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Auckland Lake Assessments

2024

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1 Executive Summary

Auckland Council contracted Submerged Environmental to assess the ecological condition of eleven lakes using the Lake Submerged Plant Indicators (LakeSPI) methodology. These assessments are part of the council's statutory environmental monitoring requirements and were completed between November and December 2024.

Across the 11 surveyed, 18% (Rototoa and Pokorua) were classed as being in high ecological condition, 9% (Whatihua) in moderate condition, 36% (Pupuke, Ōkaihau, Kawaupaku, and Kuwakatai) in poor condition and 27% (Spectacle, Slipper, Tomorata, and Te Kanae) in a non-vegetated state.

A comparison in LakeSPI score between the two most recent assessments indicate that two of the lakes (Whatihua and Kuwakatai) are likely in a declining state. Two lakes (Pupuke and Ōkaihau) showed signs of improvement, and the remaining seven lakes are in a stable state with nominal shifts in the overall LakeSPI scores.

None of the surveyed lakes achieved an A band for either of the NPS-FM 2020 National Objective framework Native Condition Index and Invasive Impact Index attributes. Lakes Pokorua (B band) and Rototoa (C band) were the only lakes that scored above the national bottom line for the Native Condition Index attribute, the remaining 82% of surveyed lakes were all in D bands.

All the vegetated lakes except for Rototoa (B band) and Kuwakatai (D band) scored C bands for the Invasive Impact Index attribute. This attribute does not apply to non-vegetated lakes (Slipper, Spectacle and Tomorata), so no banding is presented.

Auckland lakes face multiple threats including invasive species (macrophytes and fish), poor riparian buffers, eutrophication, climate change and extreme weather events.

The 2024 Auckland Lakes Assessment highlights the need for site specific lake management plans aimed at maintaining the current high value lakes and restoring the impacted lake where possible. Suitable monitoring programs should be developed in tandem to ensure accurate impact identification and intervention effectiveness.

2 Introduction

Auckland's lakes have a rich history shaped by both natural processes and human activity. The majority of these lakes are dune lakes, formed in low-lying areas where sand dunes created natural depressions that subsequently flooded. Dune lake ecosystems are classified as a globally threatened ecosystem type and the density of these lakes across the upper North Island is of international significance (VanTassel et al., 2019).

Historically, Auckland lakes were vital for early Māori communities and European settlers, providing food and water as well as holding great cultural significance (Carr, 2006). Over time, these lakes became increasingly important for recreational activities and some now serve as important venues for competitive sporting events (Hall & Stoffels, 2006).

The Auckland region has a relatively low number of lakes compared to the rest of the North Island. The Freshwater Ecosystems of New Zealand geo-database identified 108 freshwater bodies across the region that are 1 hectare or bigger in size (Schallenberg et al., 2024). Most of these water bodies are classified as artificial or induced lakes and consist of irrigation ponds, farm dams, water reservoirs and flooded wetlands.

Nineteen of the 21 naturally formed lakes, larger than 1 ha, in the region are classified as dune lakes (aeolian lakes) (Snelder, 2006). These lakes are largely concentrated along the western and northeastern coasts of Auckland. Lake Pupuke is a volcanic crater lake and is the only waterbody of its kind in the Auckland region, Lake Tomorata is considered as a dune lake however, its dystrophic nature and lacustrine wetland complex are characteristic of a peat lake typology. The remaining lakes are typical examples of dune/aeolian lake systems.

The following priority lakes have been identified in Schedule 2 of the Auckland Unitary Plan (operative in part) as Natural Lakes Management Areas:

Te Arai Lakes (Ngāroto Lakes) - Lake Spectacle, Lake Slipper and Lake Tomorata.

South Kaipara Lakes - Lake Rototoa, Lake Kuwakatai, Lake Te Kanae and Lake Kereta.

Muriwai Lakes - Lake Ōkaihou, Lake Wainamu, Lake Kawaupaku and Lake Paekawau.

Auckland City Lakes - Lake Pupuke.

Āwhitu Lakes - Lake Pokorua, Lake Whatihua and the two Pehiakura Lakes (Big & Small).

Historically, Auckland's natural lakes would have been in a clear-water macrophyte dominant state with healthy native submerged plant communities (Tanner et al., 1986; Cunningham et al., 1957 & Cunningham et al., 1953) however, the current state indicates that most of these lakes have, either already transitioned to or, are trending towards a turbid algal dominant state with depauperate macrophyte assemblages (de Winton, 2022; Duggan & Hussain, 2021; Groom, 2021; Hamill & Lockie, 2015).

Almost all of the region's 13 monitored lakes are situated in lowland catchments and are surrounded by high impact land use activities such as production forestry and exotic pasture grazing. Lake Kawaupaku and, to a lesser extent, Lake Te Kanae are the exceptions. These lakes are surrounded by steep sloped low impact native bush sub-catchments. Lake Kawaupaku is situated in the headwaters of the catchment and has minimal anthropogenic influence while Lake Te Kanae is a lowland lake, but the bulk of the sub catchment is clad in native bush. Lake Pupuke is the only natural urban lake and is situated in a heavily modified residential catchment, while the rest of the lakes are surrounded by production forestry and agricultural activities.

Auckland's lakes have been heavily impacted by land use intensification, invasive species, eutrophication and sedimentation, leading to declines in water quality and native biodiversity (de Winton, 2022; Duggan & Hussain, 2021; Groom, 2021; Hamill & Lockie, 2015). Agricultural runoff in particular has been identified as a key driver of eutrophication, algal blooms, and reduced water clarity in low-lying dune lakes (Larned et al., 2020; Mladenoff, 2016; Schock et al., 2014; Abell et al., 2011; Heathcote & Downing, 2012; Quinn et al., 2009; Cullen et al., 2006).

The drainage of wetlands and removal of riparian vegetation have further exacerbated these issues. The spread of invasive species including aquatic macrophytes (*Elodea canadensis*, *Egeria densa* and *Ceratophyllum demersum*) and fish (koi carp, rudd, perch and tench) have also significantly impacted lake health and has contributed to

the devegetation and/or native macrophyte collapse seen in several lakes across the region (de Winton, 2022; Duggan & Hussain, 2021; Hamill & Lockie, 2015).

To monitor and manage these impacts, the Auckland Council undertakes several environmental monitoring initiatives in accordance with the statutory requirements outlined in the Auckland Unitary Plan (operative in part) and the National Policy Statement for Freshwater Management (NPS-FM). The Lake Submerged Plant Indicators (LakeSPI) survey is part of the monitoring tools used to assess the ecological condition of lakes. The data provides integrated ecological context to the State of the Environment Water Quality assessments. Under the directive of the NPS-FM, there has been a recent increase in effort towards conserving and restoring Auckland's lakes. Several reforestation projects, invasive species control programs, and improved land management practices initiatives are already in place across the region's lakes.

Auckland Council has engaged Submerged Environmental Ltd to conduct LakeSPI surveys and general lake health assessments at 11 lakes that form part of the State of the Environment monitoring network.

This report will focus on the updated LakeSPI scores for each lake, descriptions of the macrophyte assemblages, current impacts/threats, general ecological health, comparisons of changes in ecological condition over time, and scoring against the NPS-FM National Objective Framework attributes for LakeSPI metrics.

3 Methodologies

Eleven lakes were surveyed between November and December 2024 to assess overall lake ecological health (Table 1). The surveys involved collecting data to facilitate the calculation of LakeSPI (Lake Submerged Plant Indicators) scores, as well qualitative information to support conclusions on the current state and key threats.

Visual assessments of the sub-catchment and riparian areas were done from the water as well as from surrounding high points. The width, extent, depth and condition of the riparian margins was assessed. Sub-catchment characteristics that relate to lake health were also noted, these included land use, stock access, vegetation extent, abstraction/drainage activities, overland flow, erosion and slope.

Table 1: List of the 11 surveyed lakes indicating their grouping, location and most recent survey date.

Lake	Lake group	Location	Latest survey date
Slipper	Te Arai Lakes (Ngāroto Lakes)	36°10'19.9"S 174°37'47.1"E	7/12/2024
Spectacle	Te Arai Lakes (Ngāroto Lakes)	36°10'47.3"S 174°37'46.0"E	7/12/2024
Tomorata	Te Arai Lakes (Ngāroto Lakes)	36°11'36.4"S 174°38'57.5"E	29/11/2024
Rototoa	South Kaipara Lakes	36°30'48.5"S 174°14'10.6"E	19/12/2024
Kuwakatai	South Kaipara Lakes	36°31'43.9"S 174°14'07.4"E	9/11/2024
Te Kanae	South Kaipara Lakes	36°34'40.5"S 174°17'17.0"E	9/11/2024
Ōkaihau	Muriwai Lakes	36°48'33.1"S 174°26'24.8"E	13/12/2024
Kawaupaku	Muriwai Lakes	36°53'39.7"S 174°27'29.7"E	13/12/2024
Pupuke	Auckland City Lakes	36°46'53.8"S 174°45'57.4"E	16/12/2024
Pokorua	Āwhitu Lakes	37°11'34.7"S 174°37'57.7"E	8/12/2024
Whatihua	Āwhitu Lakes	37°16'31.7"S 174°40'11.6"E	8/12/2024

3.1 LakeSPI Assessments

LakeSPI (Lake Submerged Plant Indicators) assessments were the focus of the in-lake surveys. LakeSPI is a monitoring and management tool that uses submerged aquatic plants as a proxy for general lake ecological condition.

Representative sites across the littoral zone of each lake were assessed to ensure adequate spatial and habitat representation. The survey locations from the previous assessments were used to ensure comparability across the combined LakeSPI dataset. At each site, divers score a series of vegetation metrics (Figure 1) over a 2 metre wide transect that runs perpendicular from shore to the deepest vegetation extent (Clayton & Edwards, 2006). The vegetation metrics are used to calculate the following three indices as per Clayton & Edwards, 2006:

1. **Native Condition Index** – This represents the native character of vegetation based on the diversity and quality of indigenous plant communities. Higher scores indicate healthy, diverse submerged vegetation with good extent and cover. This index is derived using the following measurements:
 - Native maximum depth – the maximum depth at which native plants occur at more than 10% cover within any 2 m² surveyed area.

- Native ratio – the proportion of the vegetated transect consisting of native macrophytes.
- Charophyte meadows – the maximum depth at which charophytes form meadows exceeding 75% cover within any 2 m² surveyed area.
- Native diversity – the presence of representative species for key native plant community types.
- Native distribution – the presence of any of the three key native plant communities deeper than 5 metres.

2. **Invasive Impact Index** – This represents the invasive character of vegetation based on the degree of impact by invasive species. Higher scores signify greater impacts from exotic species. This index is derived using the following measurements:

- Invasive ratio – the proportion of the vegetated transect consisting of invasive weeds.
- Invasive species impact – represented by the top ranked (most invasive) weed species present at each transect.
- Invasive depth impact – the maximum depth at which invasive plants occur at more than 10% cover within any 2 m² surveyed area.
- Nature of invasive cover – the nature of the weed bed development.
- Invasive maximum height – the maximum weed height achieved in any 2 m² surveyed area.

3. **LakeSPI Index** – This is an amalgamation of components from both the Native Condition Index and Invasive Impact Index and provides an overall indication of lake condition. Higher scores are indicative of better in-lake conditions.

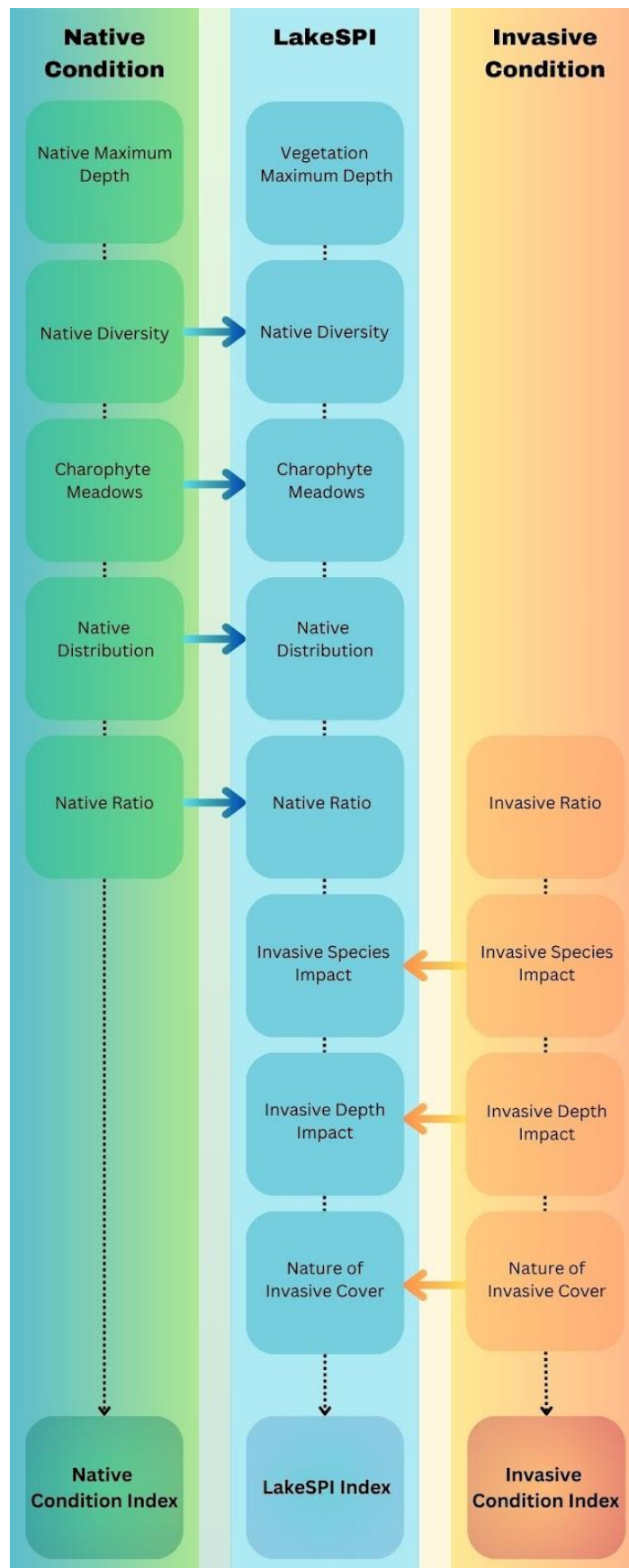


Figure 1: Conceptual flow of submerged plant metrics used to produce a Native Condition Index, Invasive Condition Index and LakeSPI Index (adapted from Clayton & Edwards, 2006).

To account for differing lake typologies each of the LakeSPI indices are expressed as a percentage of a lake's maximum scoring potential. Due to the effect that depth has on macrophyte extent, the maximum scoring potential is calibrated to the maximum depth of the target lake.

A narrative for lake condition was generated based on the LakeSPI results. Scores of > 75% are considered excellent, > 50 – 75% is high, > 20 – 50% is moderate, > 0 – 20% is poor and 0% is non-vegetated.

An indication of the significance of a change in LakeSPI scores was done in accordance with the general guidelines developed by Clayton and Edwards, 2006. An extent of change in any of the indices of 0 - 5% indicates no significant change, >5 – 10% is indicative of a possible change, >10 – 15% indicates a probable change and >15% confirms a notable change. New incursions of a more invasive weed species also represent a state change as there will be a significant increase in the Invasive Impact Index.

An assessment of monthly water quality profile data (temperature, dissolved oxygen & pH) was done to understand the possible impacts of seasonal stratification, hypolimnetic deoxygenation and surface algal blooms on macrophyte establishment. This analysis is not presented for the non-vegetated polymictic lakes as persistent stratification does not occur and macrophyte establishment is primarily limited by other factors. The analysis for the monomictic lakes is included in the lake specific discussions.

3.2 NPS-FM Attribute Bands

The National Policy Statement for Freshwater Management (NPS-FM) has incorporated two LakeSPI indices as attributes within its National Objectives Framework (NOF) (NPS-FM 2024, Appendix 2B, Tables 11 and 12). These attribute bands are based on the Native Condition Index and Invasive Impact Index scores. Degraded lakes with attribute bands below the national bottom line require regional councils to develop action plans with the goal of achieving an enhanced target state within reasonable time frames. Lakes that are naturally below the national bottom line are exempt from this requirement and a target attribute state below the national bottom line is accepted. Central government requires that the Native Condition Index and

Invasive Impact Index attributes are evaluated every three years. For non-vegetated lakes, the Invasive Impact Index cannot achieve an A band, as lakes without submerged vegetation cannot be categorised as either invaded or uninvaded and therefore are not assigned a band

Table 2: National Objectives Framework attribute table for LakeSPI indices. Native Condition Index and Invasive Impact Index attribute bands from the NPS-FM (2020, Appendix 2B, Tables 11 and 12).

Attribute Band	Native Condition Index	Invasive Impact Index
A	>75%	0*
B	>50 and ≤75%	>1 and ≤25%
C	≥20 and ≤50%	>25 and ≤90%
National bottom line	20%	90%
D	<20%	>90%

*Note the Invasive Impact Index for non-vegetated lakes is excluded from the A band no band assigned.

4 Lake Assessments

This section will discuss each lake separately. The individual lake reports include a summary report card and detailed discussions on the LakeSPI metrics and additional data and observations that were used to assess the overall ecological health.

The lakes are grouped under five geographical groupings (Figure 2). The Te Arai Lakes (Ngāroto Lakes) (Tomorata, Spectacle and Slipper), the South Kaipara Lakes (Rototoa, Kuwakatai and Te Kanae), the Muriwai Lakes (Ōkaihau and Kawaupaku), the Auckland City Lakes (Pupuke) and the Āwhitu Lakes (Pokorua and Whatihua).



Figure 2: Location of the 11 surveyed lakes and their most recent LakeSPI status.

4.1 Te Arai Lakes (Ngāroto Lakes)

The Te Arai Lakes consist of three shallow dune lakes known as the Ngāroto Lakes complex. This complex is located along the northeast coast of the region near the Northland boarder and includes Lake Spectacle, Lake Slipper and Lake Tomorata.

These lakes were heavily impacted by Cyclone Bola (March 1988) and it is likely that this extreme event has contributed to the persistent non-vegetated state seen across off three lakes.

4.1.1 Lake Spectacle

Lake Spectacle

07/12/2024



Ecological Condition: Non-vegetated

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	0%	N/A

Summary

Lake Spectacle has been in a non-vegetated state since 1988 due to poor substrate, limited light penetration and encroaching emergent vegetation. High nutrient loads from intensive agriculture and internal nutrient recycling sustain algal blooms, further reducing light penetration and degrading substrate conditions. Invasive fish, particularly rudd, disrupt potential regeneration by grazing on new growth. Ongoing eutrophication perpetuates a turbid, algal-dominated state, rendering the lake in a degraded, non-recovering condition.

Depth: 4.5 m

Size: 44 ha

Type: Dune



General Description



Photo plate 1: South facing view across Lake Spectacle.

Lake Spectacle is located in the Rodney District near the northern border of Auckland ($36^{\circ}10'47.3''\text{S}$ $174^{\circ}37'46.0''\text{E}$). This lake is the largest of the Te Arai/Ngāroto Lakes and is approximately 44 hectares. Under the Auckland Unitary Plan (operative in part) this lake is classified as a Natural Lakes Management Area, Outstanding Natural Landscape and an Outstanding Natural Feature.

Lake Spectacle is part of a complex of shallow polymictic coastal dune lakes. Its depth varies across the lake, with an average depth of 2.5 m and a maximum depth of 4.5 m. Despite its size, the water quality of this lake is worse than the smaller Te Arai/Ngāroto Lakes and has been devoid of aquatic macrophytes for approximately three decades. The lake is currently considered as supertrophic with a Trophic Level Index of 6.1 (Unpublished Auckland Council data, 2024).

The only in/outflow is a large, well defined drainage channel that connects Lake Spectacle to the neighbouring Lake Slipper (Photo plate 2). This channel was 0.5 – 1

m deep and the base was lined with a thick layer of silt and organic debris. No submerged macrophytes were found in the channel.



Photo plate 2: Channel that links Lake Spectacle to Lake Slipper.

A series of farm drains were noted along areas of the lake with poor riparian vegetation (Video 1). Aerial imagery shows several drain-like features entering the riparian margin and it is likely that these drains carry a notable portion of the catchment derived contaminant load.



Video 1: Farm drain entering the lake from the adjacent paddock.

Catchment Characteristics

The 662.47-hectare catchment area surrounding Lake Spectacle is almost entirely pastoral grazing land (high producing exotic pasture), some of which is on steep sloped paddocks draining directly to the lake (Video 2). The outer edge of the catchment along the eastern boundary consists of production forestry and a newly constructed quarry operation. This combination of high impact land use activities on highly permeable soils contributes to the nutrient enrichment and sedimentation of the lake.

The surrounding area has some small, low-lying wetlands, but they are in poor condition and small relative to the size of the catchment and lake. As a result, their ability to attenuate contaminants is extremely limited. These catchment characteristics have contributed to the current poor lake condition.



Video 2: Surrounding pastoral land use on steep sloped hills.

Riparian Characteristics

The riparian vegetation is predominantly raupō reedland that backs onto manuka/kanuka scrub, it forms an almost contiguous band around the lake (Video 3). The average width of this emergent vegetation is 10 -15 m, with some areas along the eastern bank being as wide as 30 m and others as narrow as 2 m.



Video 3: Intact riparian margin with dense emergent vegetation.

The emergent vegetation is mature and forms a dense buffer around most of the lake however, the contaminant attenuation capacity is moderate considering the size of the surrounding catchment and the high impact land use activities. Stock were seen close to the lake edge in several paddocks along the western bank, these areas are

intensively grazed and slope directly toward the lake (Video 4). Several sections of the riparian margin were in poor condition with limited vegetation and signs of stock access to the water (Video 4).



Video 4: Steep grazed paddock draining to an impacted riparian margin with limited vegetation and signs of stock access.

Verly little bare earth and hill side erosion was seen which indicates that the primary contaminant from the adjacent land use is likely nutrients.

Invasive alligator weed (*Alternanthera philoxeroides*) was found across ~30% of the lake perimeter. It formed a 1 – 2 m wide band along the outer edge of the emergent vegetation with a concentration across the northern and eastern banks (Video 5).



Video 5: Alligator weed (*Alternanthera philoxeroides*) along the outer edge of the emergent vegetation.

Biodiversity

Lake Spectacle has moderate to high biodiversity value as it supports a variety of wetland birds including nationally and regionally threatened species such as the Australasian bittern (*Botaurus poiciloptilus*), Fairy tern (*Sternula nereis*), Fernbird (*Megalurus punctatus*) and Spotless crake (*Porzana tabuensis*).

Four pied shags (*Phalacrocorax varius*) were seen during the survey as well as approximately 100 paradise shelducks (*Tadorna variegata*) and 50 Canadian geese (*Branta canadensis*). The high avian bioload is likely a significant contributor to the elevated trophic state of the lake.

No fish were observed during the survey however, native common bullies (*Gobiomorphus cotidianus*) and shortfin eels (*Anguilla australis*) are thought to be reasonably abundant in the lake as they serve as prey for foraging wetland birds (Auckland Council unpublished data, 2022). The invasive coarse fish Rudd (*Scardinius erythrophthalmus*) has been detected in the lake (New Zealand Freshwater Fish Database). These fish disrupt natural food webs and graze on macrophytes which has been attributed to the prolonged devegetated state of the lake. The lack of macrophytes creates a cascading collapse of ecosystem functions and significantly impacts the overall health of the lake.

In-lake Description

Lake Spectacle has been in a degraded state since the 1980s and the current in-lake conditions are reflective of persistent eutrophication and the associated ecological impacts.

The lake was isothermal during the survey and had a constant temperature of ~22 °C. The water had a lot of suspended matter and visibility was limited to 10 cm or less. The poor visibility is likely due to a combination of wind-induced sediment remobilisation, tannins from the emergent vegetation, and high suspended algal volumes (Video 6).



Video 6: Suspended organic matter in the water column.

There is a lot of decomposing organic matter along the edge of the emergent vegetation. The remainder of the substrate consisted of a > 1 m thick layer of organic floc and silt on top of a deep mud base (Photo plate 3). A consolidated sandy base was found near the access point and areas with limited emergent vegetation.



Photo plate 3: Diver retrieving black anoxic sediment with high organic content.

No benthic algal growth was detected on the lakebed and epiphytic growth was only seen on the parts of emergent vegetation near the surface (10 – 25 cm deep). This could be a result of the limited photic depth and persistent wind driven turbulence.

The high concentration of suspended organic matter, poor water clarity and inappropriate substrate conditions have prevented submerged vegetation from establishing.

Submerged vegetation

LakeSPI assessments were done along three survey transects in Lake Spectacle (Figure 3). Additional investigations were conducted along representative sections of the lake to assess general lake health and the influences of various riparian and sub-catchment typologies.

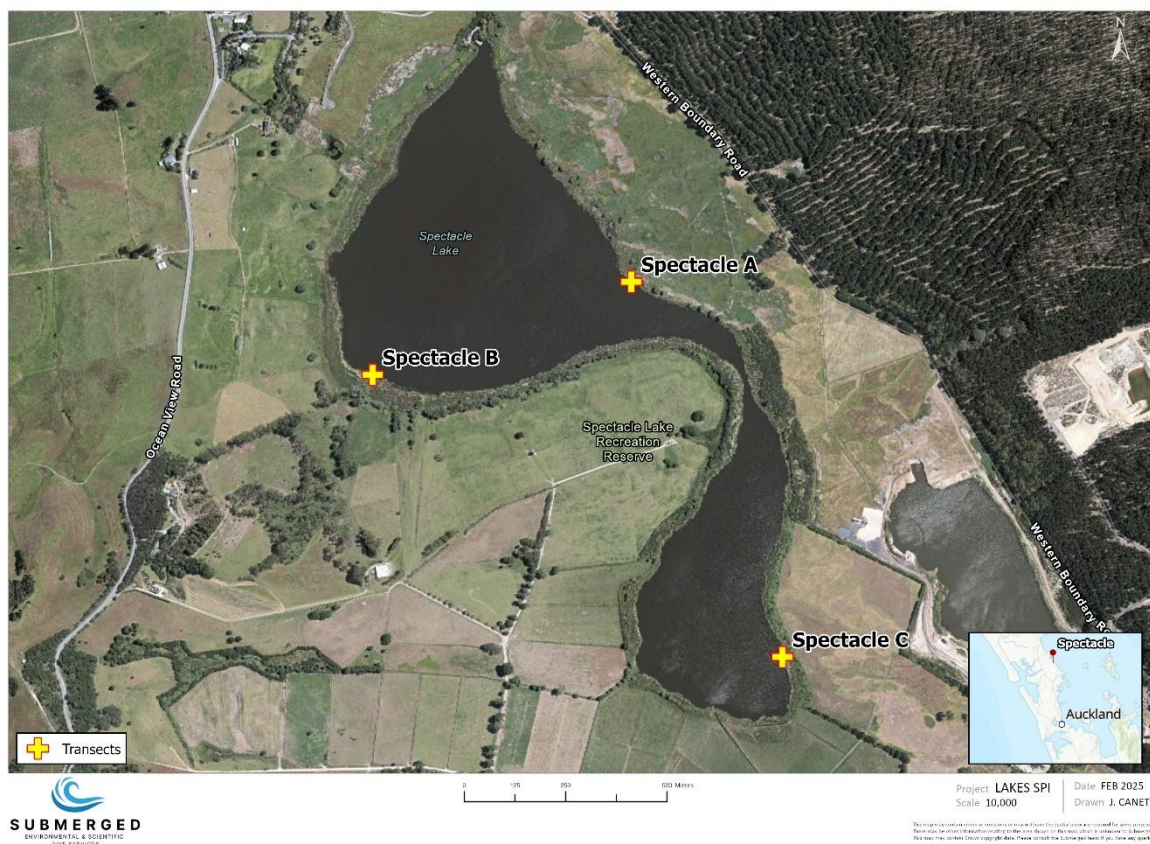
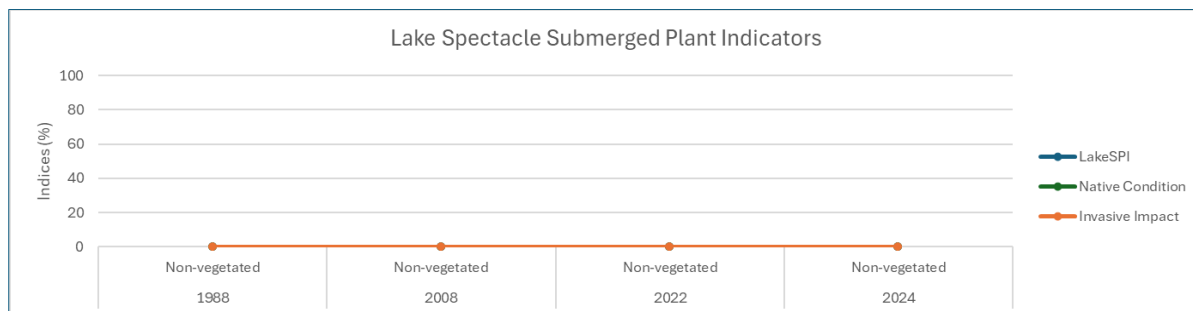


Figure 3: Lake Spectacle LakeSPI survey transects.

Lake Spectacle has been classified as non-vegetated since the first LakeSPI survey in 1988. No submerged vegetation was seen anywhere during the 2024 survey and the lake was assigned a default LakeSPI Indices of 0% (Figure 4).

The non-vegetated state places the lake in a D band for the Native Condition Index National Objectives Framework attribute. (Figure 4) The Invasive Impact attribute is not applicable to non-vegetated lakes. Lake Spectacle is completely devoid of submerged vegetation making any recovery above the national bottom line for the

Native Condition Index unlikely. The poor in-lake conditions mentioned above prevent natural macrophyte regeneration and limit the viability of the native seed banks.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Non-vegetated	0	0	0
April 2022	Non-vegetated	0	0	0
October 2008	Non-vegetated	0	0	0
August 1988	Non-vegetated	0	0	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	N/A

Figure 4: LakeSPI Indices for Lake Spectacle expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

Decades of intensive agriculture in the catchment have led to ongoing water quality issues, resulting in this lake being quoted as having some of the worst water quality in the Auckland region (Hamill et al., 2015 & Gibbs et al., 1999). The depauperate water quality conditions create a cycle of high nutrient concentrations that fuel seasonal algal blooms. These blooms senesce over winter and create large deposits of organic matter on the lakebed that decompose and fuel subsequent blooms.

This cycle significantly impacts macrophyte growth by limiting light penetration and altering the substrate characteristics, including the formation of localised anoxia at the sediment-water interface. The maximum photic depth during the survey was assessed as 0.5 m deep, almost no light passed this depth, and the lakebed was completely dark past 1 m. Video 7 shows a descent through the water column illuminated with a 5000-lumen light, this video shows the impact of both the tannins and suspended organic matter on light availability at depth.



Video 7: Representative descent from through the water column.

The poor substrate and extremely limited photic depth have created conditions that are unlikely to support the regeneration of native macrophytes. The shallower areas along the lake margin are occupied by dense emergent vegetation, that extend to a depth of 1.5 – 2 m deep, which excludes any macrophyte establishment in areas of the littoral margin with suitable conditions. The encroaching emergent vegetation is considered a secondary macrophyte limiting factor as it is part of natural lake succession.

Additional stresses that restrict macrophyte growth are the herbivorous rudd (*Scardinius erythrophthalmus*) that are known to have been present in this lake since 1979 (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). Any new growth from historic seed banks is likely to be grazed by these fish before the macrophytes reach maturity.

Threats

High impact catchment land use activities have resulted in excessive nutrient loads entering the lake. This eutrophication, in combination with invasive coarse fish, have caused a cascading collapse in ecosystem function that has kept the lake in a stable non-vegetated state.

Catchment derived nutrient loads are still a threat to the lake, but the in-lake organic deposition is likely contributing significantly to the overall trophic state. The high dissolved nutrient concentrations support a high suspended algal biomass that

eventually decomposes on the lakebed. This decomposition releases nutrients into the water but also creates anoxic conditions that alter the reduction oxidation (REDOX) potential at the sediment-water interface. This chemical alteration promotes the release of sediment bound nutrients and creates a process known as internal loading.

Lake ageing is one of the dominant drivers responsible for maintaining a non-vegetated state in Lake Spectacle. As shallow lowland lakes transition to wetland systems it is common for emergent vegetation to continually encroach into the lake and displace submerged macrophyte from the upper littoral zone. The increased organic matter input and natural tannins from the emergent vegetation reduces the photic depth to the maximum depth at which the emergent vegetation has colonised. This process simultaneously limits the upper and lower macrophyte extent and eventually leads to conditions where sustainable growth cannot be maintained. Without submerged macrophytes there is limited in-lake competition for dissolved nutrients and no lakebed stabilisation which results in a turbid, algal dominant eutrophic state.

The continual grazing pressure and bioturbation from invasive fish species exacerbate these issues by further reducing water clarity and prohibiting macrophyte regeneration from seed banks.

4.1.2 Lake Slipper

Lake Slipper

07/12/2024



Ecological Condition: Non-vegetated

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	0%	N/A

Summary

Lake Slipper has remained in a non-vegetated state since 2008. Poor substrate conditions, limited light penetration and encroaching emergent vegetation prevent macrophyte establishment. High nutrient inputs from intensive agriculture, in-lake organic matter decomposition and the connection to Lake Spectacle accelerates eutrophication. Invasive fish like rudd further disrupt macrophyte regeneration. These combined factors maintain a turbid, algal-dominated state with no recovery of submerged macrophytes.

Depth: 4.5 m

Size: 9 ha

Type: Dune

General Description



Photo plate 4: Southwest across Lake Slipper.

Lake Slipper is located in the Rodney District near the northern border of Auckland ($36^{\circ}10'19.9''\text{S}$ $174^{\circ}37'47.1''\text{E}$). This lake is the smallest of the Ngāroto lakes and is approximately 9 hectares. The lake is devoid of macrophytes and a Trophic Level Index (TLI) of 5.8 (Unpublished Auckland Council data, 2024) puts Lake Slipper in a supertrophic state.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area and Natural Lakes Management Area.

