Department of Conservation
Te Papa Atawhai

NIWA
Taihoro Nukurangi

Technical Report on Vegetation Status in Waituna Lagoon: 2009–2025

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Layout: Aarti Wadhwa – Spectra Design Ltd (rt@spectradesign.co.nz)

Contents

Introduction

This technical report accompanies the summary report on vegetation status in Waituna Lagoon in 2025 (de Winton et al. 2025). We review the lagoon conditions over the period of vegetation monitoring from 2009 to 2025 and update current vegetation status according to findings in 2025. Specifically, we assess changes in vegetation status over time with water level management, comprising artificial opening to the sea for drainage, and the unpredictable, natural process of lagoon barrier closure.

As background to the summary report, this technical report describes water level, mouth opening status and duration (Section 1). The report also summarises recent lagoon conditions based on monitoring of indicators of water quality carried out by Environment Southland (Section 2). We provide descriptions of monitoring methods undertaken and present summaries of data and analyses (Sections 3, 4 and 5). Finally, 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 Waghorn 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 lagoon 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

By the time of the annual summer monitoring in January 2025 (20-22 January 2025) the lagoon had been open to the sea for 117 days (Figure 1, Figure 2). Therefore, the target of three months of closed conditions prior to vegetation monitoring (Lagoon Technical Group 2013) was not achieved in 2025 (Figure 1, Figure 2). Nor was it achieved previously in 2024 (Figure 1, Figure 2), although vegetation monitoring in that year was delayed until April by the presence of a toxic algal bloom.

Periods of high water level (>2 m) were a feature of the 2025 and 2024 monitoring years (Figure 2). These high levels were in response to meteorological conditions, but also the permeability of the coastal barrier in allowing water to seep to the sea.

There were two openings in the previous 2024 year. In January 2024, the lagoon was opened to the sea by Environment Southland at a moderate water level (1.46 m above sea level (asL)) to disrupt a toxic algal bloom (cyanobacteria). Consequently, the lagoon was open for 2 months and it closed just 15 days before the delayed *Ruppia* monitoring in April 2024 (Figure 2). A subsequent emergency opening in September 2024 was in response to high water level, when levels were >2.3 m asl for 31 consecutive days, including 12 days at or above 2.5 m asl. This latter opening persisted up to the 2025 vegetation monitoring and beyond.

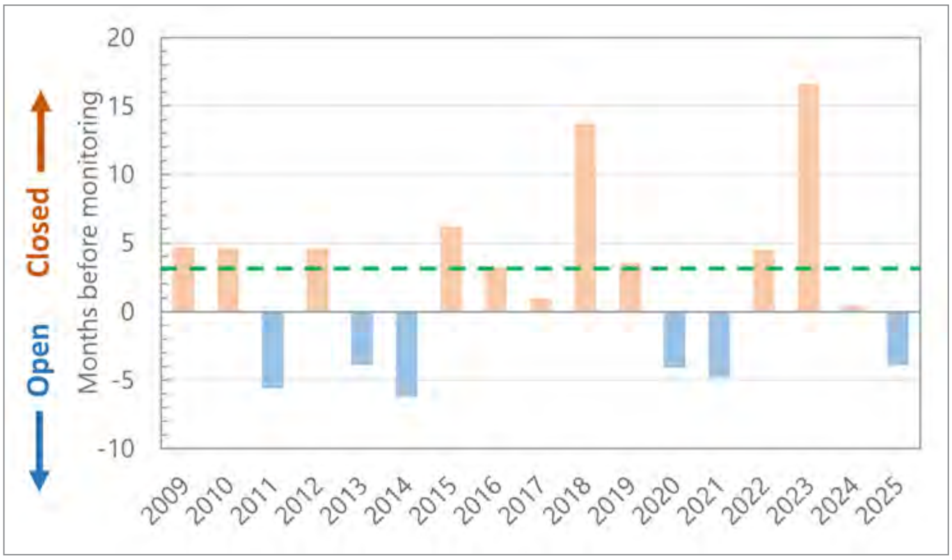


Figure 1: Diverging bar plot showing the number of months for which Waituna Lagoon was open or closed prior to monitoring (as indicated by the y axis). The dotted line indicates the ecological target of three months of lagoon closure before monitoring.

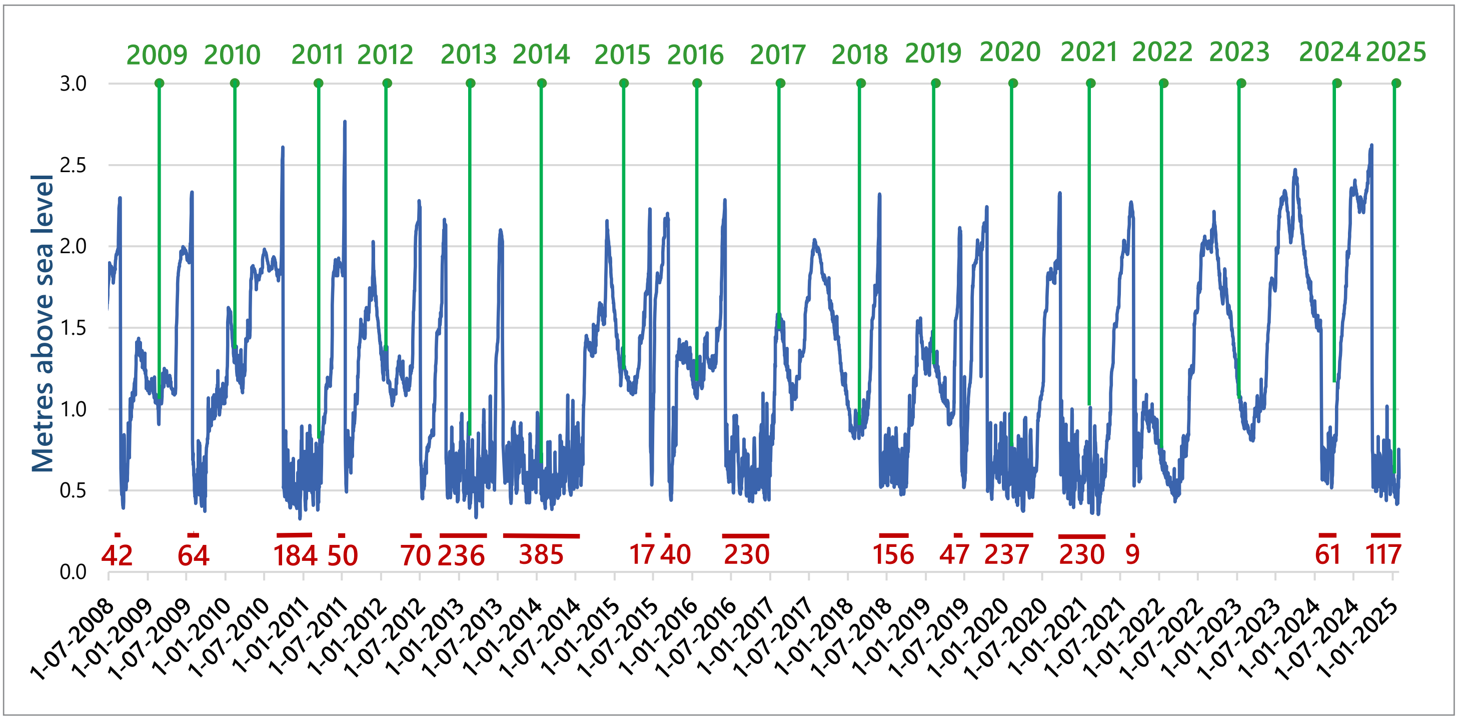


Figure 2: Plot showing the continuous water level time series for Waituna Lagoon, measured at Waghorn Road. Periods of lagoon opening are indicated by horizontal red lines. The number of days during which the lagoon was open correspond to the red numbers. Finally, the annual summer vegetation monitoring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

Discussion

Waituna Lagoon has been mechanically opened to the sea for land drainage purposes approximately once a year over the last c. 100 years. Lagoon closure following artificial opening is a natural process, driven by the effect of tides, currents and waves on redistribution of the gravel in the coastal barrier. Water level in a closed lagoon is controlled by inflows, evaporation and drainage to the sea by percolation through the coastal barrier. The regime of artificial openings had led to longer periods when the lagoon was open to the sea.

