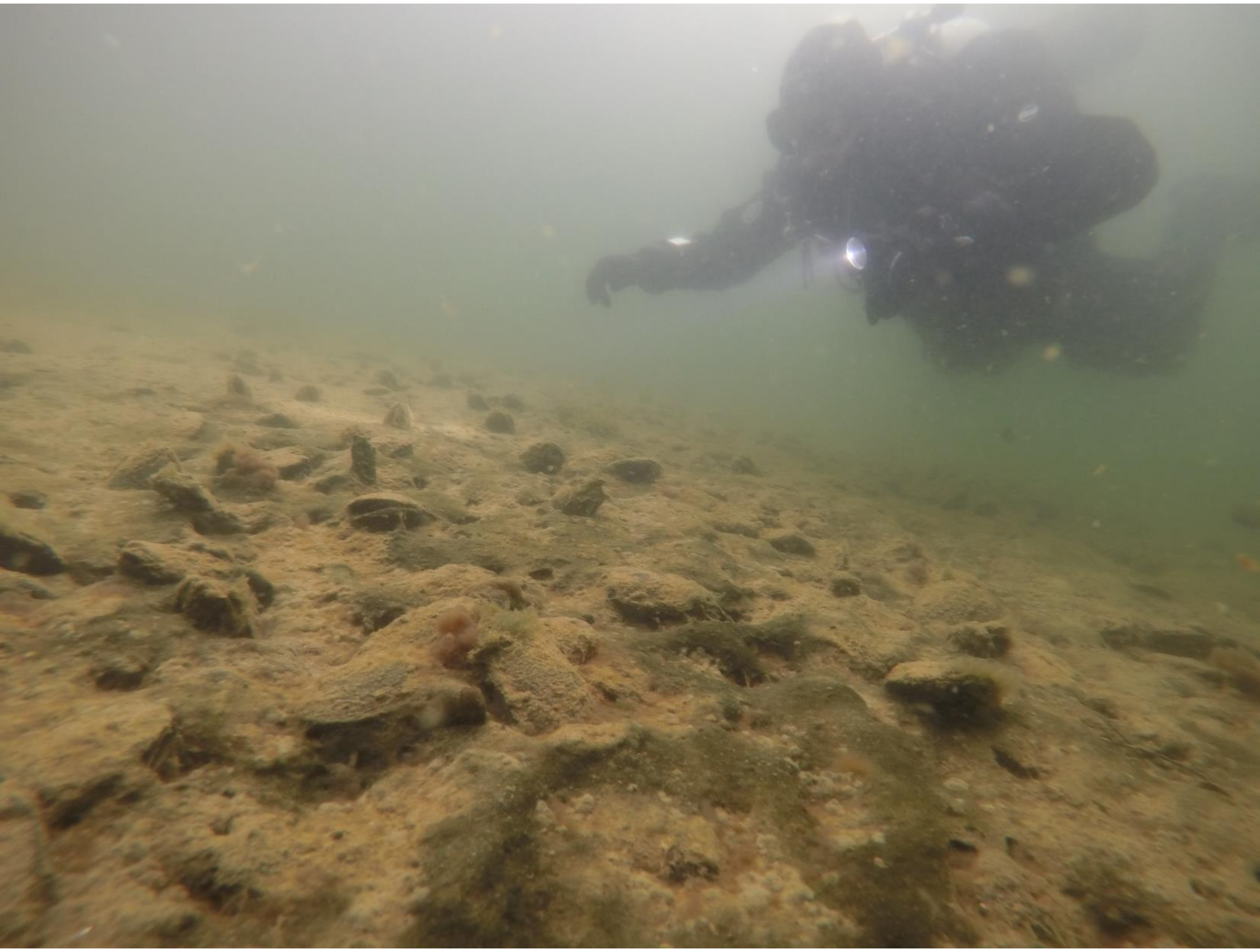
Lake Rototoa Kākahi Survey

Method Development & Preliminary Results



AOTEAROA LAKES
CITIZEN SCIENCE FOR OUR LAKES

AOTEAROA LAKES

CITIZEN SCIENCE FOR OUR LAKES

Table of Contents

Foreword

Ebrahim (Ebi) Hussain

Founder & Principal Scientist, Aotearoa Lakes

Nzlakesorg@gmail.com

Acknowledgements

I would like to thank the following people and organisations: Aotearoa Lakes Team for all their hard work and dedication, without their ongoing volunteer support this project would not have been possible. Sue Clearwater for her support and advice during the survey development process.

1 Introduction

Lake Rototoa is a long-term State of the Environment monitoring site and has always been considered as one of the best dune lakes in the region. The lake condition has steadily declined over recent years and the introduction of several pest species (fauna and flora) has exacerbated the issues.

Lake Rototoa historically supported a wide variety of native biota including diverse macrophyte communities and extensive freshwater mussel (Kākahi) beds. The introduction of invasive coarse fish between 1999 and the early 2000's had a significant effect to the native ecology in the lake.

In 2019 the Auckland Council obtained funding under the Natural Environment Targeted Rate for an aquatic pest management programme at Lake Rototoa with the primary focus being on pest fish. This programme was developed to address the impacts caused by pest fish and implement a long-term management programme aimed at pest eradication.

There have been several fish community surveys done through the years and macrophyte condition is routinely assessed as part of the regional LakeSPI programme however, there is little information on the Kākahi populations aside from anecdotal comments and observation noted during fish/macrophyte surveys. Kākahi are a keystone species and perform multiple ecosystem functions. It is known that pest fish, particularly perch, can have significant impacts on Kākahi populations. To establish a robust understanding of Kākahi ecology and the impacts of pest fish on these species in Lake Rototoa, a baseline Kākahi population assessment and monitoring programme is required.

The council did not have a dedicated work plan involving detailed Kākahi surveys and long-term monitoring programmes, so they partnered with Aotearoa Lakes, which is a non-profit environmental charity organization. The initiative uses volunteer scientists and technical SCUBA divers to develop and operate sub-surface monitoring programmes and project specific data collection events. The key focus of Aotearoa Lakes is to work collaboratively with government and research organisations and collect meaningful data that can be used to develop better environmental management strategies.

The Aotearoa Lakes team initially approached the council in September 2019 with a project plan to develop standardised, repeatable Kākahi survey techniques. The goal was to use the developed methodologies to obtain a baseline assessment of Kākahi populations and identify key environmental impacts and population limiting factors. The baseline assessment and methodologies will be used to conduct ongoing monitoring and, follow up surveys to assess the population extent change over time in response to anthropogenic stressors and pest fish management. This data will provide a potentially useful ecological metric that can be used to gauge ecological gains as a result of increased pest fish management.

This report will discuss the Kākahi monitoring programme method development, survey techniques and initial results from the Aotearoa Lakes team. This is the preliminary assessment of methods and results which will feed into future programme developments. This report will also provide a brief overview of Lake Rototoa including a summary of water quality and ecology.

2 Background Information

2.1 Lake Rototoa

Lake Rototoa is a monomictic dune lake situated on the north west coast of Kaipara South Head. The lake has a surface area of 1.39 km^2 and a maximum depth of 27 m, it is the largest and deepest of a series of sand dune lakes found along the region's western coastline.

Lake Rototoa is of great cultural value to the local Iwi; the name Rototoa translates to "Lake of the Warrior" and is part of a line of lakes known as "the Footsteps of Kawharu" who was a famous Māori warrior. This lake is also esteemed for its natural beauty and it is often referred to as the jewel in the Auckland crown. The mesotrophic state of this lake can be largely attributed to its 4.08 km^2 catchment composed of native bush, pine forestry, and deer farming.

Lake Rototoa is also known for having a diverse population of native submerged macrophytes and large freshwater mussel beds, both of which are increasingly rare in the Auckland region. However, the lake is under threat and the lake condition has deteriorated in recent history. Though the exact cause of this deterioration is not known, it is likely a result of eutrophication, land use activities, pest invasion, and climate change.

2.2 Water Quality

According to State of the Environment monitoring data Lake Rototoa was considered as oligotrophic pre 2014 (TLI4 ≤ 3.0). Since 2015 the lake has been classified as mesotrophic

(TLI4 3.0 – 4.0). The annual average total nitrogen concentration has gone from 0.21 mg/L in 2013 to 0.34 mg/L in 2018, a similar trend is seen with total phosphorus concentration where the concentrations increased from 0.004 mg/L in 2013 to 0.006 mg/L in 2018. The visual clarity has declined significantly, in 2013 the annual average secchi depth was 7.45 m compared to 3.0 m in 2018.

The increased trophic state, elevated nutrient concentrations and reduction in water clarity is indicative of eutrophication. Temperature and dissolved oxygen profiles show that the lake stratifies over the warmer seasons and experiences hypolimnetic deoxygenation and anoxia during peak stratification.

2.3 Freshwater Mussels (Kākahi)

Freshwater mussels are one of the most imperiled organisms on Earth and populations are declining globally with 70 percent of species considered at risk or threatened, including three species endemic to New Zealand. *Echyridella menziesii* is classified as declining, *Echyridella aucklandica* is considered nationally vulnerable, and *Echyridella onekaka* is naturally uncommon (Grainger et al., 2014 & Catlin et al., 2017). These species are often geographically isolated and can only be found in a few locations.

Global freshwater mussel population decline has been attributed to the loss of habitat associated with eutrophication and sedimentation as well as general pollution (Catlin et al., 2017). In Lake Rototoa, the loss of native intermediate host fish (dwarf inanga and bullies) through predation from invasive species is a significant contributor to their reduction in numbers (McDowall, 2002 & McDowall, 2011). Unlike their marine counterparts, freshwater mussels cannot anchor themselves to a substrate. Instead, they bury themselves into the sediment which makes them vulnerable to increased sedimentation that can result from erosion in the catchment as well as from excessive organic matter like algal blooms. These species are filter feeders so fine silt can clog their gills and suffocates them leading to widespread mortality (Phillips, 2007).

Mussels are an important part of a lake ecosystem; as biofilters and bioturbators they filter out nutrients, algae, bacteria, and fine organic material which helps purify the water (Collier et al., 2016). They have an average filtration capacity of 1 liter per mussel per hour (Walker et al., 2001) but rates of 1.6 to 1.8 liters/hour/g have been recorded (Phillips, 2007) and if present in large enough numbers, they can filter the entire volume of a small lake within days. They also oxygenate the sediment by moving it around which decreases anoxia and stems sediment nutrient remobilization. Aside from their ecological importance, these mussels were once a valuable food source for many Māori and the shells were used as cutting utensils.

