the lagoon had generally clearer water than previous monitoring occasions, despite a closed lagoon status being associated with higher eutrophication risk. Cooler water temperatures recorded in 2019 might have been less conducive to phytoplankton growth.

3. Sediment Characteristics

Methods

At each monitoring site (Figure 3), four replicate samples 15 x 15 cm and 6 cm deep were cut from the lake bed, using a flat based garden hoe, and carefully lifted to the surface.

Each sample was assessed for:

- Substrate type, (described as combinations of soft or firm mud, sand and gravel) was assigned a score from 1 to 10 describing increasing hardness.
- Depth (cm) to a blackened layer in the substrate, which indicates sulphide accumulation (elsewhere referred to as the redox potential discontinuity layer, Stevens and Robertson 2007). Depth was categorised into five classes: surface, >0–2, 2–4, >4 cm and layer not recorded.

Results

Sediment composition in 2019 was similar to previous years 2012 to 2017, but had an increased proportion of harder substrates than was assessed in 2009–2011 and in 2018 (Figure 6).

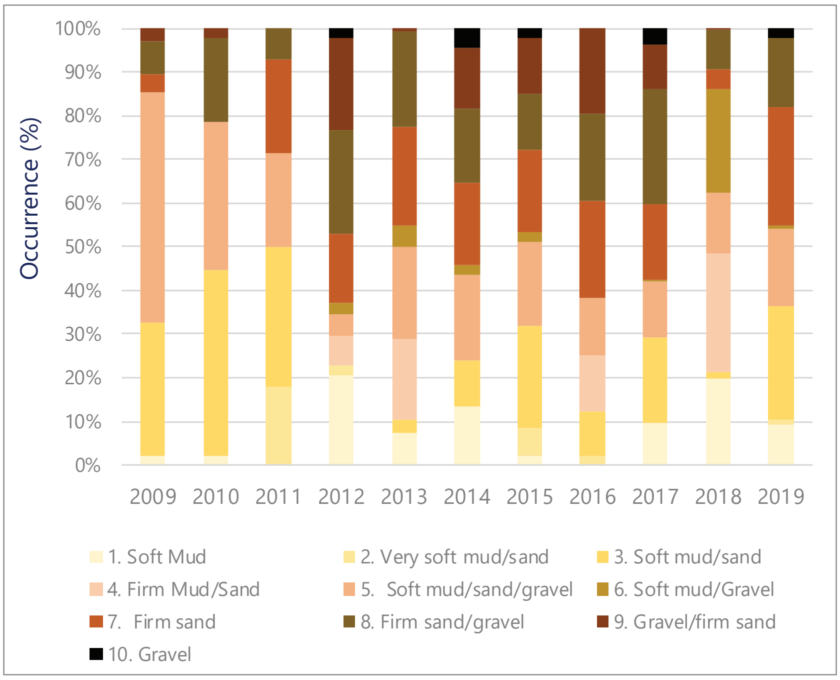


Figure 6: Bar plot illustrating the composition in substrate type (% occurrence), recorded during each of the annual monitoring surveys. Substrate types are numbered from softer to harder.

In 2019, the sediment depth to a blackened layer was not recorded at 39% of sites (i.e., was deeper than c. 6 cm). A discernible layer within the top 2 cm was visible at 34% of sites (Figure 7). Therefore, sediments in 2019 appeared to be more oxygenated than in 2009–2011, 2013 and 2017–2018 when 50% of records had a blackened layer present at, or near the sediment surface.