Under a natural water level regime, the lagoon would have been closed to the sea with openings occurring in the decadal to century time scales (Hume et al. 2016). Periods where the barrier opened would have been short-lived in comparison. The barrier would have only breached naturally when sufficient pressure built from high water levels in the lagoon, and/or when severe storm waves overtopped the barrier.

In recent years prior to 2024, Waituna Lagoon had been artificially opened under conditions of the Resource Consent (20146407-01), which expired in early 2022[1]. Consent conditions permitted opening at a level of 2 m in winter, or 2.2 m asl over spring to autumn. However, because this consent had lapsed, openings in 2024 and 2025 were not specifically related to water level. Instead, the January 2024 opening by Environment Southland was made under emergency works powers (Resource Management Act) in response to a toxic algal bloom (cyanobacteria) to 'prevent imminent and severe ecological harm'. The subsequent September 2024 opening was also to prevent ecological harm, by flushing nutrients and sediment, while also considering the needs of *Ruppia*. Although the intention was to provide time for the lagoon to close before summer, closure of the coastal barrier cut did not eventuate via the combination of wind and sea conditions required.

A new resource consent application to open the lagoon has been applied for by joint applicants, Te Rūnanga o Awarua, Department of Conservation and Environment Southland, with the primary purpose to establish a new opening regime focused on the ecological health and cultural values of Waituna Lagoon.

[1] https://www.waituna.org.nz/about-waituna-lagoon/resources/lagoon-managment

2. Temporal Physico-chemical Conditions

Methods

Water quality monitoring data for Waituna Lagoon was obtained from Environment Southland from 2009 to 2025. Data from the central lagoon sampling site was used to indicate changes in conditions over time to simplify temporal patterns. Seven parameters were plotted between 2009 and 2025:

1. Chlorophyll-*a* (Chl-*a*, mg l^{-1}).
2. Salinity (Practical Salinity Unit, PSU).
3. Total Nitrogen (TN, g m^{-3}).
4. Total Phosphorus (TP, g m^{-3}).
5. Total Suspended Solids (TSS, g m^{-3}).
6. Turbidity (NTU).
7. Temperature (°C).

Where water quality parameters were reported below detection limits, we plotted a value equal to half that detection limit. Timing and duration of lagoon openings is indicated in relation to water quality parameters.

Results

Elevated salinity levels (PSU) in Waituna Lagoon are related to the opening regime (Figure 3a), generally spiking when the lagoon is open and declining following closure. Salinity reductions are initially rapid following closure and fall slowly to low levels (freshwater conditions) presumably with dilution from catchment inflows (Figure 3a). Salinity had declined to <1 PSU prior to the January 2024 opening but was higher at 3.5 PSU prior to the September 2025 opening (Figure 3a). After opening events salinity can approach the value of seawater (Figure 3a), but levels in 2025 (and 2024) were not as high as observed during extended openings during previous years.

Water temperature immediately prior to the 2025 and 2024 vegetation monitoring events (Figure 3a) at c. 17°C was intermediate to warm years (e.g., 2012, 2018, 2023) and cool years (e.g., 2014, 2016, 2017).

Although a high peak of Chl-*a* (>0.035 mg l^{-1}) had been seen previously in winter 2020, a cluster of values that approached or exceeded this value were recorded from July 2023, including a record Chl-*a* value of 0. 316 mg l^{-1} in January 2024 (Figure 3b). The latter was the algal bloom that precipitated an emergency opening of the lagoon. Chl-*a* declined after the opening but had climbed briefly to 0.042 mg l^{-1} by late June 2024 before the September 2024 opening (Figure 3b). Average Chl-*a* values had reduced by the September 2024 to January 2025 period but were higher than the same period for 2020 to 2023.

High nutrient concentrations, particularly TN, were apparent over winter 2023 immediately before the algal bloom but showed ongoing declines following the two lagoon openings in 2024 (Figure 3b). TN levels over spring/summer before the 2025 vegetation monitoring were less than for the same period in the previous five years.

Record TSS and turbidity measurements in the lagoon in January 2024 were associated with the algal bloom. Both parameters showed a reduction following the consecutive lagoon openings (Figure 3c).

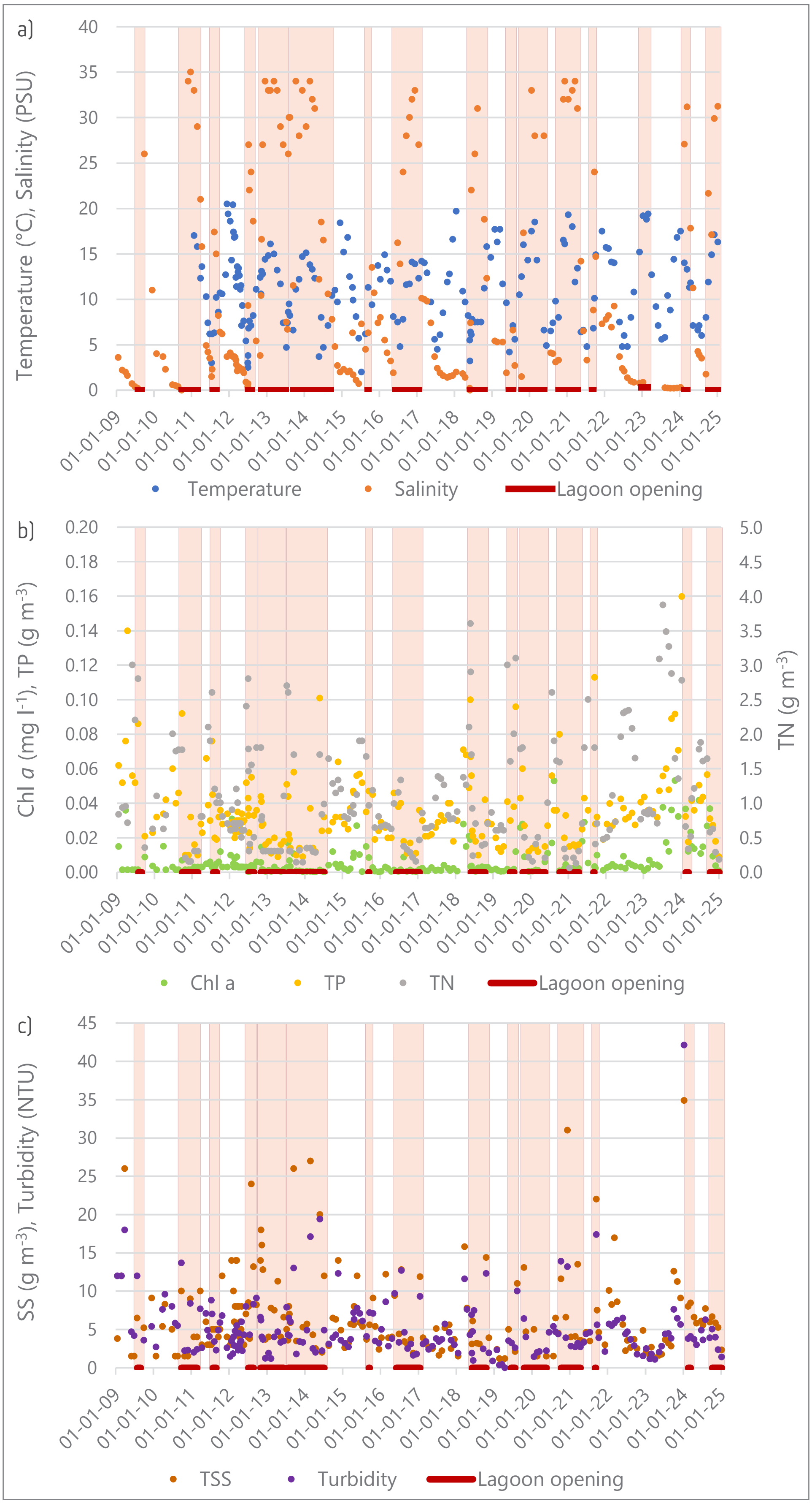


Figure 3: a) Time series of temperature and salinity, b) Chlorophyll-*a* (Chl-*a*), total phosphorus (TP), and total nitrogen (TN), and c) Total suspended solids (TSS) and turbidity at the lagoon centre sampled over 2009 to 2025.