Similarly to the rest of the Te Arai/Ngāroto Lakes, Lake Slipper is a shallow polymictic coastal dune lake. Its depth varies across the lake, with an average depth of 2.5 m and a maximum depth of 4.5 m. Two defined in/outflows were observed on site. There is a channel that has been dug and periodically maintained between Slipper and Spectacle, a second channel exists on the northern tip of the lake and seems to drain toward the coast.

Catchment Characteristics

The 714.36-hectare catchment area surrounding Lake Slipper is predominantly pastoral (high producing exotic pasture) and production forestry operations with a 31-hectare block of native forest north of the lake. The high impact catchment land use contributes to the nutrient enrichment of the lake, primarily through diffuse surface water flows after rainfall events. The sandy soils, typical of the coastal dune systems, create relatively rapid surface runoff and nutrient transport into the lake. The surrounding landscape includes a few small, low-lying wetlands, which provide some level of nutrient attenuation, but their extent and efficacy are limited. These catchment characteristics contribute to the eutrophication of this system.

Riparian Characteristics

The riparian vegetation is predominantly raupō reedland and forms an almost contiguous band around the lake (~75%), however the width and quality of this vegetation is variable. The northeastern tip of the lake has the least intact riparian margins and largely consists of exotic grass, a fragmented 0.5 - 1 m wide strip of emergent reeds and an average vegetated riparian width of 0.5 - 4 m (Photo plate 5). The quality of this vegetation is moderate to poor and offers limited buffering capacity (Video 8).



Photo plate 5: Representative area of the Northeast bank indicating poorly vegetated riparian margins, fragmented reed beds and exotic grassland.



Video 8: Comparison of the northern and southern riparian condition along the northeast outlet channel.

The western and southwestern riparian margins are of better quality and are bordered by 20 m of native scrub. The southern bank is bordered by a 30 m wide wetland complex that transitions into native scrub and exotic pasture (Video 9). This area provides the highest buffering capacity that attenuates contaminants from the adjacent pasture. The southeastern banks have intact riparian margins that extend into wetland features with a maximum width of 30 m (Video 9). The average width of emergent reeds is 5 m. This vegetation provides some nutrient attenuation however, the adjacent slopes have noticeable farm drains and appear to be heavily grazed, so it is likely that this area contributes elevated levels of nutrient runoff to the lake.



Video 9: Southwestern view of the lake indicating the intact southern riparian margin.

Alligator weed (*Alternanthera philoxeroides*) has spread prolifically across the lake and forms an almost continuous 1 – 2 m wide band along ~75 % of the lake perimeter (Video 10). This encroachment shades out large sections of the littoral zone, further preventing macrophyte establishment.



Video 10: Continuous Alligator weed band along the outer edge of the emergent vegetation.

Biodiversity

Lake Slipper has moderate to high biodiversity value as it supports a variety of wetland birds including nationally and regionally threatened species such as the Australasian bittern (*Botaurus poiciloptilus*), which was sighted during the survey, Fairy tern (*Sternula nereis*), Fernbird (*Megalurus punctatus*) and Spotless crake (*Porzana tabuensis*). Several pied shags (*Phalacrocorax varius*) and brown teal (*Anas chlorotis*) were also observed during the assessment.

Native common bullies (*Gobiomorphus cotidianus*) and shortfin eels (*Anguilla australis*) are known prey species for the wetland birds that inhabit the lake, and it is assumed that they exist in reasonable numbers (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). No native fish were observed during the survey however, this is likely a result of the poor in-lake conditions.

The invasive coarse fish Rudd (*Scardinius erythrophthalmus*) has been detected in the lake and a dead rudd was seen along the northeastern outlet during the survey (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). These fish disrupt natural food webs and graze on macrophytes which has been

attributed to prolonged devegetated states in shallow lowland lakes such as Lakes Slipper and Spectacle. The lack of macrophytes creates a cascading collapse of ecosystem functions leading toward a turbid algal dominant system.

In-lake Description

Lake Slipper is connected to Lake Spectacle and has exhibited the same persistent degraded state. The current in-lake conditions are indicative of excessive eutrophication and a prolonged devegetated state.

The lake was isothermal during the survey and had a constant temperature of ~22°C. Similarly to Lake Spectacle the visibility was limited to 50 cm in the top metre of water and 10 – 20 cm below that. There was a high concentration of suspended organic matter throughout the water column and light penetration was largely limited to 0.5 – 0.8 m deep. The poor visibility is likely a result of wind-induced sediment remobilisation, tannins from the emergent vegetation, and high suspended algal volumes.

There is a lot of decomposing organic matter along the edge of the emergent vegetation and signs of localised anoxia were common. The substrate was firmer than Lake Spectacle and had less large organic debris. The general substrate profile had a 15 cm layer of soft mud, silt and organic floc on top of a firm mud base. The softer surficial layer was thicker toward the centre of the lake where a consolidated base could not be found.

The high concentration of suspended matter, poor water clarity and inappropriate substrate conditions have prevented submerged vegetation from establishing.

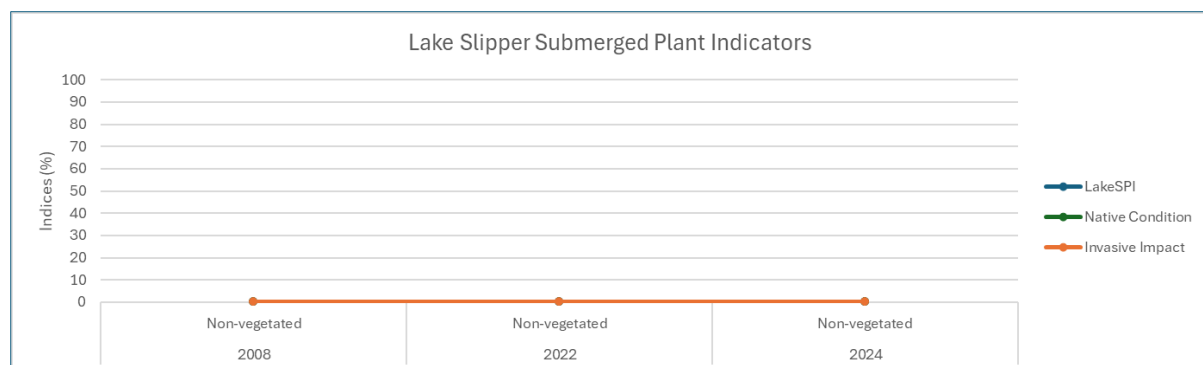
Submerged vegetation

LakeSPI assessments were done along three survey transects in Lake Slipper (Figure 5). Additional areas were dived to confirm substrate characteristics, emergent vegetated depth extent and general lake health.

Lake Slipper has been classified as non-vegetated during all recorded surveys. No submerged vegetation was seen during the 2024 assessment and the lake was assigned a default LakeSPI Indices of 0% (Figure 6).



Figure 5: Lake Slipper LakeSPI survey transects.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Non-vegetated	0	0	0
April 2022	Non-vegetated	0	0	0
October 2008	Non-vegetated	0	0	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	N/A

Figure 6: LakeSPI Indices for Lake Slipper expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The non-vegetated state places Lake Slipper in a D band for the Native Condition Index National Objectives Framework attribute (Figure 6). The Invasive Impact attribute is not applicable to non-vegetated lakes. The lake is completely devoid of submerged vegetation, making any recovery above the national bottom line for the Native Condition Index unlikely. The poor in-lake conditions prevent natural macrophyte regeneration and limit the viability of the native seed banks.

Intensive agricultural activities in the catchment and the linkage to Lake Spectacle have led to ongoing water quality issues including seasonal algal blooms.

High dissolved nutrient concentrations drive seasonal algal blooms that die off in winter and create widespread deposits of organic matter on the lakebed. This cycle adversely affects macrophyte growth by reducing light penetration, altering substrate characteristics and causing localised anoxia at the sediment-water interface.

The maximum photic depth during the survey was assessed as 0.8 m deep and no light was seen passed the 1 m depth mark. Video 11 shows a representative transect perpendicular to shore running toward the centre of the lake. The video was taken using a 5000-lumen light which illustrates the impact of both the tannins and suspended organic matter on light availability at depth.

Most of the shallow lake margin is densely populated with emergent vegetation and a band of floating alligator weed, this encroaching vegetation displaces macrophytes from the upper littoral zone (0.5 – 2 m deep). The unfavourable substrate and limited photic depth prevent macrophyte regeneration and establishment in the deeper parts of the littoral zone. As a result, there is no suitable habitat for any significant macrophyte establishment left in the lake.



Video 11: Representative transect perpendicular to shore running toward the centre of the lake.

Threats

Intensive catchment land use has led to excessive nutrient inputs into the lake, causing eutrophication. Together with invasive coarse fish, this has triggered a loss of ecosystem function and resilience which has kept the lake in its current degraded state.

Nutrient loads from the catchment, including direct drainage from Lake Spectacle, and the decomposition of in-lake organic matter contributes to the lake's high trophic state. High bioavailable nutrient concentrations promote a large algal biomass that subsequently decomposes on the lakebed. This decomposition releases nutrients back into the water while creating anoxic conditions at the sediment-water interface. This REDOX shift encourages the release of nutrients bound in the sediment, driving internal loading processes.

Lake ageing is also a dominant driver behind the persistent non-vegetated state. As shallow lowland lakes transition to wetland systems it is common for emergent and floating vegetation to continually encroach into lake and displace submerged macrophyte from the upper littoral zone. The increased organic matter input and natural tannins from the emergent vegetation reduces the photic depth to the areas already occupied by emergent species. This process limits both the upper and lower macrophyte extent and eventually leads to conditions where sustainable growth cannot be maintained. Without submerged macrophytes there is limited in-lake

competition for dissolved nutrients and no lakebed stabilisation which results in a turbid, algal dominant eutrophic state.

Continued grazing and bioturbation from invasive fish species further degrade water clarity and prevent the regeneration of macrophytes from seed banks.

4.1.3 Lake Tomorata

Lake Tomorata

29/11/2024



Ecological Condition: Non-vegetated

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	0%	N/A

Summary

Lake Tomorata is classified as non-vegetated with macrophyte covers less than 10%. Native species are confined to shallow margins due to poor substrate, encroaching emergent vegetation and low light penetration. Invasive fish further disrupt macrophyte regeneration. Despite some natural recovery, invasive species, nutrient enrichment, sedimentation and recreational activities hinder large-scale restoration, leaving the ecosystem vulnerable to ongoing degradation.

Depth: 5.6 m
Size: 16 ha
Type: Dune/peat

General Description



Photo plate 6: Northern bank with a view toward the western sub-catchment.

Lake Tomorata, located in the Rodney District north of Auckland (36° 11' 32" S 174° 38' 55" E), is the only monitored dystrophic water body in the region. The lake is part of the Te Arai/Ngāroto lakes complex that includes Lake Spectacle and Lake Slipper. Tomorata is the second largest lake in the Ngāroto lakes complex with an approximate area of 16 hectares.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area, High Natural Character Area, Outstanding Natural Landscape and an Outstanding Natural Feature. The lake is also regularly utilised for passive and active recreation including wake boarding and kayaking.

Lake Tomorata is classified as a shallow coastal dune/peat lake attached to a large lacustrine wetland complex. This shallow lake is classified as polymictic due to the frequent mixing driven by the prevailing easterly winds. Its depth varies across the lake, with an average depth of 2.5 m and a maximum depth of 5.6 m. The shallow depth, combined with frequent mixing, contribute to the current high trophic level index (4.8 - eutrophic) (Groom, 2021).

There are no natural in or out flow channels associated with the lake however, the large wetland complex along the southern lake edge is feed by the lake through sub-surface channels under the floating vegetation. A series of farm drains leading directly into the wetland and riparian margin were also identified.

Catchment Characteristics

The 103.34-hectare catchment surrounding Lake Tomorata differs from the other Te Arai lakes and is primarily utilised for production forestry however, the 83-hectare sub-catchment is predominantly high producing exotic grassland (Photo plate 7). As a result, the lake is subject to pressures from land use activities, including nutrient runoff, sedimentation, and altered hydrological patterns. The underlying geology of the sub-catchment consists of sandy soils typical of coastal dune systems, with anthropogenic variations in permeability leading to relatively high surface runoff into the lake during rainfall events. This catchment typology is a primary contributor to the elevated trophic state of the lake, as nutrient rich runoff from agricultural and forestry can accelerate eutrophication.



Photo plate 7: Southern view across Lake Tomorata indicating the dominant land cover (pasture along the east and a mix of native scrub and exotic forestry along the west).

Riparian Characteristics

The riparian vegetation is sparse along most of the northern margin and the area around the public access/boat ramp is primarily a sandy beach (Photo plate 8). The eastern bank is fringed with a narrow 2 - 5 m non-contiguous band of emergent reeds that backs onto manuka/kanuka scrub and exotic forestry (Photo plate 8). A large lacustrine wetland creates an extensive buffer along the western and southern banks (Photo plate 9). The width of this wetland buffer varies from 67 m at its narrowest point, near the boat ramp, to 578 m at the widest point midway along the western bank. The wetland along the southern bank is connected to a wider wetland feature that includes a smaller lake, the width of this entire complex is 257 m at its widest point. The remaining sections of the western and southern banks have an average width of 115 m.



Photo plate 8: Northern & eastern banks indicating the transition from bare beach to vegetated riparian margins.



Photo plate 9: Western bank indicating a wide band of emergent reeds transitioning into native scrub with an Australasian bittern in the foreground.

The wider lake/wetland complex is classified as Biodiversity Focus Area (BFA) by the Auckland Council as it contains the only two known sites of mānuka, greater wire rush, restiad reedland (WL2) and some of the best remaining examples of herbfield (lakeshore turf) (WL15) in the region (Singer et al., 2017).

Biodiversity

Lake Tomorata has high biodiversity value and supports a variety of aquatic species. The lake is frequently used by wetland birds including nationally and regionally threatened species such as the Australasian bittern (*Botaurus poiciloptilus*) (Photo plate 9), Fairy tern (*Sternula nereis*), Fernbird (*Megalurus punctatus*) and Spotless crake (*Porzana tabuensis*). Tomorata is also one of the few locations in the region where regionally threatened kākahi (*Echydella menziesi*) and Black mudfish (*Neochanna diversus*) are still found. Native common bullies (*Gobiomorphus cotidianus*), longfin eels (*Anguilla dieffenbachii*) and shortfin eels (*Anguilla australis*) are also abundant in the lake (Video 12) (New Zealand Freshwater Fish Database).



Video 12: Common bullies in the shallow littoral margin.

The invasive coarse fish Rudd (*Scardinius erythrophthalmus*) and Tench (*Tinca tinca*) were present in high numbers prior to the sustained control programme implemented by the council. Koi carp (*Cyprinus carpio*) (Photo plate 10) have also been confirmed in low numbers in the lake (a large adult was sighted during the survey). These invasive fish species disrupt natural food webs, cause excessive bioturbation and exert predatory pressure on native macroinvertebrates and macrophytes. As a result, these exotic fish have impacted the biodiversity and water quality of the lake which contributed significantly to a decline in overall lake health.



Photo plate 10: Koi carp at 1.8 m deep along the eastern lake edge.

In-lake Description

Lake Tomorata has undergone several state changes since the first assessment in 1988. The lake has periodically swapped between vegetated and non-vegetated states. The current non-vegetated eutrophic state is reflective of the intensive agricultural activities within the wider catchment.

Water clarity/visibility during the survey ranged from 1.5 – 2 m, the natural tannins and increased suspended matter along the wetland fringe created localised areas with less than 1 m visibility. Wind-induced sediment remobilisation was limited, and the suspended algal volumes were qualitatively assessed as low compared to previous survey conditions.

The lake was largely isothermal during the survey with an average temperature of 22 °C. A localised thermocline was noted along the southeastern portion of the lake where the surface temperature was 22 – 23 °C and 20 °C past 3 m deep. The exact cause of this localised stratification is unknown and might be a result of the prevailing winds and steeper bathymetry.

The substrate in the deeper sections of the lake (> 2.4 m) was soft and silty with a thick (> 45 cm) layer of organic silt (Video 13). In some places consolidated sediments were found more than a metre below the loose surface sediments. A thick layer of clay and peat was found below the loose surface sediment in several locations along the lakebed, which suggests that the lake may be perched or capped in the deeper bowl.



Video 13: Substrate along the deep central bowl.

The shallow (0 – 2 m) areas along the northern and eastern portions of the lake largely consisted of a consolidated sandy base with a thin layer of organic floc, fine silt and detritus. The northern littoral margin has limited accumulation of organic debris, which can be explained by the lack of riparian vegetation and extent of recreational activities that can cause anthropogenic dispersal of accumulated organic matter. The eastern lake margin is steeply sloped and had large deposits of riparian derived detritus/organic debris at the base of the sloping lakebed between 3 – 4 m deep (Video 14).



Video 14: Representative transect through the eastern littoral margin.

The substrate along the western and southern margins were loose and unconsolidated. A thick (> 0.5 m) surficial layer of fine silt and organic floc sits above the deeper more consolidated sediment. Organic debris was found buried at various depths through the sediment strata. Large deposits of decomposing organic matter were seen along the edge of the lacustrine wetland to a depth of 2.4 m (Video 15). The accumulation of detritus was highest along the southern boundary of the lake and parts of the southwestern margin. The lakebed adjacent to the wetland in these areas is flat, which contributes to the accumulation of organic debris. Limited to no organic debris was seen beyond the 3 m depth contour.

There was limited benthic algal growth however, thick clumps of epiphyton were regularly seen at the base of the emergent vegetation.



Video 15: Organic debris deposition in the shallow littoral margin.

Submerged vegetation

LakeSPI assessments were done along five survey transects in Lake Tomorata (Figure 7). Additional investigations were conducted along representative sections of the lake to assess macrophyte recovery post coarse fish control as well as general lake health and the influences of various riparian and sub-catchment typologies.

Lake Tomorata has been classified as non-vegetated since April 2022. During the November 2024 survey the lake-wide submerged vegetation cover was less than 10% and the lake was assigned a default LakeSPI Indices of 0% (Figure 8).



Figure 7: Lake Tomorata LakeSPI survey transects.

Despite the assigned non-vegetated state, the following native macrophyte species were found in the wider lake during the survey; *Nitella pseudoflabellata*, *Nitella leonhardii*, *Nitella* sp. aff. *Cristata* and *Chara australis*. These species were absent from the survey transects and covers exceeding 10% were noted in discrete areas outside of the LakeSPI survey areas. *Utricularia gibba* was the only exotic macrophyte species observed with single stems widely distributed amongst the emergent riparian vegetation (Photo plate 11).



Photo plate 11: *Utricularia gibba* amongst the organic debris in the shallow littoral zone.

Where macrophytes were found, the maximum depth extent was 2.6 m with majority of the growth occupying the shallow margin between 0.8 – 1.9 m.

The eastern lake margin has a flat sandy plateau that leads to a steep slope extending to 4 m deep. Both the eastern transects (E & B) were devoid of macrophytes however the wider area between these transects had sparse macrophyte growth in the form of single stems and small clumps. Three larger clumps/beds of *Nitella* sp. aff. *Cristata* were seen along the southeastern end of the lake (near transect E) and ranged in size from 2 - 9 m² with covers exceeding 10% in two of the beds larger than 4 m² (Video 16).



Video 16: Large *Nitella* bed growing amongst the detritus in southeastern end of the lake.

The upper extent of the macrophytes found along the eastern part of the lake seem to be governed by the encroaching emergent vegetation and turbulence. The macrophyte growth preferentially occupied the shallows between 0.5 – 1.2 m in areas with limited emergent vegetation and 1.5 – 1.7 m in areas with denser emergent growth. The substrate along the deposition zone at the base of the sloping lakebed is unsuitable for macrophyte growth and receives limited light penetration. As a result, no macrophyte growth was seen past 2 m deep.

The southern lake margin (between transects C & E) had the lowest macrophyte cover observed during the survey. This is likely a result of the emergent vegetation forming floating rafts that shade the shallow lake margin from 0.5 – 2.1 m (Video 17). The large deposits of organic debris in this zone also limit the establishment of macrophytes (Video 17). A few small clumps of *Nitella sp. aff. Cristata* with 3 – 5 short stems each were the only macrophytes seen in this zone, the plant condition was poor, and majority of the growth was blackened and brittle.



Video 17: Emergent vegetation encroaching into the upper littoral zone.

The western lake margin (transect A - C) had the highest macrophyte cover and widest distribution, transects D and C where the only survey transects that had macrophyte growth along the survey line. The average cover across both these transects was 5%. However, vegetated areas larger than 4 m² and covers exceeding 10% were observed in the area between transect D and C (Video 18).



Video 18: Mature *Nitella* bed along the western littoral margin.

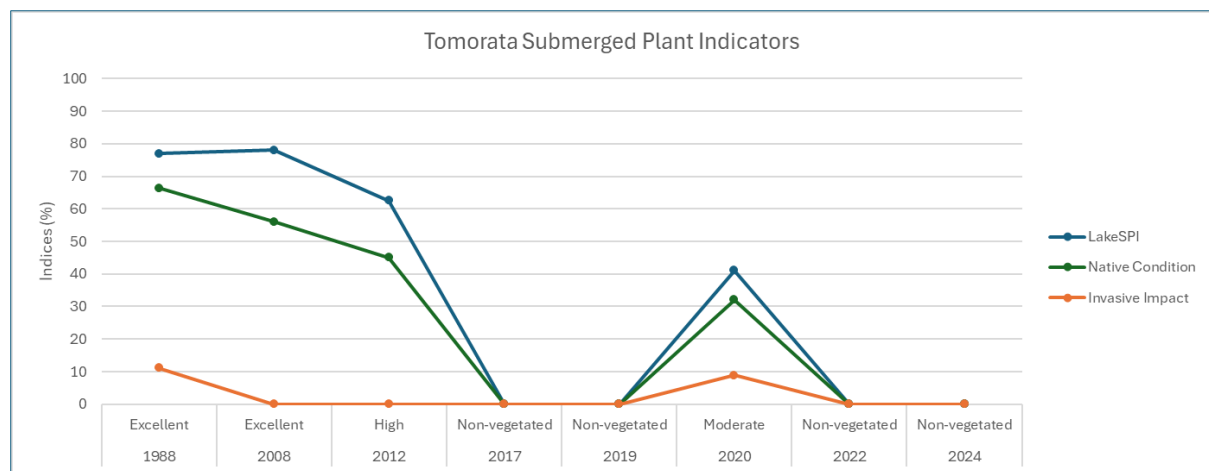
The upper macrophyte extent along the western lake margin was limited by the encroaching emergent riparian vegetation, the lower extent was regulated by photic depth. The combination of these limiting factors has resulted in a narrow zone, adjacent to the outer edge of the emergent vegetation, that is suitable for macrophyte growth.

The general growth across the lake consisted of sparsely distributed single stems, small clumps and germlings (Video 19). As a result, the overall lake-wide macrophyte cover remains less than 10%, which under the LakeSPI assessment criteria places Lake Tomorata in the non-vegetated category. The general macrophyte condition was moderate to poor with epiphytic growth seen on most macrophytes. There were no signs of grazing damage from herbivorous coarse fish which is an indication that the intensive pest fish removal activities are having a positive impact.



Video 19: Single stems and small clumps of *Nitella* in the shallow littoral zone.

The non-vegetated state places the lake in a D band for the Native Condition Index National Objectives Framework attribute (Figure 8). The Invasive Impact attribute is not applicable to non-vegetated lakes. Tomorata is below the national bottom line for the Native Condition Index, natural macrophyte regeneration could bolster this score if water quality is improved and the invasive fish population is maintained at a low level. The viability of the native seed bank is a limiting factor that needs to be considered in tandem with the catchment and in-lake interventions. Maintaining strong biosecurity measures will ensure that the lake remains free of invasive species.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
November 2024	Non-vegetated	0	0	0
April 2022	Non-vegetated	0	0	0
November 2020	Moderate	41	32	8.9
June 2019	Non-vegetated	0	0	0
May 2017	Non-vegetated	0	0	0
April 2012	High	62.5	45	0
October 2008	Excellent	78	56	0
August 1988	Excellent	76.9	66.3	11.1

	Native Condition Index	Invasive Impact Index
NOF Attribute Band	D	N/A

Figure 8: LakeSPI Indices for Lake Tomorata expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The results from this survey show that natural regeneration is actively occurring in discrete locations outside of the survey transects. Additionally, the distribution of macrophytes across the shallow littoral zone has increased compared to previous assessments. The limited photic depth and substrate condition are still a concern however, the ongoing coarse fish control and improved land management practices would likely facilitate greater macrophyte regeneration.

Threats

Lake Tomorata is facing significant ecological challenges, primarily due to nutrient enrichment, invasive species, and anthropogenic pressures from the surrounding catchment as well as recreational boating. Decades of intensive agriculture and

production forestry in the catchment have led to ongoing water quality issues, resulting in degrading water quality trends.

The poor substrate condition and high concentrations of tannins have created conditions that are unlikely to support the regeneration of native macrophytes at a scale where ecological enhancements will be apparent. The shallower areas along most of the lake are occupied lacustrine wetlands and dense emergent vegetation which excludes macrophyte establishment in the more suitable upper littoral zone. This encroaching emergent vegetation pushes the macrophytes into deeper water below the appropriate photic depth. As a result, macrophyte growth is confined to a very narrow portion of the upper littoral zone. This narrow extent offers little resilience against edge effects and increases the vulnerability of the macrophytes to climate change.

The herbivorous rudd (*Scardinius erythrophthalmus*) and benthivorous tench (*Tinca tinca*) have also contributed to the non-vegetated state through excessive grazing and substrate disturbance. Any new macrophyte growth from historic seed banks are grazed or uprooted by these fish before they reach maturity. The Auckland Council is actively managing these invasive fish through a long-term sustained control plan funded by the Natural Environment Targeted Rate (Studholme, B. pers. comms, 2024) however, water quality and substrate condition will remain a limiting factor despite the reduction in invasive species pressures.

The unregulated use of powered watercrafts (wake boarding boats & jet-skis) on the lake is having ongoing impacts. The shallow lake is prone to sediment remobilisation from watercraft wakes which reduces water clarity, buries macrophyte germlings, uproots established macrophytes. The benthic disturbance also causes the resuspension of sediment bound nutrients which contributes to eutrophication. Additionally, these powered vessels create wakes that impact the edge of the wetland where it capsizes bird nests and dislodges large rafts of emergent vegetation.

4.2 South Kaipara Lakes

The South Kaipara Lakes are a cluster of large deep dune lakes along the northwest coast of the Kaipara peninsula. As part of this assessment the following South Kaipara Lakes were surveyed: Rototoa, Kuwakatai and Te Kanae.

4.2.1 Lake Rototoa

Lake Rototoa

19/12/2024



Ecological Condition: High

Indices	Score	NPS-FM Attribute band
Native Condition Index	48.7%	C
Invasive Impact Index	8.9%	B

Summary

Lake Rototoa is in high ecological condition with a diverse native macrophyte community. Hornwort control efforts have been effective in managing this invasive species. Native macrophyte cover and extent has declined with increased fragmentation and bare lakebed areas indicating persistent stress. Key threats include an extension of the anoxic hypolimnion and the large population of coarse fish. Additional risks include introductions of new invasive species, nutrient enrichment from catchment runoff, and internal loading.

Depth: 27.5 m

Size: 107 ha

Type: Dune

General Description



Photo plate 12: North facing view across lake Rototoa indicating the sub-catchment land cover (pasture along the east and native bush along the west).

Rototoa is situated on the northern tip of the Kaipara South Head Peninsula (36°30'48.5"S 174°14'10.6"E). It is the largest freshwater lake in the Auckland region, covering approximately 106.6 hectares. The lake is known for its clear waters and is a popular location for recreational water activities. Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area, High Natural Character Area, Outstanding Natural Landscape and an Outstanding Natural Feature.

Rototoa is the only true mesotrophic lake in the Auckland Council monitoring network. It has a Trophic Level Index of 3.3, indicating moderate nutrient levels and relatively good water quality (Unpublished Auckland Council data, 2024). Rototoa is a deep, monomictic lake, with an average depth of 13 m and a maximum depth of 27.5 m. It is isothermal and mixes fully during winter and stratifies into two to three thermally distinct layers in summer.

There is a small inflow along the northern tip of the lake that drains a steep block of native bush. However, the lake is primarily fed by rainfall and groundwater, with no surface outflows. The lake is surrounded by steep slopes which contribute significant volumes of diffuse overland flow into the lake.

Catchment Characteristics

The catchment surrounding Rototoa covers approximately 407.52 hectares, and the wider area is dominated by pine forestry and high producing exotic pasture. The western and northern lake margin is surrounded by a contiguous steep sloped block of manuka/kanuka scrub and indigenous broadleaved hardwoods. The southern and eastern banks have a gentler gradient and are predominantly utilised as pastoral land with native scrub bordering the lake edge.

The band of native bush and patchwork of small wetlands around the lake acts as a buffer that attenuates contaminant laden runoff from the wider catchment. The attenuation capacity of this buffer is limited due to the steep nature of the underlying slopes and excessive grazing of the understory by feral deer.

The terrestrial vegetation assemblage has been impacted by Cyclone Gabrielle (February 2023). Several land slips and large sections of buried vegetation were noted. The taller canopy of manuka/kanuka has fallen and in some areas made way for a canopy dominated by nikau palms, this is particularly evident in the northern arm and along parts of the western bank (Video 20).

The sandy coastal dune soils are highly permeable which limits the amount of surface runoff and, increases the lake's susceptibility to groundwater related nutrient inputs from activities such as forestry and agriculture in the wider catchment.



Video 20: Western bank with cyclone induced land slip & altered vegetation assemblage.

Riparian Characteristics

The riparian zone around Lake Rototoa is well-preserved, with a wide band of native vegetation surrounding much of the lake.

The terrestrial vegetation within the riparian margin, including species like raupō, mānuka, flax and sedges (Video 21), provides buffering against nutrient and sediment inputs from the surrounding catchment however, significant impacts were noted during the 2024 survey. The understory throughout most of the native bush is poor and has been heavily impacted by feral deer browsing (Video 21). The depauperate understory and cyclone induced erosion allows organic rich soil and detritus to flow into the lake during rainfall events. This is exacerbated by the steep nature of the surrounding sub-catchment.



Video 21: Sub-catchment & riparian margin with sparse understory.

The emergent vegetation largely consists of *Eleocharis sphacelate*, *Machaerina articulata* and *Machaerina arthropphylla* with an average width of 10 - 15 m. This reed line borders approximately 70% of the lake and forms wetland features in some areas, particularly along the northern and eastern shores. This riparian buffer contributes significantly to the lake's water quality, helping to filter contaminants and stabilise the shoreline, reducing erosion. Cyclone Gabrielle (February 2023) has caused localised breaches in this contiguous reed line and has buried large section that are open to colonisation by exotic terrestrial species (Video 22).



Video 22: Cyclone induced slip & bank erosion along the eastern shore.

Biodiversity

Rototoa has high biodiversity value and supports a range of common and threatened native species. The riparian areas and native scrub around the lake provide important roosting habitat for New Zealand dabchick (*Poliocephalus rufopectus*), fernbird (*Megalurus punctatus*), grey duck (*Anas superciliosa*) several shag species and a wide variety of common terrestrial species.

Common bullies (*Gobiomorphus cotidianus*) are abundant throughout the lake as well as the threatened (conservation status pending) dwarf inanga (*Galaxias gracilis*). Dwarf inanga were initially released into Rototoa as a prey species for trout and is now the only known location of this fish outside of the Dargaville lakes in Northland. Banded kōkopu (*Galaxias fasciatus*) have also been found in the inflowing stream that enters the northern arm of the lake (New Zealand Freshwater Fish Database), however no in-lake sightings have been reported.

Rototoa is one of two known lake bound population of kākahi (*Echyridella menziesii*) in the region that still has live mussels across multiple areas. During the 2024 survey several historic kākahi beds were found and estimated to have a density of 40 – 50 per m² (Video 23). Where live kākahi were found the average densities were only 1 – 5 mussels per m² or less.



Video 23: Historic freshwater mussel (kākahi) bed with dead adult size shells.

There has been documented declines in the population and recent mass mortalities related to Cyclone Gabrielle (February 2023) however, active conservation initiatives are currently being undertaken by the Auckland Council (Jones, M., Studholme, B.

pers. comms, 2024). All kākahi (dead & alive) found during the survey were mature adults with majority being in the 51 – 60 mm size class and the remainder in >61 mm size classes. There appears to have been a mass kākahi mortality event within the past couple of decades as most of the dead shells are intact and of the same size class. The assumption is that these mussels are largely from the same cohort and that several failed spawning events lead to limited recruitment resulting in the adult population eventually dying of old age.

The emergent riparian vegetation and extensive charophyte beds also provide good habitat for other common aquatic invertebrates that are fundamental to the in-lake food web.

Coarse fish, such as perch (*Perca fluviatilis*) and tench (*Tinca tinca*) as well as mosquitofish (*Gambusia affinis*) have established large populations within the lake. Several schools of juvenile perch were sighted during the 2024 assessment which indicates active recruitment is occurring (Video 24), and benthic feeding pits were common on the lakebed indicating a high degree of benthivorous feeding from tench. Rudd (*Scardinius erythrophthalmus*), goldfish (*Carassius auratus*) and koi carp (*Cyprinus carpio*) are also present but in lower numbers than the perch and tench. These exotic fish displace native species and exert excessive grazing pressure on the submerged macrophytes which results in ecosystem health degradation and reduced environmental resilience (de Winton et al. 2002 & Dugdale et al. 2006).



Video 24: School of juvenile perch.

In-lake Description

The lake was stratified during the survey with a distinct thermocline at 6.5 m deep. The visibility was 5 m and reduced to 3 m below the thermocline. There was limited suspended organic matter and light penetration within the epilimnion was good.

The substrate in the shallows (0 – 3 m) was firm and sandy with minimal fine silt, particularly on the steeper sloped areas. The substrate along the outer edge of the emergent reeds (0.1 – 2.5 m with some areas 2.8 – 3 m) was firm and sandy with a layer of decomposing organic matter. The substrate along the upper macrophyte extent (3 – 5 m) was still sandy but had a 5 - 15 cm surficial layer of soft silt. The lakebed past 5 m deep was generally soft with a 45 cm to 1 m thick layer of loose, fine silt.