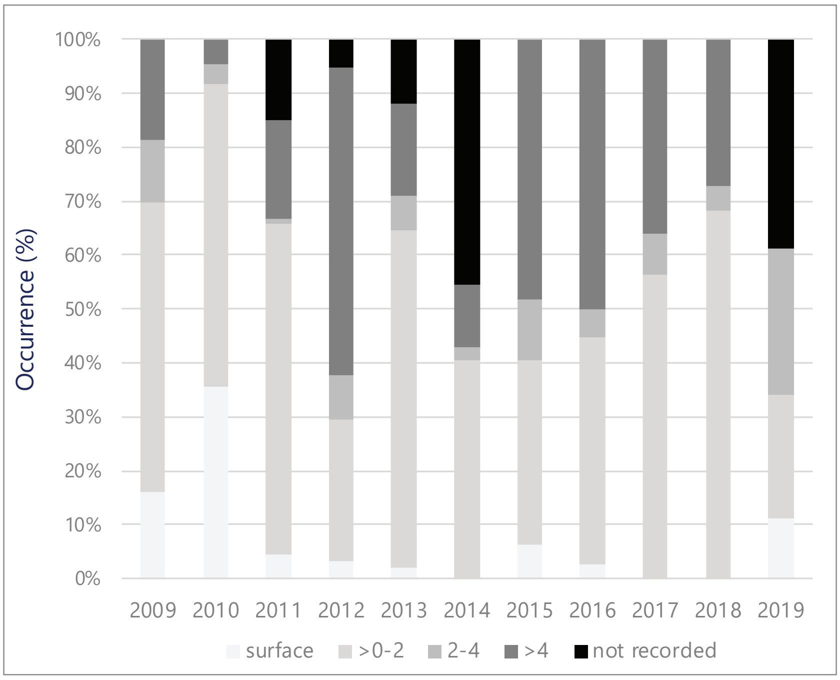


Figure 7: Substrate depth to a blackened layer shown as occurrence (% records) for five incremental depth categories.

Discussion

Changes in substrate type within Waituna Lagoon towards more widespread soft mud habitat are seen as a deterioration in ecological condition (Stevens and Robertson 2007). Softer substrates were more prevalent over 2009 to 2011, and again in 2018. However, conditions in 2019 showed a return to harder substrates seen over 2012 to 2017. The sediment depth to blackened layer may indicate where substrates have lower oxygen status. A low oxygen status can be associated with nutrient release from sediments or the build-up of substances that are toxic for plant growth. Measurements made in 2019 show an improvement over 2017 and 2018, with the blackened layer apparently moving deeper within the sediment horizons (surface is more oxygenated and 'healthier').

4. Vegetation Development

Methods

At each site (Figure 3), four 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 sample was assessed for:

- Presence of submerged plant species and/or macroalgae types and their cover as %. Where covers were previously recorded as a cover score range[1] in 2009 and 2010, these were translated to a mid-point value.
- Height of each macrophyte species present (cm). Where heights were previously recorded as a range[2] in 2009 and 2010, these were translated to maximum value of the range.
- Life stage of *Ruppia* spp. (vegetative, flowering or post flowering).

Cover and height of *Ruppia* was averaged across the four replicates at each site. Biomass index for *Ruppia* was calculated as the product of average cover and height at each site.

From 2013 onwards, macrophyte observations were also made at each site by snorkel/SCUBA diver within a circular area of 10 m diameter. The maximum and average cover scores and height were recorded for each macrophyte species and macroalgae present.

Results

Vegetation composition

In 2019, 45 sites recorded *Ruppia* species and only one site (Site 1.1) recorded no live, attached macrophyte material (Figure 8). The most frequently encountered macrophytes in hoe samples were *Ruppia polycarpa* (42 sites), *R. megacarpa* (15 sites), *Myriophyllum triphyllum* (15 sites) and the charophyte *Lamprothamnium macropogon* (15 sites). Macroalgae contributed significantly to the vegetation with *Cladophora* spp. being the dominant component of filamentous green algae at 39 sites, and *Ulva intestinalis* recorded at 27 sites (Figure 8).

Previously, numerous sites without plants were recorded when the lagoon had been open for c. 4-6 months, such as in 2011 (29 sites), 2013 (26 sites) and 2014 (32 sites). In 2019, Site 1.1. (Figure 3) showed widespread collapse of the *R. megacarpa* bed that is frequently observed in this enclosed bay.

Ruppia species have been the most frequently encountered submerged plants in hoe samples over all sampling years, with *R. polycarpa* more common than *R. megacarpa* except in 2011 (Figure 8). Occasionally the two *Ruppia* species occurred in combination and could not be accurately distinguished (*Ruppia* species in Figure 8). *R. megacarpa* has been recorded at more sites over 2018 and 2019 than previously. The freshwater macrophyte *Myriophyllum triphyllum* contributed more to vegetation composition in 2009–10, 2018 and 2019. The charophyte *Lamprothamnium macropogon* has been conspicuous in contributing to vegetation over the last five years of monitoring as well as 2009 and 2012 (Figure 8).