Discussion

Two lagoon openings in 2024 led to higher and variable salinity measurements leading up to the 2025 vegetation monitoring. However, improvements in Chl-*a*, nutrient concentrations, TSS and turbidity measurements occurred after openings that would be beneficial to vegetation development.

The Environment Southland monitoring results are in keeping with expected increased salinity, lowered temperature and nutrients under open lagoon status (de Winton and Mouton 2018). However, total suspended solids are usually lower under a closed lagoon, potentially in association with higher vegetation abundance. Both total suspended solids and turbidity were strongly influenced by the algal bloom early in 2024.

Lagoon mouth status and the timing of lagoon openings are major drivers of chemical conditions in the lagoon, but seasonal signals were also strong for temperature, nutrients and suspended solid concentrations (Schallenberg and Tyrell 2006, Schallenberg et al. 2010, Hodson 2017, de Winton and Mouton 2018). In turn, these physico-chemical conditions will influence the spatio-temporal development of aquatic vegetation in Waituna Lagoon (Robertson and Funnell 2012, Lagoon Technical Group 2013, de Winton and Mouton 2018).

In the following section (Section 3), we describe the physico-chemical conditions at the time of monitoring in 2025 and compare with previous annual monitoring over a range of mouth status.

3. Annual Physico-chemical Monitoring

Methods

The location of 47-48 monitoring sites are shown in Figure 4. (One site could not be sampled due to the migration of the coastal spit from 2014 onwards).

At each monitoring site, measurements were made 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 commenced in 2011.

The surface and bottom water quality measurements were previously found to be highly correlated (Spearman r >0.9, de Winton and Mouton 2018). We therefore employed average values for each parameter. In years where sites were dry we took water quality measurements close by if possible. The data is illustrated using box plots for each year (each annual monitoring event).

Figure 4: 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. Site T8–9 has been removed due to migration of the coastal barrier.

Results

At the time of the 2025 monitoring, salinity was generally high in the lagoon (average 27.9 PSU) due to the open status that had persisted for almost four months (Figure 5). Higher salinity (average >15 PSU) was observed when the lagoon was open to the sea in 2011, 2014, 2020 and 2021, but an open lagoon in 2013 was associated with low salinity. The year 2024 had intermediate salinity, as the lagoon had been closed for only 15 days at the time of monitoring.

In 2025, the lagoon was open to the sea and was tidal (Figure 2). Water quality parameters could not be recorded at twenty-two sites because they were dry. The average depth of the other sites was 0.45 m. Water depth in 2025 was similar to monitoring during the years 2011, 2013, 2014, and 2021 when the lagoon was also open to the sea (Figure 5). In 2024, all monitored sites were submerged, and their average depth was 0.84 m.

The average water temperature during monitoring in 2025 was 19.6°C, which is the highest value recorded, although a relatively wide range of values was recorded (Figure 5). An average of 16°C to 18°C has been recorded for most monitoring years (Figure 5). In 2024, average monitored water temperature at 11.8°C was substantially lower than the other years (Figure 5) but this was due to monitoring being delayed until April after the earlier presence of a toxic algal bloom.

The average dissolved oxygen concentration (DO) in 2025 was 8.24 mg l^{-1}, being intermediate to previous monitoring years (Figure 6). The lowest recorded DO value during the 2025 monitoring was 7.7 mg l^{-1} (Figure 6), which still represented 80% saturation. The average DO concentration in 2024 was higher at 10.0 mg l^{-1}.

Average turbidity during the 2025 monitoring was 4.4 NTU, which was lower than the average of 10.1 NTU recorded during the 2024 monitoring and amongst the lowest years recorded (Figure 6). Despite the low average depth of the lagoon in 2025, resuspension of bottom sediments by wind driven wave action was not obvious in the turbidity records. In keeping with the low turbidity, average black disc measurements in 2025 were amongst the highest previously recorded and increased from the 2024 monitoring event (Figure 6).

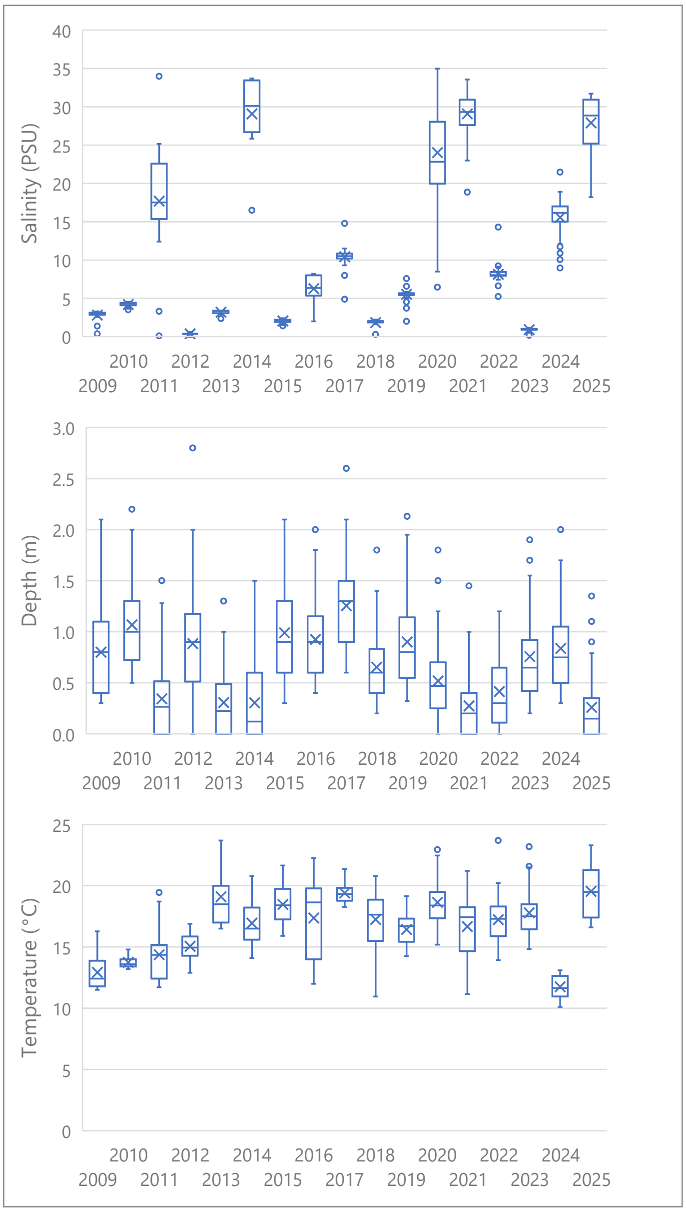


Figure 5: Box and whisker plots of salinity (top), depth (middle) and temperature (bottom) over all monitoring years. (n= 48 or 47).