Adults can live to over 50 years and have an average life expectancy of 20 – 25 years (Grimmond, 1968). They are hardy animals which means that residual adults are not reflective of viable, self-sustaining populations (Rainforth, 2008 & McEwan, 2012). Mature adults can reach sizes over 100 mm in length but typically range from 60 – 84 mm.

Their life cycle is complicated and differs from marine mussel species. They typically spawn during summer when females lay eggs into a space above their gills and the males ejaculate sperm directly into the water (Phillips, 2007). The females suck sperm laden water into their gills where it fertilizes the eggs. The larvae develop into glochidia while in the mantel of the female until spring when they are released into the water (McEwan, 2012). The glochidia attach to the pectoral fins, mouth and head of native galaxiids and bullies, these fish transport the glochidia until they drop off and mature further (Clearwater et al., 2014). There is little information around how they mature and migrate through the final parts of their life cycles however there has been research on key extent limiting factors.

Bed establishment tends to be influenced largely by substrate type and stability (James et al., 1998), they prefer soft sand and mud so that they can easily bury themselves, but fine silt can clog their gills. Large beds are typically found on gentle sloping lake beds with an even bathymetric gradient (Phillips, 2007). The upper bed extent can be limited by fluctuations in water level and wave action, the lower bed extent is heavily influenced by macrophyte establishment and water quality (particularly in stratified systems). Dissolved oxygen is considered a major limiting factor for the lower bed extent. James et al., 1998 suggests dissolved oxygen concentrations above 5mg/L is likely to be the threshold for long term bed viability.

2.4 Fish

Lake Rototoa was once considered a regionally significant trout (*Oncorhynchus mykiss*) fishery. Fish & Game began stocking the lake with trout in 1915 and had to maintain the stocking due to a lack of natural spawning habitat (Ling et al., 2019). Dwarf inanga was introduced in 1986 as a food source for trout but stocks were not maintained. Fish & Game conducted fish surveys from 1986 to 1997 to monitor growth and condition of stocked rainbow trout, no record of any other exotic species was found during this time (Ling et al., 2019).

Perch (*Perca fluviatilis*) were illegally introduced to the lake in 1999 and were noted by Fish & Game during survey between 1999 and 2007 (Ling et al., 2019). Additional exotic/coarse fish species have been introduced through time; rudd (*Scardinius erythrophthalmus*) and goldfish (*Carassius auratus*) have been reported since 2002, tench (*Tinca tinca*) have been found in recent surveys and gambusia (*Gambusia affinis*) have become abundant since 2004 (Ling et al., 2019).

The lake also supports several native species including common bullies (*Gobiomorphus cotidianus*), dwarf inanga (*Galaxias gracilis*) and banded kokopu (*Galaxias fasciatus*), there has been a steady decline in native fish population since the introduction of coarse fish.

A recent survey by Waikato University in 2019 (Ling et al., 2019) used a variety of fish methods to investigate the type and numbers of fish species still present in Lake Rototoa. Common bullies were found at a rate of between 4 to 17 fish per 10 traps (Gee minnow and Fyke nets). This survey as well as previous surveys noted a significant decline in bully populations during 2002 to 2006 and again in 2019 where almost no individuals were sighted in the littoral zone in Honeymoon Bay (once a hot spot for bullies). Only two dwarf inanga were found during the 2019 survey and no individuals or schools were seen during snorkel surveys, this result is similar to the 2005 and 2006 surveys. Pre 2005 dwarf inanga were seen in schools of more than 100 individuals and there was on average 18 schools per 100 m of lakebed. The number of coarse fish caught in 2019 was of most concern, in particular the number of perch. A total of 244 perch, 4 trout, 6 goldfish, 30 tench and an abundance of gambusia was found however, no rudd were caught.

Coarse fish are known to have a significant effect on lake water quality. Rowe, 2003 determined that increased coarse fish biomass was strongly correlated with declining water quality in northern New Zealand lakes. North Island Oligotrophic and mesotrophic lakes like Rototoa are often phosphorus limited and exotic fish have the capacity to increase the in-lake phosphorus loading (Lyons et al., 2016). This allows for greater algal/phytoplankton growth and increased eutrophication and commonly results in a reduction in water clarity. The combination of perch and tench in high numbers has been shown to increase chlorophyll-a concentrations and cause a reduction in macrophytes and molluscs (Brönmark, 1994). Predatory pest fish like perch have significantly impacted the native fish populations and have led to the near extinction of dwarf inanga in the lake.

2.5 Submerged Macrophytes

Lake Rototoa has a current LakeSPI scores of 67% which is considered to be in the high condition category (De Winton, 2019). This condition score is primarily a result of a high native condition index (54%) which reflects that widespread charophyte meadows and stands of native pondweeds. The lake historically had no significant invasive plant species impacts until 2007 when hornwort (*Ceratophyllum demersum*) incursion occurred in the northern arm of the lake, alien bladderwort (*Utricularia gibba*) has also been recorded in the shallows (De Winton, 2017 & De Winton, 2019). Both invasive species have not proliferated and overrun the lake resulting in an invasive plant index of 11% in 2019 (De Winton, 2019).

High condition lakes like Rototoa are under-represented in the region compared to lakes nationally and are under increasing pressures due to eutrophication, and anthropogenic activities in the catchment (De Winton, 2017). Additionally, the impacts of pest fish species have recently contributed to the decline in macrophyte condition (De Winton et al., 2002 and Dugdale et al., 2006), the 2019 surveys noted extensive sediment disturbance, associated with benthivores pest fish, along the lower macrophyte extent (De Winton, 2019). The 2017 LakeSPI assessment noted significant shifts in macrophyte condition and a reduction in the maximum depth extent of plants, from between 11.4 m to 12.2 m in 2010, down to between 9.8 m to 11.5 m in 2017 (De Winton, 2017). The widespread coverage of benthic blue-green cyanobacteria algal mats has increased in recent history and have been widely documented in the 2019 survey (De Winton, 2019). The reduction in macrophyte extent and development of benthic algal mats are indicative of eutrophication and a reduction in water clarity.

The LakeSPI score has steadily been declining since the initial 1984 surveys. The 1984 survey had a LakeSPI score of 74% which dropped to 70% when the 2005 survey was done (De Winton, 2017). In 2007 a different set of transect sites were used and resulted in a score of 72%. These locations were re-surveyed in 2010 and the resulting score had dropped to 61% (De Winton, 2017). In 2017 the score dropped again to 59% which is lowest value yet (De Winton, 2017) however, the overall LakeSPI score increased to 67% during the 2019 survey (De Winton, 2019).

3 Survey Methodology & Development

This section will discuss the site scoping, method development and current survey protocols created by the Aotearoa Lakes team.

3.1 Literature Review

There are several marine and freshwater mussel survey protocols available nationally and internationally however, there is limited available information on Kākahi specific applications and New Zealand case studies.

The international literature was sourced predominantly from the United States Environmental Protection Agency, United States Fish and Wildlife, United States Geological Survey, various state specific regulatory agencies as well as international universities and other environmental/conservation groups (Carlson et al., 2008; Hanshue et al., 2019; Cheng, 2017; Phillips et al., 2007; Catlin et al., 2017; Fenwick, 2018). The majority of this literature revolved around surveying marine mussels and freshwater mussels in a stream/river environment. The marine surveys were more applicable as the general environmental characteristics and mussel bed extent were more closely related to the lentic environment, we will be working in. Both the riverine and marine surveys included various quantitative and qualitative survey methods. The primary means of survey was the use of transects laid in fit for purpose manner with visual or tactile observations being noted at set intervals. The use of quadrats was unanimously used when calculating population densities. For non-riverine and marine surveys transects were laid across the longest axis of a defined mussel bed with quadrats placed at set intervals.

New Zealand surveys are heavily skewed to riverine and wadable survey methods. Many regional councils and environmental groups have conducted Kākahi surveys in rivers across New Zealand, these surveys used similar techniques to the ones described above. The Catlin et al., 2017 protocol was the most comprehensive riverine Kākahi specific monitoring protocol and is used as the basis of the Waikato Regional Council Kākahi monitoring programme. Some of the methodology from this protocol was applicable to non-wadable surveys but the techniques are best suited to wadable streams. In terms of lake-based surveys both Greater Wellington and Horizons Regional Councils have undertaken Kākahi monitoring projects however, majority of these surveys were done in shallow lakes (lakes Wairarapa and Waipu) using protocols suited for wadable depths. Dr Sue Clearwater (NIWA) developed a method that NIWA have used to survey Kākahi in deeper water (Fenwick et al., 2018). This method involves laying a transect across a defined mussel patch and performing a visual and tactile search. Quadrats were placed randomly in the mussel patch and outside of the mussel patch, these quadrats were intensively searched to a depth of 10 cm. Additionally the first 100 live mussels were placed in a catch bag and brought to the surface for further measurements (size, sex and condition). This method was considered to be the most appropriate for the conditions at Lake Rototoa.