Areas along the eastern bank tended to have a high concentration of fine clay like silt whereas the western bank had a sandy base with a cap of organic rich sediment. This is likely a result of the differing underlying geology and surrounding land cover.

Limited benthic algal growth was seen during the 2024 survey. The upper littoral margin had epiphyton covering sections of shallow macrophytes, in particular pondweed and hornwort. Benthic mats were observed in parts of the shallow littoral margin, but the bulk of the growth was seen below 5 m deep (Video 25).



Video 25: Benthic algal mats & coarse fish feeding pits along the lakebed.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Rototoa (Figure 9). Additional investigations were conducted along representative sections of the lake to assess the impacts of Cyclone Gabrielle (February 2023), freshwater mussel populations as well as general lake health and the influences of various riparian and sub-catchment typologies.

Lake Rototoa supports a healthy diverse population of submerged macrophytes, particularly in the shallower areas of the lake and, as a result it has maintained a high ecological condition since 1988 (Figure 10).

Nine native macrophyte species were recorded during the survey, three charophytes (*Chara australis*, *Chara fibrosa* & *Chara globularis*), three *Nitella* species (*Nitella leonhardii*, *Nitella pseudoflabellata* & *Nitella hyalina*), two pondweeds (*Potamogeton ochreatus* & *Potamogeton cheesemani*) and one turf species (*Glossostigma elatinoides*). Three invasive species were noted (*Ludwigia palustris*, *Utricularia gibba* & *Ceratophyllum demersum*). The highest species diversity was observed in the upper littoral zone from 0.5 – 3 m, below 5 m *Chara australis* formed a monoculture with small, isolated stands of *Potamogeton ochreatus*.

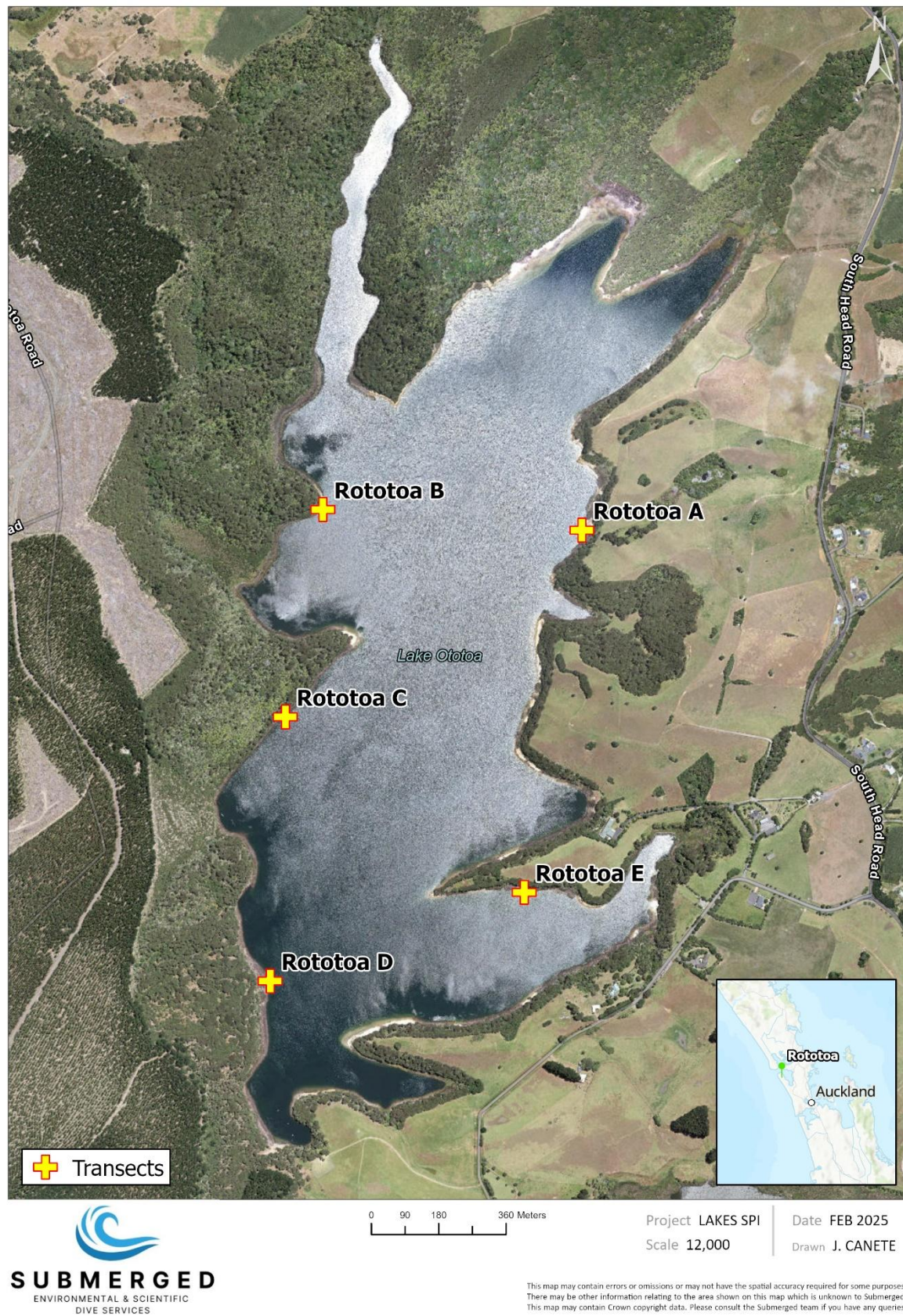


Figure 9: Lake Rototoa LakeSPI survey transects.

The general vegetation assemblage pattern consists of emergent reeds from 0.2 – 2.5 m deep with *Chara australis*, *Chara fibrosa*, *Chara globularis*, *Nitella hyaline*, *Nitella pseudoflabellata* and *Nitella leonhardii* growing amongst the emergent reeds (Video 26). *Utricularia gibba* was common amongst the emergent reeds (Video 26).



Video 26: Native macrophytes growing amongst the emergent reeds.

Low to moderate covers of *Chara australis*, *Chara fibrosa* and *Chara globularis* with short stems of *Potamogeton ochreatus* forming a sparse canopy extended from the edge of the emergent reeds (0.5 m) to 3 m deep (Video 27).



Video 27: Representative shallow macrophyte assemblage.

A ~50 m wide band of bare lakebed, occasionally with sparse charophyte cover, was commonly seen separating the shallow charophytes from the pondweeds

(*Potamogeton ochreatus* & *Potamogeton cheesemanii*) that formed a distinct band from 3 – 5 m deep (Video 28).



Video 28: Transition from bare lakebed with sparse charophyte cover to the pondweed belt at 3 m deep.

Chara australis dominated the deeper macrophyte extent from 5 – 8 m with some beds extending to 9 m. The shallower sections of the charophyte meadows (5 – 6 m) often had tall stems of pondweed (*Potamogeton ochreatus* & *Potamogeton cheesemanii*) with gradually decreasing cover toward the maximum vegetated depth (Video 29).



Video 29: Dense charophyte meadow with tall stems of pondweed.

Chara australis was the only macrophyte that formed significant covers along the maximum vegetated depth extent (7 – 9 m) (Video 30). The charophyte meadows seen

between 5 – 6 m began to thin out and fragment into small to medium sized beds along the outer edge of the maximum vegetation extent (7 – 9 m) (Video 30). Below 9 m the lakebed was completely bare and devoid of macrophyte growth.



Video 30: Lower macrophyte depth extent with fragmented charophyte meadows.

Macrophyte condition was good overall. There were sections of the upper littoral zone (0.5 – 3 m) where the macrophytes were coated with epiphyton and the deeper sections (> 6 m) had larger clumps of charophytes covered with benthic algal mats. The mid depth macrophyte growth had a light dusting of organic floc/epiphyton but no algal mats. The pondweed in several of the shallow bays were bleached which is a likely result of light intensity and temperature (Video 31).

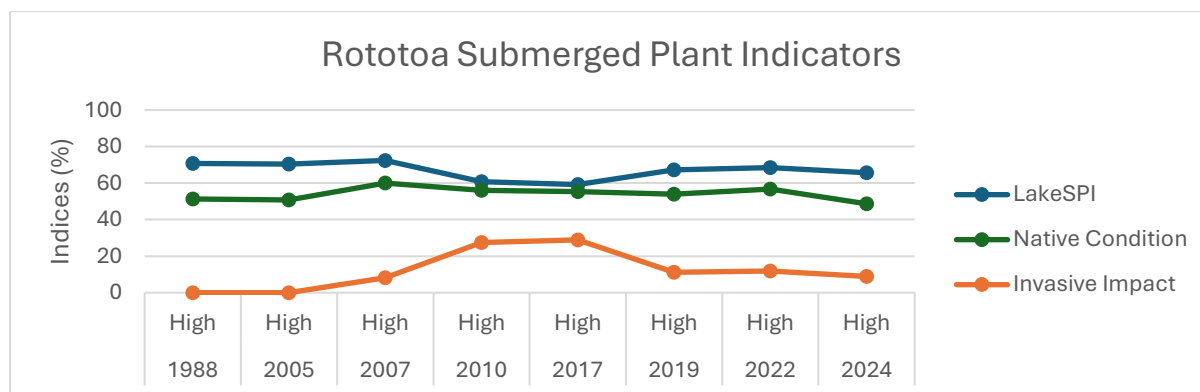


Video 31: Shallow pondweed with epiphyton & bleaching.

The LakeSPI score was similar between the 2022 and 2024 assessments, with a nominal 4.09% decrease which is indicative of a stable state (Figure 10). A 14.16% decrease was calculated for the Native Condition Index, which is indicative that a change in this metric is probable. A decrease in the overall maximum vegetated depth extent from 10.9 m in 2022 to 9.2 m in 2024 and the sparse vegetation cover seen along transects C and D are the key drivers behind this decline. The largest change was a 25.29% decrease in the Invasive Impact Index which is a direct result of the active hornwort control carried out by the Auckland Council under the Natural Environment Targeted Rate. Hornwort was not found along any of the survey transects. *Utricularia gibba* and *Ludwigia palustris* were the only invasive macrophyte species detected in the survey areas and are the sole contributors to the current Invasive Impact Index score.

The native species diversity and moderate cover has resulted in a C band for the Native Condition Index National Objectives Framework attribute, the score is marginally below a B band and natural fluctuations could result in a higher future banding (Figure 10). The Invasive Impact Index attribute is in a B band due to the persistent presence of *Utricularia gibba* and *Ludwigia palustris* (Figure 10). The active hornwort control is contributing to maintaining this B band by containing hornwort to discrete areas outside of the survey transects. A continued reduction in the hornwort biomass will prevent the spread to other parts of the lake where it could be factored into the LakeSPI assessments and as a result, drop the Invasive Impact Index attribute band.

Native macrophytes form moderate to high covers along the upper littoral zone (0.5 – 7 m), contributing to the lake's clear water and supporting aquatic life. These submerged plants play an important role in nutrient cycling, oxygen production, and providing habitat for fish and invertebrates however, signs of degradation were apparent. Large sections of reduced vegetation cover (< 10%) and bare lakebed were commonly observed as well as fragmentation of charophyte meadows. A significant loss in the maximum vegetated depth extent and loss of species diversity toward the deeper portion of the littoral zone are also indicators of persistent stress.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	High	65.6	48.67	8.89
March 2022	High	68.4	56.7	11.9
June 2019	High	67.2	54	11.1
May 2017	High	59.2	55.3	28.9
February 2010	High	60.8	56	27.4
November 2007	High	72.4	60	8.1
October 2005	High	70.4	50.7	0
February 1988	High	70.8	51.3	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	C	B

Figure 10: LakeSPI Indices for Lake Rototoa expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The in-lake stressors have confined most of the vegetation to a band along the mid-depth contours. The upper macrophyte extent appears to be driven by water level, encroaching emergent vegetation, turbulence and heat/light intensity (Video 32). The lower macrophyte extent is primarily governed by photic depth and anoxic conditions in the hypolimnion below 6.5 m deep (Video 32).



Video 32: Representative transect across the macrophyte extent indicating the concentration of growth along the mid-depth contours.

Photic depth is thought to be the primary limiting factor regulating deep water macrophyte growth however, water quality profile data from 2020 to 2024 indicate persistent seasonal patterns that contribute to the reduction in the maximum vegetated depth extent (Figure 11).

Summer stratification creates hypolimnetic deoxygenation that has increased in extent over recent years allowing anoxic water to encroach further into the littoral zone. Figure 11 indicates that since 2022 the upper extent of the hypolimnion has increased and created anoxia in the shallows (< 10 m) over the stratification season. A corresponding decrease in pH is also seen throughout the hypolimnion (Figure 11). This expansion of acidic low dissolved oxygen conditions has contributed to the recession of macrophytes from ~ 11 m in 2022 to ~ 9 m in 2024.

The seasonal surface pH is higher over the warmer stratification period and is likely driven by an increase in planktonic respiration associated with summer algal blooms. The pH across 2022 – 2024 appear to exhibit less pronounced summer alkalinization which suggests a lower phytoplankton biomass. These conditions promote a deeper photic depth and imply that an expansion of the anoxic hypolimnion has a greater effect on the lower macrophyte extent in Rototoa than a seasonally reduced photic depth.

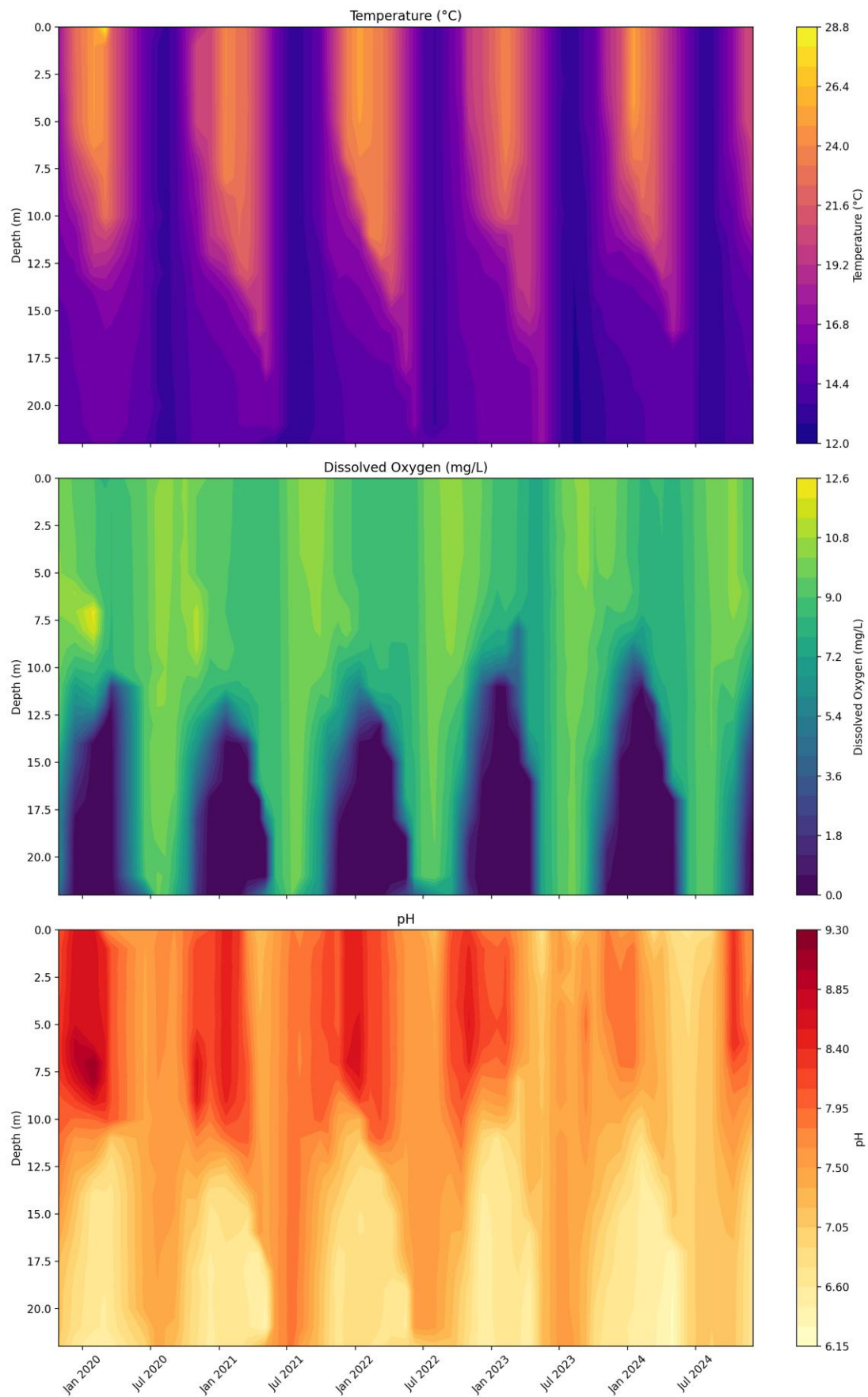


Figure 11: Lake Rototoa water quality profiles indicating recent seasonal patterns.

Threats

The potential expansion of Hornwort is a constant threat however, sustained control is proving effective in containing this species to discrete locations and reducing the overall biomass.

The large coarse fish population is likely the biggest in-lake threat. These exotic species disrupt ecosystem functions while simultaneously adding nutrients to the system through excrement. Their benthivorous feeding contributes to an increase in turbidity and the release of sediment bound nutrients. Zooplanktivory by juvenile coarse fish creates a reduction in the zooplankton biomass leading to reduced grazing pressure on phytoplankton. This allows seasonal algal blooms to exploit the high nutrient availability and increase in size and frequency. This regime shift could cause a permanent reduction in the photic depth with a corresponding recession in the maximum vegetated depth extent.

The potential introduction of additional invasive species poses a significant risk to Lake Rototoa. The lake is routinely used by the public for a variety of recreational activities and the introduction of aggressive species such as *Egeria densa*, golden clam, grass carp and catfish could push the system into a rapid decline. Considering the ecological value of the lake it is important to manage the biosecurity pathways and avoid the introduction of any additional stressors. Regular surveillance is recommended so that new incursions are detected and contained early.

Water quality is a continuous concern for the lake, the catchment derived nutrient loads combined with likely internal loading drive eutrophication. The morphology of the lake and macrophyte biomass provides a high degree of resilience to trophic state changes however, if a tipping point is exceeded and macrophyte collapse occurs the lake could deteriorate rapidly and assume a new stable degraded state. Tracking internal and external nutrient loads should be done at a resolution where nuanced changes can be detected and proactive management implemented to prevent further degradation.

4.2.2 Lake Kuwakatai

Lake Kuwakatai

09/11/2024



Ecological Condition: Poor

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	100%	D

Summary

Lake Kuwakatai is in a highly impacted condition with signs of further deterioration due to the extensive hornwort infestation, high pest fish biomass and seasonal algal blooms. The maximum hornwort depth extent has reduced but the cover and density of the growth has increased. No native macrophytes were observed and regeneration is unlikely considering the entire photic depth is colonised by hornwort, any localised regrowth will likely be grazed or uprooted by invasive fish before any significant establishment can occur.

Depth: 15 m
Size: 27.8 ha
Type: Dune

General Description



Photo plate 13: North facing view across lake Kuwakatai.

Lake Kuwakatai is situated on the Kaipara South Head Peninsula in the Auckland region (36°31'41"S 174°14'12"E). This seasonally stratified coastal dune lake covers approximately 27.8 hectares and has a maximum depth of 15 m.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area, High Natural Character Area and an Outstanding Natural Landscape.

Lake Kuwakatai is classified as supertrophic, with a Trophic Level Index (TLI) of 5 and has remained in a poor state for almost a decade (Unpublished Auckland Council data, 2024). The elevated in-lake nutrient levels have contributed to the ongoing degradation of water quality and recurring seasonal algal blooms.

The lake is primarily fed by rainfall and groundwater, with no clearly defined surface inflows or outflows. Despite its proximity to Rototoa, these lakes are not linked via surface flows.

Catchment Characteristics

The catchment area surrounding Lake Kuwakatai spans approximately 816.37 hectares and is dominated by pastoral farming, which has a significant impact on the lake's nutrient status. A large production forestry block runs along the northwest margin of the lake which further contributes to the contaminant loading.

The lake is bordered by a 250 m wide block of indigenous forest along the western and northwestern margins that transitions into a thin strip (≤ 50 m) to the east. The native vegetation along the entire southern margin of the lake is confined to a narrow fringe with patches of more established bush. The eastern end of the lake feeds a small wetland formed by the extension of the emergent reed bed. The northern arm of the lake has a complex of small wetland features that transition into a larger lacustrine wetland.

The non-contiguous nature of the buffer around the lake and the intensive pastoral land use activities have led to increased nutrient runoff, particularly nitrogen and phosphorus, which enter the lake via diffuse overland flow. The sandy soils, typical of the coastal dune systems, allow for rapid infiltration of surface flows which contribute to persistent nutrient enrichment of the underlying aquifer, this nutrient laden water enters the lake via groundwater recharge.

Riparian Characteristics

The riparian zone around Lake Kuwakatai is relatively narrow (0.5 - 3 m wide) and fragmented (Photo plate 14). Approximately 65% of the lake perimeter has emergent vegetation, the reed line is frequently broken by bare areas, collapsed banks and areas where the manuka/kanuka scrub extends into the lake (Photo plate 14). The condition of the wider riparian margin is poor and consisted of large sections of exotic pasture and/or heavily grazed native scrub (feral deer are responsible for the depauperate understory) (Photo plate 14).

The northern arm of the lake is surrounded by an extensive lacustrine wetland and the southeastern section of the lake has a more intact band of native vegetation, including raupō, flax (harakeke), and mānuka, providing better buffering capacity for surface runoff. Overall, the riparian zone is insufficiently wide and lacks the dense vegetation

needed to filter contaminants effectively. The absence of a robust riparian buffer has contributed to the lake's eutrophic condition.

Several landslides were visible along the steep sloped northern bank, the pastoral southern sub-catchment exhibited no signs of recent erosional issues (Photo plate 14). The lake is entirely fenced along the southern boundary which excludes stock from the adjacent paddocks, however, the northern boundary is unfenced and backs onto native scrub and forestry which support a sizable feral deer population.



Photo plate 14: Depauperate riparian margin – *Top row:* Land slips, damaged understory & narrow fragmented riparian margin; *Bottom row:* Fallen trees & exotic grass in the riparian margins.

Biodiversity

Lake Kuwakatai supports a poor level of biodiversity for its size and location. The majority of the species diversity consists of avifauna. The wetland features, emergent reed beds and blocks of native bush serve as important roosting habitat for both wetland and terrestrial bird species. Common native birds are often seen at the lake however, the diversity and abundance of birdlife is lower than in other less impacted lakes such as Rototoa and Te Kanae. A total of 30 black swans, 8 Canada geese, 22

paradise shelducks and 4 shags were seen during the 2024 survey as well as large amounts of avian faeces.

Common bullies (*Gobiomorphus cotidianus*) are the only native fish species regularly sighted in the lake, however none were seen during the 2024 survey (New Zealand Freshwater Fish Database). Coarse fish including perch (*Perca fluviatilis*), goldfish (*Carassius auratus*), tench (*Tinca tinca*) and rudd (*Scardinius erythrophthalmus*) have commonly been recorded in Kuwakatai during the past decade (New Zealand Freshwater Fish Database). No coarse fish were observed underwater during the 2024 survey however, extensive feeding pits were seen across the lakebed which is indicative of a high level of benthivorous feeding activity (Video 33). Two large koi carp (*Cyprinus carpio*) were seen from the surface in the shallows along the lake edge, these fish have been recorded in previous LakeSPI assessments (NIWA reports 2022 and 2017). Hornwort has been recorded in the lake since 1999, and it is thought that it had established prior to that date.

These invasive species have significantly altered the lake and are primary contributors to the deteriorating water quality and ecological health.



Video 33: Benthic feeding pits on the lakebed created by coarse fish.

In-lake description

The lake was stratified during the survey and had two distinct thermoclines, one at 2.7 m and a second at 5.5 m. A sulphide haze formed along the second thermocline from

4 - 5 m deep and is likely a result of the decomposing hornwort and phytoplankton (Video 37).

Visibility was approximately 2 m in the epilimnion and 4 m in the hypolimnion. The epilimnion had high concentrations of suspended particulate matter and clusters of algae. The hypolimnion was dark and notably clearer but still had suspended aggregates of algae (Video 34).



Video 34: Suspended algae in the hypolimnion.

The general bathymetric profile of the lakebed could not be assessed due to the wide, almost continuous band of hornwort that extends across the entire littoral zone. The substrate past the maximum hornwort depth extent (6.5 m) was firm and sandy with minimal organic floc and benthic algal mats. This is presumably a result of the dense hornwort growth attenuating catchment derived sediment and organic matter, limiting its distribution across the lake.

The substrate along the northern arm of the lake had a 25 - 50 cm thick layer of organic silt, presumably due to the influx of organic matter from the surrounding wetland.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Kuwakatai (Figure 12). Additional investigations were conducted along representative sections of the lake to assess the extent of the hornwort invasion and potential cyclone related impacts.

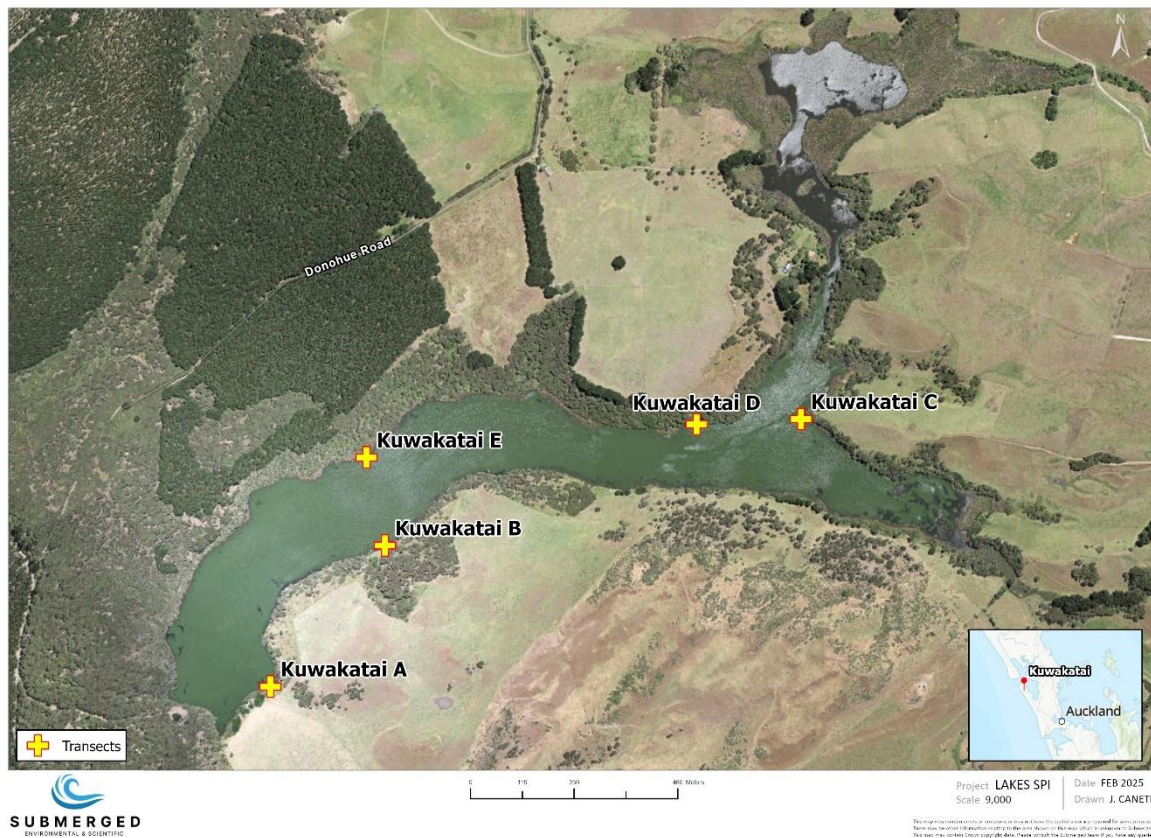


Figure 12: Lake Spectacle LakeSPI survey transects.

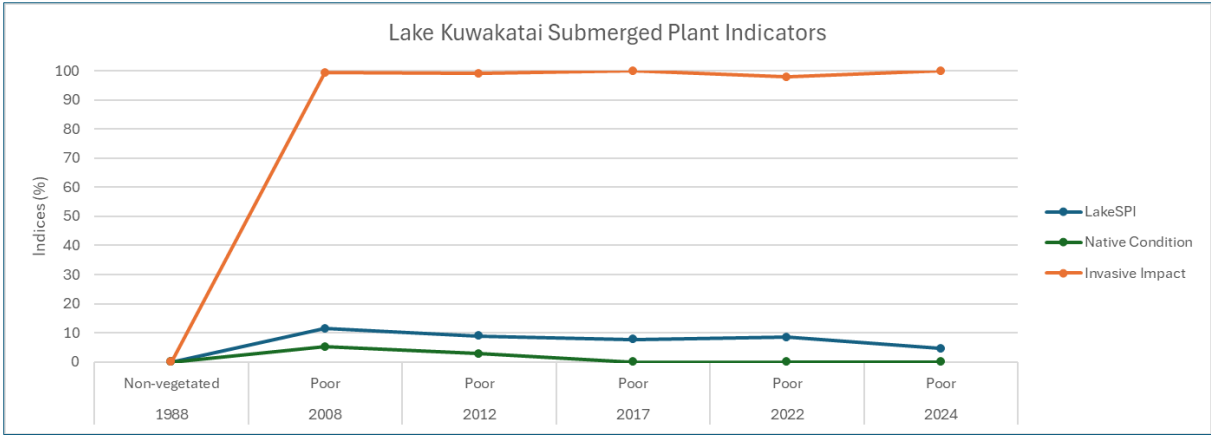
Lake Kuwakatai has been classified as being in a poor condition since November 2008, a 44.94% decrease in the LakeSPI score from 2022 to 2024 indicates a declining state. This declining state is related to the proliferation of invasive hornwort (*Ceratophyllum demersum*), absence of native macrophytes and the reduction in maximum vegetated depth extent from 7.9 m in 2022 to 6.5 m in 2024. The extent of the hornwort infestation is reflected in the Invasive Impact score of 100% (Figure 13).

No native submerged vegetation was seen along any of the survey transects in November 2024 and the lake was assigned a Native Condition score of 0% (Figure 13).

Video 35 is a representative transect extending from a depth of 7 m to 5 m at the base of the lower hornwort extent, this video illustrates the non-vegetated nature of the hypolimnion, the dense hornwort growth that occupies the epilimnion as well as the visible substrate characteristics.



Video 35: Representative transect from the bare hypolimnion to the outer edge of the dense hornwort growth in the epilimnion.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
November 2024	Poor	4.68	0	100
March 2022	Poor	8.5	0	97.8
May 2017	Poor	7.7	0	100
February 2012	Poor	9	2.8	99.1
November 2008	Poor	11.5	5.2	99.3
February 1988	Non-vegetated	0	0	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	D

Figure 13: LakeSPI Indices for Lake Kuwakatai expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The hornwort dominated state and lack of native submerged vegetation places the lake in a D band for both the Native Condition Index and Invasive Impact Index National Objectives Framework attributes (Figure 13). Significant improvements in these attribute bands are unlikely without intensive interventions. The hornwort extent occupies the entire littoral zone making control measures difficult to implement. The shallow hornwort beds are suitable for herbicide application however the deeper growth will be challenging to target.

Hornwort formed a wide, almost continuous, band around the entire lake that extends up to 100 m from shore in some areas, the average width across the lake was assessed as 50 m wide. This band created a dense closed canopy (85 - 100% cover) from 0.2 m to a maximum of 6.5 m deep (Video 36). The growth was almost surface reaching in all locations with some stands measuring 5.2 m tall. Signs of persistent anoxia were noted along the underlying substrate below the hornwort beds.



Video 36: Dense hornwort growth in the upper littoral zone.

There was a defined line along the 5 m depth contour where the dense hornwort band ended. Past 5 m, hornwort formed fragmented beds that eventually dispersed into small clumps and isolated stems past 6 m (Video 37).



Video 37: Lower hornwort extent with sparse cover and poor macrophyte condition.

The condition of the hornwort deteriorated significantly past 4 m deep and exhibited etiolated stems, loss of colour and increased epiphytic cover (Video 38).



Video 38: Etiolated hornwort below the thermocline.

Hornwort was the only submerged vegetation detected during the underwater surveys, however a 7.5 m² patch of *Glossostigma elatinoides* was seen west of the entry point along the southern bank. Patches of *Ludwigia palustris* were also seen amongst the emergent vegetation in the southwestern bay.

The Invasive Impact score has increased by 2.25% since the 2022 survey, this change is due to the increased average hornwort cover from ~75% to almost 100%. Hornwort is thought to be less palatable to herbivorous fish which allows it to thrive in the lake

despite the high coarse fish biomass (Lake et al. 2002). Hornwort is also more resilient to wind induced disturbance and upheaval because it can exist as a free-floating plant and regenerate from small fragments. It is possible that high winds associated with the recent cyclones have acted as a dispersal mechanism for hornwort across the lake.

The Native Condition score remained the same as the 2022 assessment (0%) as no native submerged vegetation was seen along any of the survey transects. The overall LakeSPI score dropped by 44.94%, this significant change is attributed to the reduction in the maximum vegetated depth extent from 8.6 m to 6.5 m. The reduced vegetated extent is potentially due to a reduction in photic depth, possibly caused by an influx of sediment and nutrients from Cyclone Gabrielle or an intensification of seasonal algal blooms.

Figure 14 indicates strong seasonal stratification with acidic anoxic water encroaching into the shallow littoral zone (< 5 m). Seasonal pH fluctuations (Figure 14) are difficult to interpret, due to the large biomass of surface reaching hornwort. The receding macrophyte extent seems to be governed, to a large degree, by an expansion of the upper hypolimnion extent and a reduction in photic depth.