[1] 1 = 1–5%, 2 = 5–10%, 3 = 10–20%, 4 = 20–50%, 5 = 50–80%, 6 = 80–100%

[2] <5 cm, 5–15 cm, 15–30 cm, 30–50 cm, 50–80 cm, 80–100 cm

Filamentous green macroalgae were more frequently encountered in hoe samples in 2019 than they were in 2018, and at similar occurrence to that recorded over 2015–2017. *Ulva intestinalis* was most frequently recorded, with *Cladophora* spp. (plotted as filamentous green algae) also common in 2019 (Figure 8).

In contrast to recent years, the diatom *Bachelotia antillarum* was the most commonly encountered macroalgal type in 2014 (Figure 8). *Bachelotia* was noted as widespread in 2009 and 2010 (Robertson and Stevens 2009, Stevens and Robertson 2010). However, the hoe did not sample this algae successfully and results were not able to be adequately quantified or included in the results plotted in Figure 8.

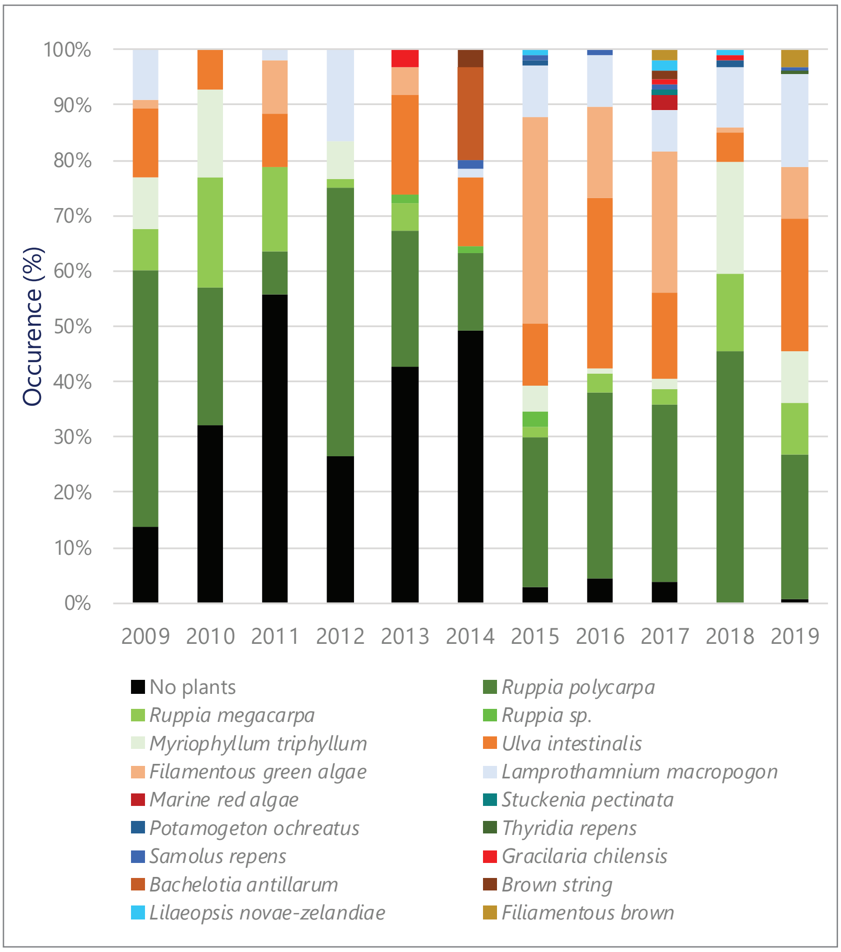


Figure 8: Vegetation composition shown as relative frequency of occurrence (sites recorded) for species or vegetation groups.