3.2 Site Scoping

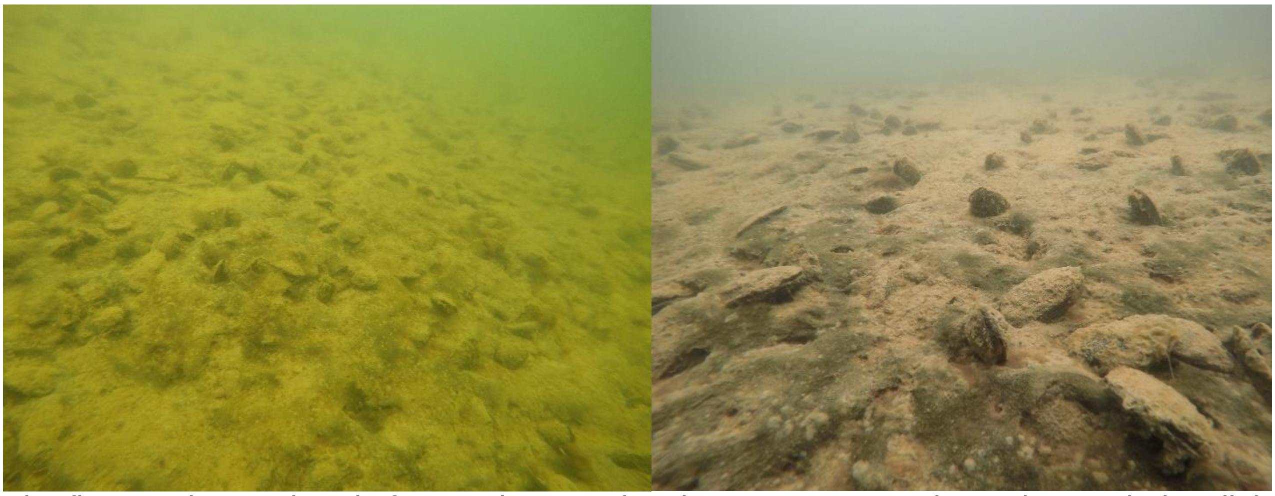
To assess the feasibility and application of the NIWA method (Fenwick et al., 2018) an initial site scoping was done to assess Kākahi bed characteristics. There is very little information on the habitat preferences and bed extent of Kākahi in Lake Rototoa.

The initial scoping was done in the south eastern panhandle of the lake and covered approximately 600 m of lakebed (Figure 1). A team of two divers, using diver propulsion vehicles, entered the water west of the public access point (near the entrance into the panhandle) and travelled east parallel to the shore until they reached the end of the panhandle, they then continued west along the opposite bank until the panhandle opened up into the main lake (Figure 1).

Figure 1: South east panhandle depicting initial diver scoping route

According to NIWA surveys Kākahi tend to form patches where they occur in high densities separated by areas of no mussels however, this was not the case in Lake Rototoa. The dive team documented an almost contiguous band of mussels along the entire search area.

Image 1: Contiguous mussel beds



The first continuous band of mussels started at the survey start point and extended until the north east corner of the panhandle (point A, Figure 1), no mussels were found between point A and point B (Figure 1). The second contiguous bed started at point B and extended to the end of the survey area and beyond. All mussels were identified as *Echyridella menziesii.*

Image 2: Echyridella menziesii from Lake Rototoa

The upper extent of the mussel beds was dictated by riparian vegetation, the beds began at a depth of 1.8 to 2 m and mirrored the reed line parallel to shore. The lower extent was largely limited by the macrophyte beds that started at a depth of 4 m and extended to 10 m. There was a noticeable substrate change after 5 – 8 m and the surficial sediment turned from sand to a fine silt. This substrate change could possibly be limiting factor for bed establishment.

No mussels were found past the lower extent of the macrophyte beds (10 – 12 m). There were dense macrophyte beds at the end of the panhandle between point A and B which explained the lack of mussels (Image 3).

Image 3: Dense charophyte beds on the eastern end of the panhandle

The macrophytes beds across the scope area started less than 1 m away from the end of reed line (1.2 – 1.5 m deep) and extended to the maximum depth in that area (11 m). The macrophyte beds were composed of dense charophyte meadows with isolated stands of pondweed. A coarse search within the macrophytes around the end of the panhandle was done to confirm that no mussels were present.

The mussel beds from point B to the end of the survey line displayed similar characteristics to the opposite bank however the bathymetric slope of this bank was steeper and had less macrophyte coverage.

Based on the initial observation the NIWA method was not suited for this type of mussel bed establishment. Mussels did not establish in defined patches but rather in contiguous bands limited by riparian and macrophyte extent. As a result, an adapted methodology was needed.

3.3 Survey & Metadata Requirements

There were limitations to the NIWA method (Fenwick et al., 2018), and we wanted to capture a wider variety of metadata and bed extent information, so we developed a stratified survey approach and habitat information sheet.

The key survey method requirements were as follows:

- It must be rapid and simple enough to be conducted by a team of 2 – 4 divers within standard bottom time limitations.
- It must be quantitative to allow for accurate counts, size classing, age classing, sex classing, distributions and density calculations.
- It must be repeatable across sites and location through time. This will facilitate follow up surveys and can reflect long term population changes.
- The results from all sites must be comparable to allow for a lake scale population assessment.
- It must be suitable for mussel beds with a variety of dimensions.
- It must be suitable for all depths and habitats.
- It must integrate bed extent information including limiting factors and habitat preferences.
- It must be expandable to include additional metrics such as condition and sex assessments.
- It must accommodate general on-site metadata such as fish occurrence, macrophyte cover and species assemblage, substrate changes, thermocline depth, signs of anoxia, benthic algal mats etc.

3.4 Survey Protocol

The survey team should consist of at least two divers (three to four is preferable) and appropriate surface support and crew. The optimum dive team number was four, one diver placing the quadrats and performing the counts, a second diver measures the live mussels and records the size class and count information, the third diver documents transect and bed specific metadata including video transects and, the forth diver remains free of tasks and serves as a safety diver.

The divers first visually assess a 100 m long section of contiguous mussel bed and mark out the most densely populated 50 m section using markers/pegs.

The upper and lower depth extent of the mussel bed is recorded and details regarding macrophyte cover and species assemblage, substrate type, bathymetric slope, benthic algal mats, signs of anoxia, areas of increased sediment disturbance or deposition, sighted fish species as well as other general bed scale environmental observation are noted.

A 50 m line is then laid across the marked bed along the upper extent of the bed parallel to the shoreline along a constant depth contour, the depth contour should reflect the upper extent of the mussel bed. Pegs are placed at 10 m intervals along the 50 m line starting from the beginning. The six pegs (0 m, 10 m, 20 m, 30 m, 40 m, 50 m) will mark the start point of the perpendicular transects. The starting point of all transects are logged using a handheld GPS unit.

A tape is then laid perpendicular to the 50 m line, starting at each peg and extending down to the maximum depth extent recorded for the entire bed. A 0.25 m^2 (0.5 m x 0.5 m) quadrat is placed at 2 m intervals along the transect starting at the peg. Each quadrat is excavated to a depth of 10 cm (hand depth), all mussels in the quadrat are identified, counted and placed into size classes, dead mussels are counted separately and approximately sized. All mussels are placed back in the quadrat after being counted and measured. The depth and length along the transect of each quadrat is recorded as well as transect specific observations (macrophytes, thermoclines, substrate changes, signs of anoxia and sighted fish species). A full video pass of each transect is done from start to finish, this allows for a detailed review of each transect post dive.

Ten live mussels per transect are randomly selected and placed into a catch bag for detailed measurements, sexing and assessment of shell condition. An additional 40 live mussels are collected at random across the entire 50 m bed after the last transect is complete. This will result in a sample of 100 randomly selected individuals that are representative of the entire bed. The detailed measurements, sexing and shell condition assessment is done on the surface by shore crews.