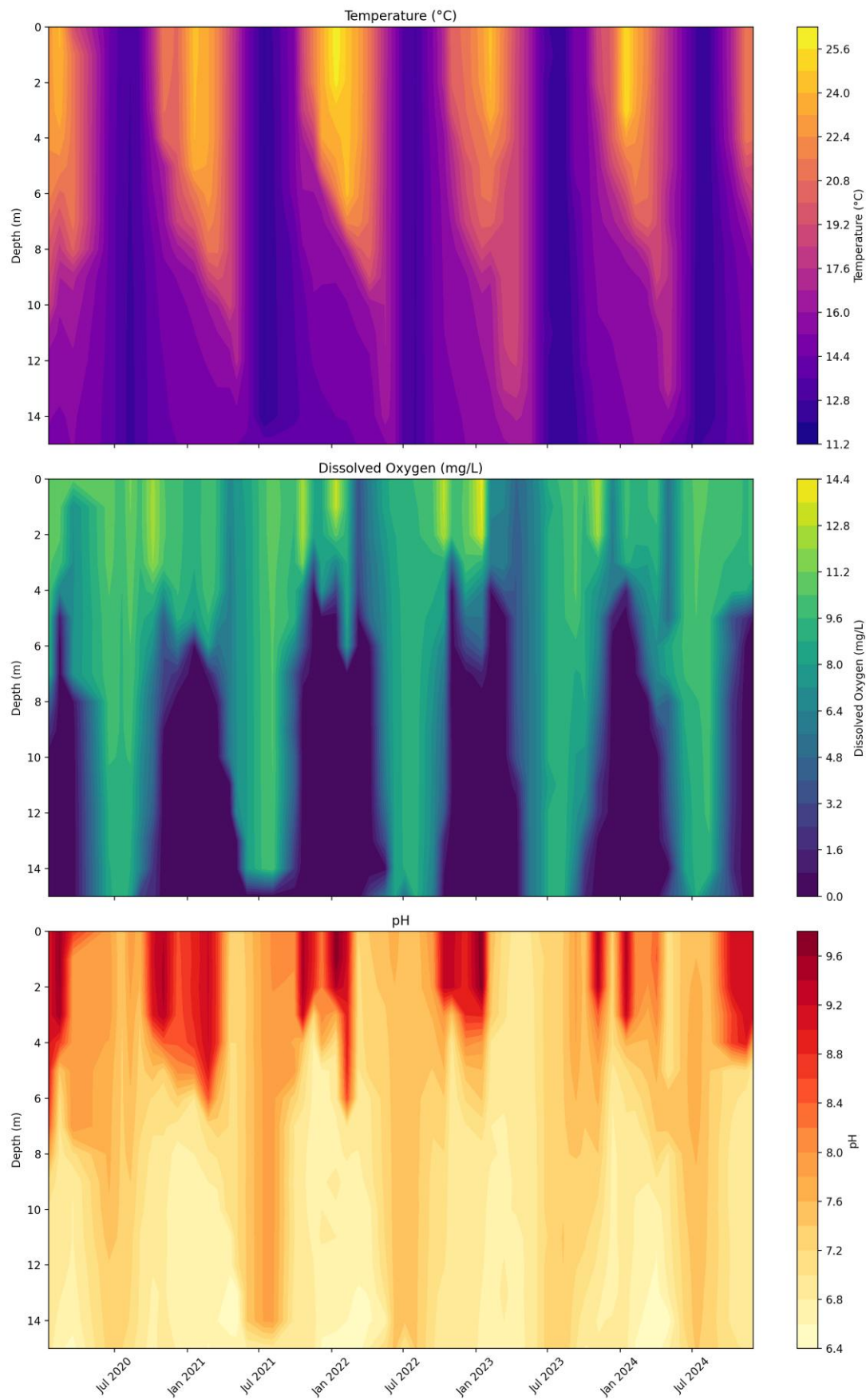


Figure 14: Lake Kuwakatai water quality profiles indicating recent seasonal patterns.

Threats

The primary threat to Lake Kuwakatai is the extensive hornwort infestation. This aggressive macrophyte has dominated the littoral zone and occupied the entire photic depth of the lake. Dense hornwort growth significantly impacts lake environments by altering water movement, sediment characteristics, increasing water temperatures, and causing diurnal fluctuations in oxygen and pH levels (Ejankowski & Solis, 2015, Staryer, 2010).

Signs of persistent anoxia was commonly observed amongst the dense hornwort bed which is a result of water stagnation, localised temperature increases and decomposition of dead hornwort material. This decomposition releases ammonia and shifts the REDOX potential of the sediment, which in turn causes the remobilisation of sediment bound phosphorus (Si et al., 2020). The combination of these influences has likely contributed to the continued elevated trophic state in Lake Kuwakatai.

Hornwort growth is influenced by nutrient availability, particularly ammonia and phosphorus which likely enters the lake through agricultural runoff from the surrounding catchment. This species can exist in a free-floating state with modified leaves that are able to exploit dissolved nutrient concentrations throughout the water column (Ejankowski & Solis, 2015). It can also adapt to various light levels, enabling it to photosynthesise at unexpectedly deep depths. These abilities have allowed hornwort to overrun the lake and exploit deteriorating water quality conditions that are suboptimal for native macrophyte species.

The localised increase in temperature and anoxia amongst the hornwort beds negatively affect native biodiversity, displacing species that prefer cooler, oxygen-rich waters. These transformative effects could explain the lack of fish and macroinvertebrates observed during the survey. The displacement of littoral biodiversity often leads to a collapse in ecosystem function and resilience.

The herbivorous pest fish have also contributed to the elimination of native submerged vegetation through excessive grazing and substrate disturbance (Staryer, 2010; Bunnell et al., 2011; Gerdeaux, Anneville & Hefti, 2006). Coarse fish regularly feed on large zooplankton as juveniles which reduces the grazing pressure of phytoplankton, this cascading trophic collapse creates and maintain a high algal biomass environment (Wells, 1999; de Winton et al., 2009; Collier & Grainger, 2015).

Large sections of surrounding sub-catchment consist of pastoral land and production forestry. These high impact land use activities combined with the narrow fragmented emergent vegetation and sparse riparian understory likely leads to increased nutrient and sediment loading. The combination of this increase in catchment derived nutrients and in-lake nutrient loads creates conditions that support a high algal biomass. These seasonal algal blooms senesce over winter and decompose which releases additional nutrients that fuel subsequent blooms. The decomposition process in combination with natural stratification creates persistent anoxia at the sediment water interface which promotes the release of sediment/iron bound phosphorus. Persistent algal blooms and eutrophication result in a reduction in the portion of the lakebed that is suitable for macrophyte establishment.

The feral deer population has caused widespread damage to the surrounding native scrub along the northern boundary of the lake. The sparse understory has a greatly reduced the filtration capacity and provides limited stabilisation of the steep slopes that extend into the lake. Catchment derived contaminants (sediment, nutrients & organic debris) likely wash into the lake relatively unobstructed during heavy rainfall events.

4.2.3 Lake Te Kanae

Lake Te Kanae

09/11/2024



LakeSPI Score

0%

Ecological Condition: Non-vegetated

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	0%	N/A

Summary

Lake Te Kanae remains in a non-vegetated state due to macrophyte covers $< 10\%$. Native macrophytes were seen outside of the survey areas. Invasive hornwort had receded since 2022 however, significant beds persist along the southern bay. Cyclone-induced landslides have exacerbated sedimentation and nutrient inputs, reducing water clarity and photic depth. The lake risks transitioning into a higher trophic state, with minimal potential for natural recovery without targeted interventions.

Depth: 18 m
Size: 5.6 ha
Type: Dune



General Description



Photo plate 15: North facing view of Lake Te Kanae.

Lake Te Kanae is part of a series of dune lakes situated along the west coast of Kaipara South Head. This lake is situated on the outer edge of a large coastal dune system (36°34'39"S 174°17'18"E). This small 5.6-hectare lake has a maximum depth of 18 m and stratifies seasonally.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area, High Natural Character Area and an Outstanding Natural Landscape.

Lake Te Kanae has a Trophic Level Index of 4.1 which indicates that it is slightly eutrophic but can be considered on the border between mesotrophic and eutrophic (Unpublished Auckland Council data, 2024). The lake has moderate nutrient levels and relatively good water quality compared to many other coastal lakes in the area, this is likely a product of its depth relative to size and the low impact catchment land use.

The lake has no notable in/outflows and is likely fed by groundwater recharge, rainfall and diffuse overland flow.

Catchment Characteristics

The catchment surrounding Lake Te Kanae spans 42.44 hectares of native forest and scrubland with some low-intensity pastoral grazing along the outer catchment boundary. The loose sandy soils typical of coastal dune environments allow for rapid drainage and runoff following rainfall events which is typically associated with increased sediment and nutrient inputs.

The high native forest cover surrounding the lake and a reasonably intact understory helps to mitigate excessive nutrient and sediment runoff. A small area of wetland, located along the northeastern bank acts as a buffer and provides some level of attenuation for contaminants draining off the steep slopes that border the northern portion of the lake.

Riparian Characteristics

The riparian zone around Lake Te Kanae is relatively intact, with a well-established band of native emergent vegetation along 80% the lake's perimeter. Raupō reedland, flax, and sedges form an almost continuous band averaging 3 - 5 m in width. The emergent reed line is broken in some parts by bare areas, collapsed banks and areas where the manuka/kanuka scrub extends into the lake (Photo plate 16). The northern arm of the lake has a 10 - 15 m wide lacustrine wetland that stretches along the outer edge of the northern bay (Video 39).

The riparian and emergent vegetation provides good buffering capacity, helping to filter contaminants and slow nutrient runoff into the lake. The southwestern margin of the lake is less vegetated, with a mix of exotic grasses and only occasional patches of native reeds, contributing to a lower quality riparian buffer in that area.

Several large landslides were seen on the steep slopes that run along the northern and eastern lake margin (Photo plate 16). These landslides and slips are likely a result of Cyclone Gabrielle (February 2023). Other erosional issues such as bank collapses and bare earth were also noted along the more exposed sections of the lake margin.



Video 39: Lacustrine wetland along the outer edge of the northern bay.



Photo plate 16: Cyclone induced damage in the riparian margin – Top row: Fallen trees & damaged riparian vegetation entering the lake; Bottom row: Land slips & bare earth on the steep slopes adjacent to the riparian margin.

Biodiversity

Lake Te Kanae has moderate biodiversity value, supporting a variety of native and migratory and wetland birds. Large amounts of waterfowl faeces were seen across the lakebed indicating a high biomass of aquatic avifauna. Although no sightings of nationally threatened bird species were recorded, the lake and its wetlands are an important habitat for various waterfowl and native invertebrates.

Native common bullies (*Gobiomorphus cotidianus*) are abundant throughout the lake (Video 40). Invasive rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) have been reported in high numbers and koi carp (*Cyprinus carpio*) have been detected using eDNA (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). Feeding pits were observed throughout the littoral zone which is indicative of benthivorous feeding from these invasive fish species.

These invasive species contribute to the degradation of lake health by disrupting food webs, reducing macrophyte biomass and causing excessive bioturbation.



Video 40: Common bullies in the shallow littoral margin.

In-lake description

The lake was stratified during the survey and had a distinct thermocline at 4.4 m. A sulphide haze extended from 0.5 m to 4 m and is likely a result of the decomposition of organic matter along the base of the emergent vegetation (Video 41). The shallow lake margin (0 - 3 m) had large deposits of woody debris, detritus and fallen manuka/kanuka trees.



Video 41: Woody debris, decomposing organic material & sulphide precipitate in the upper littoral zone.

Visibility was approximately 2 m in the epilimnion and 4 m in the hypolimnion. The epilimnion exhibited high concentrations of suspended particulate matter and a brown tannin-stained hue, likely originating from the emergent vegetation. In contrast, the hypolimnion was dark but clear, with minimal suspended particles.

The majority of the lakebed slopes steeply from the base of the emergent vegetation (2.8 m) at a constant gradient until 4 m deep where the gradient becomes less steep but continues to slope past 7 m. The deep in-lake deposition zone is likely deeper than the maximum dive depth of 8.5 m recorded during the survey. The northern end of the lake has a gentler bathymetric gradient and significantly more organic matter deposition because of the bordering wetland. The substrate in this area had a 0.8 - 1 m thick layer of soft silt and organic floc. This area also had higher covers of benthic algal mats (Video 42) which in places reached more than 25% cover with an average of 15% cover across the entire northern arm. This is indicative of possible localised nutrient enrichment.



Video 42: Benthic algal mats along the deeper contours of the northern bay.

The majority of the substrate in the 0 - 4 m depth contour was firm and sandy with a 0.5 cm layer of fine silt/organic floc. The substrate was similarly firm and sandy past 4 m but with no woody debris and less surficial silt. There were almost no benthic algal mats past 4 m and only a few fragmented clumps were seen but the total area per location was less than 4 m².

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Te Kanae (Figure 15). Additional investigations were conducted along representative sections of the lake to assess the current extent of hornwort and the impacts of Cyclone Gabrielle (February 2023).

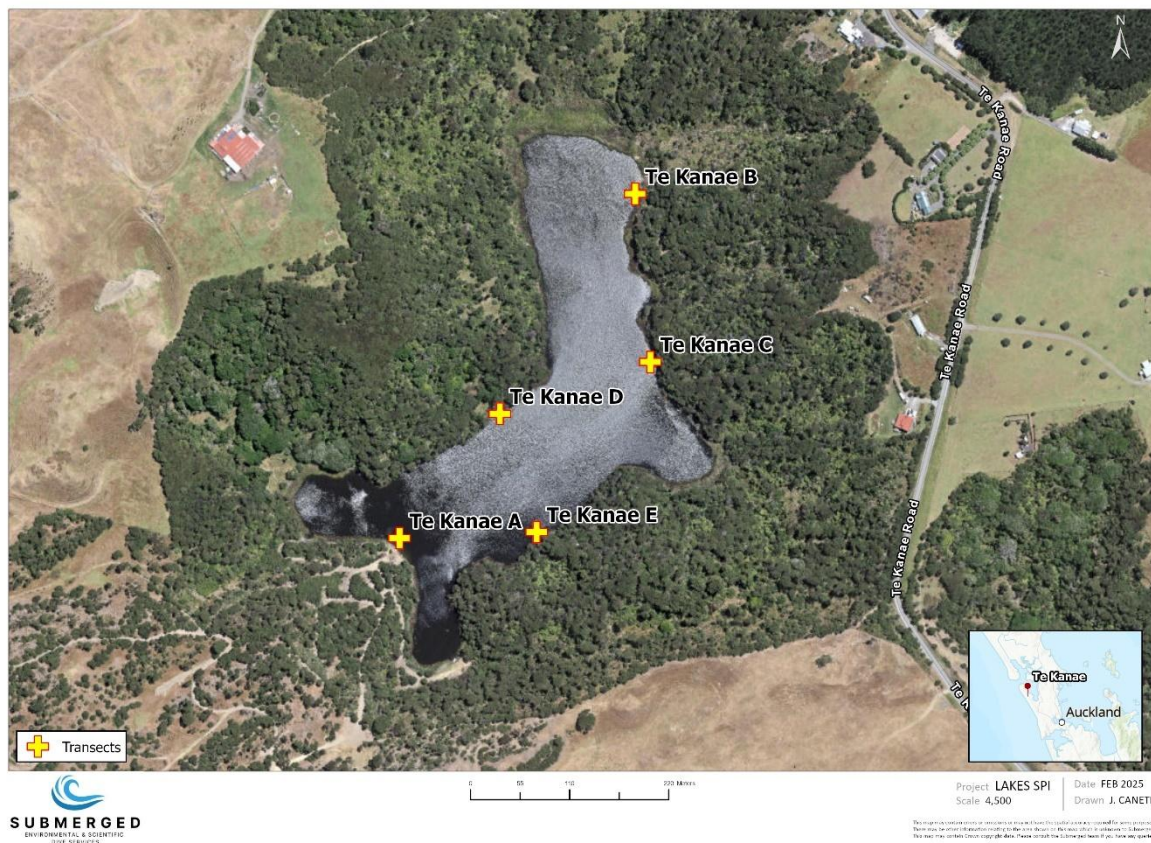
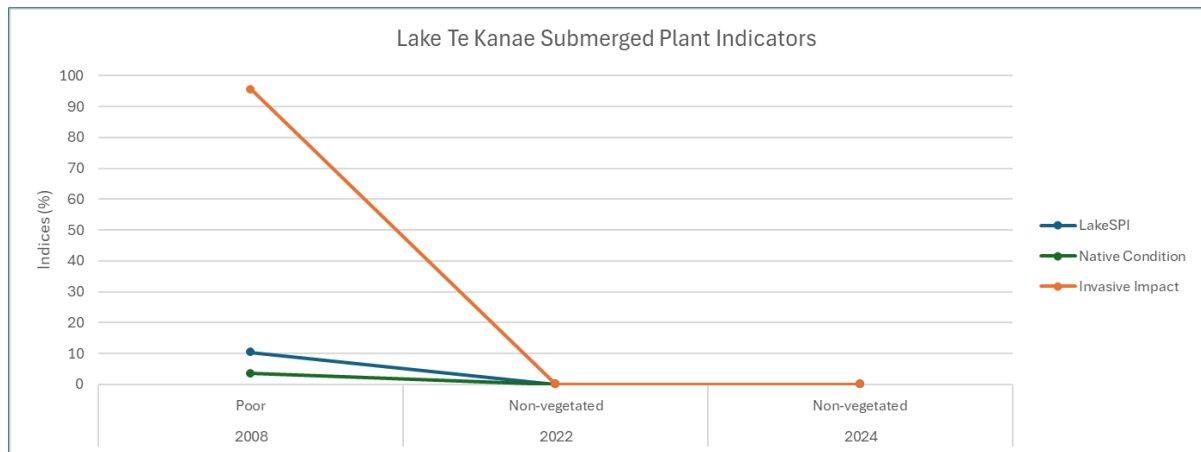


Figure 15: Lake Te Kanae LakeSPI survey transects.

Lake Te Kanae has been classified as non-vegetated since March 2022. No significant submerged vegetation (> 10% cover) was seen along any of the survey transects in November 2024 and the lake was assigned default LakeSPI Indices of 0% (Figure 16).

The non-vegetated classification, resulting from the low macrophyte cover, places the lake in a D band for the Native Condition Index National Objectives Framework attribute (Figure 16). The Invasive Impact attribute is not applicable to non-vegetated lakes however, significant hornwort (*Ceratophyllum demersum*) growth was found in discrete locations outside of the survey transects (Video 43).

Single stems and small isolated clumps of hornwort (*Ceratophyllum demersum*) were seen in parts of the littoral zone but did not achieve covers higher than 10% along any of the survey transects. The southern bay (not on a transect) had an extensive bed of short growing hornwort along the edge of the emergent vegetation, this was the largest and densest bed observed during the survey (Video 43). This bed decreased in density as it extended into the shallow sandy areas on the sides of the bay.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
November 2024	Non-vegetated	0	0	0
March 2022	Non-vegetated	0	0	0
October 2008	Poor	10.4	3.6	95.6

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	N/A

Figure 16: LakeSPI Indices for Lake Te Kanae expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.



Video 43: Hornwort bed along the southern bay.

Small clumps of hornwort were seen amongst the sparse emergent vegetation in these exposed sandy areas, the lack of riparian vegetation along this bay has led to increased sediment deposition and the burial of hornwort patches (Video 44).



Video 44: Hornwort in the shallows along the southern bay with sections of burial from recent sedimentation.

The hornwort extent has reduced since 2022 where it formed low covers from 0.8 m to 3.5 m deep. During the 2024 survey no hornwort was found deeper than 1.5 m and majority of the growth occurred as isolated stems and small clumps. The only significant growth detected was confined to the southern and western bays. This reduction in extent could be a consequence of Cyclone Gabrielle (February 2023), large amounts of sediment entered the lake during the cyclone, and subsequent rainfall events, leading to extended periods of reduced water clarity. The reduced photic depth and sediment deposition in the upper littoral zone could have regulated the growth of hornwort. If conditions change and hornwort were to expand into the wider lake the Invasive Impact Index will be below the national bottom line. There is a high chance of Invasive Impact Index band switching between surveys in this lake.

Video 45 is a representative transect extending from a depth of 8.5 m to 0.5 m, this video illustrates the non-vegetated nature of the majority of lake as well as the substrate characteristics and delineation between the hypolimnion and epilimnion.



Video 45: Representative transect from 8.5 m to 0.5 m indicating the non-vegetated nature of the lake & substrate characteristics.

Discrete pockets of additional macrophyte species were also found in the shallow margin outside of the survey areas. The southern bay had duckweed (*Lemna disperma*), *Azola rubra*, *Ludwigia palustris* and isolated stems of surface reaching *Potamogeton cheesemanii* amongst the emergent vegetation. Small clumps of *Utricularia gibba* were seen on the large woody debris adjacent to the emergent reed line in several locations across the lake.

Figure 17 indicates strong seasonal stratification and an increased expansion of the anoxic hypolimnion into the shallow littoral zone (< 5 m), during 2023 and 2024 this anoxia extended to almost 2 m deep. The pH profiles indicate persistent alkalinisation of the surface water, likely resulting from a high phytoplankton biomass that is hindering the photic depth in the lake (Figure 17). These conditions inhibit macrophyte establishment and will possibly prevent significant regeneration from occurring.

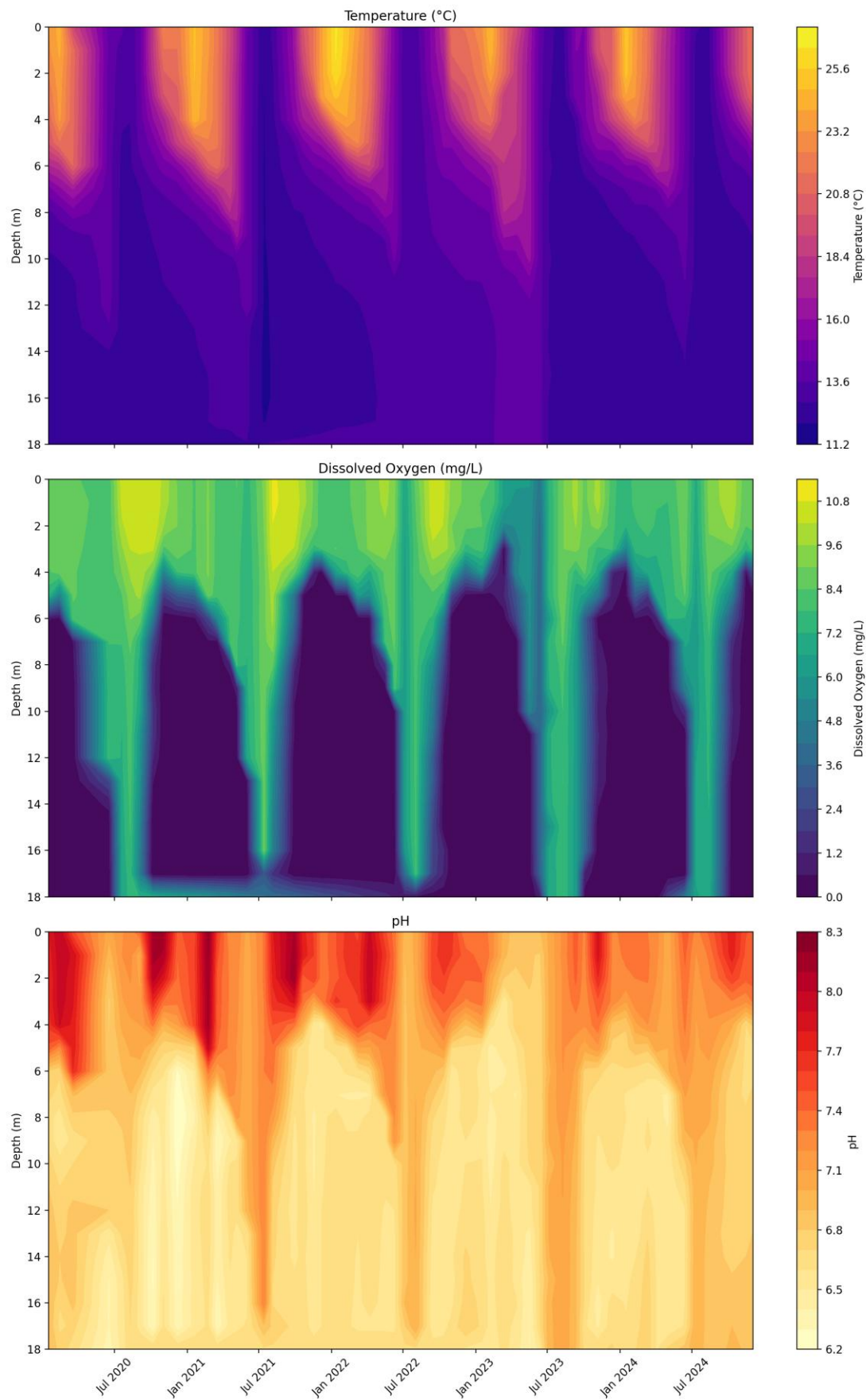


Figure 17: Lake Te Kanae water quality profiles indicating recent seasonal patterns.

Threats

The primary threats to Lake Te Kanae observed during the 2024 survey relate to the impacts of invasive species and cyclone induced erosional issues.

Despite a reduction in hornwort extent since 2022, this invasive species still presents a high risk and it is possible that it could eventually overrun the littoral zone. This type of growth impacts lake environments by altering water movement, changing sediment characteristics, increasing water temperatures, and causing large diurnal fluctuations in oxygen and pH levels (Ejankowski et al., 2015 & Staryer, 2010). Significant hornwort growth is currently confined to discrete locations along the shore and low covers elsewhere in the littoral margin. This makes control measures easier to implement and herbicide application would have a high success rate. Urgent control is recommended as the chance of eradication drops as the hornwort biomass and extent increases.

The immediate sub-catchment is forested with an intact understory so excessive anthropogenic nutrient inputs are unlikely to be the primary driver behind the eutrophic state. The lack of submerged vegetation reduces the in-lake nutrient assimilation capacity, allowing suspended algae/phytoplankton to exploit the nutrient rich environment and proliferate. The high algal biomass creates an annual bloom and bust cycle that releases nutrients and fuels subsequent blooms.

The cyclone induced landslides have contributed significant sediment and organic matter loads to the lake which has reduced water clarity and introduced a long term in-lake nutrient source. These impacts have had transformative changes to parts of the littoral zone and have created conditions that are unlikely to support the regeneration of native macrophytes. The shallower areas along most of the lake are occupied by dense emergent vegetation which further excludes any macrophyte establishment in the more suitable portions of the upper littoral zone.

The herbivorous rudd (*Scardinius erythrophthalmus*), benthivorous tench (*Tinca tinca*) and koi carp (*Cyprinus carpio*) have also contributed to the non-vegetated state through excessive grazing and substrate disturbance (Staryer, 2010; Bunnell et al., 2011; Gerdeaux et al., 2006). Coarse fish species feed on large zooplankton as juveniles which reduces the grazing pressure of phytoplankton, this cascading trophic collapse creates and maintains a high algal biomass environment (Wells, 1999; de Winton et al., 2009; Collier & Grainger, 2015).

It is unclear if the lake will remain in a steady state or worsen as a result of the increased organic matter deposition and lack of submerged vegetation. Significant macrophyte regeneration is unlikely considering the suitable parts of the upper littoral zone are occupied by emergent vegetation and/or hornwort, any regrowth in the deeper parts of the lake will likely be grazed or uprooted by invasive fish before any significant establishment can occur.

The lake is currently on the cusp of transitioning into a higher trophic state and the lack of macrophytes, reduced photic depth and increased organic matter deposition are indicators of a permanent state change. Natural regeneration of native macrophytes is limited however, it is possible that hornwort could increase in extent.

4.3 Muriwai Lakes

The Muriwai Lakes are located along the west coast, toward the centre of the region. Lakes Ōkaihau and Kawaupaku are deep dune lakes that are part of this geographic lake group.

4.3.1 Lake Ōkaihau

Lake Ōkaihou

13/12/2024



Ecological Condition: Poor

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	83.7%	C

Summary

Lake Ōkaihou has undergone significant changes in recent years including the expansion of exotic floating vegetation and the transformation of the sub-catchment into a golf course. The lake remains in a poor ecological condition with limited hornwort expansion and no native macrophytes. In-lake conditions indicate that the lake is at risk of transitioning into a turbid, non-vegetated algal dominant state if the existing pressures remain. Controlling hornwort is recommended as the infestation is still at a manageable scale.

Depth: 12 m
Size: 5.7 ha
Type: Dune

General Description



Photo plate 17: North facing view across Lake Ōkaihou.

Lake Ōkaihou is located on the west coast of Auckland ($36^{\circ}48'33.1''\text{S}$ $174^{\circ}26'24.8''\text{E}$) and is on the southern end of a chain of coastal dune lakes that extend from the tip of South Head to Muriwai Beach. This small 5.7-hectare lake has a maximum depth of 12 m and stratifies seasonally. The lake is bordered by a sandy beach that connects to a large dune system extending toward the coast.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area and an Outstanding Natural Feature.

Lake Ōkaihou is classified as eutrophic, with a Trophic Level Index of 4.4 (Unpublished Auckland Council data, 2024). These elevated nutrient levels are, in part, attributed to the high impact land use surrounding the lake and presence of invasive species.

Lake Ōkaihou has no outflow, but two intermittent inflows drain a wetland feature along the southern bank.

Catchment Characteristics

The catchment surrounding Lake Ōkaihou covers approximately 91.53 hectares and is largely occupied by native manuka/kanuka scrub (51%). However, the surrounding sub-catchment is almost entirely high producing exotic grassland, forestry and bare dunes with scattered remnants of scrubland and wetland features.

The recent development of a new golf course is currently underway and has created large areas of bare earth (Video 46). The site is in the early stages of earthworks and will change significantly over the upcoming year. It is likely that the bare earth will be converted to golf greens, sand bunkers and natural features which could return habitat value and buffering to portions of the lake edge.



Video 46: Alterations to the riparian margin resulting from the golf course development.

The sandy dune soils that dominate the area allow rapid infiltration however the steep sloped pastoral sub-catchment promotes high runoff during rainfall events. This rapid drainage of high impact land use and development contributes sediment and nutrient loads to the lake. The wetland areas that surround the lake acts as a partial contaminant filter, but the overall buffering capacity is limited due to the depauperate nature of the wetlands and the steep gradient of the adjacent slopes.

Riparian Characteristics

The riparian margin is poor across the entire lake, the emergent vegetation is concentrated along the southern bay with only narrow fragmented clumps seen elsewhere. Approximately 15% of the lake perimeter has emergent vegetation with an average width of 0.5 m. The terrestrial portion of the riparian margin is poorly vegetated with the majority of the vegetation consisting of exotic grass, bare earth and sparse manuka/kanuka scrub.

The northern end of the lake is completely bare as a result of the golf course development, the exposed dunes slope directly into the lake with no emergent

vegetation or riparian buffer. Mature trees and riparian vegetation have been cleared along the northern bank (Video 47). Woody debris was left on the side of the lake and large trees and branches were seen in the lake along the cleared sections (Video 47). This debris will form a long-term source of organic matter and could cause localised impacts.



Video 47: Riparian impacts resulting from the golf course development.

The eastern section of the lake has a narrow-fragmented band of raupō reedland and patches of native sedges that provide buffering against runoff (Photo plate 18). The average width of this riparian zone is less than 1 m however, the southeast section has more established riparian vegetation (Photo plate 18).



Photo plate 18: Section of the southeastern riparian margin with emergent reed beds that back onto native scrub.

The western and southern banks are largely bordered by short homogenous exotic pasture with little other emergent vegetation and areas of bare soil resulting in less buffering capacity. This bank has limited to no emergent vegetation and often had undercut banks and bank collapses (Photo plate 19).



Photo plate 19: Representative section of the western and southern riparian margins indicating limited emergent vegetation, exotic grass cover and bank erosion.

The southern tip of the lake is bordered by a small wetland feature, extending about 15 m from the shore however, this feature is still dominated by exotic pasture and provides limited buffering capacity (Photo plate 20). The fragmented emergent vegetation is surrounded by exotic lilies that form a large surface aggregation across the entire bay (Photo plate 20).



Photo plate 20: Southern tip of the lake with the exotic lilies in the foreground, fragmented emergent vegetation in the midground and the exotic pasture dominant wetland feature in the background.

Cyclone Gabrielle (February 2023) had impacted the slopes surrounding Lake Ōkaihou to a lesser degree than some of the other Auckland lakes however, cyclone related landslips and other erosional issues resulting from the grazed pasture and golf course development were observed along all banks (Photo plate 21).



Photo plate 21: Representative photos of common erosional features observed on site including landslips and grazing related erosion.

Biodiversity

Lake Ōkaihou supports a large population of Canadian geese (*Branta canadensis*) with more than 100 sighted during the survey. The large biomass is evident by the amount of faeces seen across the lakebed (Video 48).



Video 48: Bird faeces & benthic feeding pits on the lakebed.

The removal of mature trees, riparian vegetation and the general disturbance from the golf course development could impact the native birdlife as refugia is limited.

Common bullies (*Gobiomorphus cotidianus*) have been detected in the past however, no native fish species were seen during the survey. The invasive *Gambusia affinis* was abundant amongst the shallow hornwort beds and alligator weed. Populations of invasive coarse fish including rudd (*Scardinius erythrophthalmus*), tench (*Tinca tinca*) and perch (*Perca fluviatilis*) have been detected recently, and the presence is in part confirmed by the benthic feeding pits seen along the shallow lakebed (Video 48) (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). The presence of these invasive species has contributed to the degradation of the lake and have exacerbated the effects of eutrophication.