Ruppia abundance

In 2019 the average cover of *Ruppia* sampled by the hoe method was 36%, similar to the highest previous recorded average of 40% in 2016 (Figure 9). However, covers in 2019 were more uniform than was the case in 2016. In 2019, 43% of sites exceeded 30% cover for *Ruppia* species. Five sites had ≥80% cover in 2019, of which four sites recorded *R. megacarpa* that formed covers up to 100%. Out of the 23 sites that have previously recorded high *Ruppia* cover (≥80%), over half (58%) recorded *R. megacarpa*. In 2019, Site 1.1, which has previously had high covers of tall *R. megacarpa* had undergone a macrophyte collapse, with the loss of most biomass but some fallen, unattached stems remaining.

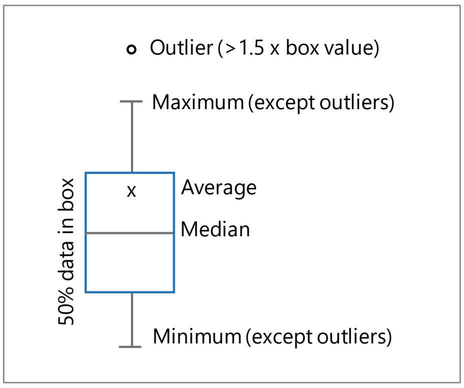


Figure 9: Box and whisker plots of *Ruppia* cover (top), height (middle) and derived biomass index (bottom) over monitoring years. Average of measurements at monitoring sites (n= 48 or 47). Dotted line represents the lagoon-wide target for *Ruppia* cover of 30% identified by the Lagoon Technical Group (2013).

Additional macrophyte observations by divers at sites have correlated with the results from the hoe method (Figure 10). However, observations tended to give higher average covers than the hoe method, particularly where hoe covers were low (Figure 10). This may reflect the patchy nature of *Ruppia* clumps. Average lagoon wide cover of *Ruppia* using the diver observations in 2019 was 50%. Average covers for the lagoon based on the diver observation method have also exceeded 30% for the years 2015, 2016 and 2018.

An average height for *Ruppia* in 2019 of 36 cm (Figure 9) was similar to the value recorded in 2015 (32 cm) and the highest recorded to date. Two outlier heights for sites of >100 cm (Figure 9) were associated with *R. megacarpa* records. Similarly, the 13 sites over previous monitoring years that had higher average height of ≥75 cm were associated with *R. megacarpa*, either alone or in combination with *R. polycarpa*. *Ruppia* heights estimated by diver tended to be higher than those based on hoe samples (Figure 10).

'Biomass index' is calculated as the product of average cover times height at sites using the hoe method and is a proxy for biomass in *Ruppia*. In 2018, average biomass lagoon-wide was the highest recorded so far (Figure 9). Eight sites in 2019 recorded an average biomass of ≥3000, with *R. megacarpa* contributing at five of these sites. In previous years the high outliers of ≥3000 biomass index (21 sites) were disproportionately represented by *R. megacarpa* (67%).