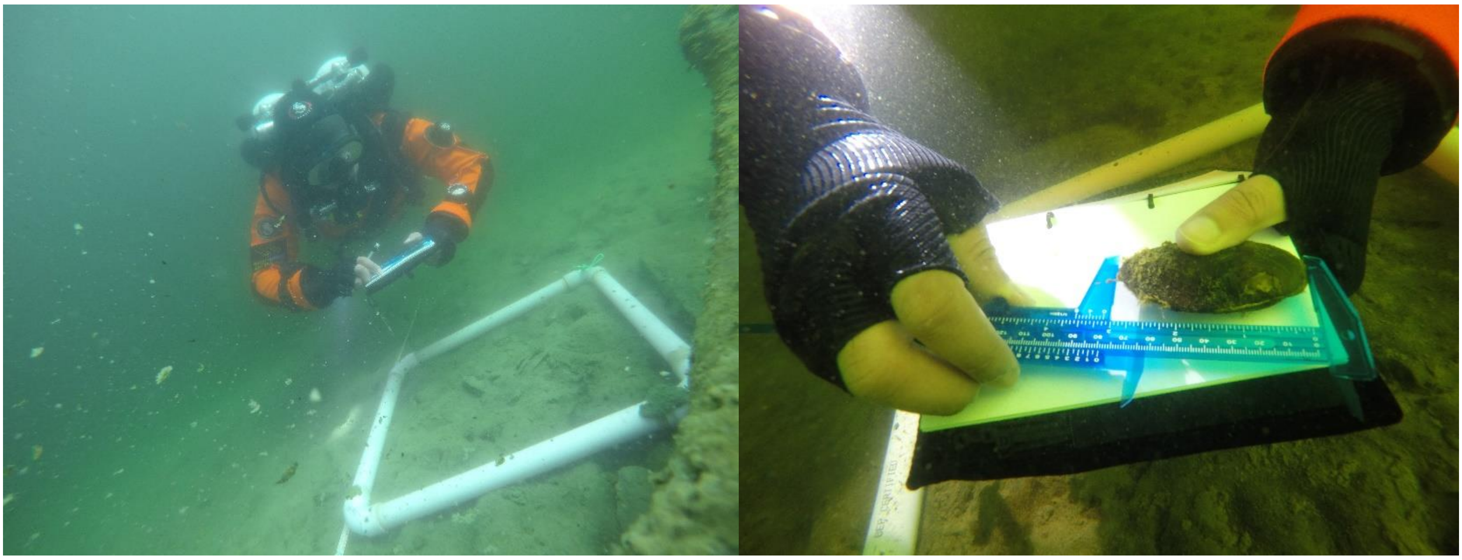


Image 4: Diver counting and measuring mussels in a quadrat

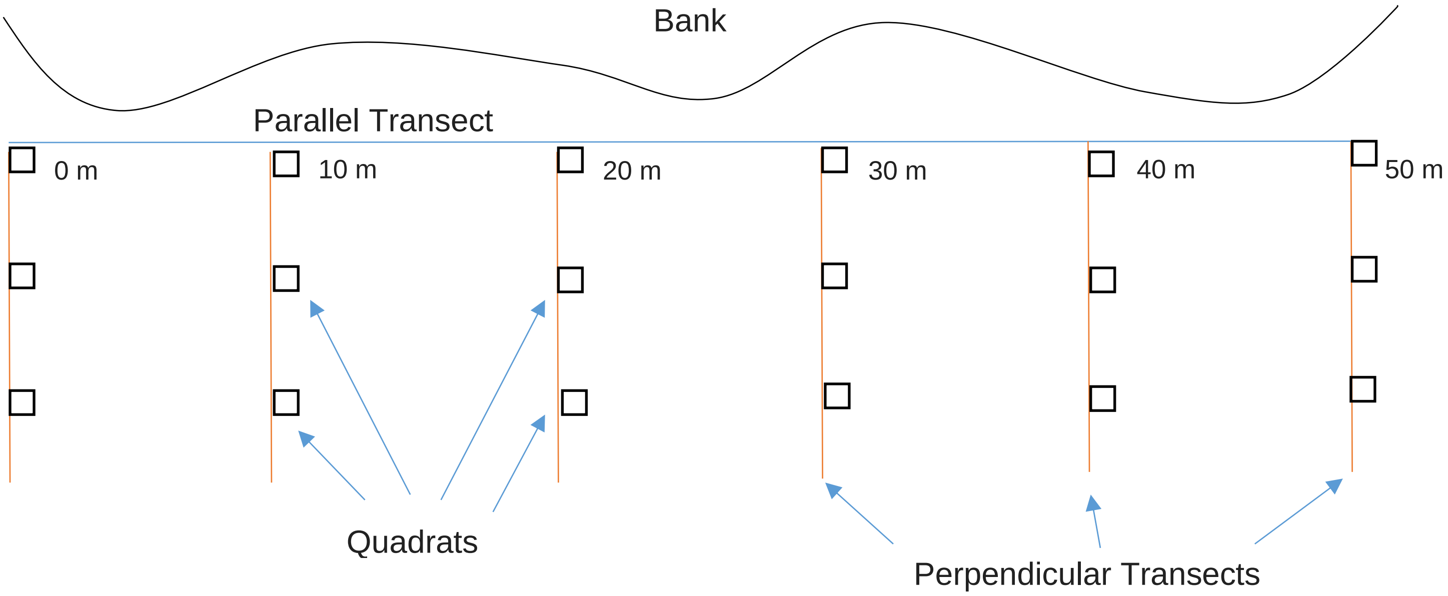


Figure 2: Schematic of survey methodology

4 Initial Results

To test the effectiveness of the survey methodology described above a series of trial surveys were done. Three separate beds with differing characteristics were chosen to trial the survey methods. These surveys were done by the same team on three separate days: 28th of September 2019, 8th of February 2020 and the 22nd of February 2020.

The three beds represent the general bed types observed in Lake Rototoa (Figure 3). Bed 1 (Slippery Rock) was deep and has a relatively steep gradient and bathymetric slope, this bed was also representative of open water beds. Bed 2 (Public Access 1) had a narrow band of mussels between the reed edge and the macrophyte beds and was very shallow with a gentle slope, bed 3 (Public Access 2) had characteristics that were between beds 1 and 2 with a moderate depth and slope.

Figure 3: Overview and location of all three surveyed mussel beds

It should be noted that detailed macrophyte identification and surveys was not done and macrophytes were identified in-water. As a result, only common macrophyte species within the dominant groups (charophytes and pondweeds) were identified and there is a possibility that other species exist amongst the beds.

The survey protocol outlines a process whereby live individuals are collected at random for detailed measurements, condition assessments and sexing. This was not done during this initial survey trail because of limited surface support and the potential stress that this process would place on the remaining live individuals.

Refer to Appendix A for the full result tables and survey notes.

4.1 Bed 1 – Slippery Rock

This bed is on the eastern bank of the lake, outside of the panhandle in the main open water body (Figure 4).

Figure 4: Location of bed 1 (Slippery Rock) and bed 3 (Public Access 2)

The mussel bed started close to shore at a depth of 0.5 m and extended west into the lake for 30 m to a maximum depth of 10 m. The average slope of the bed was 1V:3.16H. Perpendicular transects were laid due south extending into the lake at 10 m intervals. Six 30 m transects were laid across the 1500 m^2 mussel bed, 96 quadrats were placed, resulting in a total quadrat area of 24 m^2. A total of 1027 *Echyridella menziesii* were counted with an average of 10.70 mussels per quadrat, this resulted in a bed density of 42.79 mussels per m^2. Out of the 1027 mussels 823 (80.14%) of them were dead leaving only 204 (19.86%) live individuals. All live mussels were larger than 50 mm, 12 individuals were placed in the

51 – 60 mm size class, 68 individuals were classed as 61 – 70 mm and the remaining 124 individuals were all greater than 70 mm in length. The dead mussels were not measured but were all in the 60 – 70 mm size class or larger. Majority of the mussels were found between 0.5 and 3 m deep (0 – 14 m along the transect) with dense patches occurring along the 1 to 2 m depth contour (4 – 10 m along the transect), there were fewer individuals found between 4 and 5 m and almost none after 6 m deep (a distinct thermocline was noted at 6 m). A visual search was done to a maximum depth of 14 m, but no mussels were found beyond the 10 m depth contour.

The bed had well established macrophyte beds that occurred in patches throughout the survey area. The shallow littoral areas had clumps of charophytes (*Chara australis/fibrosa* and *Nitella spp.*) with stands of pondweed (*Potamogeton cheesemanii* and *Potamogeton ochreatus*) in between. There were sporadic clumps of pondweed from a depth of 0.5 – 1.5 m (0 – 6 m along the transects) and bigger stands from 1.5 – 3.5 m deep (6 – 16 m along the transects). No pondweed species were seen deeper than 4 m. Charophytes were the dominant macrophyte across the survey area and extended from a depth of 1 m down to 5.5 m with some beds occurring at 10 m. The shallower charophyte beds appeared to be dominated by *Chara australis. Nitella* species, (*Nitella hyaline* & *Nitella leonhardii*), were more abundant in the deeper sections of the survey area and dominated the lower extent of the beds at a depth of 10 m. There was no significant macrophyte cover past 10 m in depth and small isolated clumps of charophytes persisted to a maximum depth of 12 m after which there was no macrophyte growth at all. Widespread sediment disturbance, associated with benthivores pest fish, were seen along the lower extent of the macrophyte beds. No hornwort (*Ceratophyllum demersum*) was identified within the survey area. The charophyte meadows were covered by organic silt which was seen across the entire survey area.

There were dense benthic algal mats across the survey area from a depth of 6.5 m to 10 m and beyond. These algal mats densely covered the deeper macrophyte beds. There was distinct substrate change past the 10 m depth contour, the steeper shallower areas had a sandy substrate with a thin layer of surficial silt, as the gradient of the lakebed flattened out at 10 m deep the substrate turned to semi liquid fine silt. This semi liquid silt was more than an arm's length in depth and very mobile, even slight movements caused the silt to resuspend into the water column.

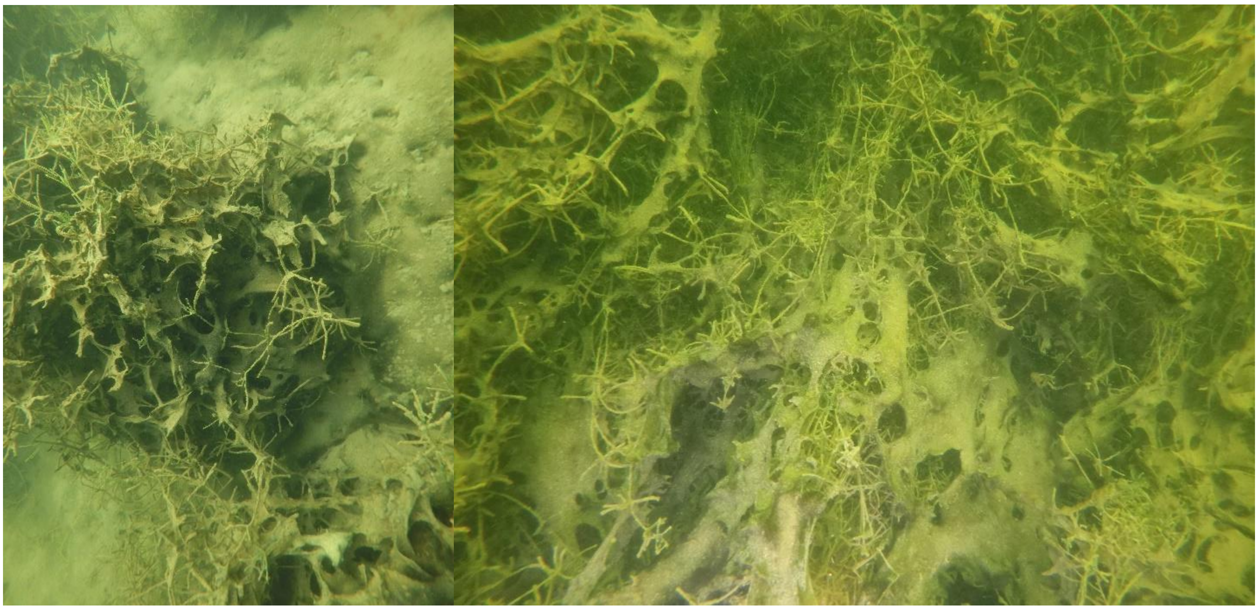


Image 5: Charophytes covered by benthic algal mats

Gambusia were sighted in high numbers in the shallow littoral areas and two perch were seen at 6.7 m deep. There was visible pest fish induced sediment disturbance past the 6 m depth contour.

The upper extent of this mussel bed appears to be dictated by water level and wave action. The upper depth of the bed is 0.5 m which is just below the permanent water level mark. The substrate from 0.5 m and above has visible signs of wave induced disturbance and several shells were found in this area with bite marks. Rats and seagulls are known to eat Kākahi from the shallow areas of the lake. The lower extent of the bed stopped at the beginning of the charophyte stands, where present, at a depth of 10 m. Almost no Kākahi were found past the 6 m thermocline indicating that there may be some thermal and dissolved oxygen limitations. The dissolved oxygen concentrations at the depth of the thermocline was not measured and it is not known if this area experiences prolonged periods on anoxia. The change in substrate is clearly a limiting factor as it is unable to support any bed establishment, the depth and semi fluid nature of the silt is unsuitable for mussels or macrophytes. These deeper sections were almost fully covered by benthic algal growth (Image 6).