In-lake description

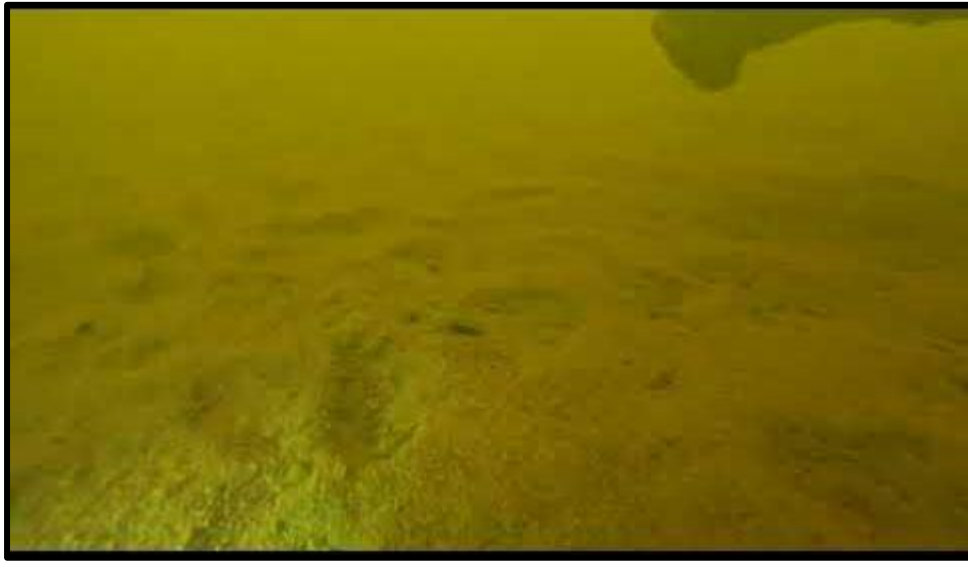
The lake was stratified during the survey and had a distinct thermocline at 3.8 m. The visibility in the epilimnion was 3 m and dropped to near zero at 4 m, no light penetrated past 4.5 m deep.

A dense ~1 m thick layer of suspended organic matter was found resting on top of the thermocline from 2.5 - 3.5 m deep. The decomposition of this material created a sulphide layer that extended across the open water section of the lake. Smaller localised sulphide precipitates were seen in other parts of the lake but did not form persistent widespread layers.

There were relatively low concentrations of suspended matter in the upper epilimnion however, a significant increase of suspended solids was observed in the hypolimnion. This is possibly due to the organic matter being neutrally buoyant in the denser stagnant cold water, so it stays in suspension longer than it would in the epilimnion.

The substrate in the shallows (0 - 1.5 m) along the northern bay and sections of the western lake margin was compacted and hard with a thin (1 - 5 cm) surficial layer of silt, these areas have a gentle gradient toward the deeper central bowl (Video 49). The substrate along the eastern and southern areas were softer with a thicker layer of silt and organic floc, these areas slope steeply to 3 m where there is a distinct deposition zone that creates the softer, muddy substrate. The substrate got progressively softer

toward the deeper central portion of the lake and had a thick (> 1 m) layer of fine silt and organic floc. No consolidated base was found in areas past 5 m deep.



Video 49: Compacted substrate conditions in the shallows.

No benthic algal mats were seen in the shallows (< 2.8 m), but discrete patches formed along the 3.5 - 4.5 m depth contour. No benthic algae were seen deeper than 5 m due to an absence of light. The concentration of algal mats between 3.5 – 4.5 m likely corresponds to the development of the sulphide layer above the hypolimnion, the decomposing organic matter, anoxic conditions and higher ammonia create conditions that promote the formation of benthic algal mats.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Ōkaihu (Figure 18). Additional investigations were conducted along representative sections of the lake to assess the extent of the hornwort invasion and the cyclone related impacts.

The submerged vegetation in Lake Ōkaihu is limited and largely consists of sparsely distributed hornwort (*Ceratophyllum demersum*) along the shallow lake edge. Small patches of *Glossostigma elatinoides*, along the western arm and northern bay, was the only native macrophyte species seen during the survey. *Utricularia gibba* was also recorded amongst the floating and emergent vegetation however, it did not form large aggregations as commonly seen in other lakes across the upper north island.

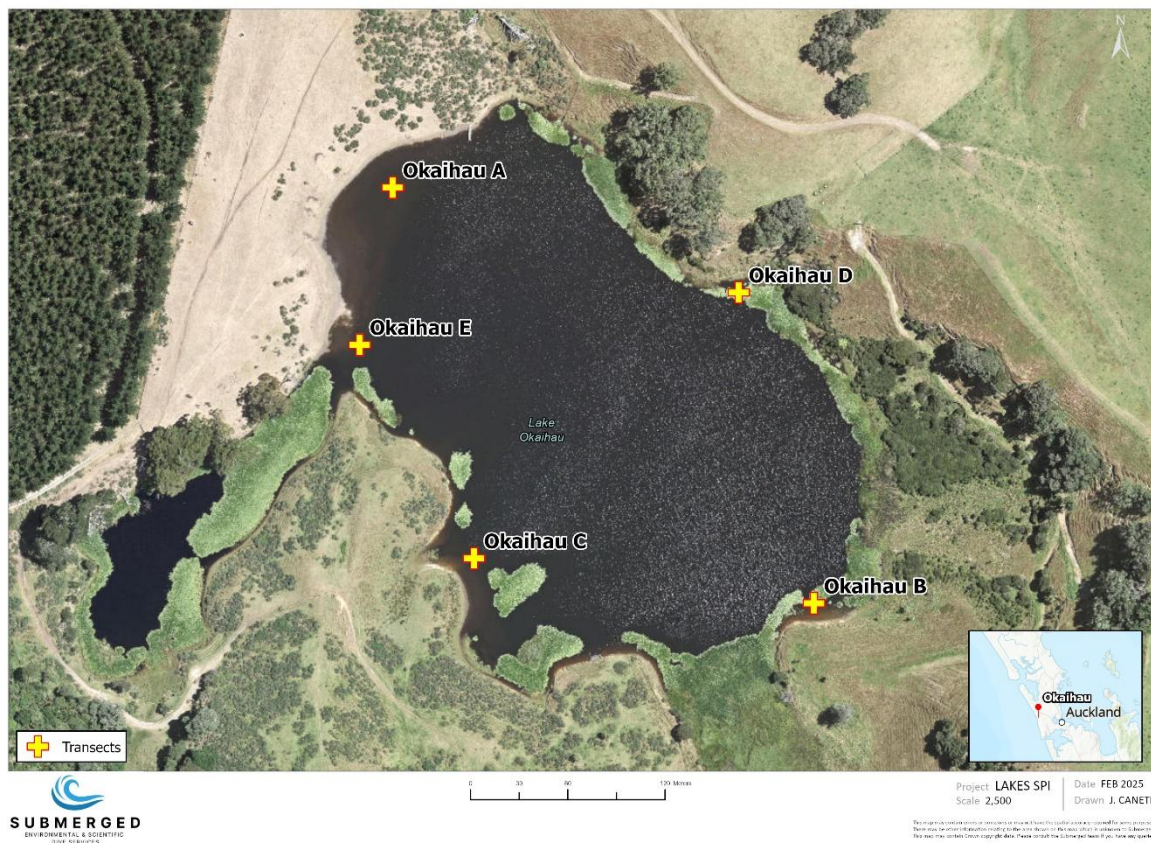


Figure 18: Lake Ōkaihou LakeSPI survey transects.

Floating species created a wide band along 75 - 80% of the lake margin. The western arm was almost entirely covered with exotic waterlilies (*Nymphaea cultivars*) (Video 50) and the southern end of the lake had a 20 - 30 m wide band of waterlilies (*Nymphaea cultivars*) and alligator weed (*Alternanthera philoxeroides*) (Video 50). The rest of the lake had sections of alligator weed (*Alternanthera philoxeroides*), water primrose (*Ludwigia peploides*) and waterlilies (*Nymphaea cultivars*) ranging from 2 - 5 m wide. The dense floating vegetation has shaded out large sections of the lake and rendered them unable to support macrophyte growth.



Video 50: The western arm of the lake choked with exotic lilies.



Photo plate 22: Southern bay choked with waterlilies.

Hornwort was sparsely distributed throughout the lake and primarily occurred as small clumps and single stems with covers of 1 - 5 % (Video 51). The overall plant condition is good with minimal signs of prolonged stress and almost no epiphytic coating.



Video 51: Representative hornwort growth indication low cover, short single stems & small clumps.

Dense beds of hornwort were found in discrete locations along the western bay near transect C (Video 52) and the southern bay near transect B (Video 53). In both cases hornwort formed a 10 m wide band along the upper littoral margin with almost 100% cover between 0.3 - 1.8 m deep. The maximum depth at which hornwort was detected was 2.9 m and the tallest stand reached 140 cm, the average height was 36 cm.



Video 52: Dense hornwort growth in the upper littoral zone along the western bank.



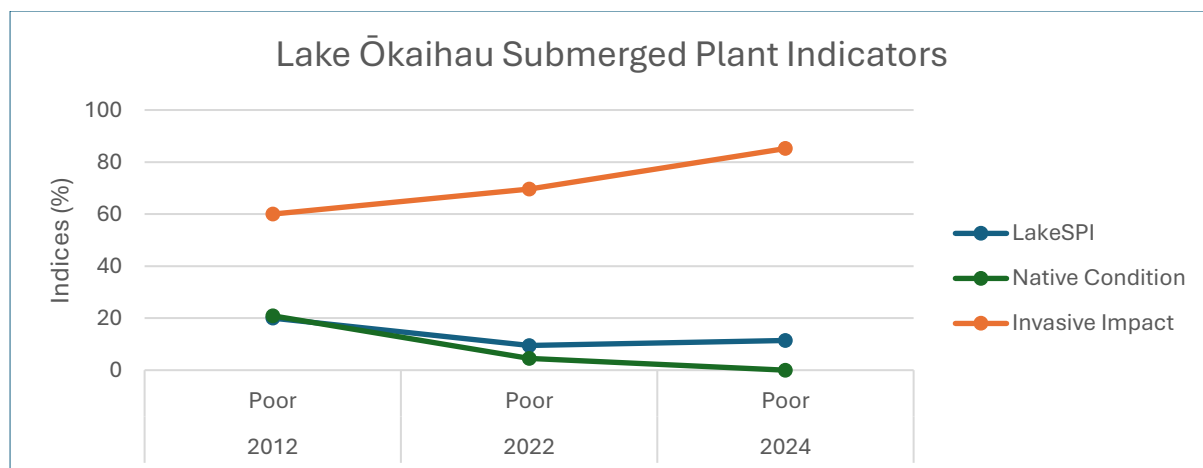
Video 53: Tall dense hornwort growth along the southern bay.

The floating vegetation has shaded out large sections of the lake, hornwort can still be found growing in the light wells amongst the waterlilies. Short, isolated stems were also found along the outer edge of the alligator weed band. The shading effect of the floating vegetation acts as a hornwort control measure and is preventing the expansion of this invasive species into the wider littoral margin. The lower vegetated depth extent is limited by photic depth and anoxia.

Lake Ōkaihou remains in a poor ecological condition with a LakeSPI Index of 10.91%, the 14.84% increase in the overall LakeSPI score is indicative of an improving state however, the trend across the three assessment (2012, 2022 & 2024) is not statistically significant (Figure 19). This increase and the 20.26% increase in the Invasive Impact Index were attributed to the increase in hornwort cover and extent along transects B and C.

A notable drop in the Native Condition Index from 4.5% in 2022 to 0% in 2024 is due to no native macrophytes being detected along the survey transects (Figure 19). Previous assessments mention remnants of charophytes, but none were found anywhere during the 2024 survey. The absence of native macrophytes have also contributed to the higher Invasive Impact Index of 83.70% calculated in 2024.

Egeria, charophytes and milfoils have all be lost since 2012 indicating that the lake is tracking toward a persistent poorly vegetated state with the potential to shift into a non-vegetated state if the pressures continue.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Poor	10.91	0	83.70
March 2022	Poor	9.5	4.5	69.6
February 2012	Poor	20	20.9	60

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	C

Figure 19: LakeSPI Indices for Lake Ōkaihou expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The absence of native submerged vegetation places the lake in a D band for the Native Condition Index attribute (Figure 19). The presence of hornwort throughout the littoral zone and the establishment of dense beds in discrete locations results in a C band for the Invasive Impact Index attribute (Figure 19). The potential expansion of hornwort could result in the Invasive Impact Index attribute dropping below the national bottom line if no control measures are implemented. It is unlikely that the Native Condition Index attribute will improve as the reduced photic depth, expansive floating vegetation and encroaching hornwort are limiting any native macrophyte recovery.

The high nutrient concentrations and poor water clarity restrict the photic zone, preventing extensive submerged vegetation growth. The absence of significant macrophyte beds has negative implications for the lake's ecological health, reducing habitat complexity and making the lake more susceptible to algal blooms. The expansion of floating vegetation further hinders the establishment of submerged vegetation, contributing to the lake's degraded condition. The alligator weed has displaced submerged macrophytes from the wetted edge to 1.2 m deep across the

majority of the lake perimeter, waterlilies have overrun entire bays and form floating rafts in the open water section of the lake.

Figure 20 indicates persistent alkalinisation of the surface water which is likely due to a large phytoplankton biomass. This suggests that the photic depth remains impeded throughout most of the year. Since 2022 acidic anoxic water extends from the deeper portions of the hypolimnion to near the surface during peak stratification (Figure 20). This almost surface reaching anoxia and reduced photic depth inhibits macrophyte growth and prevents natural regeneration from seed banks. If these conditions continue it is possible that the lake will transition into non-vegetated state.

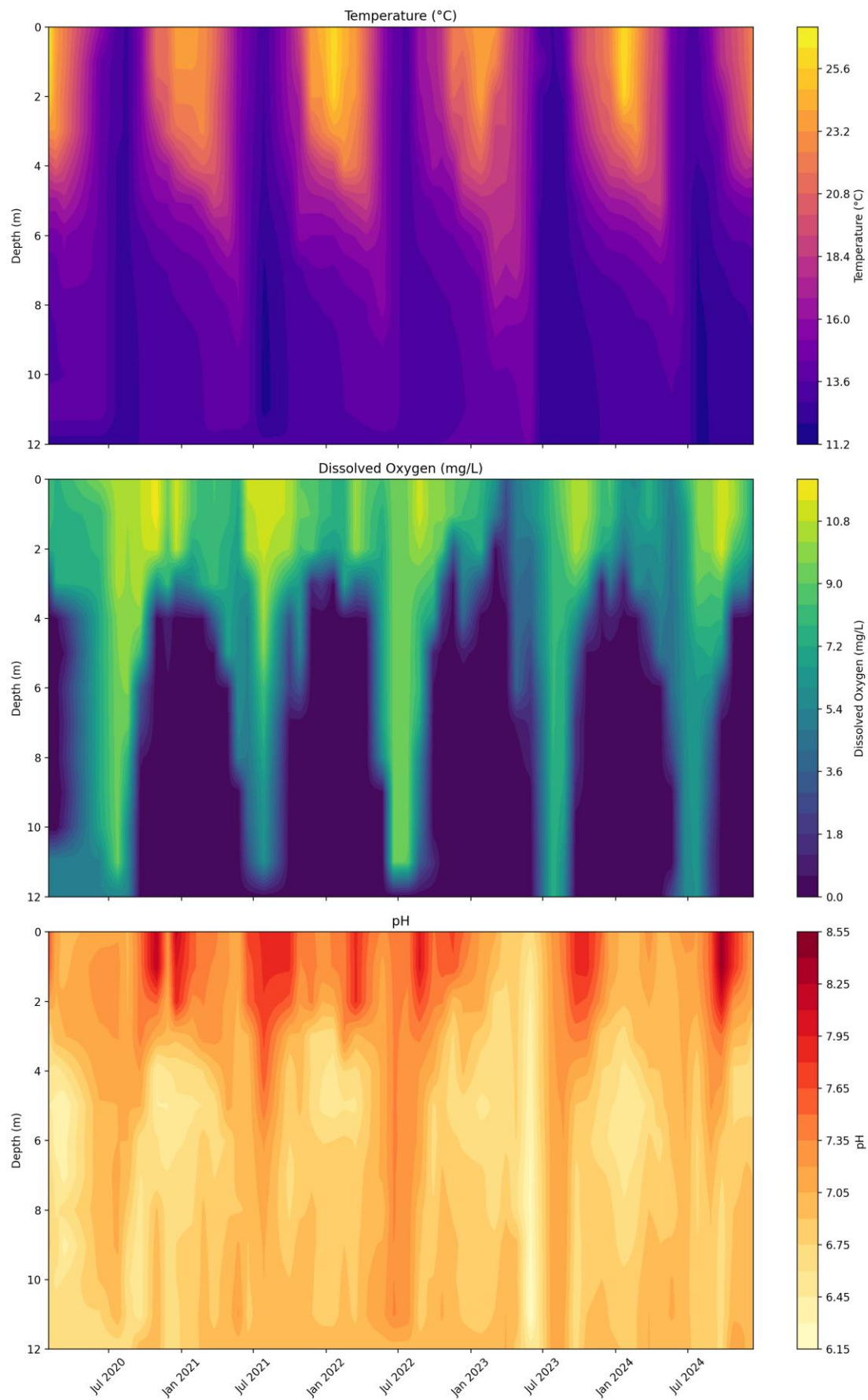


Figure 20: Lake Ōkaihou water quality profiles indicating recent seasonal patterns.

Threats

The primary threats to Lake Ōkaihou are related to water quality. The hornwort has not overrun the lake and appears to be contained to a few large beds and sparsely distributed stems. The floating vegetation is likely acting as a control measure preventing hornwort from expanding into the shallower bays. Controlling hornwort at this scale has been shown to be effective using diquat. The larger beds are confined, shallow, easy to access and are not coated with large amounts of organic/algal material which makes them ideal for diquat applications. The remaining growth is distributed across the shallow lake margin and controlled spraying at those depths is effective. Targeting hornwort growing amongst the floating vegetation will be challenging.

The expansion of exotic floating vegetation is a threat to the native biodiversity values however, they are still performing key ecosystem services such as nutrient assimilation, habitat provision and hornwort control. Controlling this exotic floating vegetation should be carefully considered as removing it could allow hornwort to increase in extent, a further consequence could be an increase in dissolved nutrients and persistent algal blooms.

The lake stratifies strongly, and large amounts of suspended organic matter were observed in the hypolimnion which indicates that a sizable internal nutrient source likely exists in the deeper central bowl. The seasonal stratification and the associated hypolimnetic deoxygenation likely cause periods of internal phosphorus loading. These internal nutrient loads combined with the catchment derived nutrients, originating from the surrounding grazed pasture, will continue to drive eutrophication in the system. An additional future concern is the potential use of large amounts of liquid fertiliser, commonly associated with maintaining golf greens. The underlying soil is porous, and the static water level is relatively shallow in the area. Regular applications of liquid fertiliser through irrigation systems could leach excess bioavailable nutrients into the lake and accelerate the eutrophication process.

The impacts of coarse fish exacerbate the issues by adding grazing pressure to the macrophytes and zooplankton while simultaneously adding nutrients to the system through excrement. They contribute to an increase in turbidity and the release of sediment bound nutrients through benthivorous feeding. Zooplanktivory reduces the

zooplankton biomass resulting in a reduction in grazing pressure on phytoplankton which allowing seasonal algal blooms to increase in size and frequency.

Considering the already shallow photic depth, high likelihood of internal loading and loss of submerged vegetation through time, Lake Ōkaihau is at risk of transitioning into a turbid non-vegetated algal dominant state. The potential for macrophyte recovery is limited due to excessive shading from floating vegetation and ongoing water quality degradation.

4.3.2 Lake Kawaupaku

Lake Kawaupaku

13/12/2024



Ecological Condition: Poor

Indices	Score	NPS-FM Attribute band
Native Condition Index	0%	D
Invasive Impact Index	88.2%	C

Summary

Lake Kawaupaku is in a poor condition with signs of possible further deterioration due to cyclone induced impacts and invasive species pressures. The lake is vulnerable to macrophyte collapse events and a sustained reduction to the maximum vegetated depth. No native macrophytes were observed and regeneration is unlikely considering the entire photic depth is colonised by *Egeria densa*, any localised regrowth will likely be grazed or uprooted by invasive fish before any significant establishment can occur.

Depth: 22 m
Size: 9.8 ha
Type: Dune

General Description



Photo plate 23: South facing view across Lake Kawaupaku indicating the steep native bush clad catchment.

Lake Kawaupaku is a 9.8-hectare coastal dune lake situated on the west coast of Auckland ($36^{\circ}53'39.7''\text{S}$ $174^{\circ}27'29.7''\text{E}$). This lake is classified as eutrophic, with a Trophic Level Index of 4.6 (Unpublished Auckland Council data, 2024). This lake is also prone to seasonal algal blooms which is reflective of its nutrient enriched state.

Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area, Outstanding Natural Character Area, Outstanding Natural Landscape and an Outstanding Natural Feature.

Lake Kawaupaku stratifies seasonally and has a maximum depth of 22 m. There are two natural streams associated with the lake, an inflow that enters the lake along the southeastern bank and an outflow that drains the lake along the northwestern bank.

Catchment Characteristics

The 82.2-hectare catchment surrounding Lake Kawaupaku consists entirely of native bush. Unlike most dune lakes in the region, the underlying geology surrounding Lake Kawaupaku is a volcanic conglomerate with limited porosity which means the lake is likely influenced by diffuse sheet flow rather than groundwater recharge.

The elevated trophic state of the lake is likely not related to the low impact catchment land use and could be a result of invasive species impacts. Large schools of rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) have caused a cascading collapse in ecosystem function which coupled with high covers of *Egeria densa*, have accelerated eutrophication processes.

Riparian Characteristics

The riparian zone surrounding Lake Kawaupaku is variable in width and quality, emergent vegetation formed a fragmented fringe along ~75 % of the lake edge with an average width of 0.5 - 3 m (Video 54). The northern and western banks feature a narrow strip of riparian vegetation, mostly consisting of raupō reedland and small patches of native sedges. The terrestrial vegetation extends from the surrounding slopes into the riparian margin and consists of native scrub and tall canopy species that often overhang into the lake (Video 54).



Video 54: Representative riparian margin with native scrub, overhanging trees and an emergent reed line.

The southeastern bay is bordered by a more extensive wetland system, with a 20 m wide zone of native scrub and wetland plants that helps to filter some contaminants before they reach the lake.

In general, the riparian width is narrow and provides limited buffering against nutrient and sediment runoff from the steep sloped sub-catchment. The native bush clad slopes have an organic rich topsoil with a thick layer of humus, which creates nutrient rich overland flow that drains into that lake during rainfall events.

Large areas of bare soil, collapsed banks and land slips were commonly seen across the steep slopes (Photo plate 24). The larger slips are a result of Cyclone Gabrielle (February 2023) however, there is evidence of historical erosional issues pre Cyclone Gabrielle. These erosional issues have created sizable deposits of sediment and organic matter along the littoral margin.



Photo plate 24: Cyclone induced land slips.

Biodiversity

Lake Kawaupaku supports moderate biodiversity and is home to several species of wetland birds, including the New Zealand dabchick (*Poliocephalus rufopectus*) and the grey teal (*Anas gracilis*), both of which are regionally significant. More than 10 pied shags (*Phalacrocorax varius*) were seen roosting on the overhanging vegetation, the localised concentration of faeces below the overhanging trees suggests that these vegetation features are commonly used by birds. Avian faeces was commonly seen throughout the lake and is indicative of a large resident bird population.

Native common bullies (*Gobiomorphus cotidianus*) are abundant in the lake (Video 55) and shortfin eels (*Anguilla australis*) have been detected (New Zealand Freshwater Fish Database). Invasive coarse fish, rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) are known to occur in high numbers however none were sighted during the 2024 assessment (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). Extensive benthic feeding pits on the lakebed as well as widespread grazing damage on the apical portion of the *Egeria* stems are indicative of a high coarse fish population.



Video 55: School of bullies in the shallow littoral zone.

In-lake description

The lake was stratified during the survey and had a distinct thermocline at 3.8 m. The visibility in the epilimnion was limited to 0.8 m and reduced to near zero in the deeper parts of hypolimnion where light penetration was absent.

A thick sulphide layer had formed above the thermocline between 2.7 - 3.7 m deep. This layer is likely a result of organic material settling on the denser cold water in the hypolimnion and decomposing. Entrainment of dinoflagellates into the lower portion of the thermocline contribute to the decomposing organic matter load trapped between the epilimnion and hypolimnion. Sulphide was also commonly seen near the base of dense *Egeria* beds where large amounts of plant material were decomposing. The avian faeces and detritus from the steep sub catchment add to the organic matter input and contribute to the persistent suspended sulphides seen in the littoral margin.

Cyclone induced landslides have altered the lakebed at the base of the large slips. Topsoil and sediment have buried submerged macrophytes and limited *Egeria* regrowth (Video 56). The substrate at the base of the slips consists of rock, sand and stone as well as large pieces of organic debris. Entire manuka, kanuka and pohutokawa trees were seen on the lakebed. The slips have also created a continuation of the surface slope so that the adjacent hill drops at a constant gradient toward the maximum lake depth, there is no shallow littoral plateau in these areas (Video 56).



Video 56: Substrate alterations & macrophyte burial/exclusion caused by land slips.

The substrate throughout the rest of the lake was soft with thick layers of organic floc and decomposing detritus. The substrate below the *Egeria* beds showed signs of persistent anoxia and had large amounts of decomposing plant material. Benthic algal mats were common (~75% cover) along the outer edge of the deeper *Egeria* beds (Video 57). The shallower sections of the lake had limited benthic algal growth however, epiphyton was seen coating macrophytes between 0.2 – 0.5 m deep.



Video 57: Benthic algal mats along the outer edge of the deep *Egeria* beds.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Kawaupaku (Figure 3). Additional investigations were conducted along representative sections of the lake to assess the impacts of Cyclone Gabrielle and the extent of the *Egeria densa* invasion.

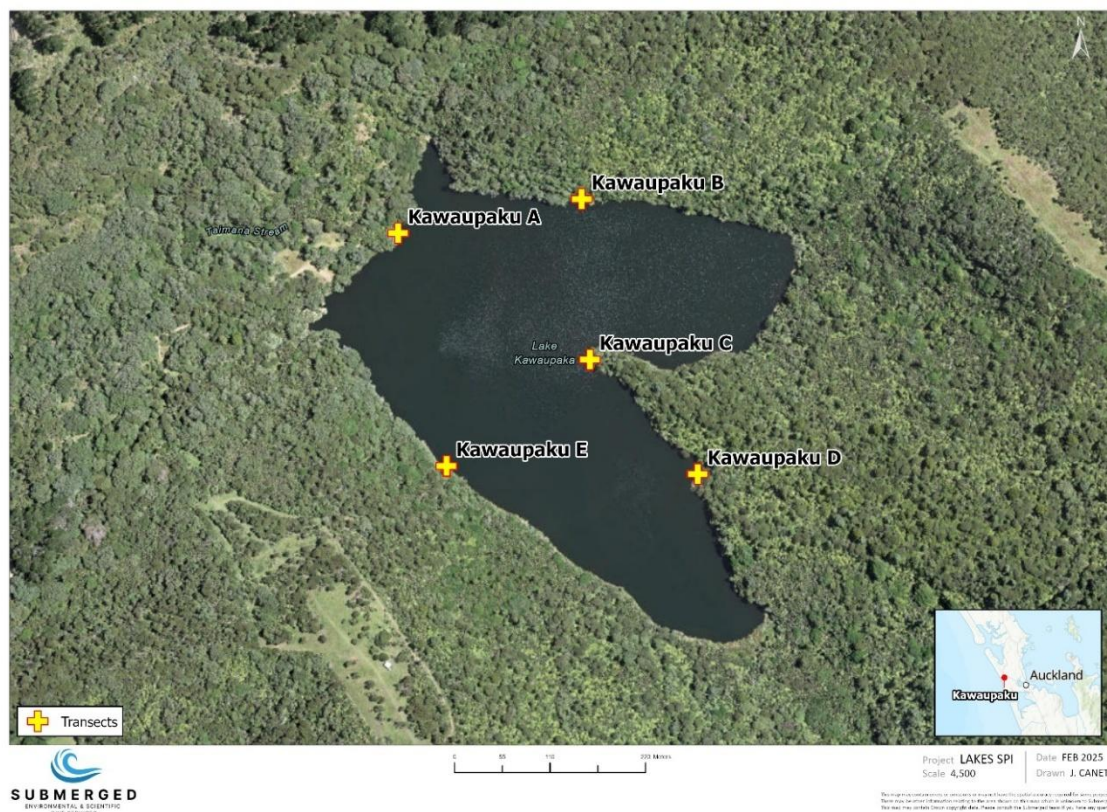
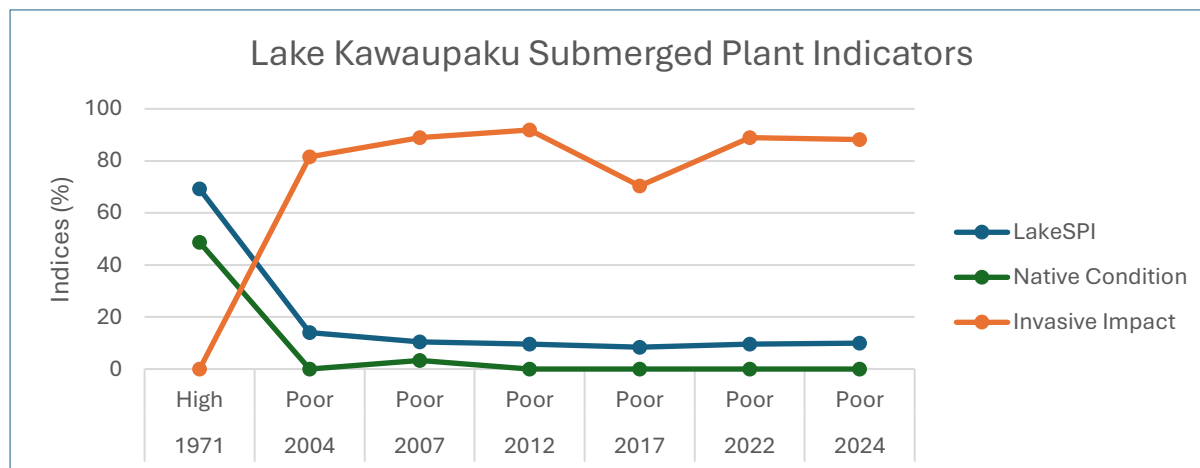


Figure 21: Lake Spectacle LakeSPI survey transects.

Lake Kawaupaku has been classified as being in a poor condition since April 2004 with similar LakeSPI scores indicating a stable state. This impacted state is largely due to the proliferation of invasive *Egeria densa* and the large pest fish biomass. No native macrophytes were observed and *Egeria densa* was the only macrophyte species recorded. A small patch of alligator weed (*Alternanthera philoxeroides*) was seen near transect D and it's likely that there are other discrete clumps across the lake edge.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Poor	10	0	88.15
March 2022	Poor	9.6	0	88.9
May 2017	Poor	8.4	0	70.4
February 2012	Poor	9.6	0	91.9
November 2007	Poor	10.4	3.3	88.9
April 2004	Poor	14	0	81.5
January 1971	High	69.2	48.7	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	D	C

Figure 22: LakeSPI Indices for Lake Kawaupaku expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The extent of the *Egeria* infestation is reflected in the Invasive Impact score of 88.15% and Native Condition score of 0% (Figure 22). These scores are consistent with the

2004 – 2022 assessments which indicate that the lake has been in a poor but stable condition for the past two decades.

The lack of native submerged vegetation places the lake in a D band for the Native Condition Index National Objectives Framework attribute (Figure 22). A C band was calculated for the Invasive Impact Index attribute due to the extent of *Egeria densa* however, the lake is close to slipping below the National Bottom Line of 90%. *Egeria* control would be challenging in Lake Kawaupaku, and the viability of a native seed bank is likely low. As a result, recovery into higher attribute bands is unlikely even with management interventions.

Egeria formed an almost continuous band along the littoral margin from 0.2 – 4.1 m deep with an average width of 10 – 15 m wide. In some areas the *Egeria* band extended up to 25 m out into the lake. The beds typically formed covers exceeding 75% with denser formations achieving 95 – 100% cover. The average height of the *Egeria* was 95 cm with taller stands reaching 2.5 – 3.5 m.

The general growth pattern consisted of dense short beds in the shallows (0.2 – 1.5 m) followed by dense taller beds between 1.5 – 2.5 m deep, the beds gradually became less dense toward the maximum vegetated depth of 4.1 m (Video 58). The reduction in density was offset by an increase in plant height with the tallest stems reaching almost 4 m high. This growth pattern is driven by the ambient light conditions and fluctuating water level.



Video 58: Representative transect from the lower macrophyte extent to surface.

The lower macrophyte extent is primarily limited by photic depth and possibly anoxia. Short dense beds form in the shallows where light availability is optimum, less dense but taller stands form along the mid-section of the photic zone where light availability allows for both tall mature plants and new shoots to grow. The deeper contours have prolonged periods of insufficient light over summer where algal blooms reduce the photic depth further, these conditions favour taller plants and limit the establishment of new growth.

The previous survey in 2022 recorded a maximum vegetated depth of 4.9 m which is 0.8 m deeper than the maximum vegetated depth recorded in the 2024 survey. It is assumed that this reduction in the maximum vegetated depth is either a result of natural variation or a consequence of the cyclone related impacts on water clarity. The lack of new shoots and shorter plants along the lower macrophyte extent is indicative of an increased susceptibility of a deep water macrophyte collapse. Despite the invasive nature of *Egeria densa*, the loss of macrophyte extent and biomass would result in cascading effects including a reduction in in-lake nutrient assimilation, sediment stabilisation and habitat provision.

As expected, the plant condition also worsened along the depth gradient. *Egeria* beds in the shallows were vibrant with firm stems, the deeper growth often appeared yellow in colour with foliage melting and soft stems. The section of *Egeria* along the edge of the emergent vegetation were covered (50 – 75%) with epiphyton which would ultimately lead to a drop in plant condition, however this was not widespread across the lake.

Cyclone induced landslides have impacted the upper macrophyte extent and in some part the entire vegetated depth profile. Sediment, rocks and organic debris have buried large *Egeria* beds with limited to no regrowth in areas where major slips had occurred (Video 59).