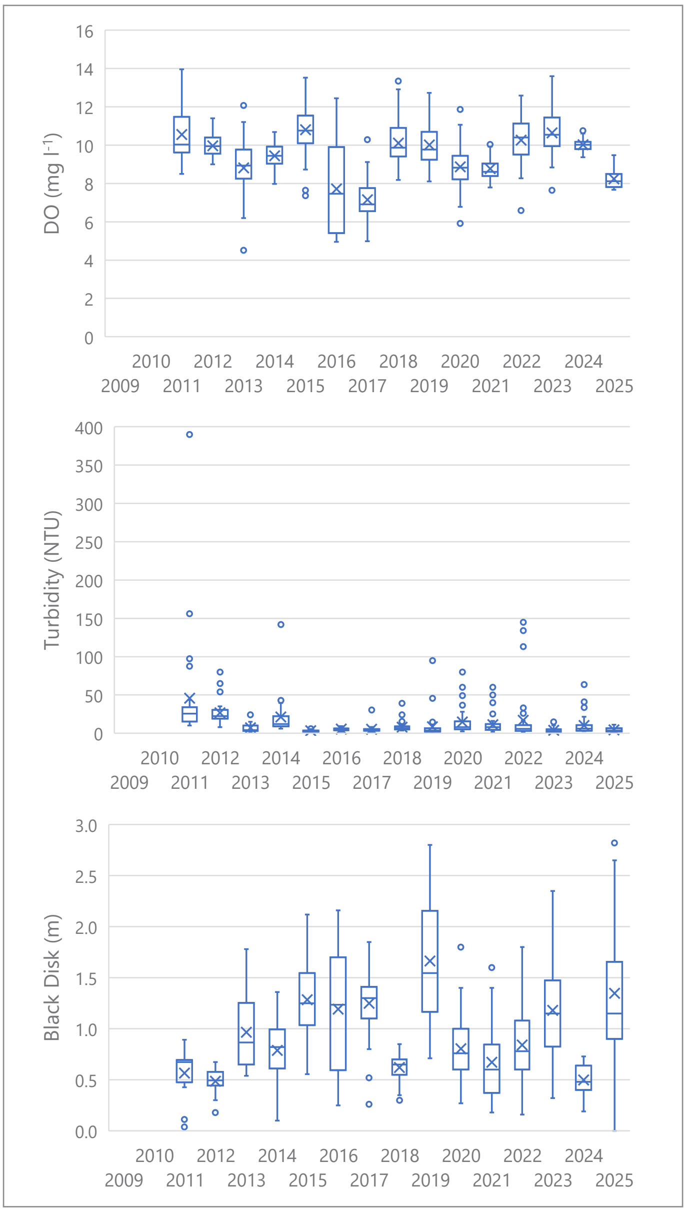
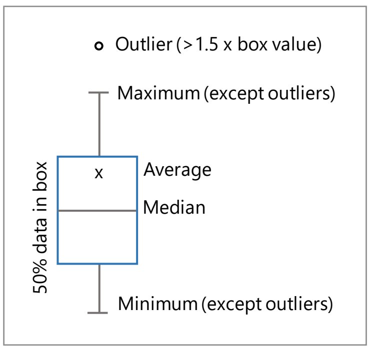


Figure 6: Box and whisker plots of DO (top), turbidity (middle) and black disk (bottom) at the monitoring sites (n = 48 or 47), from 2011 to 2025.



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

Discussion

The high salinity and low water depth at the time of the 2025 annual vegetation monitoring were typical of an open lagoon system. However, temperature was unusually high for the open lagoon, when water exchanges with the sea tend to reduce water temperatures.

Extreme salinities are thought to reduce growth rates of *Ruppia megacarpa* seedlings (Gerbeaux 1989). Fluctuating salinity, as would be expected from combinations of tidal exchange and freshening event from rain in an open lagoon, had a negative impact on the growth of a *Ruppia* species (La Peyre and Rowe 2003). The direct influence of low water depths and tidal flows on *Ruppia* losses is a knowledge gap.

Apart from the high salinity and limited water depth (22 dry sites), other water quality conditions appeared to be suitable for *Ruppia* development in summer 2025. DO levels during the 2025 vegetation monitoring were above levels considered necessary for healthy aquatic life. Water clarity was relatively high and together with the limited lagoon depths would have provided a light climate for rapid growth.

4. Sediment Characteristics

Methods

At each monitoring site (Figure 4), four replicate samples 15 x 15 cm and 6 cm deep were cut from the lakebed, 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), and was assigned a score from 1 to 10 describing increasing hardness.

Results

Sediments assessed at vegetation monitoring sites in 2025 were predominantly harder or coarser substrates (>50% categories 7 to 10, Figure 7). By contrast, fine substrates (categories 1 to 3) were amongst the least common substrates noted in 2025.

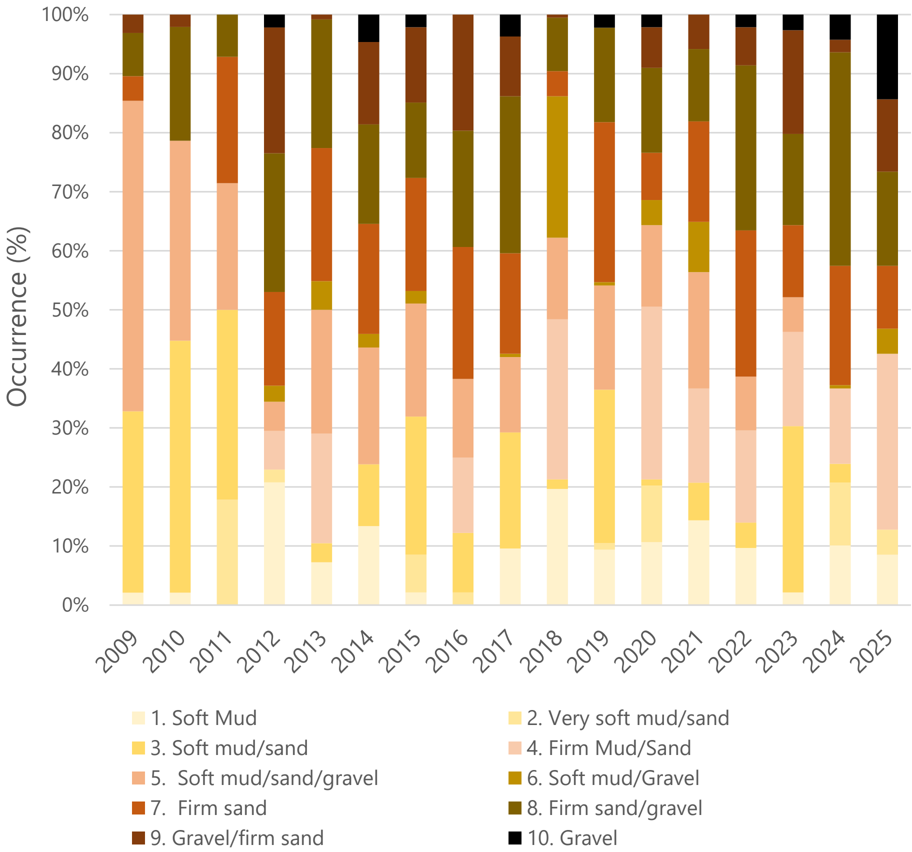


Figure 7: Bar plot illustrating the composition in substrate type (% occurrence), recorded during each of the annual monitoring surveys. Substrate types are numbered from softer to harder.

The predominance of harder or coarser substrates noted in 2025 under an open lagoon may reflect the preponderance of dry sites or those shallow sites washed by tidal exchanges, which is likely to have seen the redistribution of fines. There was no evidence of increased sand prevalence that might indicate intrusions of marine sand during the lagoon openings.