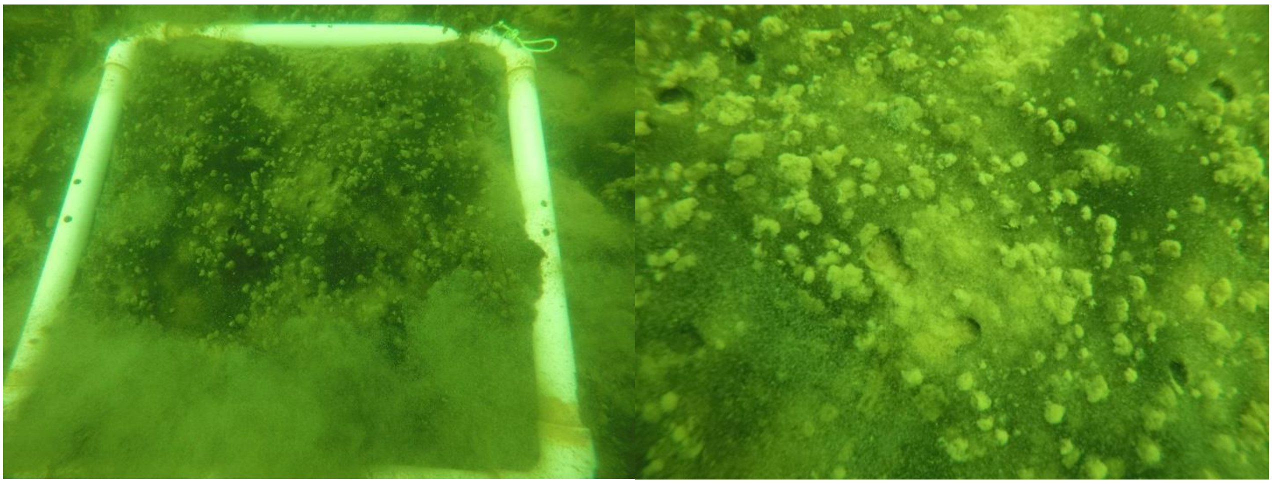


Image 6: Benthic algal growth past the substrate change

4.2 Bed 2 – Public Access 1

This bed is on the eastern bank the panhandle due north of the public access beach (Figure 5).

Figure 5: Location of bed 2 (Public Access 1)

This bed was very shallow with a gentle slope of 1V:1.21H and uniform sandy substrate. The mussels were confined in a narrow band between the end of the reeds (1.2 m deep) and the start of the dense charophyte beds (4.5 m deep). The length of the mussel bed was limited to 25 m because of macrophyte and riparian vegetation growth at the northern end of the survey area. The riparian vegetation ended on a steep slope, at the base of this slope dense charophyte meadows started and extended to the maximum depth of the panhandle. This meant no significant mussel beds/patches could establish.

Image 7: Northern end of the survey site showing the steep sloped bed with riparian vegetation and macrophyte beds

The survey area could not be extended further south as this area is heavily disturbed by recreational users and will likely not be representative of natural shallow mussel beds. As a result of these constraints perpendicular transects were laid every 5 m.

Thirty quadrats were placed, along six 8 m transects extending east into the lake, spanning the 200 m^2 bed resulting in a total quadrat area of 7.5 m^2. A total of 184 *Echyridella menziesii* were counted with an average of 6.13 mussels per quadrat. The overall bed density was 24.53 mussels per m^2. Out of the 184 mussels 162 (88.04%) were dead and only 22 (11.96%) were still alive. All live mussels were larger than 70 mm except 2 individuals that were placed in the 61 – 70 mm size class. The dead mussels were not measured but were estimated to all be larger than 70 mm. The majority of the mussels were found in relatively dense bands between the 2.0 and 3 m depth contours (0 – 3 m along the transect). High numbers were also found between the 3.5 and 4.2 m depth contour along the second, third and fourth transects (6 – 8 m along the transect). A visual search was done to a maximum depth of 5.5 m, but no mussels were found beyond the start of the macrophyte beds.

There were well established macrophyte beds across the survey area and charophytes formed dense expansive meadows from a depth of 4.5 m until 5.5 m (maximum depth for the upper end of the panhandle). The entire upper end of the panhandle was vegetated from a depth of 4.5 m onward. There were isolated stands of *Potamogeton cheesemanii* and *Potamogeton ochreatus* between 3 and 4 m deep however, bulk of the macrophyte growth composed of charophyte species. *Chara australis* appeared to be more abundant that the other charophyte species throughout the top end of the panhandle. *Nitella* species (likely *Nitella leonhardii*) were seen across the mid and deeper charophyte meadows. No macrophytes were seen shallower than 3 m along the survey area except for a clump of charophytes at 2.4 m deep on the last transect. No significant benthic algal mat coverage was noted in the survey area however, large schools of gambusia were seen throughout the panhandle. No hornwort (*Ceratophyllum demersum*) was identified within the survey area.

The upper extent of the shallow beds in the panhandle are dictated by the end of the reed line and water level. The reeds end at a depth of 1.5 – 2 m which is just below the permanent water level mark. Due to the sheltered nature of the panhandle there was little evidence of wind/wave induced disturbance along the upper extent of this bed. The lower extent of the mussel bed mirrored the start of the charophyte meadows, and no mussels were found past 1 m into the charophyte meadows.

Image 8: Charophytes limiting the lower bed extent

4.3 Bed 3 – Public Access 2

This bed is on the southern bank of the lake at the mouth of the panhandle, due south of the public access beach (Figure 6).

Figure 6: Location of bed 3 (Public Access 2) and bed 1 (Slippery Rock)

This bed was deeper than bed 2 but not as deep as bed 1. The general slope of the bed was 1V:2.59H and extended to a depth of 7.2 m. The riparian vegetation extended into the lake and grew to a depth of 1.8 m which marked the start of the mussel bed. Perpendicular 14 m transects were laid due west extending into the lake at 10 m interval. Only four perpendicular transects were completed across this bed due to complications with the dive team. Two of the divers had trouble equalising and had to abort the dive, Aotearoa Lakes does not condone solo diving which meant the remaining two transects could not be completed. A follow up survey will be done to complete the survey at a later date.

Twenty-nine quadrats were placed across the 420 m^2 survey area resulting in a total quadrat area of 7.25 m^2. A total of 393 *Echyridella menziesii* were counted with an average of 13.55 mussels per quadrat and the overall density was 54.21 mussels per m^2. Out of the 393 mussels 335 (85.24%) were dead and only 58 (14.76%) were still alive. All live mussels were larger than 50 mm. Three individuals were placed in the 51 – 60 mm size class, 17 were classed as 61 – 70 mm and the remaining 38 were larger than 70 mm in length.

Image 9: Individual Kākahi from the three size classes (left: >70 mm, middle: 61 – 70 mm, right: 51 – 60 mm)

Unlike beds 1 and 2 there was no clear distribution pattern based on depth or length along the transect. Mussels did not occur in defined bands along depth contours and were more spread out across the survey area in comparison to the previous beds. The first transect had high Kākahi numbers at a depth of 2.5 m and between 4 – 5 m, no mussels were seen after 6 m. The second transect had the highest densities between 1.7 – 3 m with high numbers also seen at 6.7 m. Transect three and four had high numbers between 1.7 – 3 m and again from 4 – 6.6m.

Image 10: Representative image of the even Kākahi distribution pattern across bed 3

This bed was not as densely vegetated as the previous two. It had established vegetation however, the macrophytes were not evenly distributed across the survey areas resulting in numerous bare patches. The reed line ended at a depth of 1.8 m and macrophytes were only seen from a depth of 3.2 m until 6.6 m. A visual assessment of macrophytes was done outside of the survey area to a maximum depth of 12 m and only sparse clumps of charophytes were seen past 8 m, there was no macrophyte coverage past the 10 - 11 m depth contour. Transect 1, 2 and 4 had isolated stands of *Chara australis* and possibly *Chara fibrosa* between the 3 – 5 m depth contour, the rest of the transect was bare until a depth of 9.3 m which was outside the survey area. Transect 2 also had small clumps of *Potamogeton ochreatus* and *Potamogeton cheesemanii* at 3.6 and 5.2 m deep. Transect 3 was the most vegetated transect and had *Potamogeton cheesemanii* and *Potamogeton ochreatus* stands from 3.4 m to 6.6 m deep with dense clumps of *Chara australis, Chara fibrosa* and possibly *Nitella* species along the 4 – 5 m depth contour. No hornwort (*Ceratophyllum demersum*) was identified within the survey area. Widespread sediment disturbance, associated with benthivores pest fish, were seen along the lower extent of the macrophyte beds

There was a distinct thermocline at 7.2 m deep and small patches of benthic blue-green algal mats near the lower end of the transects (>7 m). There was also a notable substrate change from sand to soft mud and silt past the 7 m depth contour. Benthic algal cover became denser in this area.

The upper extent of the Kākahi bed begins just after the reed line ends at a depth of 1.8 m which is reflective of the permanent water line.

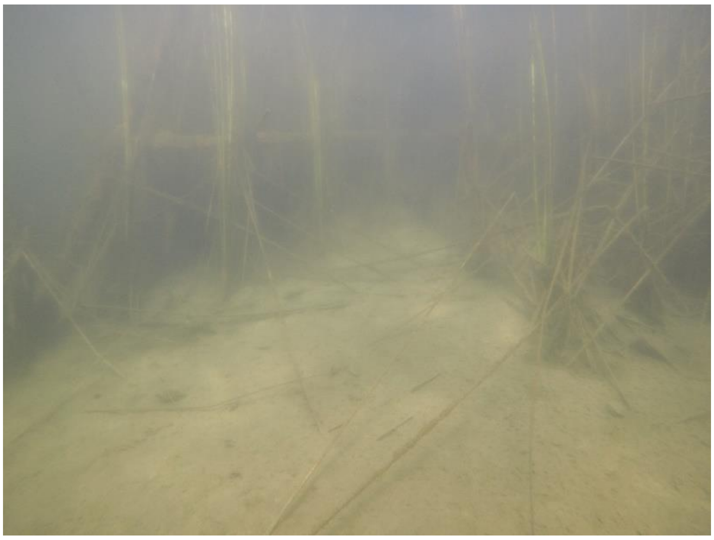


Image 11: Upper bed extent adjacent to the end of the reed line

Like bed 1 the lower extent appears to be influenced by the thermocline and substrate change along the 7 m depth contour. Again, this indicates that there may be some thermal and dissolved oxygen limitations in the lake past a certain depth. The dissolved oxygen concentration at the depth of the thermocline was not measured and it is not known if this area experiences prolonged periods of anoxia. The change in substrate is clearly a limiting factor as it is unable to support any bed establishment.