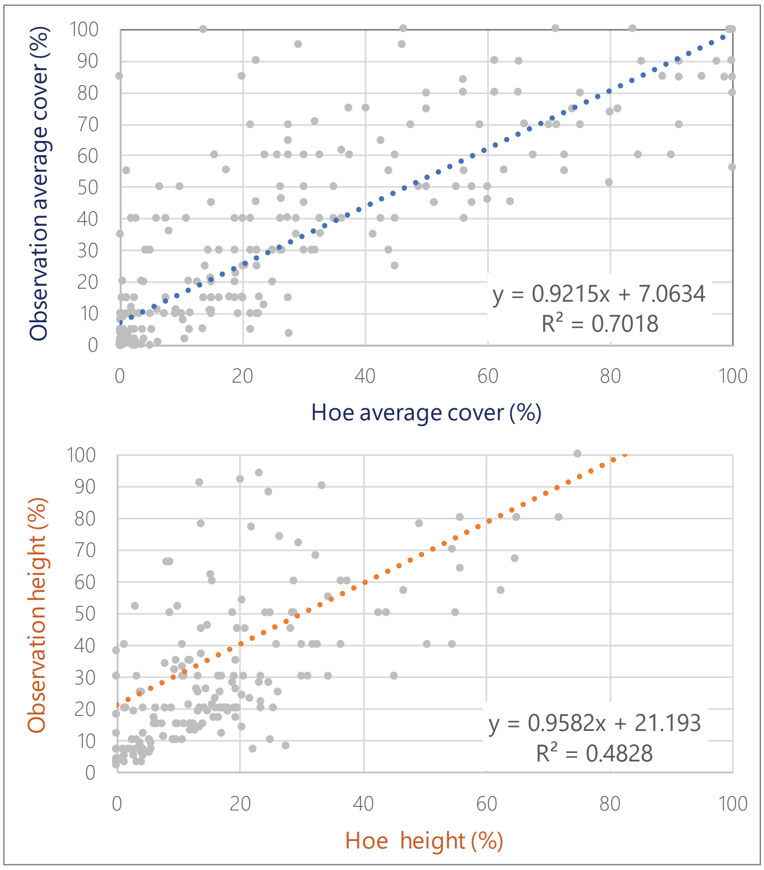
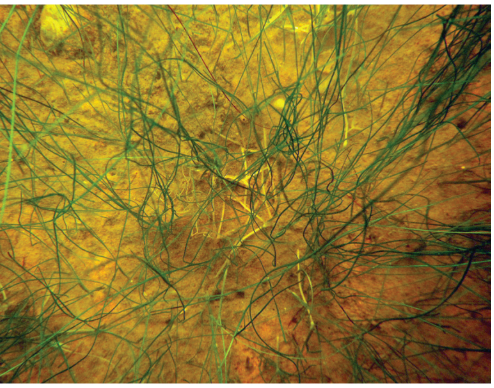


Figure 10: Relationship between *Ruppia* cover (top) and height (bottom) estimated from hoe samples and diver observations within a 10 m diameter area at each site.

Ruppia life-stage

In 2019, 54% of *Ruppia* hoe samples were graded as vegetative and 46% as flowering (Figure 11). This reproductive status is similar to those previous years where the lagoon was closed for three months or more before monitoring (2009–10, 2012, 2015–16 and 2018). By contrast, those years where the lagoon was open or closed for less than three months before monitoring (2011, 2013–14 and 2017) had low levels of reproduction recorded (Figure 11).



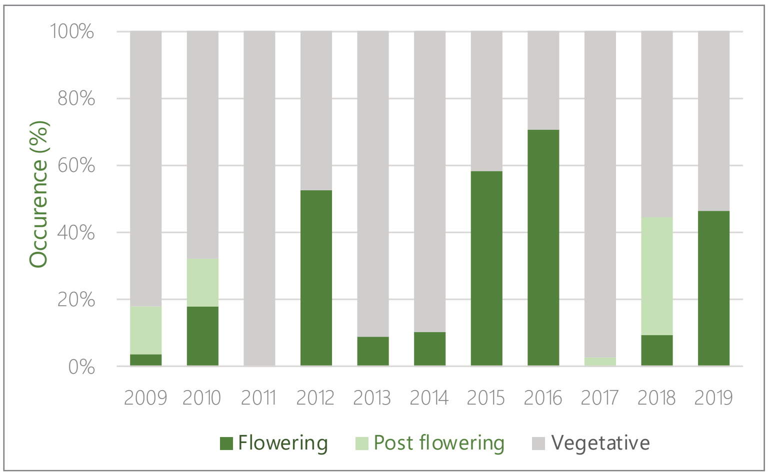
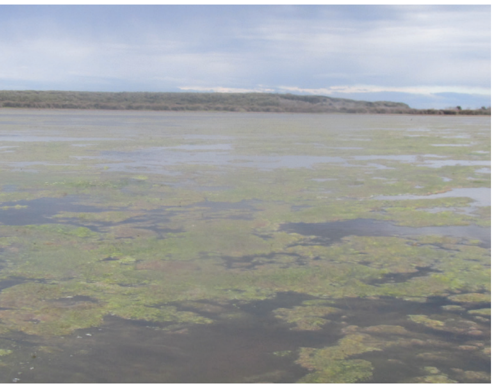


Figure 11: Life-stage category of *Ruppia* species across monitoring years as a proportion of records.