5. Vegetation Development

Methods

At each site (Figure 4), 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 was recorded for each macrophyte species and macroalgae present.

Results

Vegetation composition

In 2025, 38% of sites did not record any vegetation (Figure 8), with the majority of these being dry under the low water level and tidal range of the open lagoon. *Ruppia polycarpa* was recorded at 36% of sites, but *Ruppia megacarpa* was not recorded. *Ruppia polycarpa* was recorded at over half of the sites east to Transect 5, but only 23% of the sites from Transect 6 to the west. Monitored occurrence of *Ruppia polycarpa* in 2025 had decreased slightly from in 2024, this being the second consecutive year that the lagoon was open during the spring-summer growth season.

Other submerged or turf plants recorded in 2025 were limited to the charophyte, *Lamprothamnium* species[3], which was recorded at just two sites in the eastern side of the lagoon.

Macroalgae were relatively common at sites in 2025 (45%) despite the number of dry sites (Figure 8). Green filamentous algae (*Cladophora* species and/or *Rhizoclonium* species) were the dominant macroalgae (43% of sites). *Ulva intestinalis* was recorded at 9% of sites, all within the western half of the lagoon. Other minor macroalgae included the marine brown filamentous *Ectocarpus* species, and green filamentous *Stigeoclonium* species.

Macroalgal occurrence in 2025 had increased since monitored in 2024 following a toxic algal bloom (Figure 8). However, macroalgal occurrence during monitoring over the last three years have been lower than recorded over 2015–2017 and 2019–2022 (Figure 8). Although hoe samples are known to incompletely sample macroalgae, wider *in situ* observations by divers (section 'Macroalgal cover') confirm macroalgae results.

[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.

[3] *Lamprothamnium* species taxonomy in New Zealand is currently unclear, but likely to include *L. compactum* (M. Casanova pers comm. 23/05/2023).

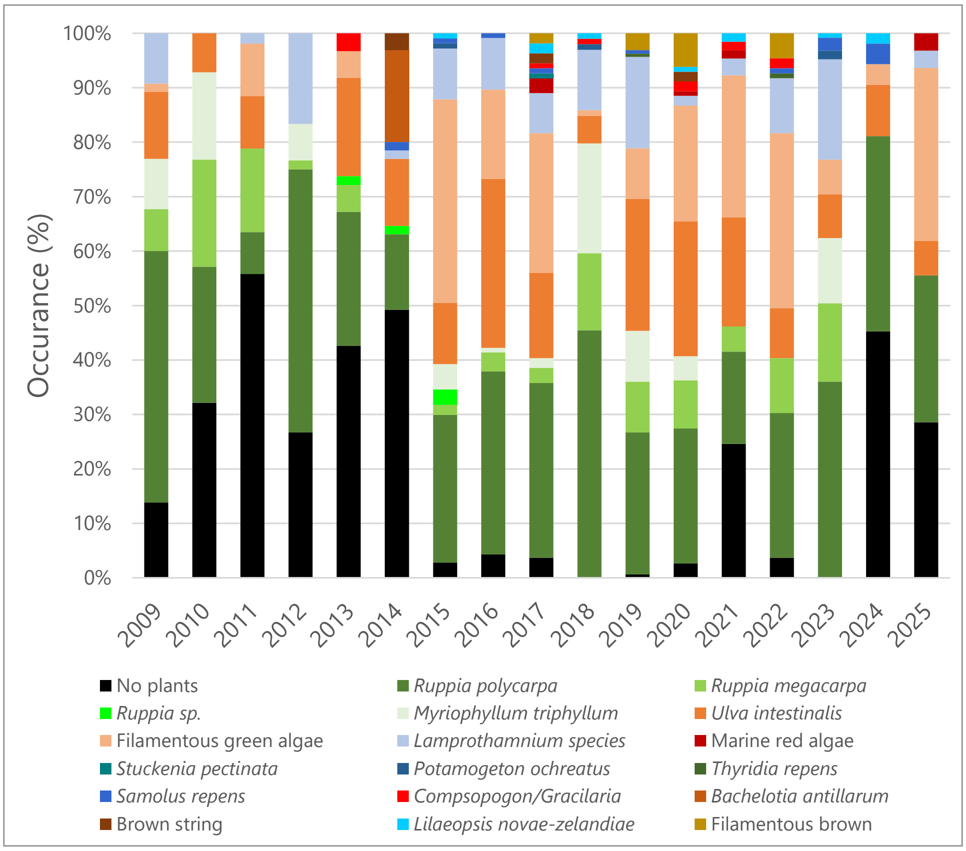


Figure 8: Vegetation composition shown as relative frequency of occurrence (sites recorded) for species or vegetation groups.

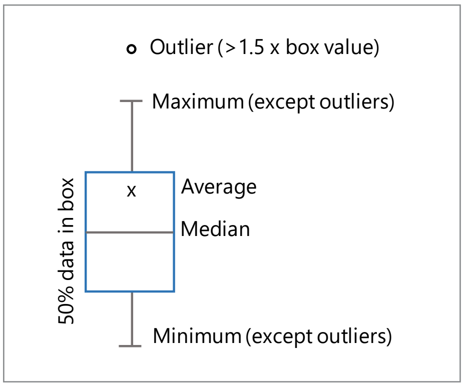
Ruppia abundance

Ruppia polycarpa cover in hoe samples in 2025 was one of the lowest of the monitoring years (Figure 9a). The average cover of 2% lagoon-wide resembled results for 2011, 2014, 2021 and 2024 (Figure 9a).

Ruppia polycarpa plants from the hoe samples in 2025 averaged 0.12 m height (Figure 9b). No plants approached 0.5 m in height. Although average plant height in 2025 was almost double that of 2024, values were low compared to previous years except for 2011–2013, 2020–2022 and 2024.

Consequently, the average biomass index calculated from cover and height in 2025 was low at an average of 38, the second lowest value on record (Figure 9c). Monitoring within the previous 2024 year provided the third lowest average biomass index of the 17 monitoring years.

The absence of *Ruppia megacarpa* in 2024 and 2025 is likely to have contributed to low biomass index values. Previously, *R. megacarpa* has been disproportionately represented amongst the taller height records and higher biomass index values.