5 Conclusion

These initial surveys covered 2120 m^2 of lakebed using 16 transect and 155 quadrats resulting in a total quadrat area of 38.75 m^2. A total of 1604 Kākahi (*Echyridella menziesii*) were counted with an average count of 10.35 mussels per quadrat. The mussel combined density across all three sites was calculated at 41.39 mussels per m^2. Out of the 1604 Kākahi found, 1320 (82.29%) were dead and only 284 (17.71%) were alive. The dead mussel shells were in a similar condition to the live individuals indicating that they may have all died during a recent mass extinction event, the difference between the dead and live mussels were often hard to discern without close inspection.

Image 12: Comparison between a live and dead mussel

This observation was distinctly different to those seen in a recent assessment of Lake Pupuke (Aotearoa Lakes comments). Historic mussel beds in Lake Pupuke were covered by paper thin shell fragments and very few complete shells, the complete shells were heavily eroded and showed signs of prolonged decomposition indicating that these populations died a long time ago (Aotearoa Lakes comments).

No juveniles were seen during any of the surveys and all the mussels were larger than 51 mm. The surveyed population is composed entirely of mature adults, 64.08% of live mussels were larger than 70 mm in length, 30.63% were between 61 to 70 mm and the remaining

5.28% was in the 51 – 60 mm size class. It is possible that the juveniles occupy a different habitat space and migrate as they develop into mature adults.

Individual dead mussels were not measured but were placed into approximate size classes, all dead mussels were larger than 51 mm with majority of them being placed in the 61 – 70 mm and >70 mm size classes. The average age of the mussels surveyed were estimated to be between 20 and 30 years old based on their size. Some larger individuals were 80 to 100 mm long and were estimated to be around 50 years old.

This ageing population and lack of younger individuals is a sign that limited to no viable recruitment had occurred in the surveyed area for more than a decade. Considering that the majority of the live mussels were at the upper end of their life expectancy and no recent recruitment was evident, the long-term viability of the surveyed population is low.

The exact reasons for this population collapse are not known however recent lake surveys (fish, water quality and macrophytes) have provided some indication as to what the possible causes may be. The recent fish surveys indicate that the primary glochidia host species have significantly dropped in numbers. Both galaxiid and bully species have declined as a result of predation by pest fish species, without these native fish Kākahi cannot effectively complete their life cycle.

The declining water quality of the lake is also a contributing factor. The lake has gone from an oligotrophic state to a mesotrophic state and has been subject to increased eutrophication. Byrne, 1998 found reproduction of some freshwater mussel species was higher in eutrophic lakes compared to oligotrophic lakes. Lake Rototoa was oligotrophic which possibly resulted in low historic reproduction rates, as the lake became more eutrophic the number of native host fish also decreased through predation by pest species, so even though the lake is becoming more eutrophic the lack of host fish means elevated reproduction rates cannot be supported.

Eutrophication also causes an increase in bioavailable nutrients which stimulates algal growth and in turn causes high organic silting.

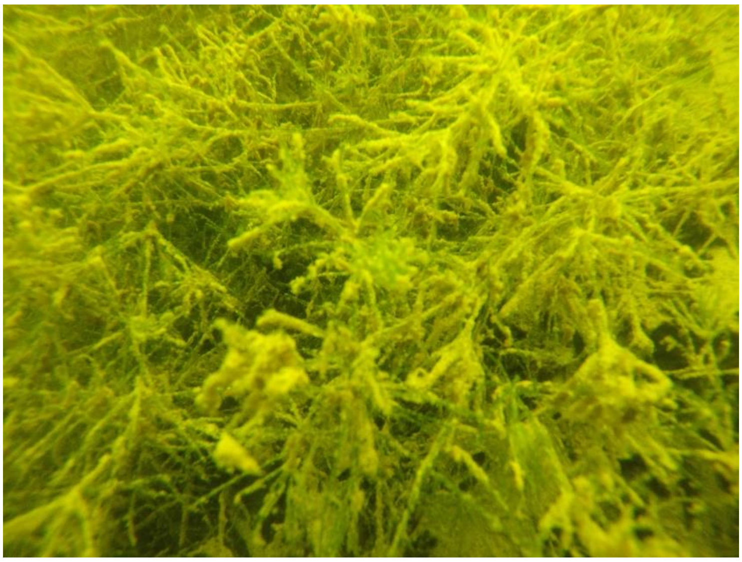


Image 13: Organic slit on charophytes

This silt settles on the lakebed and decomposes creating areas on low dissolved oxygen. James et al, 1998 suggests that Kākahi cannot survive at dissolved oxygen concentrations below 5mg/L and it is possible that the lake undergoes prolonged periods of low dissolved oxygen during seasonal stratification. The wide scale coverage of benthic blue-green algal mats further points to periods of anoxia and general eutrophication. State of the Environment monitoring data from 2019 confirms that hypolimnetic deoxygenation and anoxia occurs past 12 m.

Image 14: Blue-green algal mats

The water clarity has reduced through time which has contributed to the reduction in macrophyte extent, the lower macrophyte biomass and resulted in less nutrient assimilation and increased eutrophication. Lake Rototoa historically had good water clarity which was attributed to the low nutrient concentrations and the filtration capacity of the extensive

Kākahi population. Kākahi filtration rates generally match their food ingestion rate, once this rate has been reached no further filtration will occur (Hickey, 1995). If there is a high concentration of food (phytoplankton and zooplankton) in the water the filtration rate is likely to be low. This means that as the lake becomes more eutrophic the algal biomass increases and the Kākahi filtration rate will continue to decrease. This decrease in filtration rates will contribute to the declining visual clarity. This situation is exacerbated by the significant loss of Kākahi biomass, ultimately the loss of mussels in lake Rototoa may have facilitated a higher rate of eutrophication.

Sediment is also an issue that is known to effect mussel populations and there are visible signs of increased sedimentation however, no clear evidence of smothering or suffocation was seen. The combination of the organic silt, sediment and benthic algal growth can clog the mussel gills so there are likely to be some sediment induced population stressors.

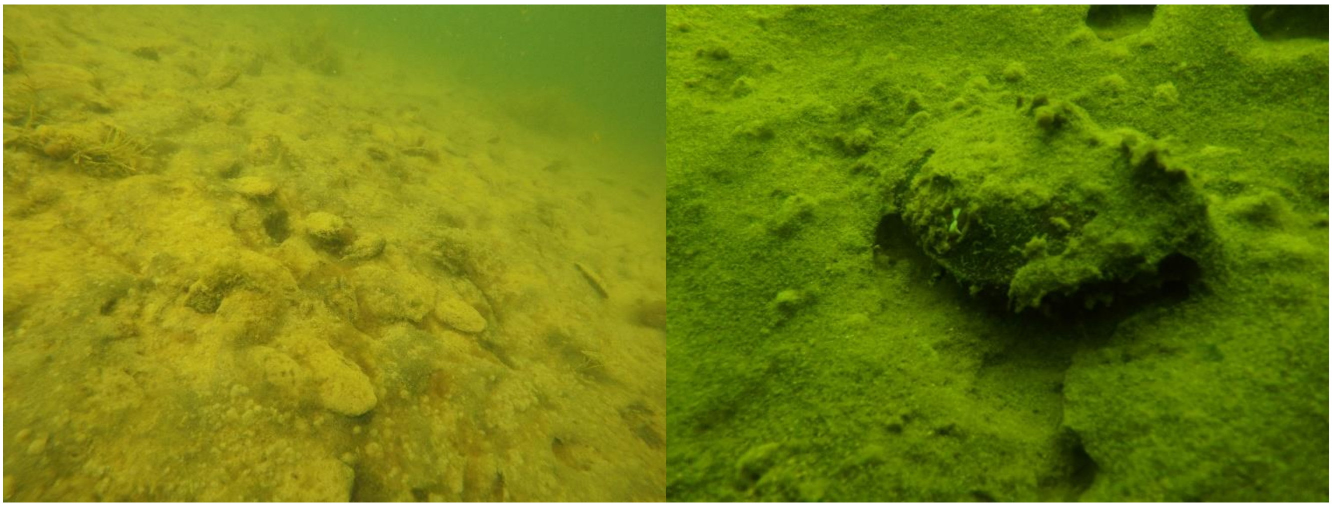


Image 15: Mussels covered by sediment, organic silt, and benthic algal growth

In terms of bed extent and bed limiting factors several key observations were made. Kākahi tended to prefer gentle slops and did not occur in great densities on steep faced slopes/shelves. The upper extent appeared to be dictated by water level, riparian vegetation extent and wind/wave induced disturbance. Kākahi beds generally established at a depth just below the permanent water line a short distance away from the end of the riparian edge. Fewer mussels were seen in shallow exposed areas with visible signs of wind/wave induced substrate disturbance. There were several shells found in bed 1 that had signs of rat bites indicating that some level of predation is occurring in the shallower areas however, this predation did not appear to limit the upper depth extent of the beds.

The lower bed extent was limited by macrophyte establishment, changes in substrate and thermoclines and potentially anoxia. Mussels were commonly found in lower numbers in macrophyte stands within the wider bed area and were not found at all within dense charophyte meadows. Kākahi tended to establish around isolated macrophyte stands rather than in them.

Image 16: Charophyte stands displacing mussels

The lower extent of the bed mirrored the start of the deeper charophyte meadows. The littoral zone had a clearly defined sections of mussels in the shallower sections (1.5 – 5 m) and dense macrophyte dominated areas in the deeper portion (6 – 10 m), which were devoid of Kākahi. No conclusions can be made around the differing Kākahi limiting potential of various macrophyte species however, it was noted that mussel densities did not appear to be as influenced by stands of pondweed as they were by dense charophyte cover. Presumably Kākahi avoid dense ground covering macrophytes and are less phased by taller more sparsely distributed vegetation.