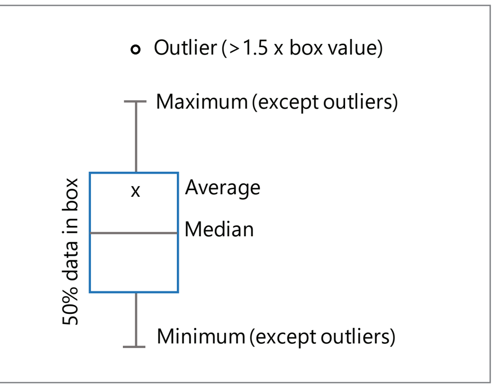


Macroalgae beds can ‘lift-off’ and grow as a surface mat in still, warm weather.

Macroalgal cover

In 2019, covers of macroalgae using the hoe method were the highest recorded during annual monitoring (Figure 12). However, algae layers were not as thick as had previously been documented, nor were floating mats observed. Monitoring in the years 2015–17 also had conspicuous development of macroalgae that exceeded 100% cover at some sites due to combinations of both benthic, epiphytic, and floating growths (Figure 12).

There was a weak correlation between macroalgal cover estimate by hoe samples and overall covers observed by divers (Figure 13). It appears that macroalgal covers are likely to be under-estimated by the hoe method, as was reported in 2009 and 2010 (Robertson and Stevens 2009, Stevens and Robertson 2010). Also, macroalgae can occur as benthic, epiphytic and floating growths, which poses problems for the benthic, hoe sampling method.



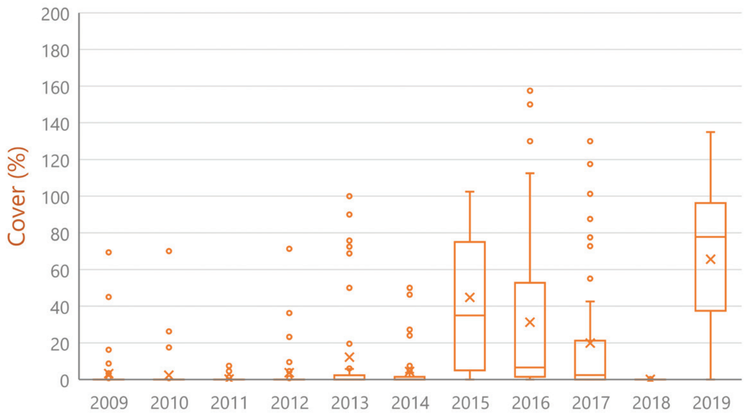


Figure 12: Box and whisker plots of macroalgae cover over monitoring years as an average of measurements at monitoring sites (n= 48 or 47).

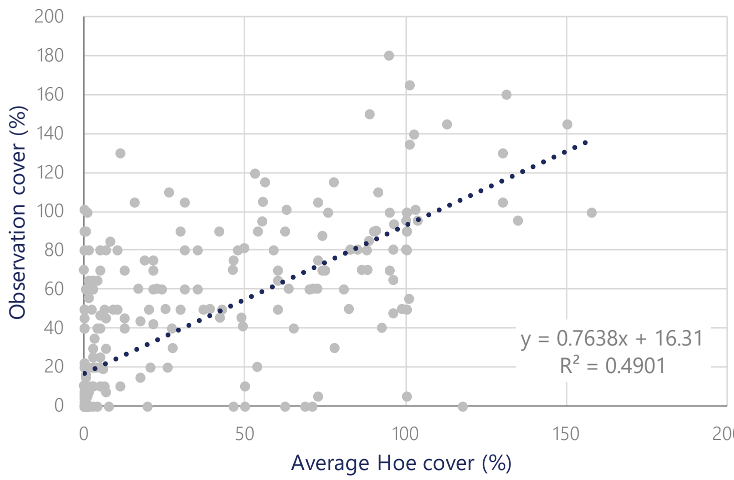


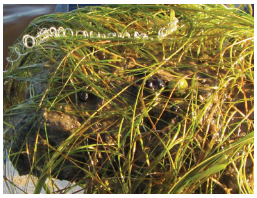
Figure 13: Relationship between macro-algal percentage cover estimated from hoe samples and diver observations within a 10 m diameter area at each site.