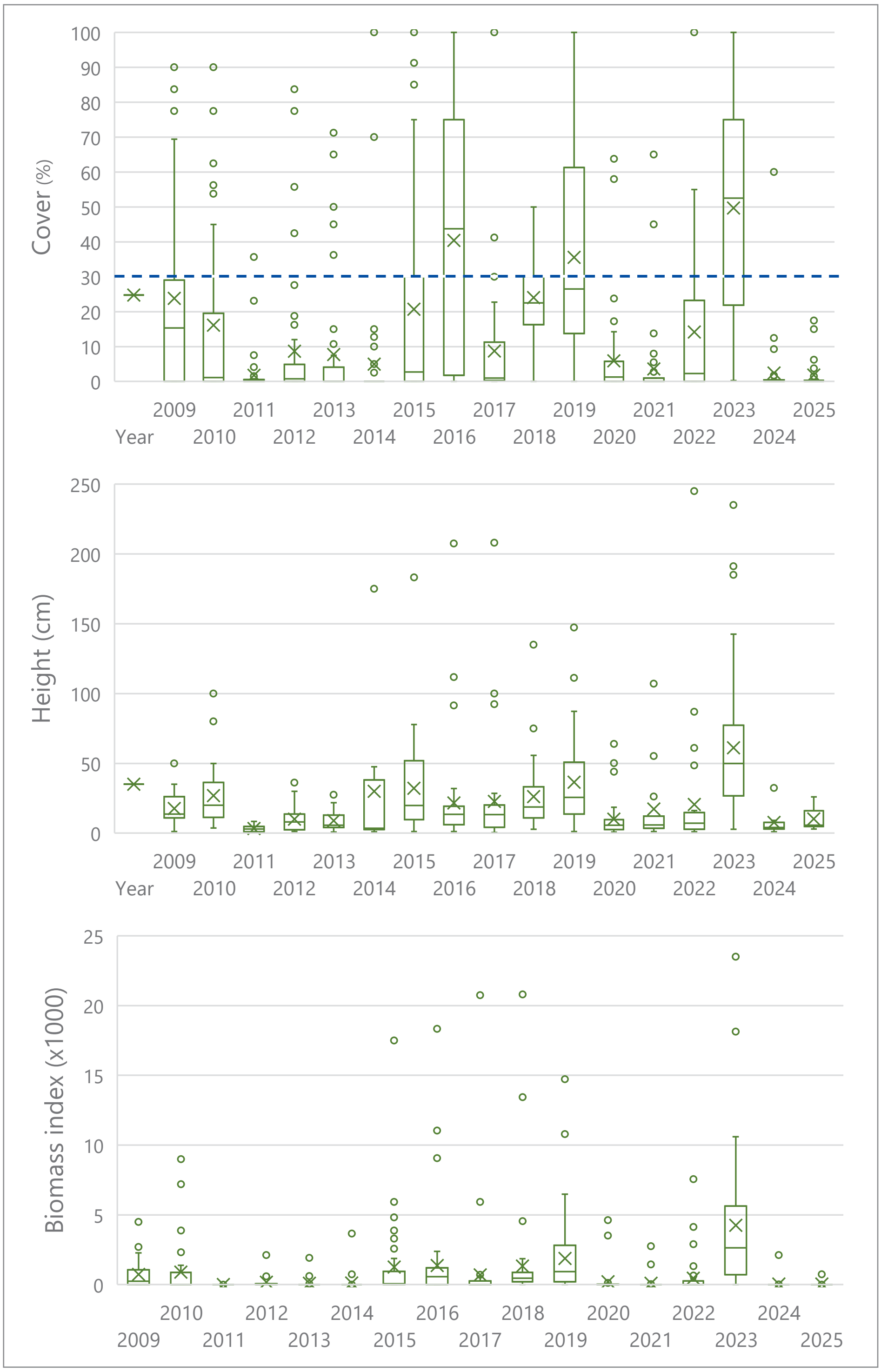
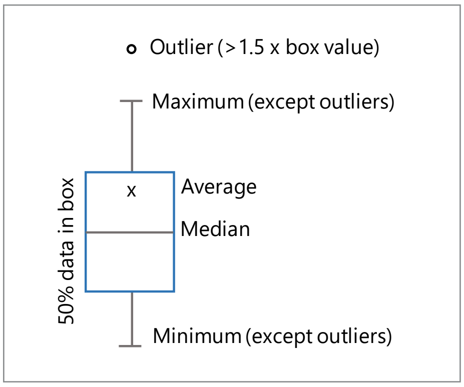


Figure 9: Box and whisker plots of *Ruppia* cover a), height b) and derived biomass index c) over monitoring years, as an average of measurements at monitoring sites (n= 48 or 47). Dotted line represents the lagoon-wide target for *Ruppia* cover of 30% identified by the Lagoon Technical Group (2013).

Diver observations of *Ruppia polycarpa* within a 10 m diameter survey area at sites gave a very similar low estimate of cover to the hoe samples in 2025 (3%) and 2024 (2.4%). Although overall there was considerable scatter between these differently scaled observations for sites (Figure 10), there was a good correlation for lagoon-wide cover (R^2 = 0.97 with intercept at 0%, data not shown), although the diver observations gave higher estimates than hoe measurements for 11 out of 13 years. Diver observations have been more likely to detect *Ruppia* than the hoe sampling method and has the tendency to report taller plants, probably because of the larger assessed area.



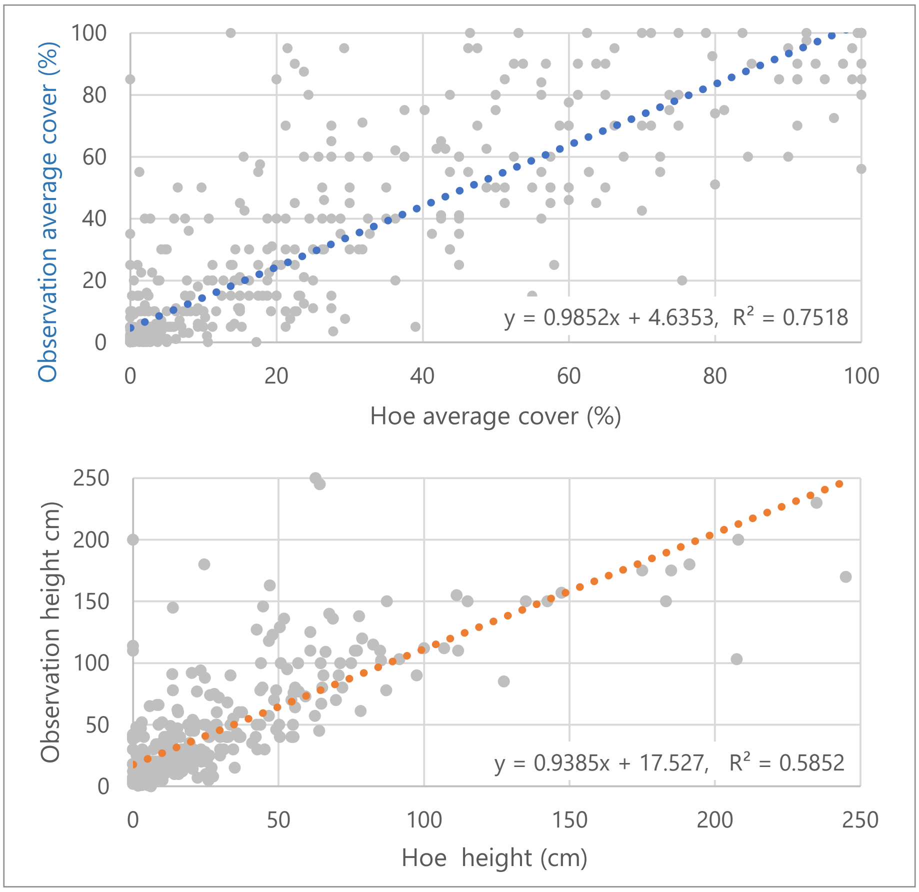


Figure 10: Relationship between *Ruppia* cover (top) and height (bottom) estimated from hoe samples and diver observations within a 10 m diameter area at each site.

Ruppia life-stage

No reproductive plants were recorded during monitoring in 2025, nor previously in 2024. Neither of these monitoring years had been closed for the three months over the main *Ruppia* spring-summer growth period before monitoring. Similarly, low reproduction (≤10% of hoe samples) was recorded in 2011, 2013-2014, 2017 and 2020-2021 (Figure 11, Table 1), all monitoring events when the lagoon was not closed over the main growing season for *Ruppia*. By contrast, the highest reproductive success was associated with the second consecutive year of closed lagoon status, for example, in 2016, 2019 and 2023 (Table 1).