Where no macrophytes were present, the lower bed extent appeared to be dictated by the thermocline separating the warmer epilimnion from the colder hypolimnion. Almost no mussels were found past the thermocline which was between 6 and 7.2 m deep during the survey period. Kākahi establishment is not known to be thermally regulated (aside from hot geothermal waters) so it is assumed that the limiting factor is in fact anoxic condition, commonly associated with hypolimnetic water. This assumption has not been validated and a more detailed investigation of stratification profiles is needed.

A clear limiting factor is the change in substrate seen past the 7 – 10 m depth contour. The substrate changes from sand with a surficial layer of silt to a semi liquid silt/soft mud. No mussels or macrophytes were found in these areas and the substrate does not appear to support and bed establishment.

Benthic algal mats were also seen covering the lower extent of some beds but did not clearly limit their establishment, Kākahi are mobile so presumably they will move if they are being smothered.

Parasites are also known to cause mussel mortalities however no investigations on parasite loads or presence were conducted.

6 Recommendations

1. Continue to survey Kākahi beds using the methodology described in this report.
2. Assess shell condition and sex during the spawning season to quantify the number and quality of gravid females.
3. Survey the following additional Kākahi beds that represent the wider lake:
   - 3.a Northern arm below the stream mouth that feeds into the lake, this area is likely to have high Kākahi numbers and possibly juveniles however this area also has the highest density of Hornwort which may impede bed establishment.
   - 3.b North eastern bays, these two bays have bathymetric profiles suited to Kākahi establishment and are largely surrounded by native bush.
   - 3.c Eastern bank near the Sheerwater Farm, this site is representative of beds receiving agricultural runoff via overland flow.
   - 3.d Western banks, two sites are recommended on this side of the lake. The first site should be near the northern end of the lake surrounded by native bush and the second site should be at the southern end of the lake near Honeymoon Bay, this site is surrounded by forestry and exhibits different sediment/substrate characteristics.
4. Install continuous temperature and dissolved oxygen sensors at the lower depth extent of the beds (10 – 12 m) during stratification to assess the potential thermal and dissolved oxygen limitation.
5. Conduct repeat surveys at the same beds every 3 – 5 years to track population size and dynamics over time.

6. Conduct repeat fish surveys every 3 – 5 years and correlate results with Kākahi surveys.
7. Obtain specialist advice on the potential impacts of parasites on Kākahi populations.
8. Maintain and increase pest fish management.
9. Conduct detailed water quality trend analysis and stratification assessment including hypolimnetic deoxygenation rates.
10. Engage with stakeholders, Iwi and local communities to raise the issues and get greater backing for Kākahi specific management plans.

7 References

Brönmark, C. 1994. Effects of tench and perch on interactions in a freshwater, benthic food chain. Ecology 75: 1818-1828

Byrne, M. 1998. Reproduction of river and lake populations of Hyridella depressa (Unionacea: Hyriidae) in New South Wales: implications for their conservation. Hydrobiologia 389, 29–43

Carlson, S., Lawrence, A., Blalock-Herod, H., McCafferty, K., Abbott, S., 2008. Freshwater mussel survey protocol for the south-eastern Atlantic slope and north-eastern gulf drainages in Florida and Georgia. United States Fish and Wildlife Services, Ecological Services and Fisheries Recourse Offices. Georgia

Catlin, A., Collier, K., Pingram, M., Hamer, M. 2017. Regional guidelines for ecological assessments of freshwater environments – standardised protocol for adult freshwater mussel monitoring in wadable streams. Waikato Regional Council TR: 2016/23

Cheng, K. 2017. Quantitative Freshwater Mussel Survey. Partnership for the Delaware Estuary. PDE FMRP Method No. 07. 6pp

Clearwater, S. J., Thompson, K. J., Hickey, C. W. 2014. Acute toxicity of copper, zinc, and ammonia to larvae (Glochidia) of a native freshwater mussel Echyridella menziesii in New Zealand. Archives of Environmental Contamination and Toxicology 66: 213–226
DOI 10.1007/s00244-013-9972-7

De Winton, M. D., Taumoepeau, A. T., Clayton, J. S. 2002. Fish effects on charophyte establishment in a shallow, eutrophic New Zealand lake. New Zealand Journal of Marine and Freshwater Research, 36: 815-823

De Winton, M., Burton, T. 2017. LakeSPI assessment of 33 Auckland lakes: 2017 update. Prepared by the National Institute for Water and Atmospheric Research, NIWA for Auckland Council. Auckland Council technical report, TR2017/028

De Winton, M. 2019. Ecological baseline and monitoring for Lakes Rototoa and Tomarata. Prepared by the National Institute for Water and Atmospheric Research, NIWA for Auckland Council. Draft Report

Dugdale, T. M., Hicks, B. J., de Winton, M. D., Taumoepeau, A. T. 2006. Fish exclosures versus intensive fishing to restore charophytes in a shallow New Zealand lake. Aquatic conservation: Marine and freshwater ecosystems, 16: 193-202

Fenwick, M. C., Clearwater, S. J. 2018. Kakahi survey of Lake Horowhenua. NIWA Client Report: 2018181HN. Prepared for Horizons Regional Council

Grainger, N., Collier, K. J., Hitchmough, R., Harding, J. S., Smith, B. J., & Sutherland, D. L. 2014. Conservation status of New Zealand freshwater invertebrates, 2013 (Report). Wellington, New Zealand: Department of Conservation

Grimmond, N. M. 1968. Observations on growth and age in Hyridella menziesi in a freshwater tidal lake. Msc thesis, University of Otago., Dunedin

Hanshue, S., Rathbun, J., Badra- Michigan, P., Bettaso, J., Hosler, B., Pruden, J., Grabarkiewicz, J. 2019. Michigan Freshwater Mussel Survey Protocols and Relocation Procedures. Michigan Department of Natural Resources, Michigan

Hickey, C., Roper, D., Buckland, S. 1995. Metal concentrations of resident and transplanted freshwater mussels Hyridella menziesi and sedimentation in the Waikato River, New Zealand. The Science of the Total Environment 175: 163-177

James, M. R., Ogilvie, S.C., Henderson, R. 1998. Ecology and potential use in biomanipulation of freshwater mussel Hyridella menziesi (Gray) in Lake Rotoroa. NIWA Client Report: HCC90210/1

Ling, N., Tempero, G., Pyper, N., Powrie, W. Prentice, M. 2019. Status of the fish community of Lake Rototoa in 2019. Draft Report. Auckland Council

Lyons, R.A., Johnson, L.K., McIntyre, B.M. 2016. Phosphorus loading rates in lakes with development and stocked fish in the Sierra Nevada Mountains, California, USA. Ecosphere 7(11): Article e01554

McDowall, B. 2002. Decline of the Kākahi: Identifying cause and effect. NIWA Water and Atmosphere 10: 8-9.

McDowall, R. M., 2011. Ikawai: Freshwater fishes in Māori culture and economy. Christchurch, Canterbury University Press

McEwan, A. 2012. Wairarapa Moana Kākahi survey. Prepared for the Wairarapa Moana Wetland Project

McEwan, A. 2015. Kākahi monitoring report. Prepared for the Wairarapa Moana Wetlands Group, Greater Wellington Regional Council, Wellington, New Zealand.

Phllips, N., Kusabs, I., Emmery, W., Row, D., Parkyn, S., van Houte-Howes, K., Edwards, T., Clayton, J., Boubee, J., Quinn, J., Martin, M., Roper, D., Hickey, C., Wilding, T. 2007. Taonga/Mahinga Kai of the Te Arawa lakes: a review of current knowledge. Draft NIWA report. Prepared for the Te Arawa Lakes Trust.

Phillips, N. 2007. Review of the potential biomanipulation of phytoplankton abundance by freshwater mussels (Kākahi) in the Te Arawa Lakes. NIWA Client Report HAM2006-125. Prepared for Environment Bay of Plenty.

Rainforth, H. J. 2008. Tiakina kia ora – protecting our freshwater mussels: A thesis submitted to Victoria University of Wellington in fulfilment of the requirements for the degree of Masters in Ecological Restoration. Victoria University of Wellington

Rowe, D., Hawes, I., Smith, J., Taumoepeau, A. 2003. Exotic fish in ARC lakes: implications for water quality decline and the development of restoration options. Auckland Regional Council Technical Report Number 2008/001

Walker, K. F., Byrne, M., Hickey, C., Roper, D.S. 2001. Freshwater mussels (Hyriidae) of Australasia. Evolution of the freshwater mussel Unionoida, pp. 5-31. Ecological Studies 145. Springer-Verlag, Berlin and Heidelberg

Appendix A – Result Tables & Survey Notes

Site	Date	Tran sect	NZTM	Quadrat	Transect length	Depth	Dead	0 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	>70	Macrophytes	Benthic algal mats	Comments
Slippery Rock	28/09/19	0m	1711186.60, 5958079.62	16	0	0.5											Pondweed stands start at a depth of 1.7m (6m along the transect) and end at a depth of 3.6m (11m along the transect)
				15	2	0.5											Charophyte beds start at 3.6m depth (11m along the transect) and end at a depth of 4.3m (13m along the transect)
				14	4		8						2	4			Benthic algal mats & charophytes start at 8.4m (24m along the transect) and extend all the way down to 10m (30m along the transect), very dense bed from 8-10m depth (24-30m along the transect)
				13	6	1.7	25						5	7	Charophytes/pond weed		
				12	8		25							1	Charophytes/pond weed		
				11	10	3.6	10						4	1	Charophytes		
				10	12	3.6	6						4	9	Charophytes		
				9	14	4.3							1	4			
				8	16		1					2					
				7	18	6.0	2					1					
				6	20							1					
				5	22		1										
				4	24	8.4									Charophytes	Dense	
				3	26										Charophytes	Dense	
				2	28										Charophytes	Dense	
				1	30	10.0						1			Charophytes	Dense	
Slippery Rock	28/09/19	10m	1711176.48, 5958081.07	15	0	0.5											Dense mussel patch from 0.5m depth to 3.7m depth (0.5m - 3m along transect)
				14	2	0.5											Pondweed from a depth of 1.6m to 2.7m depth (1.6m - 11m along the transect)
				13	4	1.2	10						3	5			Charophyte bed at 4.7m depth (15m along the transect)
				12	6	1.7	40						2	2	Pond weed		Charophyte bed from 9.5m to 10m depth (28m-30m along the transect)
				11	8	2.2	25						2	4	Pond weed		
				10	10	3.0	14						2	6	Pond weed		
				9	12	3.8	5						1	1			
				8	14	4.5	6							2	Charophytes		
				7	16	5.4	6						2				
				6	18	6.0	3					1					
				5	20	6.7	2										
				4	22	7.3	2										
				3	24	8.0										Dense	