Video 59: Transect below a land slip indicating the impacts to the upper macrophyte extent.

Egeria regrowth was seen at the base of minor slips and along the outer edges of the major slips (Video 60), it is likely that the bare areas will eventually be colonised as the lakebed stabilises.



Video 60: Transect from the base of the slope to surface along the outer edge of a slip.

The Egeria beds are resilient to minor sediment inputs and organic matter deposition. Large deposits of woody debris, not associated with landslides, were commonly seen throughout the littoral margin and is a result of the steep loped sub-catchment. This deposition did not appear to limit the upper extent of the Egeria and dense beds had established amongst the debris (Video 61).



Video 61: *Egeria* amongst the woody debris & organic material along the lake edge.

Aside from the cyclone induced impacts, Lake Kawaupaku exhibits intense seasonal algal blooms, reflected by the strong seasonal alkalinisation of the surface water, and persistent anoxia that extends to ~2 m during peak stratification (Figure 23). These conditions limit the upper and lower macrophyte extent and would favour surface reaching species such as the invasive *Egeria densa*. The effect of this regulation is evident by the confined macrophyte growth and if conditions persist or worsen it is possible that a shallow water macrophyte collapse could occur. Recovery from such an event would be unlikely considering the in-lake condition would hamper natural macrophyte regeneration from seed banks.

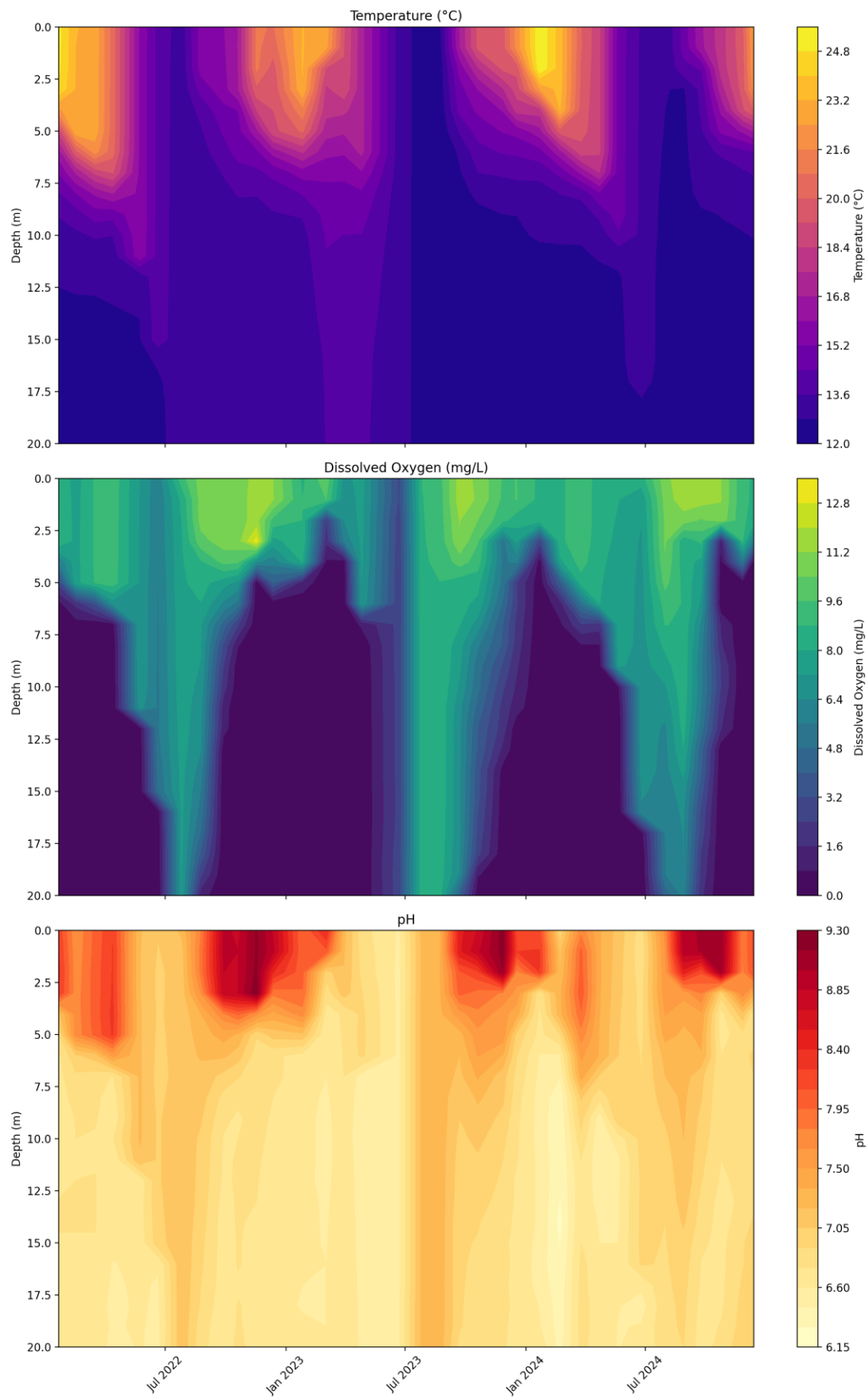


Figure 23: Lake Kawaupaku water quality profiles indicating recent seasonal patterns.

Threats

The primary threats to Lake Kawaupaku include extensive *Egeria densa* growth, cyclone induced impacts and the large biomass of coarse fish.

Egeria densa has dominated the littoral zone and occupied the majority of the photic depth in the lake. Similarly to hornwort, dense *Egeria* growth significantly impacts lake environments by altering water movement, sediment characteristics, increasing water temperatures, and causing diurnal fluctuations in oxygen and pH levels (Ejankowski & Solis, 2015, Staryer, 2010, Mazzeo et al., 2003).

Persistent anoxia was frequently observed within the dense *Egeria* bed, primarily caused by water stagnation, localised temperature increases, and the decomposition of organic material. This decomposition releases ammonia and alters the sediment REDOX potential, leading to the remobilisation of sediment bound phosphorus (Si et al., 2020). These combined factors have likely sustained the elevated trophic state and impeded native macrophyte regeneration. It is unknown if a viable native seed bank exists in the lake however, considering no signs of recent native macrophyte growth were observed, it is unlikely that native regeneration will occur if current conditions persist.

The impacts of Cyclone Gabrielle (February 2023) are long lasting and have resulted in transformative effects. The large influx of sediment, organic matter and nutrient rich topsoil has created significant in-lake nutrient stores. These nutrient sources fuel lake productivity and accelerate trophic succession toward a turbid algal dominant state. A consequence of this state is a reduction in photic depth which limits macrophyte growth and reduces the overall vegetation biomass. The lower macrophyte biomass results in higher concentrations of available nutrients due to a lower in-lake nutrient assimilation capacity and sediment stabilisation. The increase in dissolved nutrient availability promotes a higher algal biomass and continues to shift the system toward a high trophic state.

The impacts of coarse fish exacerbate this cycle by adding grazing pressure to the macrophytes and zooplankton while simultaneously adding nutrients to the system through excrement. They also contribute to an increase in turbidity and the release of sediment bound nutrients through benthivorous feeding. Grazing damage on the shallower *Egeria* beds was observed however it does not appear to have significantly

suppressed the growth. Zooplanktivory has likely had a greater impact, a reduction in the zooplankton biomass results in reduced grazing pressure on phytoplankton allowing seasonal algal blooms to exploit the high nutrient availability and increase in size and frequency.

4.4 Auckland City Lakes

Lake Pupuke was the only lake that was surveyed from this group. This deep volcanic lake it is the only lake of type in the region and, is located along the east coast in the North Shore suburb of Takapuna.

4.4.1 Lake Pupuke

Lake Pupuke

16/12/2024



Ecological Condition: Poor

Indices	Score	NPS-FM Attribute band
Native Condition Index	20.7%	C
Invasive Impact Index	84.4%	C

Summary

Lake Pupuke remains in a poor condition despite a notable increase in native macrophyte extent and cover. The lake is vulnerable to deep water macrophyte collapses and a sustained reduction to the maximum vegetated depth if the current pressures persist. The combination of invasive species impacts, internal nutrient loads and recreational activities places significant pressure on the lake. Efforts to prevent new invasive species incursions should be prioritised considering the lake is regularly used by people from the neighbouring regions.

Depth: 58 m
Size: 104 ha
Type: Volcanic

General Description



Photo plate 25: South Facing view across Lake Pupuke.

Lake Pupuke is the only volcanic crater lake in the region and is located in Takapuna, on the North Shore of Auckland ($36^{\circ}46'53.8''\text{S}$ $174^{\circ}45'57.4''\text{E}$). It is Auckland's most prominent urban lake and is a popular site for water sport activities, competitive events and general recreation.

Lake Pupuke is the deepest lake in the region with a maximum depth of 58 m. It is also the second largest lake in Auckland, spanning 103.8 hectares, following closely behind Lake Rototoa. Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Urban Lakes Management Area and an Outstanding Natural Feature.

Lake Pupuke is monomictic, with complex stratification occurring during the warmer months, followed by a mixing period in winter. The lake is classified as upper-mesotrophic, with a Trophic Level Index of 4 (Unpublished Auckland Council data,

2024). This trophic state is indicative of moderate nutrient levels that at times could reach more eutrophic conditions.

The lake has no natural overland in/outflows, however there are subterranean drainage channels that discharge onto the neighbouring coastline. Historically this lake served as a receiving environment for piped stormwater, but these point source discharges have since been decommissioned. Water levels are now primarily maintained through rainfall, diffuse overland flow and groundwater recharge.

Catchment Characteristics

The catchment area surrounding Lake Pupuke is highly urbanised, covering approximately 84.69 hectares, and includes residential and commercial developments in the Takapuna and Milford areas. The lake margin consists of residential properties and three large council reserves.

The urban land use and steep sloped sub-catchment results in substantial stormwater runoff entering the lake via diffuse overland flow, particularly after heavy rainfall events. However, the large volume and deep maximum depth of the lake helps dilute the immediate impacts of incoming containment loads.

Riparian Characteristics

The riparian zone around Lake Pupuke is fragmented due to the surrounding urban development. Much of the shoreline is bordered by residential properties, public parks, and roads, leaving limited room for contiguous sections of native vegetation (Photo plate 26). Exotic garden species and manicured lawns cover the majority of the riparian margin around the lake (Photo plate 26).



Photo plate 26: Modified riparian margins – *Top:* Residential properties with maintained gardens extending to the lake edge; *Bottom:* Public park with recreational amenities (bench & boat ramp) and manicured lawn extending to the lake edge.

There are some sections, particularly around Killarney Park and Sylvan Park, where large strips of intact riparian vegetation can still be seen, these areas provide a buffer zone between the urban environment and the lake (Video 62). Pockets of emergent reeds were seen in parts of the lake, and some have been integrated into the landscaping elements of the surrounding houses. The reeds don't form significant beds and often extend for only short distances.



Video 62: Intact riparian margin with mature vegetation along the southern lake edge.

The width of the vegetated riparian zones varies significantly, from narrow strips of just 1 - 2 m in residential areas to more substantial widths of 10 - 15 m in the public parks. These riparian areas provide some filtration of pollutants before they enter the lake, but the urban nature of the catchment and the extent of impervious surfaces limit the effectiveness of natural buffering.

Biodiversity

Despite its urban setting, Lake Pupuke supports a range of biodiversity and is a hot spot for birds. The lake is home to a variety of waterfowl, including black shags (*Phalacrocorax sulcirostris*), pied shags (*Phalacrocorax varius*), Australian coots (*Fulica atra australis*), pūkekos (*Porphyrio melanotus*), New Zealand scaup (*Aythya novaeseelandiae*) as well as a large population of black swans (*Cygnus atratus*) and Canadian geese (*Branta canadensis*).

The lake and its shoreline provide important habitat for both native and introduced species, although the anthropogenic nature of the surroundings limits the presence of more vulnerable or threatened species.

Fish species in Lake Pupuke include native shortfin eels (*Anguilla australis*) and common bullies (*Gobiomorphus cotidianus*), as well as introduced recreational fishing species like rainbow trout (*Oncorhynchus mykiss*) (New Zealand Freshwater Fish Database). Common bullies are the most abundant fish species in the lake and were seen at all survey depths (0 – 10 m) (Video 63). The lake also supports a variety of

invasive aquatic species ranging from high populations of coarse fish (perch, rudd and tench), goldfish, koi carp and red-eared slider turtles to high covers of exotic macrophytes like eel grass and *Egeria* (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). The presence of these introduced species has altered natural ecosystem dynamics and has contributed to the degraded lake condition.



Video 63: Common bullies amongst the shallow eel grass beds.

This lake was once a stronghold for the threatened freshwater mussels (*Echyridella aucklandica* and *Echyridella menziesii*) which have since become extinct from Lake Pupuke. Large beds of dead shells can be seen buried beneath a thin layer of silt along the lower boundary of the littoral zone.

In-lake description

The lake was stratified during the survey and had two distinct thermoclines, the first was a subtle temperature change at 3 m and the second was a dramatic change at 6 m deep. The visibility in the epilimnion was 6 m with very little suspended matter, the visibility dropped to near zero in the sulphide layer above the 6 m thermocline then increased again to 7 m in the hypolimnion. Light penetration in the hypolimnion was limited past 9 m however the water clarity was still good with minimal suspended matter.

The 0.5 m thick sulphide layer above the thermocline (5 – 5.8 m deep) is a common feature of the lake during spring and summer. The decomposition of suspended

organic material settling in the metalimnion on top of the denser cold hypolimnion is the likely cause of this lake wide sulphide layer. Entrainment of dinoflagellates, particularly ceratium species, into the metalimnion as they migrate diurnally contribute to the decomposing organic matter load in this layer. Sulphide precipitate was occasionally seen near the base of dense *Egeria* beds where large amounts of plant material were decomposing.

The substrate in the shallows along the northern and western banks was hard rock and firm sand with a 5 cm surficial layer of soft silt. The eastern and southern banks had a softer substrate with 30 cm of silt before the consolidated sandy base. The deeper sections of the lake (> 6 m) had a thick layer of fine silt and organic floc more than a metre deep.

The areas under the *Egeria* and *Vallisneria* beds exhibited signs of persistent anoxia, the substrate was black with a > 1m thick layer of organic floc and had benthic algae. Benthic algal mats with more than 75% cover were common past the maximum macrophyte depth extent and along the outer edge of the deep water charophytes (Video 64).



Video 64: Benthic algal mats along the lower macrophyte extent.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Pupuke (Figure 24). Additional investigations were conducted along representative sections of the lake as part of a wider biosecurity surveillance effort focused on identifying new incursion.

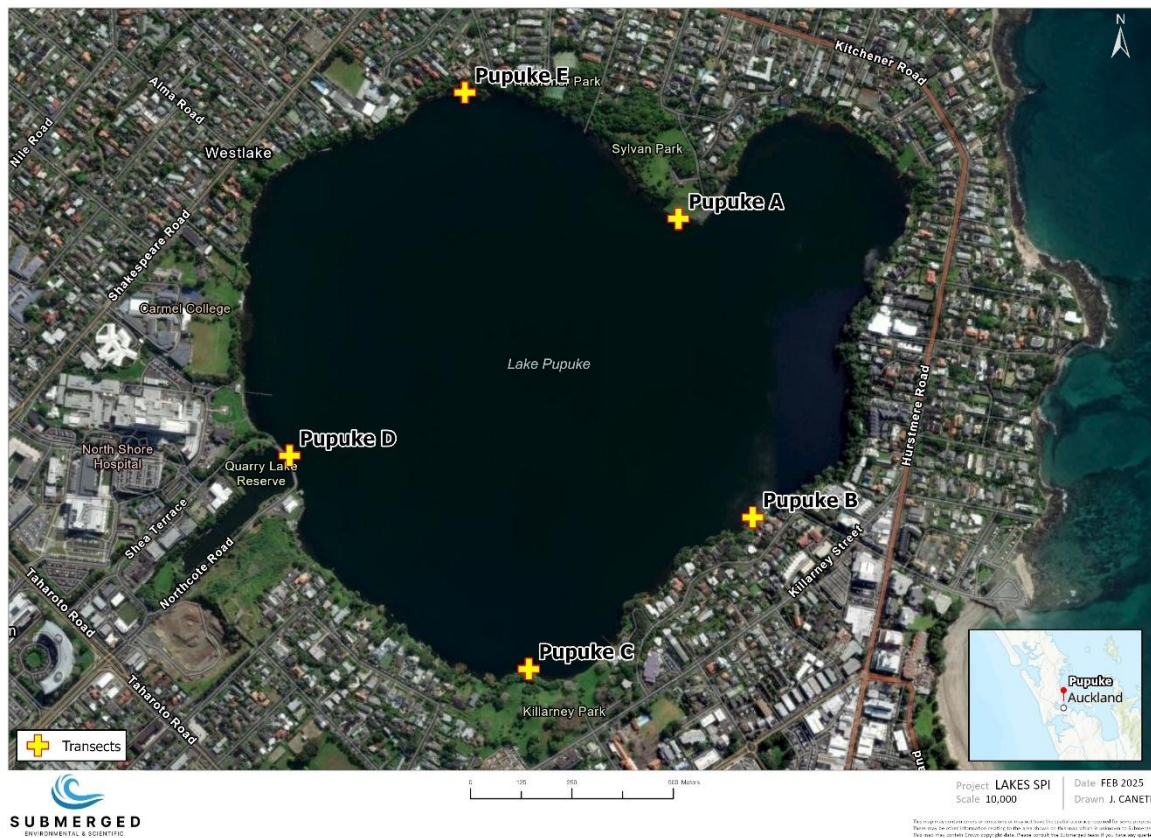


Figure 24: Lake Pupuke LakeSPI survey transects.

The submerged vegetation in Lake Pupuke follows a similar establishment pattern along most of the littoral zone.

The vegetation assemblage typically consists of a 2 - 5 m wide band of *Myriophyllum triphyllum* with a short *Vallisneria australis* understory in the shallows (0.5 – 1 m) (Video 65), a 15 - 20 m wide band of taller *Vallisneria australis* with small clumps and isolated stems of *Egeria densa* extends from 1 – 2.5 m deep, *Egeria densa* then forms a dense wide (20 – 50 m) band of tall growth from 2.5 – 7 m deep (Video 66). In some areas the *Egeria densa* band extends up to 100 m wide. The outer edge of the maximum vegetated extent (6.5 – 7.7 m) is dominated by *Chara australis* with isolated stems and small clumps of *Egeria densa* (Video 67).



Video 65: Band of *Myriophyllum triphyllum* with a short *Vallisneria australis* understory in the shallows.



Video 66: Extensive *Egeria densa* beds.



Video 67: Deep water *Chara australis* beds with low covers of *Egeria densa*.

Vallisneria australis was the tallest growing species reaching heights of 3 – 4.5 m, *Egeria densa* formed similarly tall stand but the average maximum height was slightly shorter and ranged from 2 – 3.5 m tall. The average lake wide height for *Vallisneria australis* was 160 cm and 139 cm for *Egeria densa*.

The macrophyte condition was good throughout the vegetated depth profile and the only significant damage noted was a result of grazing by black swans. The swans appear to target the *Vallisneria australis*, creating large sections of trimmed vegetation (Video 68).



Video 68: *Vallisneria australis* with apical damage from grazing swans.

The invasive species (*Vallisneria australis* & *Egeria densa*) are the dominant macrophyte and form a 50 – 75 m wide band along 80% of the lake perimeter. Several *Lagarosiphon major* clumps were seen along the Sylvan Park boat ramp area and a single stem of *Potamogeton crispus* was observed on Transect E. These species have been sighted before and have been reducing in extent over time however, *Lagarosiphon major* was commonly seen amongst the *Vallisneria australis* near the Sylvan Park boat ramp (Video 69).



Video 69: *Lagarosiphon major* amongst the *Vallisneria australis* near the Sylvan Park boat ramp.

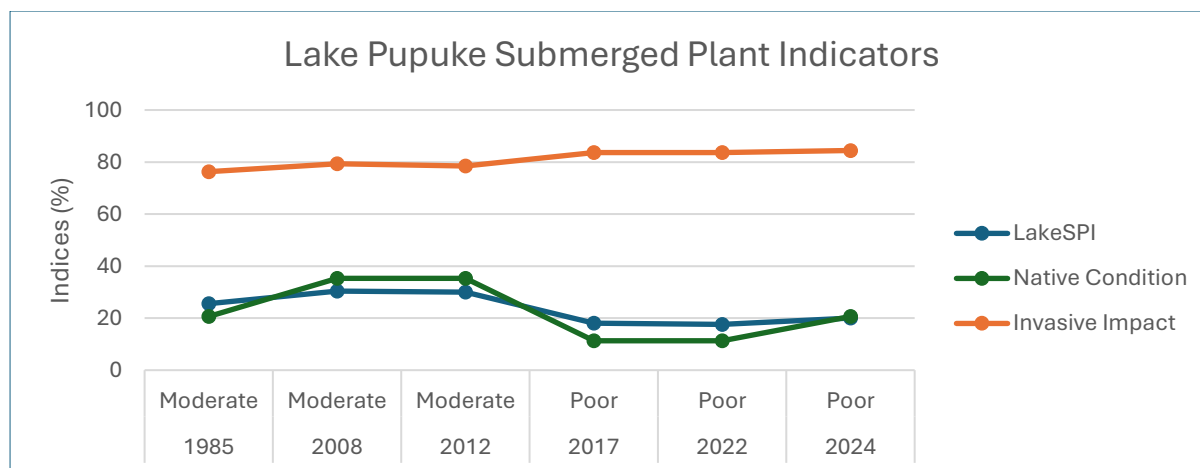
The 2024 LakeSPI assessment classified the lake as being in poor ecological condition, which is consistent with the previous assessments (2017 - 2022) however, the overall LakeSPI score of 20% puts Lake Pupuke on the cusp of improving to a moderate ecological classification (LakeSPI score > 20%) (Figure 25). This 13.64 improvement is due to a notable increase in the Native Condition Index, from 11.3% in 2022 to 20.67% in 2024, resulting from the increased presence of charophytes. Previous assessments noted sparse charophyte cover along only two of the survey transects whereas the 2024 assessment recorded charophytes along all survey transects. In addition to the increased extent and cover of charophytes, an increase in diversity was also observed. *Chara australis* was the dominant charophyte however patches of *Chara globularis*, *Nitella sp. aff. Cristata* and *Nitella hyalina* were seen at several locations around the lake. *Nitella hyalina* and *Chara globularis* were only found in low covers (< 5%) in the shallows along Sylvan Park, west of the boat ramp (Photo

plate 27), and *Nitella sp. aff. Cristata* was found amongst the *Chara australis* bed but never exceeded 15% cover.



Photo plate 27: Discrete clump of *Nitella hyalina* near the wetted edge around Sylvan Park.

The invasive macrophyte (*Vallisneria australis* & *Egeria densa*) dominated state places Lake Pupuke in the upper limit of the C band for the Invasive Impact Index attribute (Figure 25). The recent increase in native macrophyte cover, extent and diversity have resulted in a C band for the Native Condition Index attribute however, the score is 20.67% which is marginally above the National Bottom Line of 20%. These attribute bands are indicative of a lake that is prone to band switching. If a relatively minor reduction in the native vegetation extent and/or a marginal expansion in the invasive species extent occurs the lake will slip below the national bottom line.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Poor	20	20.67	84.44
April 2022	Poor	17.6	11.3	83.7
May 2017	Poor	18	11.3	83.7
April 2012	Moderate	30	35.3	78.5
October 2008	Moderate	30.4	35.3	79.3
June 1985	Moderate	25.6	20.7	76.3

Native Condition Index		Invasive Impact Index
NOF Attribute Band	C	C

Figure 25: LakeSPI Indices for Lake Pupuke expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The formation of a metalimnion sulphide layer creates acidic anoxic conditions with an increase in ammonia, which could be limiting the establishment of macrophytes deeper than 7 m (Figure 26). Considering the highest concentration of native vegetation occurs between 6 – 7.2 m deep, the reducing lower macrophyte extent will impact native species to a higher degree than the invasives. Since 2021 there appears to be a slight reduction in the extent and intensity of the anoxic metalimnion, resulting in less encroachment into the shallow littoral zone (< 10 m) (Figure 26). An increase in the summer alkalinization of the surface water indicates a possible intensification of seasonal algal blooms (Figure 26). These conditions imply the recent decline in the maximum vegetated depth extent is likely influenced by a seasonal reduction in photic depth to a greater extent than the impacts of hypolimnetic deoxygenation.

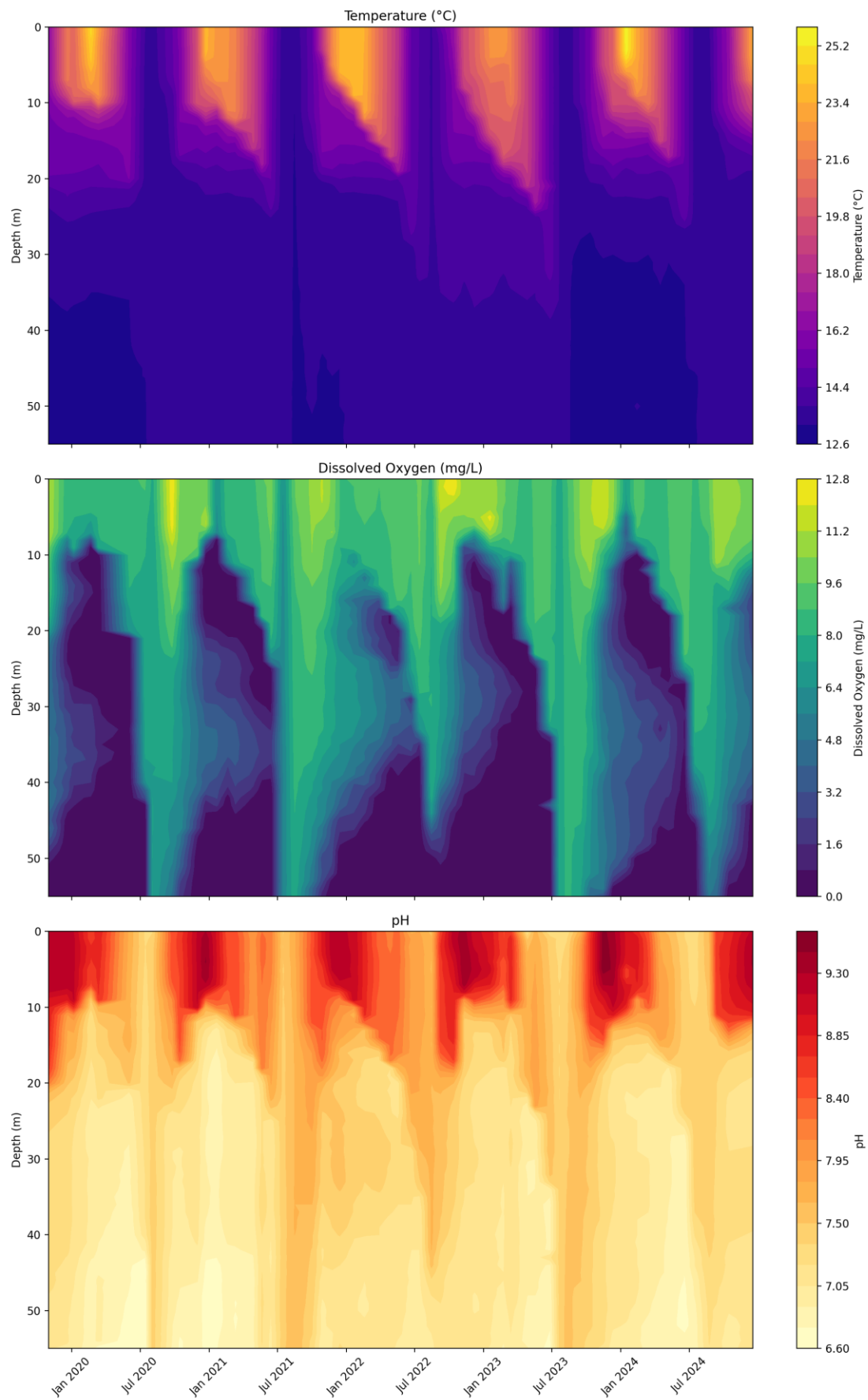


Figure 26: Lake Pupuke water quality profiles indicating recent seasonal patterns.

Threats

The primary threat to Lake Pupuke is the high biomass of invasive species. *Egeria densa* and *Vallisneria australis* dominate the littoral zone and *Egeria densa* occupies most of the photic depth in the lake. Dense invasive macrophyte growth significantly impacts lake environments by altering water movement, sediment characteristics, increasing water temperatures, and causing large diurnal fluctuations in oxygen and pH levels.

The tall, fast-growing nature of these invasive macrophytes as well as the alterations they cause to the substrate and water quality conditions inhibit native macrophyte regeneration. A viable native seed bank is evident by the native re-growth in the lake however, if the invasive species continue to dominate and the photic depth is reduced it is likely that the deep water charophytes will be placed under increasing strain.

Controlling invasive macrophytes should be carefully considered as these species continue to provide ecosystem services/functions including nutrient assimilation, lakebed stabilisation and habitat creation. Removing large quantities of these invasive macrophytes could cause adverse effects on water quality. If control is being considered, a carefully planned staged removal along with a native macrophyte regeneration plan is recommended.

Exotic coarse fish add grazing pressure to the macrophytes and zooplankton while simultaneously adding nutrients to the system through excrement. They also contribute to an increase in turbidity and the release of sediment bound nutrients through benthivorous feeding, feeding pits were commonly seen along the lakebed. Grazing damage on the *Egeria* beds was observed however it does not appear to have significantly suppressed the growth. Zooplanktivory has likely had a greater impact, a reduction in the zooplankton biomass results in reduced grazing pressure on phytoplankton allowing seasonal algal blooms to exploit the high nutrient availability and increase in size and frequency.

The potential introduction of additional invasive species is a significant risk in Lake Pupuke. The lake is routinely used for a variety of recreational activities along the many public access areas. This recreational amenity draws users from across the region as well as from neighbouring regions which presents several biosecurity pathways. The lake is already home to a variety of invasive species and the

introduction of aggressive species such as hornwort, golden clam, grass carp and catfish could push the system into a rapid decline. Considering the recreational value of the lake it is important to manage the biosecurity pathways and avoid the introduction of any additional stressors. The increase in *Lagarosiphon major* noted around the Sylvan Park boat ramp during the 2024 survey is an example of how invasive species might establish in the lake. A *Lagarosiphon major* delimitation survey is recommended as the current population appears to be at a scale where hand removal will effectively control the expansion of this species. Regular surveillance of the public access boat ramps is also recommended so that new incursions are detected and contained early.

The waterfowl population creates several impacts on the lake. The high biomass generates significant amounts of excrement that contribute to the in-lake nutrient load. The swans also graze on the shallow native milfoils and uproot large clumps of *Vallisneria australis* and *Egeria densa*. This uprooted vegetation often accumulates along the bank and decomposes which adds to the nutrient loads but also creates unpleasant odours.

Fluctuations in water quality is a continuous concern for the lake, the catchment derived nutrient load is likely low comparatively to the size and depth of the lake however, the internal nutrient load will be high (Waters & Kelly, 2019). The morphology of the lake and large macrophyte biomass provides a high buffering capacity and as a result, a high degree of resilience to trophic state changes. If a tipping point is passed, the lake will deteriorate rapidly and assume a new stable degraded state. Targeted tracking of nutrient loads (internal and external) and ecological shifts should be done to detect subtle changes and develop lake specific management plans that prevent further degradation.

4.5 Āwhitu Lakes

The Āwhitu Lakes consist of a series of shallow to moderately deep dune lakes along the west coast of the Āwhitu peninsula. Lakes Pokorua and Whatihua were the only two lakes from this complex that were surveyed during the 2024 assessment.

4.5.1 Lake Pokorua

Lake Pokorua

08/12/2024



Ecological Condition: High

Indices	Score	NPS-FM Attribute band
Native Condition Index	70.7%	B
Invasive Impact Index	50.4%	C

Summary

Lake Pokorua is dominated by native species, including charophytes, pondweeds, and milfoils, but invasive species like *Elodea canadensis* and *Egeria densa* pose significant threats. *Elodea* dominates deeper areas with dense beds displacing native charophytes. Key threats include the potential expansion of invasive macrophytes, nutrient enrichment from agricultural runoff and the large waterfowl population. In the absence of interventions, these impacts could destabilise in-lake conditions and prompt declining trends in lake health.

Depth: 3.6 m

Size: 26 ha

Type: Dune

General Description



Photo plate 28: North facing view across Lake Pokorua indicating the pastoral sub-catchment.

Lake Pokorua is a shallow coastal dune lake situated on the Āwhitu Peninsula approximately 2 km inland from the west coast ($37^{\circ}11'34.7''\text{S}$ $174^{\circ}37'57.7''\text{E}$). The lake has an area of 26 hectares, and a current maximum depth 3.6 m. Under the Auckland Unitary Plan (operative in part) this lake is classified as a Natural Lakes Management Area, Outstanding Natural Feature and High Natural Character Area.

The lake is classified as supertrophic, with a Trophic Level Index (TLI) of 5.5 indicating extremely high in-lake nutrient levels and poor water quality (Unpublished Auckland Council data, 2024). This shallow lake is identified as polymictic due to the frequent mixing driven by the prevailing westerly winds.

Pokorua, is the largest of the Āwhitu Peninsula dune lake complex and forms part of a critical ecosystem corridor across the peninsula. This spatial connectivity underscores its importance, with the lake connecting to dune ecosystems, remnant forest ecosystems and significant ecological wetlands. The lake receives inflow from

four modified farm drains distributed around its perimeter. It has one artificially maintained outflow, approximately 2 km in length, that drains to the west coast.

Catchment Characteristics

The catchment area surrounding Lake Pokorua covers approximately 559.7 hectares and consists of pastoral land with patches of native scrub and wetland. The catchment land use remains largely unchanged since 1985, with only small-scale afforestation occurring.

The sandy soils (sandy brown and sandy ultic) are typical of the Āwhitu Peninsula and allows for rapid surface water drainage. The porosity of the underlying geology and high impact land use results in elevated nutrient loads being delivered to the lake during high flow events.