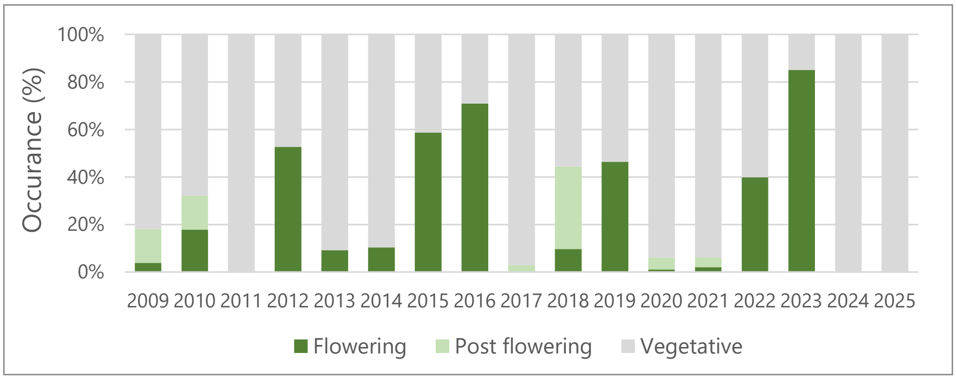
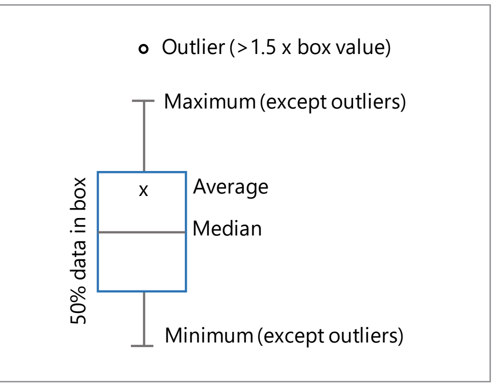


Figure 11: Life-stage category of *Ruppia* species across monitoring years as a proportion of records.

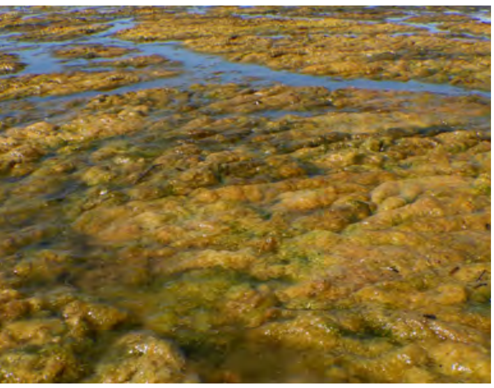
Table 1: Record of lagoon closure (months before monitoring) and reproductive success (% of hoe samples recorded as reproductive) for each monitoring year. Open lagoon shows negative value and years closed for three or more months are shaded.

Year	Months closed before monitoring	Reproduction (% samples)
2009	**4.7**	**18**
2010	**4.6**	**32**
2011	-5.6	0
2012	**4.6**	**53**
2013	-3.9	9
2014	-6.2	10
2015	**6.2**	**59**
2016	**3.2**	**71**
2017	1.0	3
2018	**13.7**	**44**
2019	**3.5**	**46**
2020	-4.1	6
2021	-4.8	6
2022	**4.5**	**40**
2023	**16.6**	**85**
2024	0.5	0
2025	-3.9	0



Macroalgal cover

In 2025, the average macroalgal cover recorded in the hoe samples was 15%. This value is intermediate to average cover values of c. 60% recorded during monitoring in 2019 and 2022 and ≤5% recorded in the years 2009–2012, 2014, 2018 and 2023–2024 (Figure 12). Previously in 2016, 2017, 2019 and 2022, macroalgae covers at individual sites have exceeded 100% on occasion (Figure 12), where different macroalgae types formed overlying layers (e.g., benthic mats and surface mats).



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

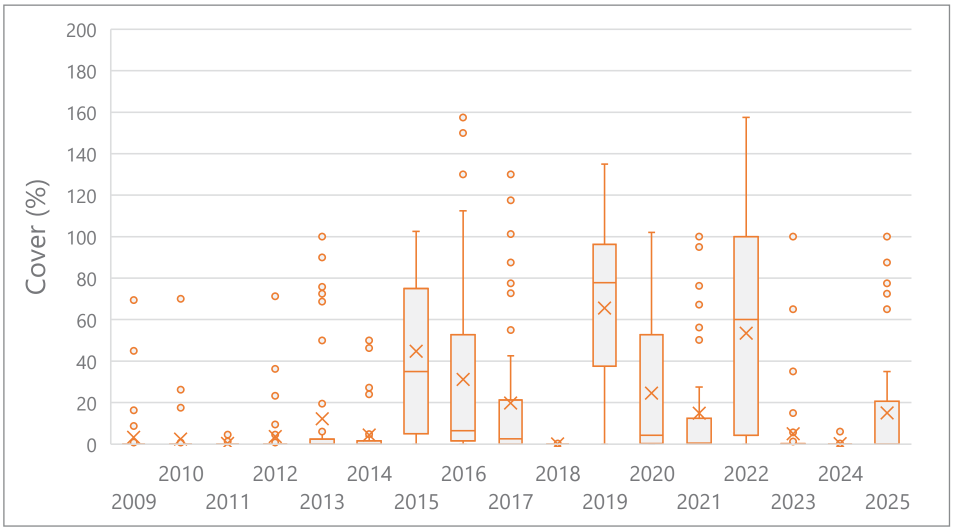


Figure 12: Box and whisker plots of macroalgae cover over monitoring years as an average of hoe measurements at monitoring sites (n= 48 or 47).

Based on diver observations over a 10 m diameter area at sampled sites in 2025, macroalgae cover was 27%. This higher estimate than derived from the hoe samples (15%) could arise from the greater area observed by divers but is also likely related to the observed dislodgement of algae as hoe samples are retrieved to the surface (e.g., Robertson and Stevens 2009, Stevens and Robertson 2010). Notably, there is considerable scatter in the correlation of the two methods at sites (Figure 13). Nevertheless, average lagoon-wide macroalgal cover for each method had a good correlation ($R^2 = 0.97$ with intercept at 0%, data not shown) data. Diver observations generally gave higher cover estimates for macroalgae.

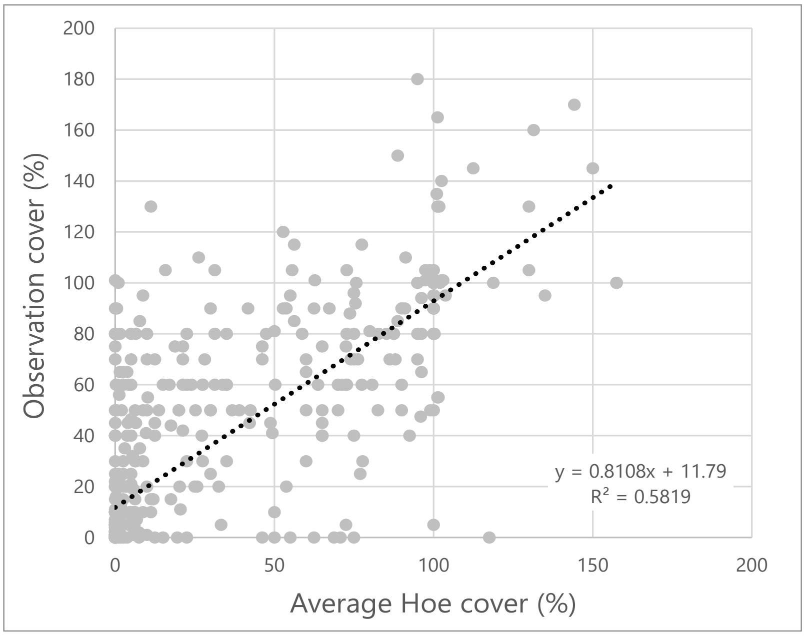


Figure 13: Relationship between macroalgal percentage cover estimated from hoe samples and diver observations within a 10 m diameter area at each site.