				2	26	8.7										Dense	
				1	28	9.4	1								Charophytes	Dense	
				0	30	10.10											
Slippery Rock	09/11/19	20m	1711166.56, 5958082.46	0	0	0.5	14						2	2			
				1	2	1.0	15					4	1		Charophytes/pond weed		
				2	4	1.0	25						2	2	Charophytes/pond weed		
				3	6	1.5	33						4	2	Charophytes/pond weed		
				4	8	1.5	52						1	5	Charophytes/pond weed		
				5	10	1.9	31							4	Charophytes/pond weed		
				6	12	2.3	24						1	8	Charophytes/pond weed		
				7	14	3.0	15						1	2	Charophytes/pond weed		
				8	16	3.7	12						2		Charophytes/pond weed		
				9	18	4.5	13							1	Charophytes		
				10	20	5.4	12								Charophytes		
				11	22	5.9	1								Charophytes		
				12	24	6.5	2										
				13	26	7.2										Dense from here onward	
				14	28	8.10											
				15	30	9.60											
Slippery Rock	09/11/19	30m	1711156.44, 5958083.98	15	0	0.5	3										Pondweed and charophytes from 0.8 to 2.6m depth (2 - 11m along transect)
				14	2	0.5	5								Charophytes/pond weed		Dense charophyte beds from 3 - 3.7m depth (12 - 14.6m along transect)
				13	4	1.2	10						3	5	Charophytes/pond weed		Charophyte meadows from 4.8 - 5.5m depth (17 - 19.4m along transect)
				12	6	1.7	38						2	2	Charophytes/pond weed		Benthic cyano mats from 5m depth (19m along transect)
				11	8	2.2	25						2	4	Charophytes/pond weed		Thermocline at 6m (20m along transect)
				10	10	3.0	14						2	6	Charophytes		
				9	12	3.8	5						1	1	Charophytes		
				8	14	4.5	6							2	Charophytes		
				7	16	5.4	6						2		Charophytes		
				6	18	6.0	3					1				Dense	
				5	20	6.7	2									Dense	
				4	22	7.3	2									Dense	

				3	24	8.0										Dense	
				2	26	8.7										Dense	
				1	28	9.4	1									Dense	
				0	30	10.0										Dense	
Slippery Rock	09/11/19	40m	1711146.25, 5958085.37	15	0	0.5	12						2	5			Small stands of pond weed between 0.5m to 1.5m depth (1 -7m along transect)
				14	2	0.5	26						1	4	Charophytes/pond weed		Dense patches of charophytes and pond weed from 1 - 4m depth (1 - 16m along transect)
				13	4	1.3	19						1	2	Charophytes/pond weed		Dense charophyte bed at 4.3 - 5.3m (16.4 - 17.6m along transect)
				12	6	1.5	30							3	Charophytes/pond weed		Deep water charophyte meadows at 10m depth (30m along transect) and beyond
				11	8	2.0	13							4	Charophytes/pond weed		Benthic cyanobacteria mats from 7m depth (21m) until the end of the transect
				10	10	2.5	13						1	4	Charophytes/pond weed		Thermocline at 6m (23m along transect)
				9	12	3.0	3							1	Charophytes/pond weed		Gambusia & perch
				8	14	4.0	7							1	Charophytes/pond weed		
				7	16	4.8	6							1	Charophytes		
				6	18	5.3	7								Charophytes		
				5	20	6.0											
				4	22	6.8										Dense	
				3	24	7.2	1									Dense	
				2	26	7.7										Dense	
				1	28	9.0										Dense	
				0	30	9.7									Charophytes	Dense	
Slippery Rock	09/11/19	50m	1711136.02, 5958086.59	15	0	0.5	3						1				
				14	2	0.5	9						1	2	Charophytes/pond weed		
				13	4	1.0	21						3	1	Charophytes/pond weed		
				12	6	1.3	21								Charophytes/pond weed		
				11	8	1.6	27						3	1	Charophytes/pond weed		
				10	10	1.9	22							3	Charophytes/pond weed		
				9	12	2.2	6								Charophytes/pond weed		
				8	14	2.7	6					1			Charophytes/pond weed		
				7	16	3.5	5						1		Charophytes/pond weed		
				6	18	4.2	1								Charophytes		
				5	20	5.0	4								Charophytes		

				4	22	5.4									Charophytes		
				3	24	6.2											
				2	26	6.7										Dense from here onward	
				1	28	7.80											
				0	30	9.30											
Results																	
Total Area Covered (m2)	1500																
Number of Quadrats	96																
Total Quadrat Area (m2)	24																
Total Mussel count	1027																
Total dead	823																
Total alive	204																
Ave mussels/Quad	10.697917																
Density/m2	42.791667																
Percent dead	80.136319																
Percent alive	19.863681																

Site	Date	Transect	NZTM	Quadrat	Transect length	Depth	Dead	0 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	>70	Macrophytes	Benthic algal mats	Comments
Public access 1	8/02/20	0m	1711300.39, 5958179.83	0	0	2.0	9								reed bed ends		Total bed was only 25m so transects were 5m apart.
				1	2	2.8	9						2	4			Maximum depth was 4.7m, charophyte meadows started from her and went to the max depth in the area (5m)
				2	4	3.3								2	charophyte stands		Reed beds limit the upper extent and mussel beds start at 2m
				3	6	4.0	2										Bed 1 is to the right of the public access beach, transects were laid due west of the bank
				4	8	4.5									Dense charophytes		Dense charophytes at end of tape at 4.5m depth
Public access 1	8/02/20	5m	1711304.82, 5958181.75	0	0	1.7	3							1			
				1	2	2.3	4							6			
				2	4	3.0	3							1	pond weed		
				3	6	3.8	8								pondweed		
				4	8	4.2	6							1	charophyte meadows		
Public access 1	8/02/20	10m	1711309.98, 5958183.27	0	0	1.2	2										
				1	2	1.6	1										
				2	4	2.1	4										
				3	6	2.9	8								pond weed clumps		
				4	8	3.5	10										
Public access 1	8/02/20	15m	171314.88,5 958184.99	0	0	1.5								1			
				1	2	2.0	3							1			
				2	4	2.4	4										
				3	6	3.5								1			
				4	8	4.2	21								charophyte meadows		
Public access 1	8/02/20	20m	171319.57,5 958186.51	0	0	1.9	13							1			
				1	2	2.1	28							1			
				2	4	3.0	15										
				3	6	3.3	4								charophyte meadows		
				4	8	4.1											
Public access 1	8/02/20	25m	1711324.80, 5958188.23	0	0	1.9											
				1	2	2.4	4								charophytes		
				2	4	2.7	1								charophyte meadows		
				3	6	3.5											

				4	8	4.2											
Results																	
Total Area Covered (m2)	200																
Number of Quadrats	30																
Total Quadrat Area (m2)	7.5																
Total Mussel count	184																
Total dead	162																
Total alive	22																
Ave mussels/Quad	6.133333																
Density/m2	24.53333																
Percent dead	88.04348																
Percent alive	11.95652																

Site	Date	Transect	NZTM	Quadrat	Transect length	Depth	Dead	0 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	>70	Macrophytes	Benthic algal mats	Comments
Public access 2	22/02/20	0m	1711258.41, 5958047.08	1	0	1.8	7								Reeds		Macrophyte beds start at 5.2m depth and 9.3m on transect
				2	2	2.5	20					2		4			Thermocline at 7.2m deep
				3	4	3.1	7										Bed 2 is to the left of the public access beach and transects were laid due west of the bank
				4	6	3.8	10							1	Charophyte stands		
				5	8	4.7	9							5	Charophyte stands		
					10	6.1											
					12	6.5											
					14	7.1											
Public access 2	22/02/20	10m	1711249.88, 5958041.19	1	0	1.7	22								Reeds		No macrophyte beds at end of transect, just barren sediment
				2	2	2.1	16						1	3			Generally a bare transect
				3	4	2.9	13							2			Signs of benthic cyanobacteria in small patches near the lower end of the transect
				4	6	3.6	4								Small stands of charophytes & pondweed		Thermocline at 7.2m deep
				5	8	4.5	5						2	1			
				6	10	5.2	6								Small stands of charophytes & pondweed		
				7	12	6	0						2	1			
				8	14	6.7	30						1	1			
Public access 2	22/02/20	20m	1711241.54, 5958035.64	1	0	1.8	17								Reeds		Most vegetated transect across the bed
				2	2	2.2	14						2				Limited macrophytes past 8m depth, sparse clumps
				3	4	3.4	4								Pondweed stands		Thermocline at 7.2m deep
				4	6	4	9						1		Dense charophytes & pondweed		
				5	8	5	21					1			Dense charophytes & pondweed		
				6	10	5.6	12								Pondweed stands		
				7	12	6.6	10								Pondweed stands		
				8	14	7.2	5						1				
Public access 2	22/02/20	30m	1711232.88, 5958029	1	0	1.8	22						2	1			Sparse charophyte stands from 3m-5m deep
				2	2	2.7	24							4			Distinct substrate changes at 7m deep, substrate changed from sandy to soft mud
				3	4	3.2	20							5	Small stands of charophytes		Signs of benthic cyanobacteria, small patches near the lower end of the transect
				4	6	4.4	4						2	3	Small stands of charophytes		
				5	8	5.2	8							1			

				6	10	5.8	7						2	2			
				7	12	6.7	2						1	4			
				8	14	7.2	7										
Results																	
Total Area Covered (m2)	420																
Number of Quadrats	29																
Total Quadrat Area (m2)	7.25																
Total Mussel count	393																
Total dead	335																
Total alive	58																
Ave mussels/Quad	13.55172																
Density/m2	54.2069																
Percent dead	85.24173																
Percent alive	14.75827																

AOTEAROA LAKES

CITIZEN SCIENCE FOR OUR LAKES