Discussion

The widely vegetated lagoon in 2019 occurred after an extended period of closed conditions. High *Ruppia* covers (second highest recorded lagoon-wide), biomass index, reproduction and increased occurrence of *R. megacarpa* all signal a good year for *Ruppia* growth. *R. megacarpa* was disproportionately associated with high cover and height of *Ruppia* vegetation. The reasons for a *Ruppia* collapse at Site 1.1 are not clear, although low visibility that constrained observations and a high turbidity measurement in bottom waters were noted for this site, which suggests a poor light climate for *Ruppia*.

Closed lagoon conditions were also conducive to the development of macroalgae, although impact on macrophytes was not substantial at the time of monitoring. Impacts are likely to be greater where mats become surface floating under warm, still conditions. Macroalgae development during the 2019 monitoring is likely related to higher water nutrient concentrations for algal growth, as higher nutrient levels are recorded when the lagoon is closed (de Winton and Mouton 2018). Meteorological conditions have been linked with macroalgae development in the past, with floating mats observed following still, warm periods.

Continuation of additional diver observations is useful where patchy vegetation distribution means small scale hoe sampling may miss information. Benthic hoe sampling has some limitations for the retrieval of macroalgae in particular.



Informing Future Lagoon Management

Results from 2019 represent the 11th year of annual monitoring at Waituna Lagoon. Over this time, varied lagoon mouth status and duration have led to widely ranging physico-chemical conditions at the time of monitoring. The vegetation monitoring results strongly suggest that a closed lagoon status over the prime spring to summer plant growth season (e.g., for at least three months prior to summer monitoring) enables greater *Ruppia* development and reproductive success than conditions associated with an open lagoon or short duration closures. Previous analysis confirms that a complex of conditions including salinity, depth, desiccation and disturbance levels, water clarity and temperature are likely to interact in determining vegetation composition and abundance (de Winton and Mouton 2018).

Ruppia development in 2019 was amongst the highest recorded during monitoring to date. It appears that during the last two years *Ruppia* development has benefited from the implementation of triggers and conditions in the 2017 Resource Consent that favour short, winter openings and more conservative controls for spring or summer openings. Moreover, recent stable conditions in spring and summer have enabled expansion by *R. megacarpa*, which acts as a strong 'autogenic engineer' in the lagoon and may lead to positive feed backs for vegetation development and persistence.

There remain unexplained variations in vegetation development including the 2019 dieback of *R. megacarpa* at a site that has previously been highly favourable for the species. Previous analysis (de Winton and Mouton 2018) linked *R. megacarpa* occurrence with deeper water sites and with a blackened sulphide layer positioned close to sediment surface. *Ruppia* species are known to be able to detoxify sulphides in shallow sediments by releasing oxygen by the roots (Azzoni et al. 2001, Gennaro et al. 2004). If photosynthesis is limited by a turbid water event, plants cannot supply oxygen to roots, and rapid root death and uprooting may follow. Generally, sediment condition in 2019 showed an improvement over some previous years, with apparent flushing/processing of fine sediments and deepening of sulphide horizons.

Macroalgae were prominent in 2019 and appeared to benefit from the same closed lagoon conditions that promote macrophyte development. However, an extended closure that is generally linked to higher nutrient levels may fuel macroalgae or phytoplankton blooms. In contrast, levels of macroalgae during drought conditions in 2018 were remarkably low, in keeping with likely lower inflows and nutrient loads during a dry summer. Although macroalgae were well developed in 2019, lower temperatures at the time of monitoring possibly limited the development of floating mats of algae. Previously, macroalgae at Waituna Lagoon have 'lifted off' during warm still conditions to form floating algal mats, which have the greatest shading impact on macrophytes. As macroalgae have the potential to compete with macrophytes for light, management of winter openings is important to flush nutrients before seasonally elevated temperatures promote macroalgae blooms.

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