Discussion

Ruppia cover, biomass index and reproductive success were all limited in 2025, as they have been previously when there has been an open lagoon status for a substantial part of the spring to early summer growth season for *Ruppia*. *Ruppia* development has been observed to decline further following two consecutive years of open lagoon status during the main growth season, for instance the 2023–2014 and 2020–2021 periods. This current 2025 monitoring represents the second consecutive year of such open conditions with 2024 also being opened in summer. Open lagoon conditions that are detrimental to *Ruppia* development are likely to include the high and fluctuating salinity levels that can reduce *Ruppia* germination and growth (Gerbeaux 1989, La Peyre and Rowe 2003) combined with tidal currents that could disturb vegetation and cause biomass loss.

In addition, only *Ruppia polycarpa* was recorded in the sampling, with *R. megacarpa* being insufficiently common to be detected. *R megacarpa* is generally considered a perennial species (Brock 1982), although both species can act like functional annuals under conditions of environmental fluctuation (Webster et al. 2023). *R. megacarpa* in Waituna Lagoon appears to need consecutive years of closed lagoon conditions during spring to summer to establish widely and for major reproduction events.

Other submerged plant species were also largely absent in 2025, contributing to a low diversity. *Lamprothamnium* species, and the freshwater milfoil *Myriophyllum triphyllum* have been more conspicuous in the years that the lagoon has been closed. Amphibious turf plants such as *Lilaeopsis novae-zelandiae* and *Samolus repens* have not been an ecologically significant component of the lagoon vegetation, but their occurrence increased in 2023 after two consecutive years of a closed lagoon over spring-summer (de Winton et al. 2023).

The importance of the eastern end of the lagoon as either a refuge for *Ruppia* or a more suitable area for recovery, was apparent again in 2025 as had been noted in previous years. In contrast, 29% of the eastern sites recorded *Ruppia* in 2024, compared to 47% of sites in the west from T6 (Figure 4). The difference between years may have been due to the location of the opening site, which was in the vicinity of Site 2.3 in 2024 when usually the lagoon is opened just west of site 7.7 (Figure 4).

In September 2024, hoe sampling was undertaken at all sites by Department of Conservation just before the decision to open the lagoon. At this time, *Ruppia* was recorded at from 53% sites at generally low covers (average lagoon cover <30%). Therefore, plants were still present although the water level at the time was high (average 2.49 m asl in September before opening). However, a lower proportion of sites (36%) recorded *Ruppia* at the time of the 2025 monitoring, which followed almost four months of open lagoon status.

It is likely that the seed bank plays a very important role in the recovery of *Ruppia* vegetation following extended openings of Waituna Lagoon. Seed viability for another *Ruppia* species (*R. maritima*) has been reported to be up to 3–5 years (Kantrud 1991, Strazisar et al. 2013), while Webster et al. (2023) found only a proportion of *R. polycarpa* seeds germinate under favourable conditions, leading to a persistent seedbank, and multiple opportunities for germination. The similarity of germination responses by *R. polycarpa* sampled from the lagoon over three years (two seasons) suggested viable seed were persisting from year to year (de Winton and Mouton 2018). Additionally, in situ observations of germination by *R. megacarpa* at Hansen's Bay in 2020 occurred a year later than the previous successful fruiting (de Winton 2020). Therefore, *Ruppia* seed banks at Waituna Lagoon appear to be perennial, persisting from year to year and unlikely to be depleted over the medium-term.

Environmental cues that promote *Ruppia polycarpa* germination have included high salinity conditions in breaking dormancy (e.g., hypersalinity in sediment porewater of drying sediment) followed by lowered salinity stimulating germination (Webster et al. 2023). The limited *Ruppia* vegetation recovery in 2025 and 2024 followed a major reproduction event for both *Ruppia* species documented in 2023 (de Winton et al. 2023). Therefore, it appears more likely that environmental conditions would be responsible for low vegetation development via germination and growth, rather than constraints of inoculum.

Macroalgae development across all monitoring years appears to be less influenced by lagoon mouth status than *Ruppia*. Instead, macroalgae appear to respond more quickly to the influence of short-term meteorological events. For instance, very rapid development of algal mats at the water surface can occur under warm, still conditions.

Macroalgal cover was moderately low during the 2025 monitoring although lagoon-wide cover exceeded the recommended <10% limit. Macroalgal cover was lower for the preceding 2024 monitoring, which was surprising given the high nutrient levels documented before the summer lagoon opening. However, it may be that the bloom of toxic phytoplankton documented at this time limited macroalgal development via shading. Also noted is the low macroalgal development in 2023 despite the long prior closure of the lagoon and associated nutrient accumulation that can fuel macroalgal growth. A low initial starting biomass of macroalgae in 2023 may have limited the community's response to increased nutrients in 2024 so that phytoplankton gained the competitive edge.



Informing Future Lagoon Management and Research

The addition of the 2025 and 2024 dataset to the 17-year long dataset of annual vegetation monitoring at Waituna Lagoon continues to provide strong evidence that artificial lagoon openings that extend into the key spring to summer growing season for *Ruppia* are undesirable. Moreover, consecutive years when opening occurs within the summer growing season often further reduces *Ruppia* abundance. The key impact of an open lagoon is likely to result from high and fluctuating salinity levels that limit plant growth rates (e.g., Gerbeaux 1989, La Peyre and Rowe 2003), acting together with loss of plant biomass under a tidally swept and disturbed system. Sensitivity to the impacts of lagoon openings is greater for *Ruppia megacarpa*, an important 'ecosystem engineer' that disproportionately contributes to vegetation height and biomass at Waituna Lagoon.

Conversely, years when the lagoon is closed during the three months leading up to summer monitoring of *Ruppia* consistently have higher plant development. Consecutive years of favourable closed conditions during this period promoted greater vegetation development reproductive success and *R. megacarpa* abundance, with the highest *Ruppia* development occurring in 2023 when two consecutive growth periods occurred without the disruption of any opening.

In contrast, opening the lagoon for direct management of macroalgae blooms would seem to have limited benefit, because there appear to be other important drivers for macroalgal development. However, an opening proved successful for disrupting a phytoplankton bloom in 2024, likely through dilution, increased salinity and flushing of nutrient-rich water with seawater.

The coastal permit that previously allowed artificial openings of Waituna Lagoon expired in early 2022. A new resource consent application for an 'ecologically optimised' opening regime has been lodged by Te Rūnanga o Awarua, the Department of Conservation and Environment Southland[4]. This application proposes a staggered transition over 16 years to an opening level of 2.5 m, together with changing time thresholds at this level of up to seven consecutive days before opening. It would also allow for additional openings for fish passage, water quality or biosecurity risk events.

The proposed resource consent conditions seek to decrease the likelihood of open lagoon status within spring-summer, and so advantage *Ruppia* development and increase the probability of reproductive success and adequate replenishment of seed banks (Robertson et al. 2021). Regularly replenished and persistent seed banks would enable *Ruppia* recovery under a scenario of low frequency disruptions caused by spring to summer openings (i.e., up to every three years) to meet additional openings for fish passage or water quality.

Recently, modelling approaches for *Ruppia* communities in coastal waterbodies have been used as a tool to guide management decision and to consider the impacts of climate change (Hensel et al. 2023, Zhai et al. 2025). Such modelling approaches may have application to Waituna Lagoon, particularly if they incorporate hydrological inputs and exchanges, as well as other potential meteorological drivers. Elsewhere for example, low annual run-off rates were an important marker of large-scale *Ruppia* recolonisation (Hensel et al. 2023), but drought was associated with major *Ruppia* die-back in another study (Zhai et al. 2025), suggesting a bespoke, location specific modelling approach is required. Concerns have been raised about climate change leading to an amplification of boom-bust cycles in *Ruppia* (Hensel et al. 2023) and the requirement for an adaptation plan ahead of climate change (Zhai et al. 2025). Therefore, considerations for a future-proofed lagoon opening regime are likely required.

[4] Waituna Lagoon Application.pdf

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