The areas directly adjacent to the lake are flat, however the wider catchment and sub-catchment consist of steep sloped pasture, with large areas of active erosion and bare earth (Video 70). The steep nature of the sub-catchment contributes to the high volume of nutrient laden sheet flow that enters the lake. The riparian buffers vary in quality and offer limited contaminant attenuation along large sections of the lake edge.



Video 70: Steep sloped sub-catchment with pasture dominant land cover.

Riparian Characteristics

The riparian zone surrounding Lake Pokorua exhibits significant variability in both width and condition, with the riparian setback ranging from as narrow as 5 metres to

over 100 metres in some areas. Vegetation within the riparian areas comprises a mix of exotic and native grasses, alongside mānuka and kānuka scrub (Video 71 & Video 72). The sparse terrestrial vegetation in these margins provides limited protection against nutrient and sediment runoff from the surrounding land use and some areas have signs of stock access and bank erosion (Video 71).



Video 71: Poor condition riparian margin with exotic grass extending into a band of emergent reeds. Bank erosion & signs of previous stock access can be seen along the lake edge.

Large sections of the lake perimeter (75 – 80%) are bordered by a wide 10 – 15 m band of contiguous emerged reeds that extend into the lake to a maximum depth of 1.8 m (Video 72). These reed lines provide good contaminant buffering and habitat for waterfowl.



Video 72: Wide band of emergent vegetation creating an intact riparian margin.

The riparian margins along the outlet stream are intact and have good vegetation assemblages ranging from emergent reeds to mature terrestrial species (Video 73). The outlet stream provides good nesting habitat for wetland birds.



Video 73: Riparian margins along the outlet stream.

Biodiversity

Lake Pokorua supports a variety of native species including threatened and at-risk avifauna. According to Schedule 2 of the Auckland Unitary Plan (operative in part) the North Island Fern Bird (*Poodytes punctatus*), Australasian bittern (*Botaurus poiciloptilus*) and New Zealand dabchick (*Poliocephalus rufopectus*) reside at the lake. Common waterfowl species also frequent the lake and have established large resident populations. More than 50 Canadian geese (*Branta canadensis*), black swans (*Cygnus atratus*) and paradise shelducks (*Tadorna variegata*) were sighted during the 2024 survey.

Several native fish species including common smelt (*Retropinna retropinna*), common bullies (*Gobiomorphus cotidianus*), shortfin eels (*Anguilla australis*) and banded kokopu (*Galaxias fasciatus*) are also known to inhabit the lake (New Zealand Freshwater Fish Database). No pest fish species have been identified in the lake and no suspicious species were sighted during the survey.

Common bullies were abundant during the 2024 survey and several shortfin eels were observed. A variety of macroinvertebrates including *Potamopyrgus antipodarum*,

water boatmen, dragonfly larvae and beetle larvae were common amongst the shallow charophyte meadows.

Historic sightings of freshwater mussels (*Echyridella menziesii*) have been reported by local landowners and iwi. Targeted searches were done along the areas where historical records had noted established beds and where vegetation cover would permit bed establishment however, no evidence of existing or historic mussel populations were found.

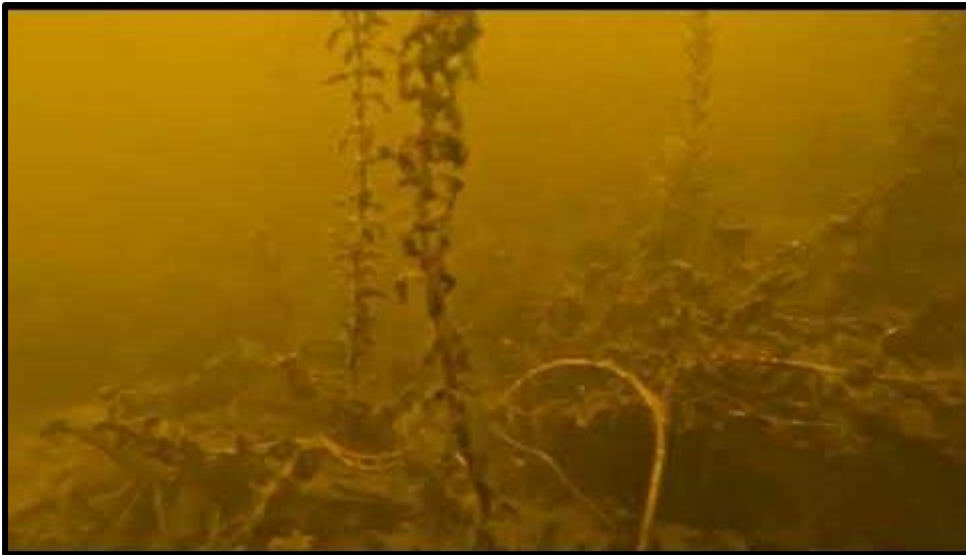
In-lake Description

The lake was isothermal during the survey with a consistent temperature of 22°C throughout the water column.

The visibility was 1.5 – 2 m and reduced in areas with localised sulphide precipitate. There was limited suspended organic matter and the brown hue in the water was largely attributed to tannins, phytoplankton and wind induce sediment resuspension. The sulphide precipitate seen in Lake Pokorua could be a result of the decomposition of organic material.

The substrate in shallow less vegetated areas had a 15 cm layer of organic floc and fine silt with a firm consolidated sandy base, this changed to thicker, soft grey mud with a surficial layer of organic silt below the charophyte meadows. Large amounts of bird faeces were seen throughout the lake and is likely a significant contribution of nutrients and *E. coli* concentrations.

Benthic algal mats were scarce to absent along the shallow lake margin (0 – 1 m). Benthic algal mats became increasingly common on the macrophytes from 1.3 m to the maximum depth of 3.6 m where it formed thick coatings over large sections of charophyte meadows (Video 74).



Video 74: Benthic algal mats covering macrophytes in the deeper sections of the lake.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Pokorua (Figure 27). Additional investigations were conducted along representative sections of the lake to assess general lake health and the influences of various riparian and sub-catchment typologies.

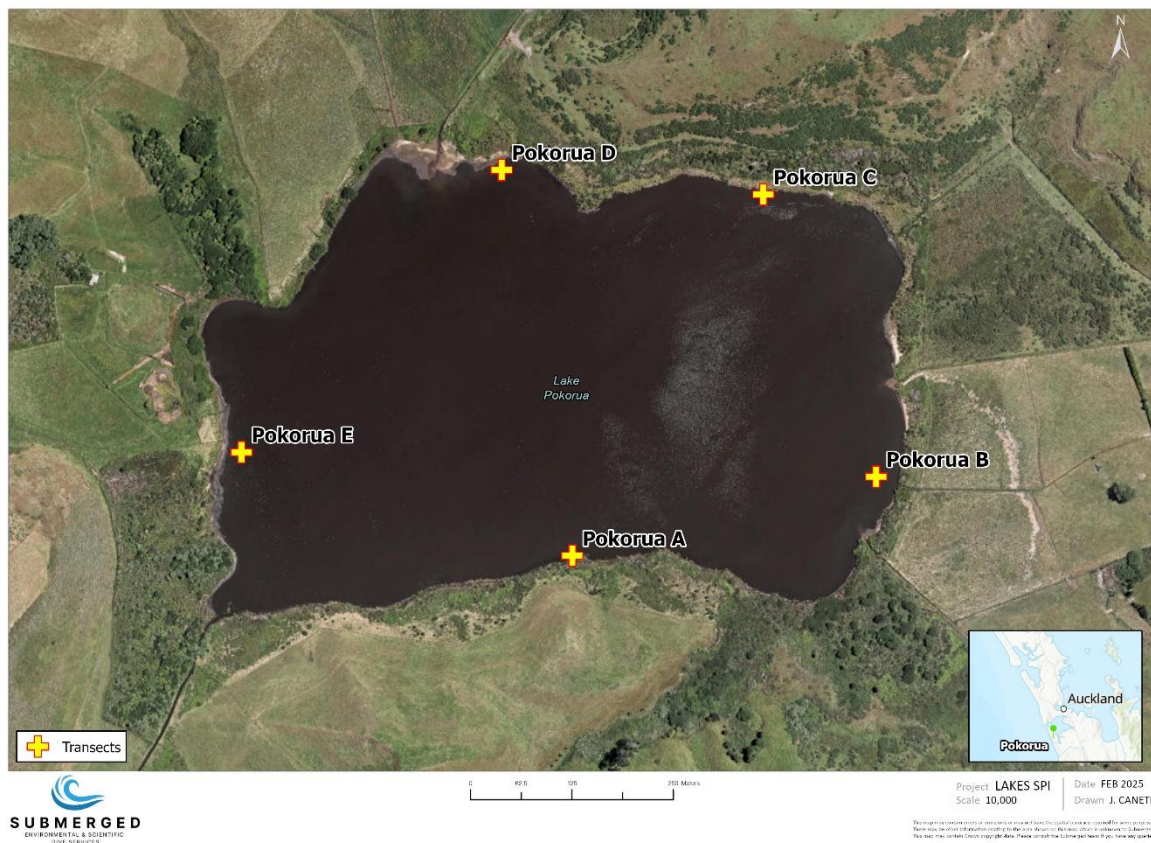
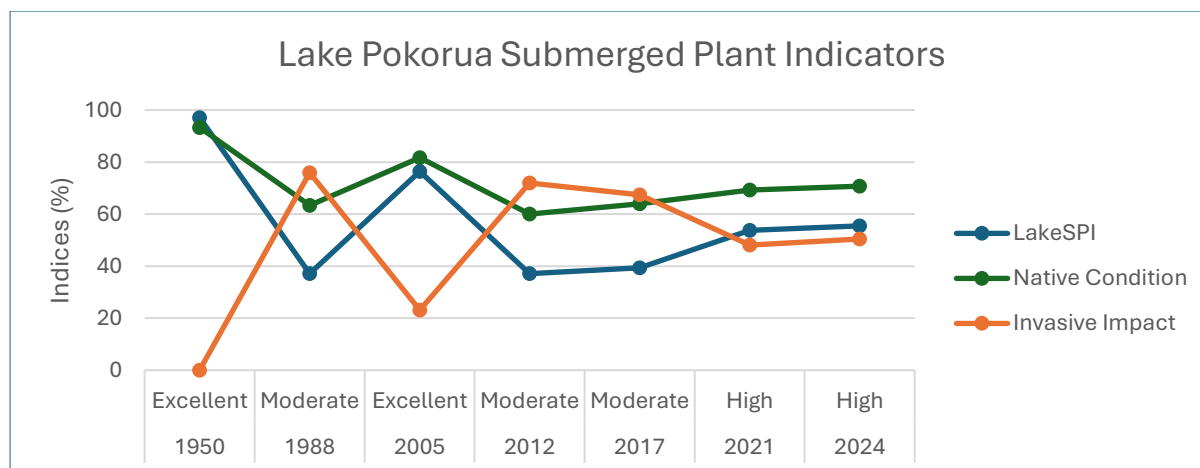


Figure 27: Lake Pokorua LakeSPI survey transects.

Lake Pokorua has been in a high ecological condition since 2021 with similar LakeSPI scores across both the 2022 and 2024 assessments which is indicative of a stable state (Figure 28). The high ecological condition is a result of the high native macrophyte diversity and extent. The lake is almost completely vegetated with a maximum depth of 3.6 m and a vegetated depth extent of 2.7 m. Majority of the vegetated depth consists of native charophytes, milfoils and pondweeds with relatively low levels of invasive species.

The high native species diversity and cover has resulted in a B band for the Native Condition Index National Objectives Framework attributes (Figure 28). The Invasive Impact Index attribute is in a C band due to the widespread establishment of *Elodea canadensis* and to a lesser degree *Egeria densa* (Figure 28). The invasive macrophytes are currently at a scale where control through herbicide application and hand removal is viable. A reduction in the invasive macrophyte biomass could result in improved attribute bands.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	High	55.43	70.67	50.37
December 2021	High	53.7	69.3	48.1
March 2017	Moderate	39.4	64	67.4
April 2012	Moderate	37.1	60	71.9
August 2005	Excellent	76.4	81.7	23.1
April 1988	Moderate	37.1	63.3	75.9
January 1950	Excellent	97.1	93.3	0

Native Condition Index		Invasive Impact Index
NOF Attribute Band	B	C

Figure 28: LakeSPI Indices for Lake Pokorua expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The general vegetation establishment pattern starts with emergent vegetation from 0.1 - 0.6 m deep then shallow charophytes with short milfoils from 1.5 - 2 m followed by a dense band of pondweed and taller milfoils from 2 – 2.5 m, the deeper sections (> 2.5 m) are dominated by dense beds of Elodea amongst the charophyte meadows with tall stands of pondweed.

Myriophyllum triphyllum, *Chara australis* and *Nitella sp. aff. Cristata* were the dominant species in the shallows (0.2 – 1 m) and frequently reached covers of 75 - 100 % (Video 75 & Video 76).



Video 75: Representative shallow macrophyte profile.



Video 76: Dense charophyte bed in the shallow littoral zone.

Elodea canadensis was present amongst the shallow charophyte meadows however, the achieved cover was lower than observed in the deeper portion of the lake. The apical tips of the *Myriophyllum triphyllum* and *Elodea* along the upper littoral margin had grazing damage from swans (Video 77).



Video 77: *Myriophyllum triphyllum* with apical damage cause by grazing swans

The swans appear to be regulating the growth of tall macrophytes in the shallows and have caused a concentration of *Elodea* in the deeper central part of the lake where it achieved covers of > 85% (Video 78).



Video 78: Dense *Elodea* & *Egeria* bed in the deeper central portion of the lake

The average lake wide *Elodea* cover was estimated at 25 - 30% of the vegetated areas which is a substantial mass considering the size of the lake. Isolated stems and small stands of *Egeria densa* were occasionally seen amongst the *Elodea* beds but never reached covers exceeding 5%. Both *Elodea* and *Egeria* formed dense canopies where present in high covers, pondweeds (*Potamogeton cheesemanii* & *Potamogeton ochreatus*) were the only native species that were able to establish amongst the dense invasive growth. These species are able to compete due to their fast growth and tall

stature. Shorter native charophytes were displaced and pushed to the outer fringes of dense invasive macrophyte beds.

Lake Pokorua has one of the highest native species diversities in the region with four charophyte species (*Chara australis*, *Chara globularis*, *Nitella sp. aff. Cristata* & *Nitella hyaline*), two pondweeds (*Potamogeton cheesemanii* & *Potamogeton ochreatus*), one milfoil (*Myriophyllum triphyllum*), *Ruppia polycarpa* and saline tolerant *Zannichellia palustris*. No turf species were found, the dense emergent reed band occupies the area of the wetted edge where turf species typically occur and the areas with no emergent vegetation had beds of exotic *Ludwigia palustris*, signs of stock access, variable water level and grazing from waterfowls, all of which impact the establishment of turf communities.

The majority of the lakebed is vegetated, and maximum vegetated depth has increased from 2.2 m to 2.7 m. This increase in macrophyte extent could be a result of an increase in water level at the time of the 2024 survey however, the vegetated extent has not receded which is indicative of a stable state. The extent and impact of invasive species (*Egeria densa* & *Elodea canadensis*) has also fluctuated over time but appears to have stabilised since 2021 with a marginal increase (4.67 %) in the Invasive Impact score between 2021 and 2024.

Threats

One of the primary threats to Lake Pokorua is the potential expansion of invasive *Elodea canadensis* and *Egeria densa*. *Elodea* is the dominant invasive species and is generally considered to have less of an impact than *Egeria*. If conditions shift to favour *Egeria densa* it is possible that this aggressive species could overrun the lake. Dense invasive macrophyte growth can significantly impact lakes by outcompeting native species, altering water movement, changing sediment characteristics, increasing water temperatures, and causing large diurnal fluctuations in oxygen and pH levels. Lake Pokorua is shallow enough that herbicide applications would be effective however, careful consideration should be given to the size of the treatment area to avoid excessive amounts of decomposing plant material. Sustained control is possible using a combination of herbicide application and manual methods (hand removal and smothering).

The large waterfowl population presents a threat and a benefit to the lake. These birds deliver high concentrations of nutrients into the lake via excrement however, the swans appear to be regulating the expansion of *Elodea* and *Egeria* through grazing. Reducing the waterfowl population is advised however invasive macrophyte monitoring and control should be done in tandem.

The surrounding agricultural catchment generates significant nutrient loads that enter the lake. The high macrophyte biomass in the lake is assimilating a large portion of the available nutrients however, water quality monitoring indicates that the lake is supertrophic. If conditions change or significant climatic events occur that cause a macrophyte collapse, it is likely that this lake will rapidly shift toward a turbid devegetated state.

Most of the lakebed is shallower than 3 m which makes fluctuations in water levels a concern. Persistent low water level conditions could reduce the upper macrophyte extent while simultaneously concentrating the in-lake nutrients. Constant fluctuations in water level have also been linked to increased phosphorus remobilisation from shallow sediment (Yuan et al., 2021).

Stock exclusion, invasive macrophyte control and riparian enhancement should be implemented as an immediate way to reduce incoming nutrient loads and maintain riparian functions. These interventions need to be done alongside wider catchment and in-lake management to have a significant impact. The enhancement potential in Lake Pokorua is high, invasive macrophyte control will likely result in an increase in native cover and an upliftment of the NPS-FM macrophyte attribute bands.

4.5.2 Lake Whatihua

Lake Whatihua

08/12/2024



Ecological Condition: Moderate

Indices	Score	NPS-FM Attribute band
Native Condition Index	30.8%	C
Invasive Impact Index	75.6%	C

Summary

Lake Whatihua is dominated by dense beds of invasive *Egeria densa*. While native pondweed persists, charophytes and turf species have declined significantly with reduced diversity and extent. The dense *Egeria* growth alters in-lake conditions and further hinders native macrophyte regeneration. Additional threats include nutrient inputs from pastoral runoff and waterfowl, invasive fish disrupting zooplankton grazing on phytoplankton, and the risk of introducing additional invasive species such as hornwort or grass carp.

Depth: 11 m
Size: 3.9 ha
Type: Dune

General Description



Photo plate 29: Eastern view across Lake Whatihua.

Lake Whatihua is situated on the Āwhitu Peninsula, southwest of Auckland (37°16'31.7"S 174°40'11.6"E). This small coastal dune lake is approximately 3.9 hectares with a maximum depth of 11 m. Under the Auckland Unitary Plan (operative in part) this lake is classified as a Significant Ecological Area, Natural Lakes Management Area and an Outstanding Natural Landscape.

Like many monomictic dune lakes in the region, Lake Whatihua is sensitive to environmental pressures and is susceptible to algal blooms during the warmer stratification period. The lake is classified as eutrophic, with a Trophic Level Index (TLI) of 4.7, indicating elevated nutrient levels that have led to reduced water quality (Unpublished Auckland Council data, 2024). Despite these challenges, Lake Whatihua remains an important natural feature of the peninsula, providing ecological value and opportunities for recreation.

The lake is primarily fed by rainwater, diffuse overland flow and groundwater recharge, with no significant natural surface inflows or outflows.

Catchment Characteristics

The 37.01-hectare catchment surrounding Lake Whatihua consists entirely of pastoral land used for livestock grazing. This land use has contributed significant nutrient loads to the lake, particularly during periods of heavy rainfall where sheet flow laden with sediment and nutrients drain into the lake. The coastal sandy soils typical of the Āwhitu Peninsula allow for rapid surface water infiltration which subsequently leads to nutrient loads entering the lake through groundwater recharge.

The majority of the lake is bordered by a narrow non-contiguous band of emergent reeds and patches of native scrub. The steep sided slopes adjacent to the lake margin are largely pastoral in nature with little to no native vegetation. The northern arm of the lake is fringed by a small wetland area. The eastern lake margin transitions into a larger wetland feature that gradually changes into mature manuka/kanuka scrubland.

These wetland areas provide some degree of filtration and nutrient attenuation however, their extent and effectiveness are limited due to the surrounding high impact land use.

Riparian Characteristics

The riparian zone around Lake Whatihua is fragmented and variable in quality. On the northern and western sides, the riparian buffer is narrow, averaging just 2 - 3 m in width, with a mix of exotic grasses and scattered native plants.

This limited buffer offers little protection from nutrient and sediment runoff originating from the adjacent pasture. In contrast, the southeastern and southern shores of the lake feature a more intact riparian zone, with wider bands of native vegetation, including raupō, harakeke (flax), and manuka (Photo plate 30). These areas, with riparian margins of 10 - 15 m in width, offer better protection against runoff and help stabilise the shoreline.

Several areas along the northern bank had signs of stock access, areas of pugging were also seen along the wetted edges of the lake in these areas. Stock access

appears to be permanently restricted, so it is assumed the browsing and pugging is a result of accidental access or historic access.

The overall fragmentation and narrow, poorly vegetated state of the riparian margins around much of the lake provide limited ecosystem functions however, active riparian restoration is underway on the northern bank. While the existing vegetation is still in its early stages and not yet providing measurable water quality benefits, it is expected to contribute to improved ecological function as it matures.



Photo plate 30: Southern shore featuring a more intact riparian margin.

Biodiversity

Lake Whatihua supports moderate biodiversity, although the eutrophic condition of the lake has impacted both the abundance and diversity of species. The lake provides habitat for a range of wetland birds, including pūkeko (*Porphyrio melanotus*), pied shags (*Phalacrocorax varius*) and the grey teal (*Anas gracilis*). The surrounding wetlands are important feeding and nesting grounds for native bird species, though the degraded water quality limits the lake's ability to support more sensitive or

threatened species. The most common waterfowl sighted during the survey were Canadian geese (*Branta canadensis*) and paradise shelducks (*Tadorna variegata*). Large flocks of these birds were seen utilising the lake and the surrounding paddocks. Native fish species, such as shortfin eels (*Anguilla australis*) and common bullies (*Gobiomorphus cotidianus*) were sighted during the survey and bullies were abundant across all survey depths (0 – 9 m). However, the presence of invasive species such as mosquito fish (*Gambusia affinis*) and koi carp (*Cyprinus rubrofuscus*) pose a threat to native fish populations (New Zealand Freshwater Fish Database, Auckland Council unpublished data, 2022). Fish & Game also actively stock the lake with rainbow trout (*Oncorhynchus mykiss*) and the lake is part of a network of recreational fishing sites across the region.

Evidence of historic mussel populations were found in several areas along the maximum vegetated depth extent (5 – 6 m) with a concentration along the southern boundary. Targeted searches were done along the areas where historical records had noted mussel beds and where vegetation cover would permit bed establishment. No signs of live mussel populations were observed in the target areas. The intact shells that were found were classified as *Echyridella menziesii*.

In-lake Description

The lake was stratified during the survey with a surface temperature 22°C and bottom temperature of 19°C below the thermocline at 4 m deep, there was a subtle temperature drop to 18°C past 6 m deep.

The epilimnion had a lot of suspended matter and visibility was limited to 0.2 – 0.5 m. The visibility increased to 4 m below the thermocline and there was noticeably less suspended matter. This is likely due to the suspended organic matter being contained in the epilimnion that sits on top of the denser cold hypolimnion. Wind induced mixing of this surface layer creates a turbid epilimnion. There was a 1 m thick mid-water sulphide layer between 3 – 4 m deep, which is a result of this organic matter accumulating above the hypolimnion and decomposing (Video 79). The visibility through this layer was near zero and it effectively shielded almost all light from penetrating into the hypolimnion (Video 79).



Video 79: Transect through the deep central bowl toward the outer macrophyte extent & into the sulphide layer.

The substrate amongst the emergent reeds and the areas of shoreline that had limited vegetation was sandy with a hard consolidated base. The substrate on the steep sloped southern boundary had a 15 cm layer of organic floc and fine silt on top of a consolidated sandy base. The substrate past the maximum vegetated depth extent was loose and consisted of a thick (>1 m) layer of soft organic floc and silt, no consolidated layer could be found in the deeper sections of the lake (Video 80). There were signs of persistent anoxia and large amounts of decomposing organic matter beneath the dense *Egeria* beds which formed a loose black substrate covered in benthic algal mats.



Video 80: Loose unconsolidated substrate in the deep central bowl.

Decomposing *Egeria densa* was also observed along the edge of the maximum vegetated depth extent however no sulphide residue or benthic algal mats were seen in the deeper section of the lake.

The high concentration of suspended matter, poor water clarity and dense establishment of tall fast growing invasive species have excluded short native submerged macrophytes from the littoral zone and regeneration is unlikely if conditions remain the same.

Submerged Vegetation

LakeSPI assessments were done along five survey transects in Lake Whatihua (Figure 29). Additional investigations were conducted along targeted section of the lake in an attempt to locate historic freshwater mussel beds and to assess the extent of the *Egeria* invasion.

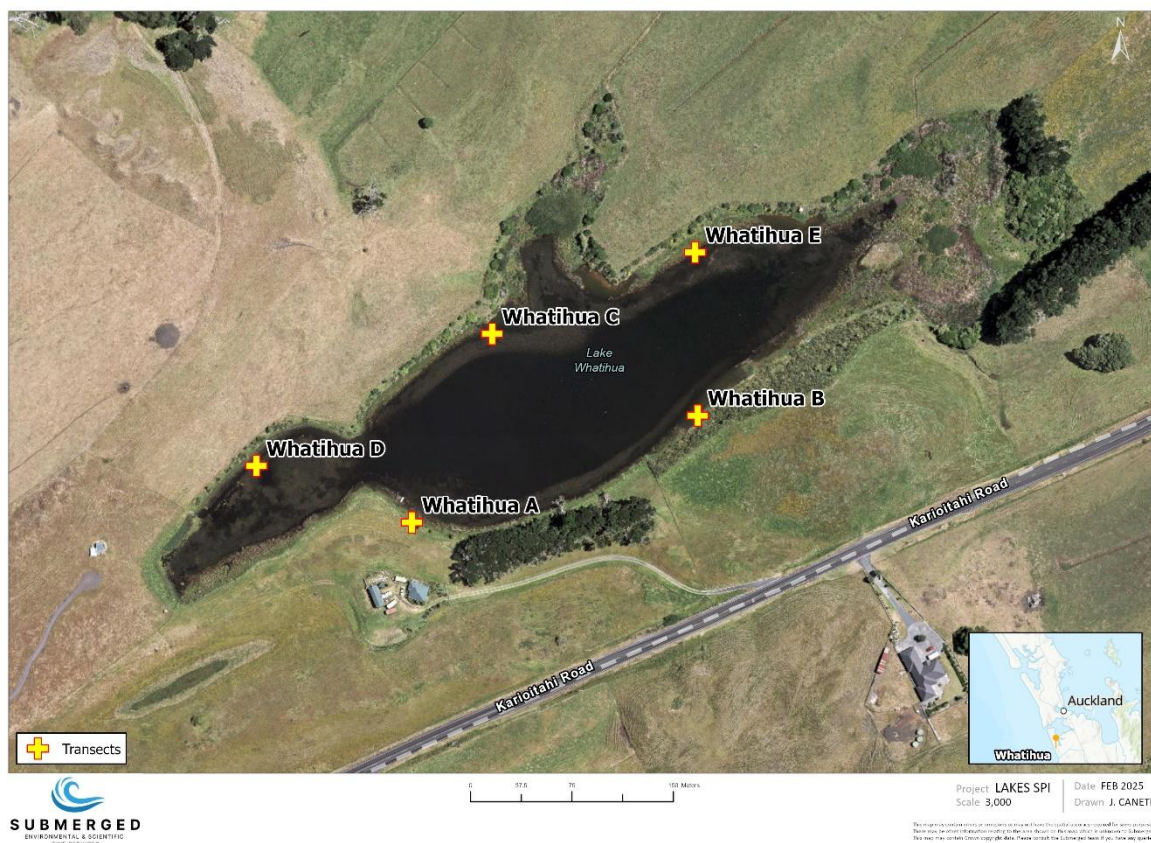


Figure 29: Lake Spectacle LakeSPI survey transects.

The submerged vegetation in Lake Whatihua is dominated by dense beds of invasive *Egeria densa* and tall stands of native *Potamogeton ochreatus*.

The general vegetation establishment pattern in Lake Whatihua begins with a 1 – 15 m wide band of emergent reeds that extends to 2.7 m deep followed by a think band of *Egeria densa* (~70 m) with *Potamogeton ochreatus* stems dispersed throughout (Video 81). The *Potamogeton ochreatus* forms a 20 – 30 m wide belt along the upper edge of the thermocline before transitioning into another 20 m wide *Egeria densa* dominant area that extends to the maximum vegetated depth of 4.7 m (Video 81). Overall, there is a ~120 m vegetated band that runs along the outer edge of the emergent reed line.



Video 81: Transition from dense *Egeria* bed into pondweed belt.

Potamogeton ochreatus generally formed the tallest sections of canopy where present in high cover and was surface reaching along the upper littoral margin (Photo plate 31). The pondweed canopy was not dense enough to shade out the *Egeria* and the understory was still dominated by dense *Egeria* growth (Video 82). The maximum height recorded for *Potamogeton ochreatus* was 4 m tall, but the lake-wide average was 1.9 m. The maximum *Egeria densa* height was 3.8 m which is shorter than the tallest stand of *Potamogeton ochreatus* however, the average *Egeria densa* height was taller with most stands reaching 2.4 m.



Photo plate 31: Surface reaching *Potamogeton ochreatus* along the northern bank.



Video 82: Canopy of native pondweed with an *Egeria* dominated understory.

Transect D was the only transect with more than one native species. It had a discrete bed of *Chara globularis* from 0.5 - 0.8 m with a maximum height of 22 cm and the average bed height was 20 cm (Photo plate 32). The bed had a cover of > 90% but the transect wide cover was 1 – 5%. Small clumps of *Nitella hyalina* were seen between 0.5 – 0.6 m with some of the taller stems reaching 18 cm, the average height was 8 – 12 cm, this species never reached covers over 1 – 5 %. *Myriophyllum triphyllum* was also seen along Transect D and was sparsely distributed with a maximum cover of 15% and an average cover of <5% along the transect. Tall stems reached 1.8 m in the deeper sections however most of the growth was between 30 – 50 cm tall.



Photo plate 32: Discrete bed of *Chara globularis* along the start of Transect D.

Small stands/single stems of *Elodea canadensis* was seen amongst the dense *Egeria densa* beds however, this species never exceeded 5% cover. Single strands of

Utricularia gibba and small aggregations of *Azola pinnata* were also seen amongst the emergent vegetation along the southern lake margin.

Lake Whatihua has been classified as having moderate ecological condition since 2005 and it remains in that state in 2024 however, there has been a 22.58% decrease in the LakeSPI score since the previous survey in 2021 which indicates the lake is currently in a declining state (

Figure 30). This is largely a result of a 35.16% decrease in the Native Condition and a reduction in the maximum vegetated depth extent from 5.1 m (> 10% cover) in 2021 to 4.7 m in 2024. The 2021 assessment noted scattered plants to a maximum of 6.1 m deep and during the 2024 assessment no plants were seen deeper the 5 m.

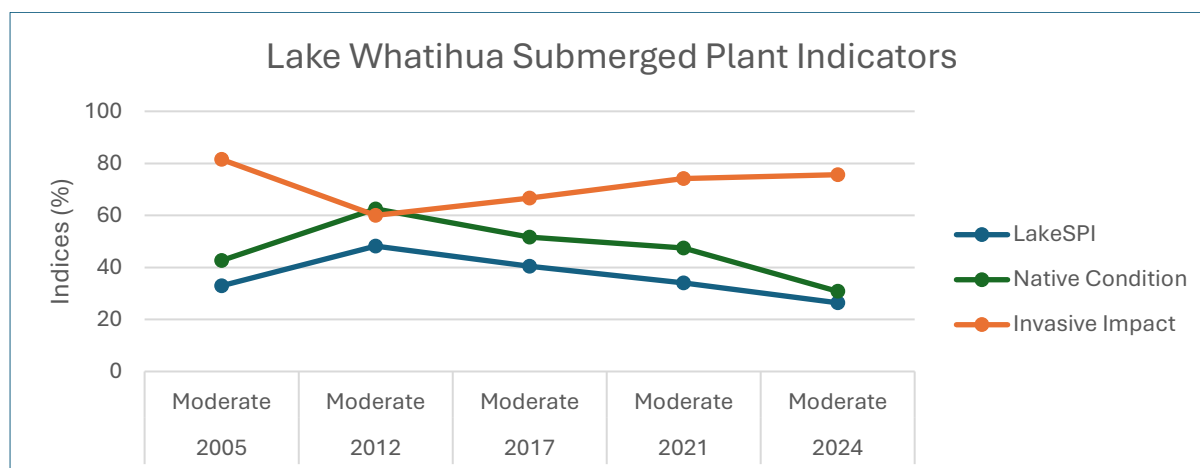
Charophytes were only observed along one of the survey transects in 2024 which also contributed to the lower Native Condition Index. The high occurrence of native pondweed across the lake and the relatively deep extent is responsible for maintaining the moderate ecological status.

The large *Egeria* biomass is offset by the high native pondweed cover resulting in a C band for both the Native Condition Index and Invasive Impact Index National Objectives Framework attributes

Figure 30). The macrophyte assemblage appears to have reached an equilibrium between the tall fast growing *Potamogeton ochreatus* and the denser shorter growing *Egeria densa*. As a result, it is likely that the attribute bands will remain stable if current conditions persist. There is however a risk that both bands will drop below the national bottom line if the maximum vegetated depth continues to recede. *Egeria* control could result in an increase in the attribute bands as there is a viable native seed bank however, the extent of the infestation makes control challenging. The mixed assemblage of pondweed and *Egeria* means that any herbicide application will impact both species, pondweed tends to recover quickly but the scale of the *Egeria* means re-colonisation of control areas is likely.

Lake Whatihua is an unusual example of an *Egeria* dominated lake that retained good native vegetation diversity over a decade. A total of 5 native submerged species were

recorded in 2024, 10 species in 2021 and 2005 (Champion & de Winton, 2005; de Winton et al., 2021), 14 species in 2012 and 13 in 2017. The 2024 assessment found no native turf species and a reduced charophyte diversity which is indicative of pressures in the upper littoral margin. Fluctuating water levels and wind induced turbulence resulting from Cyclone Gabrielle (February 2023) could have contributed to a disruption in shallow macrophyte assemblages.



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
December 2024	Moderate	26.4	30.8	75.6
December 2021	Moderate	34.1	47.5	74.1
March 2017	Moderate	40.5	51.7	66.7
April 2012	Moderate	48.2	62.5	60
August 2005	Moderate	33	42.7	81.5

	Native Condition Index	Invasive Impact Index
NOF Attribute Band	C	C

Figure 30: LakeSPI Indices for Lake Whatihua expressed as a percentage of the maximum potential value and National Objective Framework attribute bands.

The ongoing reductions in the maximum vegetated depth over recent successive surveys are likely a result of an expanding hypolimnion. Figure 31 indicates that since 2020 acidic anoxic water regularly encroaches into the shallow littoral zone (< 4 m) over the stratification period. Seasonal pH fluctuations (Figure 31) are difficult to interpret, due to the large biomass of surface reaching macrophytes, but a reduction in photic depth because of nutrient enrichment and subsequent algal blooms is likely

to be a contributing factor to the receding macrophyte extent. It is likely that the lake is declining in ecological condition with a high probability of further reductions in vegetated extent and species diversity.

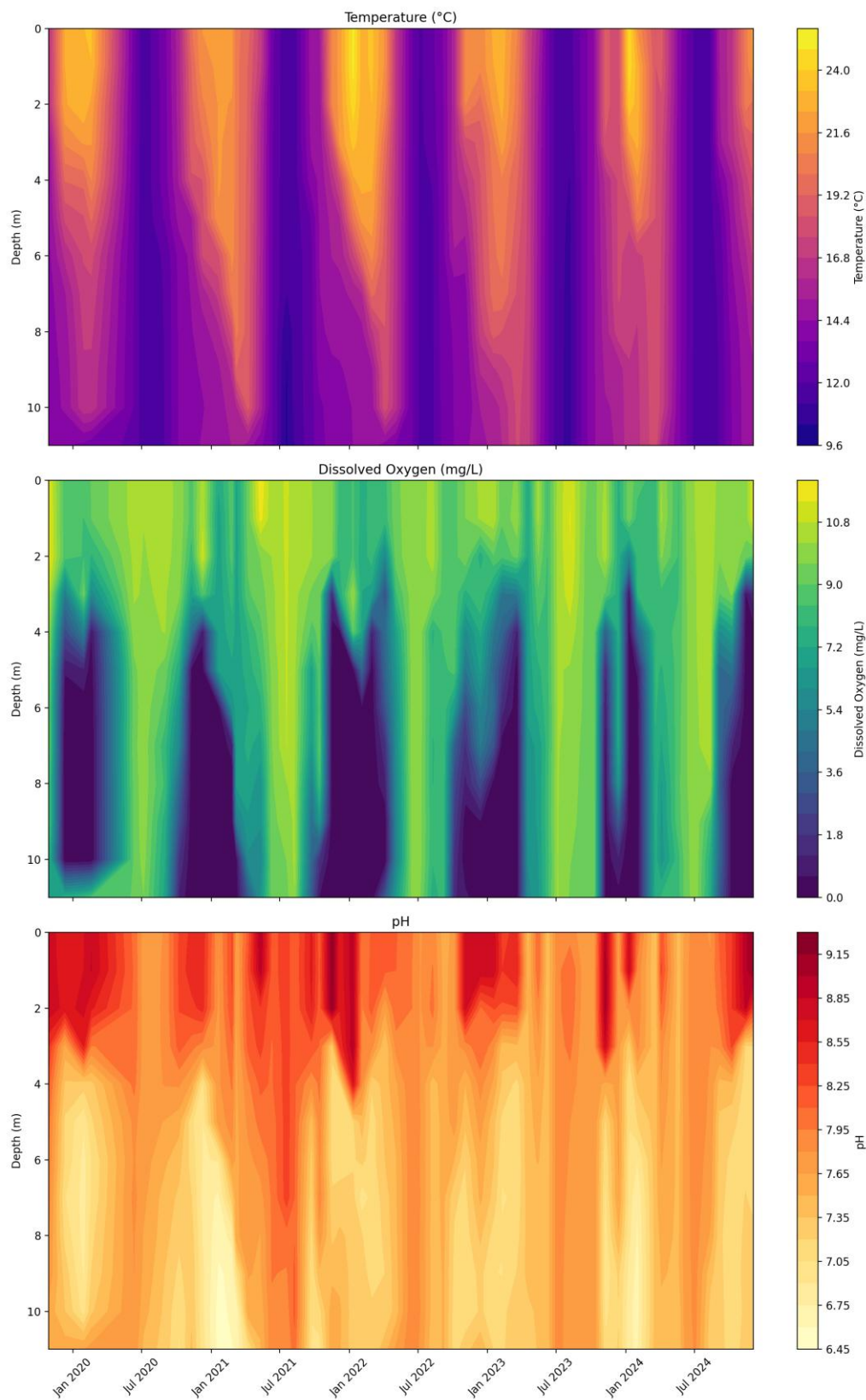


Figure 31: Lake Whatihua water quality profiles indicating recent seasonal patterns.

Threats

The primary threat to Lake Whatihua is the extensive growth of invasive *Egeria densa*. *Egeria densa* occupies the entire photic depth of the lake and has displaced native species by creating a dense fast-growing canopy. This expansive growth also impacts general ecosystem functions by reducing water movement, altering sediment characteristics, increasing water temperatures, and causing extreme diurnal fluctuations in oxygen and pH levels (Ejankowski & Solis, 2015, Staryer, 2010).

The Auckland Council has a pilot project that is investigating the feasibility of *Egeria* control using a combination of hand removal, smothering and herbicide application (M. Jones. pers. comms, 2024). A test plot was cleared in mid-2024 using hand removal with the focus on assessing regrowth, potential native regeneration and rate of colonisation. A brief investigation of the cleared area showed that a noticeable reduction in *Egeria densa* was achieved and limited recolonisation had occurred (Video 83). The effort required to clear the small area could make the widescale application of this method challenging. The rate of colonisation should be quantified as it appears that the *Egeria* is encroaching from the sides of the clearing, single stems of native pondweed and *Egeria* were seen in the centre of the clearing indicating that regrowth is occurring within 4 – 6 months of the initial hand removal. Careful consideration is required when removing large amounts of macrophytes from Lake Whatihua as these species are performing vital nutrient assimilation functions.



Video 83: Pilot site where *Egeria* was cleared using hand removal methods.

A viable native seed bank is evident by remnants of charophyte beds and well-established pondweed stands however, if *Egeria* continues to dominate the lake it is unlikely that significant charophyte regeneration will occur.

Exotic fish species are contributing to the degraded in-lake state however, widespread herbivory was not observed and has not impacted the growth of *Egeria* or native pond weed. Zooplanktivory is likely the more consequential impact as a reduction in the zooplankton biomass results in reduced grazing pressure on phytoplankton allowing seasonal algal blooms to exploit the high nutrient availability and increase in size and frequency.

The potential introduction of additional invasive species is a significant risk to Lake Whatihua. The lake is routinely used as a recreational/sport fishing location and is frequented by users from the Auckland and Waikato regions, which creates several biosecurity pathways.

The lake is already home to a variety of invasive species and the introduction of aggressive species such as hornwort, golden clam, grass carp and catfish could push the system into further decline. It is important to manage the biosecurity pathways and avoid the introduction of any additional stressors. Regular surveillance is recommended so that new incursions are detected and contained early.

Nutrient enrichment is a key driver of declining lake health, the surrounding pasture and large waterfowl population generate significant nutrient loads that enter the lake. Currently the high macrophyte biomass is assimilating a large portion of the available nutrients however, as the vegetated extent reduces so does the in-lake nutrient assimilation, resulting in a gradual shift to a high trophic state.

Fluctuations in water levels are a continuous concern for the shallow charophyte and turf species. Water abstraction should be monitored in response to climatic variations to ensure a stable water level is maintained. In addition to regulating water abstraction, stock exclusion and riparian enhancement should be prioritised. The poor-quality riparian margins provide limited buffering from the steep agricultural sub-catchment, a suitable vegetated set back should be implemented to mitigate the incoming contaminant loads.

5 Discussion

This section will summarise and discuss the overall findings from the 2024 LakeSPI assessment. The discussion will include commentary on the current state, long term trends and NPS-FM attribute bands.

5.1 LakeSPI & Current Lake Condition

Figure 32 and Table 3 presents a summary of the 2024 LakeSPI assessment that provides insights into the trends and stability of all 11 surveyed lakes. The probability of change for each LakeSPI metric was assessed using the two most recent surveys and the percentage difference was used to assess if a consequential change is likely. The state (improving, stable or declining) was assigned based on the probable change of the LakeSPI scores between the two previous assessments.

The observed variations in the LakeSPI indices indicate a dynamic interplay between native vegetation recovery and invasive species encroachment as well as the resulting impact on the overall ecological health.

Across the 11 surveyed lakes two were classed as being in high ecological condition (Rototoa & Pokorua), one in moderate condition (Whatihua), four in poor condition (Pupuke, Ōkaihau, Kawaupaku & Kuwakatai), and the remainder were non-vegetated (Spectacle, Slipper & Tomorata).

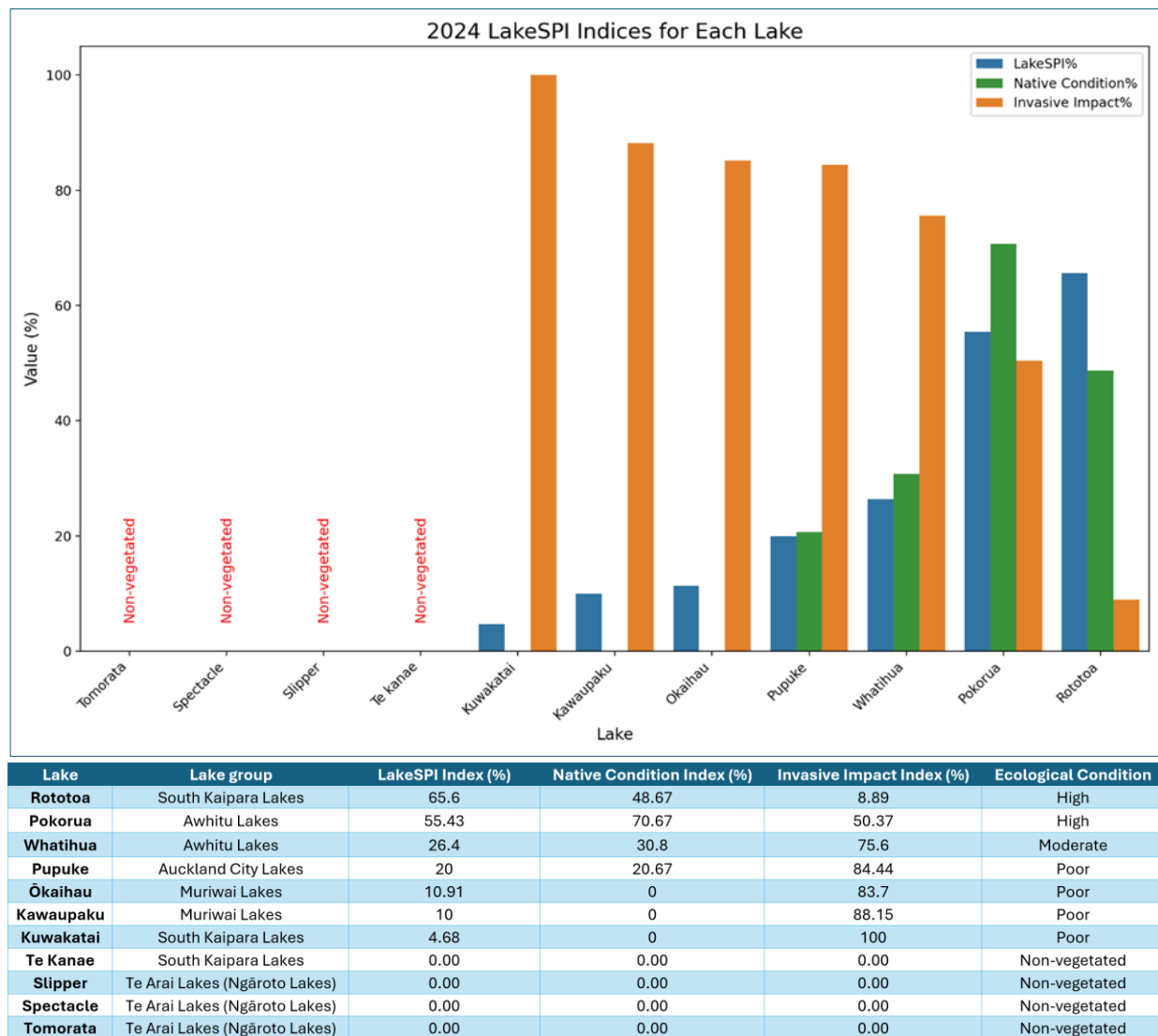


Figure 32: Summary of the 2024 LakeSPI results for all surveyed lakes.

Table 3: Summary of the percent change between the current and previous survey for all LakeSPI indices indicating the probability of change and the overall state.

Lake	LakeSPI%	% change	Change probability	Native Condition%	% change	Change probability	Invasive Impact%	% change	Change probability	State
Rototoa	65.6	-4.09	No change	48.67	-14.16	Change probable	8.89	-25.29	Change indicated	Stable
Pokorua	55.43	3.22	No change	70.67	1.98	No change	50.37	4.72	No change	Stable
Whatihua	26.4	-22.58	Change indicated	30.8	-35.16	Change indicated	75.6	2.02	No change	Declining
Pupuke	20	13.64	Change probable	20.67	82.92	Change indicated	84.44	0.88	No change	Improving
Ōkaihu	10.91	14.84	Change probable	0	-100	Change indicated	83.7	20.26	Change indicated	Improving
Kawaupaku	10	4.17	No change	0	0	No change	88.15	-0.84	No change	Stable
Kuwakatai	4.68	-44.94	Change indicated	0	0	No change	100	2.25	No change	Declining
Te Kanae	0	0	No change	0	0	No change	0	0	No change	Stable
Slipper	0	0	No change	0	0	No change	0	0	No change	Stable
Spectacle	0	0	No change	0	0	No change	0	0	No change	Stable
Tomorata	0	0	No change	0	0	No change	0	0	No change	Stable

The highest LakeSPI scores were recorded for Lake Rototoa (65.6%) and Lake Pokorua (55.43%). Both these lakes are in a stable high ecological condition with relatively well-preserved macrophyte assemblages and no significant changes to the overall LakeSPI score across the previous surveys.

Lake Whatihua is the only surveyed lake in moderate ecological condition, and it has the third highest overall LakeSPI score (26.4%). This score is primarily attributed to the vegetated extent relative to the lake depth and the high covers of native pondweed. Despite the current moderate condition this lake appears to be on a declining trajectory based on the 22.58% decrease in the LakeSPI score since the previous survey. The management efforts currently underway could stem this decline and stabilise the lake. Monitoring the effectiveness of these interventions will provide insight into the long-term trajectory of the lake.

Lake Pupuke and Lake Ōkaihau are both in poor condition with LakeSPI scores of 20% and 10.91% respectively. The LakeSPI score for Lake Pupuke increased by 13.64% which is a result of an expansion in the native charophytes and relatively high species diversity. A 14.84% increase in the LakeSPI score between the previous two surveys was calculated for Lake Ōkaihau, this was attributed to the increase in the hornwort extent and cover along two of the survey transect. In this case the expansion of invasive vegetation still bolsters the overall LakeSPI score despite limited signs of ecosystem recovery.

Lake Kawaupaku showed no significant change between the previous two surveys. The lake remains in a stable poor condition which exhibits signs of significant decline across the survey history.

Lake Kuwakatai has a LakeSPI score of 4.68% which is the lowest score out of the vegetated lakes surveyed in 2024. This lake also showed the greatest decline with a 44.94% reduction in the overall LakeSPI score between the most recent two surveys. This decline was attributed to the increased densities and cover of invasive hornwort as well as a reduction in the maximum vegetated depth extent. The lake is in a poor and declining condition with likely further deterioration.

Lake Spectacle and Slipper have been in a degraded non-vegetated state for decades and no signs of recovery were detected in during the 2024 assessment. These lakes are in a stable non-vegetated state with limited to no potential improvement. Lake

Tomorata has fluctuated between a moderate and non-vegetated state since 2017. It has remained in a non-vegetated state for the past two assessments however, the 2024 survey recorded signs of ecosystem recovery which is in part related to the coarse fish control currently being implemented. Lake Te Kane has also maintained a non-vegetated state across the previous two surveys but shows limited potential for significant recovery.

A clear deterioration in the Native Condition Index was observed in Lake Whatihua with a 35.16% decrease between the recent two surveys. The most extreme decline was seen in Lake Ōkaihau which experienced a 100% loss of native vegetation. This result highlights the severe ecosystem degradation observed in this lake. The declining Native Condition Index across the previous assessments for Lakes Ōkaihau, Kawaupaku and Kuwakatai is indicative of ongoing deterioration.

Lake Pupuke exhibited an 82.92% increase in the Native Condition Index which reflects the increase in charophyte extent and native macrophyte diversity, indicates ecosystem recovery. Lake Rototoa showed signs of an impacted native macrophyte assemblage with a 14.16% reduction in the Native Condition Index between the two recent assessments. This is a possible indication that further degradation is probable. The 2024 survey observed a reduction in the maximum vegetated depth extent and native cover which are signs of persistent pressures. Lake Pokorua showed no detectable signs of change to the Native Condition Index and is indicative of a stable state with resilient macrophyte assemblages.

The majority of the surveyed lakes are heavily dominated by invasive species with an Invasive Impact Index higher than 75%. Lake Kuwakatai (100%) had no native species representation and was completely overrun by invasive hornwort, Lake Kawaupaku (88.15%) and Lake Whatihua (75.6%) were both dominated by invasive *Egeria* with limited to no native macrophytes, Lake Ōkaihau (83.70%) had no native macrophytes and large beds of hornwort. Lake Pupuke (84.44%) and Lake Pokorua (50.37%) were the only lakes that maintained significant native macrophyte growth despite being heavily colonised by invasive species. The recent expansion of native charophytes in Lake Pupuke could be a result of these species being more tolerant to in-lake conditions allowing them to co-exist amongst the dense *Egeria* and eel grass. The *Elodea* and *Egeria* in Lake Pokorua is regulated to a degree by grazing swans. As a

result, bulk of the invasive biomass is contained to the deeper sections of the lake, allowing native charophytes to dominate the shallow upper littoral margin. Lake Rototoa (8.89%) is the only vegetated lakes surveyed during 2024 that had an Invasive Impact Index score less than 50%. Additionally, this lake showed a 25.29% decrease in the Invasive Impact Index resulting from the active hornwort control carried out under the Natural Environment Targeted Rate. The remainder of the surveyed lakes were assessed as non-vegetated with no signs of significant native or invasive macrophyte growth.

These results highlight the relationship between native and invasive macrophyte species. Figure 32 shows a clear inverse relationship where native condition increases as invasive species reduce, this figure illustrates the aggressive displacement of native macrophyte by invasive species and the consequence that colonisation has on the overall lake condition.

The findings show that colonisation of the Auckland Lakes by invasive species is a common occurrence as none of the vegetated lakes surveyed in 2024 were free of pest macrophytes. There is a need for targeted lake specific management strategies to mitigate invasive species spread and promote native vegetation recovery, Lake Rototoa is a prime example of how active management has resulted in a greatly reduced invasive macrophyte biomass.

5.2 NPS-FM Attribute Bands

The NPS-FM NOF attribute bands for the Native Condition Index and the Invasive Impact Index is presented in Table 4. None of the surveyed lakes achieved an A band for either attribute. Lake Pokorua was the only lake that scored a B band for the Native Condition Index, this band is consistent with the previous assessment. Lake Rototoa dropped from a B band in 2022 to a C band in 2024 for the Native Condition Index, this result is attributed to a reduction in the native macrophyte maximum depth extent and cover. Lakes Whatihua and Pupuke remain in a C band for the Native Condition Index however, the 2024 assessment noted that Lake Pupuke is on the cusp of transitioning into a B band due to the increased cover of charophytes. The Native Condition Index for Lakes Kawaupaku, Ōkaihou and Kuwakatai are below the national bottom line, these lakes have no significant native macrophyte growth and are

dominated by invasive species (*Egeria densa* & *Ceratophyllum demersum*). The remaining lakes (Te Kanae, Tomorata, Slipper & Spectacle) are non-vegetated and received a default score below the national bottom line.

Table 4: Native condition Index and Invasive Impact Index 2024 NOF attribute bands.

Lake	Native Condition Index Attribute Band	Invasive Impact Index Attribute Band
Rototoa	C	B
Pokorua	B	C
Whatihua	C	C
Pupuke	C	C
Kawaupaku	D	C
Ōkaihau	D	C
Kuwakatai	D	D
Te Kanae	D	N/A
Tomorata	D	N/A
Slipper	D	N/A
Spectacle	D	N/A

All the surveyed lakes except for Lake Kuwakatai were above the national bottom line for the Invasive Impact Index attribute. The non-vegetated lakes are excluded from banding for this attribute. Lake Kuwakatai has the largest infestation of hornwort out of the surveyed lakes and the entire littoral zone has been overrun, which contributes to the D band. Lake Rototoa is the only lake with a B band for the Invasive Impact Index attribute, this is consistent with the previous assessment and is an indication that the active hornwort control is successful in maintaining the band. Lake Pokorua maintains the previous C band for the Invasive Impact Index attribute as the invasive *Egeria* and *Elodea* has not significantly increased in extent or cover. Lakes Whatihua and Pupuke also remain in C bands for the Invasive Impact Index attribute and still support significant native macrophyte growth amongst the extensive exotic macrophyte cover. Lake Kawaupaku is overrun with *Egeria*, but the poor in-lake conditions maintain an invasive macrophyte extent that is graded as a C band. A

similar situation is seen with Lake Ōkaihou where dense hornwort beds are present but poor conditions have prevented this aggressive species from overrunning the lake. The attribute bands from the 2024 assessment indicate that the region's lakes suffer from a depauperate native macrophyte assemblage and widespread invasion of aggressive exotic macrophytes.

5.3 Threats & Impacts

The key impacts seen across the surveyed lakes include invasive species pressures, eutrophication stemming from agricultural land use the catchment and internal nutrient loading, as well as depauperate riparian margins.

Most of the surveyed lakes are located in pasture dominated catchments with dry stock land use activities. The impacts of these land use pressures include increased nutrient, sediment and *E. coli* discharges to the lake and excessive water abstraction. These impacts are worsened by poorly vegetated riparian margins and stock access to the lake edge. Eutrophication, often exacerbated by nutrient runoff from the surrounding areas, can lead to increased benthic algal growth, harmful surface algal blooms, oxygen depletion, and overall degradation of water quality, further stressing the lake ecosystem and potentially leading to cascading impacts on aquatic life (Łopata et al., 2019; Wang et al., 2016; Zamparas et al., 2014; Zamparas et al., 2015). All the surveyed lakes showed some degree of eutrophication linked to land use activities, except for Lake Kawaupaku which is surrounded by a native forest catchment. The nutrient enrichment in this lake is likely a result of internal loading and coarse fish induced alterations to the in-lake nutrient cycling.

High suspended algal concentrations, formation of benthic algal mats, poor water clarity, signs of persistent anoxia and a reduction in macrophyte depth extent were common signs of eutrophication seen in the surveyed lakes.

A secondary consequence of eutrophication and climate change is alterations to stratification patterns and extreme seasonal shifts in water quality throughout the water column. Longer warmer summers encourage large algal blooms, strong thermal stratification and an extension of the anoxic hypolimnion, evidence of this phenomenon was seen in the surveyed monomictic lakes. Increased trophic states produce high volumes of organic matter and the decomposition/mineralisation of this

leads to oxygen depletion and a marked decline in REDOX potential, particularly in the hypolimnion and water/sediment interface (Ross et al., 2008; Zhang et al., 2020). Incomplete mineralisation of organic matter leads to a buildup of organic sediment which, coupled with low oxygen concentrations, perpetuates persistent anoxia and the release of legacy phosphorus from the sediment (Łopata et al., 2019).

This persistent anoxia extends into the upper portion of the hypolimnion where it encroaches into the epilimnion, and in some cases displaces the surface water and reduces the epilimnion depth. The persistent expansion of the anoxic hypolimnion into shallower water limits the maximum vegetated depth and can reduce the overall macrophyte biomass. Evidence of this is seen in the deeper lakes across the region such as Lakes Rototoa, Kuwakatai, Te Kanae, Kawaupaku, Ōkaihau and Pupuke.

There are several biotic interactions and functions that maintain natural in-lake cycles. The disruption in these processes can cause cascading effects throughout the lake (Carpenter et al., 2011; Bunnell et al., 2011; Staryer, 2010). One of the major impacts on biotic interactions in lakes is the incursion of pest species (Staryer, 2010).

Invasive macrophytes were present in all vegetated lakes surveyed during the 2024 assessment. These macrophytes form extensive dense beds that create microclimates and fundamentally alter the environment around them. Common invasive species such as hornwort and *Egeria* form tall canopies that shade out large sections of the lakebed. This creates low light environments and prevents new macrophyte growth from occurring in the littoral zone. Dense macrophyte beds can attenuate incoming flows and potentially limit the distribution of external organic material. These dense beds also cause stagnation and enhanced deposition of fine sediments that would otherwise be eroded. This attenuation effect creates muddy organic rich conditions in the littoral zone, these conditions promote anoxia, increased ammonia release and sediment nutrient remobilisation. The stagnation in and around these dense macrophyte beds can create large temperature and dissolved oxygen gradients for prolonged periods. The combination of these effects creates sub-optimal conditions in the littoral zone, which has implication for wider ecosystem health considering this is typically where in-lake biodiversity is greatest. A loss in biodiversity often translates into a loss of ecosystem function and decline in overall lake health.

Increases in invasive macrophyte biomass is often associated with an increase in ecosystem productivity via enhanced phosphorus cycling from sediment and the contribution of organic matter. This increased productivity also supports a higher suspended algal mass and the seasonal recession of these blooms contributes to the decomposing organic matter on the lakebed that fuels subsequent algal blooms. Evidence of this, including thick deposits of fine organic floc and a reduced photic depth, was seen in all the surveyed lakes.

Aside from alterations to in-lake condition, aggressive invasive species actively displace native macrophytes. Most native macrophytes (charophytes) are short statured which facilitates colonisation potential from exotic species as they offer little competition for light and other resources. de Winton and Clayton (1996) found native seed numbers and species richness was often lower in lakes dominated by adventive weeds such as hornwort, *Egeria* and *Elodea*. These fast-growing macrophytes were common in the surveyed lakes and can establish in gaps between the stems of native species, this cause fragmentation of native macrophyte beds and creates tall stands of invasive species that outcompete the species below it. This is one of the ways that these adventive species quickly overrun the littoral zone and displace native macrophytes. The displacement of seed producing native species reduces the replenishment of seed banks in the lake which further limits the future re-establishment of native macrophytes (de Winton and Clayton, 1996). Seed numbers beneath invasive macrophyte beds can be less than 5% of those present under native vegetation (de Winton and Clayton, 1996). The formation of dense beds and continuous deposition of organic material alter sediment conditions and prevent native seeds from germinating (Hofstra, Adam and Clayton, 1995). The displacement of native macrophytes was clear in all lakes where invasive species had established. *Egeria* was the most common invasive species followed by hornwort, *Elodea* was only found in Lake Pokorua and eel grass was only observed in Lake Pupuke. Less aggressive invasive species such *Utricularia gibba* were also common but do not exert the same displacement pressure. The high impact invasive macrophytes have overrun the littoral zone in most of the lakes where they are present. This has resulted in a significant reduction in native cover and diversity.

Pest fish species also have a significant biotic impact on lake health. The introduction of coarse fish to the Auckland region has caused significant impacts to the surveyed

lakes. Herbivorous pest fish (rudd & carp) have contributed to the devegetation of several Auckland lakes and have contributed to a shift toward an algal dominated state (Bunnell et al., 2011; Gerdeaux, et al., 2006). The removal of vegetation exacerbates eutrophication as macrophytes play an important nutrient assimilation role in lakes. These herbivorous fish can also cause a high degree of bioturbation which contributes to the remobilisation of sediment bound nutrients and a reduction in water clarity (Staryer, 2010). Carnivorous pest fish (perch & tench) disrupt trophic chains and displace native species. This competitive displacement occurs across several trophic levels. Adult perch feed on native fish whereas juveniles are gape limited and feed on zooplankton. The increased predatory pressure on zooplankton results in a proliferation of phytoplankton, this coupled with the devegetation and bioturbation of the lakebed by herbivorous species accelerates eutrophication.

Evidence of natural lake aging was observed at several lakes during the 2024 survey (Spectacle, Slipper, Tomorata & Pokorua). It is unclear to what extent this process has been accelerated by the surrounding agricultural practices, but eutrophication is considered a key driver of lake aging, so it is likely that these high impact land use activities have hastened the progression. Lake aging is the lengthy process where a shallow lake transitions gradually toward a high nutrient wetland environment (Grover, 2022; Schallenberg, 2019). The encroaching emergent vegetation and incomplete decomposition of detritus cause sediment accumulation around the lake edge (Si et al., 2020). The continuous build-up of organic rich sediment increases the extent of the upper littoral zone that is able to be colonised by emergent species. This process ultimately leads to an expansion of the emergent vegetation band with a corresponding reduction in the upper macrophyte extent. This displacement of shallow macrophytes and turf species confines the growth to the deeper portions of the lake. In shallow eutrophic systems light penetration at these depths is often insufficient. The increase in emergent vegetation also creates a potential increase in tannins which further reduces the photic depth, preventing macrophyte establishment in the open water section of the lake.

The extent to which groundwater influences water quality and lake ecology in Auckland is unknown. Considering that the majority of the lakes are shallow dune lakes, it is likely that a permanent groundwater connection exists. The wider aquifers that likely feed these lakes are typically under agricultural land use with pasture being the

dominant land cover. The long history of agricultural practices has likely led to the eutrophication of the underlying aquifers. This contaminant groundwater is expected to seep into the lakes with varying intensity which, increases the nutrient loading.

The cumulative effects of the impacts discussed above reduce the ability for Auckland's lakes to support native macrophytes and greatly limits the potential for natural regeneration. These complex interactions highlight the importance of proactive management strategies to mitigate the degradation of the regions lakes and preserve its ecological integrity.

6 Conclusion

This section will summarise and discuss the overall findings from the 2024 LakeSPI assessment. The discussion will include commentary on the current state, long term trends and NPS-FM attribute bands.

The findings from the 2024 LakeSPI assessment highlight the complex and dynamic ecological conditions across Auckland's lakes. The results indicate that most of the surveyed lakes show clear signs of degradation due to invasive species dominance, eutrophication, and habitat loss.

Eutrophication, driven by catchment land use and internal nutrient loading, is a significant issue across most lakes, particularly those surrounded by agricultural land. The poor condition of riparian margins, nutrient enrichment and sediment sources near the lake edge contribute to declining water quality, increased algal blooms, and reduced macrophyte depth extent. Additionally, climate induced changes in stratification patterns have exacerbated oxygen depletion, further stressing native species and accelerating ecosystem degradation. Localised impacts from Cyclone Gabrielle (February 2023) have also caused transformative changes along the banks of some lakes.

The role of invasive macrophytes is a dominant factor in lake degradation, with all surveyed lakes exhibiting at least some level of invasive species pressures. Dense beds of hornwort, *Egeria*, and *Elodea* have displaced native charophytes, altering lakebed conditions and further driving ecosystem shifts towards turbid, algal

dominated states. Invasive fish species further amplify bioturbation, sediment resuspension, and trophic disruptions.

Under the National Policy Statement for Freshwater Management (NPS-FM), several lakes now fall below the national bottom line for the Native Condition Index, necessitating targeted restoration efforts. While Rototoa and Pokorua maintain B and C bands, lakes such as Kawaupaku, Ōkaihau, and Kuwakatai are classified as degraded (D band). Lake Kuwakatai is the only vegetated lake that falls below the national bottom line for both indices.

Key recommendations to halt further degradation and promote recovery include invasive species control, active biosecurity campaigns, riparian restoration, catchment nutrient management, in-lake nutrient interventions and long-term targeted monitoring.

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8 Appendix 1 – Macrophyte Species List

Species	Rototoa	Pokorua	Whatihua	Pupuke	Ōkaihau	Kawaupaku	Kuwakatai	Te Kanae	Slipper	Spectacle	Tomorata
<i>Chara australis</i>	✓	✓		✓							✓
<i>Chara fibrosa</i>	✓										
<i>Chara globularis</i>	✓	✓	✓	✓							
<i>Nitella leonhardii</i>	✓										✓
<i>Nitella pseudoflabellata</i>	✓										✓
<i>Nitella hyalina</i>	✓	✓	✓	✓							
<i>Nitella sp. aff. cristata</i>		✓		✓							✓
<i>Potamogeton ochreatus</i>	✓	✓	✓								
<i>Potamogeton cheesemanii</i>	✓	✓	✓					✓			
<i>Myriophyllum triphyllum</i>		✓	✓	✓							
<i>Ruppia polycarpa</i>		✓									
<i>Glossostigma elatinoides</i>	✓				✓		✓				
<i>Zannichellia palustris</i>		✓									
<i>Azola rubra</i>								✓			
<i>Utricularia gibba</i> *	✓		✓		✓			✓			✓
<i>Lemna disperma</i> *								✓			
<i>Ludwigia palustris</i> *		✓					✓	✓			
<i>Ludwigia peploides</i> *											
<i>Vallisneria australis</i> *				✓							
<i>Ceratophyllum demersum</i> *	✓				✓		✓	✓			
<i>Elodea canadensis</i> *		✓	✓								
<i>Egeria densa</i> *		✓	✓	✓		✓					
<i>Lagarosiphon major</i> *				✓							
<i>Potamogeton crispus</i> *				✓							
<i>Nymphaea cultivars</i> *					✓						
<i>Alternanthera philoxeroides</i> *		✓			✓	✓			✓	✓	

Note: * Invasive/exotic species