Kakahi Survey of Lake Horowhenua

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NIWA Taihoro Nukurangi

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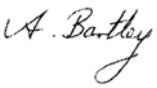	Formatting checked by:	Alison Bartley
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1 Executive summary

Kākahi (*Echyridella menziesii*) are considered a vital component of New Zealand lake and river ecosystems. Their presence in Lake Horowhenua has long been recognised but there is a lack of any empirical population data to support effective management of kākahi in the lake. To overcome this knowledge deficiency Horizons Regional Council (HRC) commissioned NIWA to implement a kākahi survey using a repeatable approach and to coincide with an annual aquatic macrophyte mapping survey. Lake Horowhenua is recognised as a taonga by local iwi Muaūpoko but has a long and tragic history of modification and pollution that has been controversial and divisive. Recently central and local government and iwi have joined together to restore Lake Horowhenua and this survey is a component of a larger plan to rejuvenate and reintroduce native species to the lake.

Predetermined transect locations were decided by consultation with Muaūpoko iwi members, and NIWA staff familiar with Lake Horowhenua. Six transects of 100m length were surveyed during one day of field sampling. Each transect was searched by a single diver. Visibility was low so a tactile (by touch) method of searching was employed which enables divers to easily detect mussels as small as 10 mm length. Mussel densities were measured by quadrat counts both inside and outside "mussel patches" which were defined as areas of relatively high mussel densities. Mussel densities were <13 to 16/m^2 inside mussel patches and 0.0 m^2 outside. Divers found no mussels along four of the six transects. Two patches of mussels were identified in the northern and eastern end of the lake with a minimum extent estimated at 8.5 m^2 and 170 m^2. Average mussel length was 90 ± 7 mm and the population structure had a strongly unimodal length distribution. Eighty-six percent of live shell lengths were in the range of 80 to 100 mm indicating that the majority of kākahi in Lake Horowhenua are 20 to 50 years old with minimal recruitment in the last 16 to 20 years. A preliminary evaluation of brood pouch status indicated that 43% were females brooding ripe larvae (glochidia) which aligns with the seasonal reproductive cycle documented for *E. menziesii* elsewhere in New Zealand. We therefore conclude that although adult mussels are producing larvae in Lake Horowhenua recruitment failure is probably occurring with poor or no survival of either larvae and/or juveniles. A likely cause of recruitment failure is poor water quality, specifically elevated pH and ammonia concentrations during the summer larval release period. Other factors may be contributing including reduced populations of host fish and/or sedimentation in juvenile habitat.

The presence of many dead adult mussels *in situ* in the sediment suggests that adult survival is also decreasing in recent years. The adult mussels may simply be aging and reaching the end of their life span or they may be affected by multiple stressors in Lake Horowhenua, particularly degraded water quality and sedimentation. The combination of an aging adult population with no recruitment (survival) of juveniles is called "extinction debt" (Tilman et al. 1994).

A kākahi resurvey at Transects 1 and 2 is recommended at an interval of 2-3 years, or earlier if there is evidence of a recruitment event, a specific concern (e.g., rapid change of land/water use in the region) or improvement. If resources permit, additional transect locations could be examined every year to provide a more comprehensive understanding of the mussel population distribution and abundance in the lake. Mussel surveys in significant tributaries to Lake Horowhenua are recommended to identify any additional mussel populations that may serve as donor populations to the lake should the mussels in the lake die out before water quality in the lake improves. In terms of maintaining mussel populations, fish access to tributaries should be ensured to allow the dispersal of mussel larvae and juveniles to additional habitat. Confirmation of the age structure by the analysis of a selection of shells by sectioning would also be useful to improve our ability to age the population.

2 Introduction

Lake Horowhenua or Punahau is a small shallow lake some 3.9 km^2 located in the Horowhenua area on the west coast of the Lower North Island. The lake lies on a sandy plain just west of Levin and 5 kilometres from the Kapiti coast. It is a shallow lake, only some 2 metres (7 ft) deep, fed by various small streams, and draining into the Tasman Sea through the Hokio Stream.

In the past the lake was surrounded by podocarp forest and it was the centre of a wetland that provided mahinga kai to Muaūpoko who have mana whenua status over the lake. The lake has been substantially degraded since European settlement; today the trees and most of the wetlands have been removed. Also between 1952 and 1987 treated sewage from Levin was discharged into the lake. These alterations have contributed significantly to the current eutrophic state of the lake.

The lake bed is owned by the Muaūpoko beneficial owners and is administered by the trustees of the Horowhenua Lake Trust. They are actively attempting to restore the wetland system to its former state (http://www.horowhenualaketrust.org/about) including mahinga kai species such as freshwater mussels.

New Zealand is home to three species of freshwater mussels *Echyridella menziesii, E. aucklandica* and *E. onekaka.* Their taxonomy and relationships to the worldwide mussel fauna has largely been explained by the work of Marshall and Fenwick who revised the New Zealand fauna and carried out a New Zealand-wide survey (Fenwick and Marshall 2006; Marshall et al. 2014). Nonetheless the distribution, abundance, and population trends of the three species remains poorly understood throughout New Zealand – although progress is being made in some regions, particularly the Waikato and Wairarapa. Freshwater mussels are called kākahi by Muaūpoko, so this name is used in the present study (although other names including kāeo, are also used in Te Reo Māori in different locations or by different iwi throughout Āotearoa New Zealand).

Both the iwi Muaūpoko and Horizons Regional Council (HRC) are concerned that the freshwater mussel populations in the lake and tributaries are in decline. Rob Warrington a trustee of the Lake Horowhenua Trust, reported that mussels were once abundant throughout the lake and were an important food source for Muaūpoko (Hamer 2015). In fact, he stated kākahi were so abundant that children in the 1960's played marbles with the "pearls" found inside the shells (R. Warrington Pers. Comm. 14 November 2017). Considering the species distribution documented in the Marshall and Fenwick studies, it seems likely that these abundant kākahi were *E. menziesii,* the most widespread species in Aotearoa. To our knowledge neither *E. aucklandica* nor *E. onekaka* have previously been found in the region.

In general terms freshwater mussels can be described as having "patchy" distributions within areas of suitable habitat. This means sampling methods must be tailored to take this "patchiness" into account when trying to characterise mussel distribution and abundance within freshwater systems.

Most studies of freshwater mussels in New Zealand have (of necessity) documented mussel populations at a location over only one to three years (e.g., James 1985; James 1987; Roper & Hickey 1994, Butterworth 2008) and we lack long term population studies. Freshwater mussels are long-lived, with the oldest *E. menziesii* aged at more than 50 years (Grimmond 1968). This means that although adult mussels may be present at a location, no larval or juvenile mussels may be surviving (i.e., 'recruiting') to replenish the population as it ages. This is known as "extinction debt" where there is a delay between the impacts on a population (or species) and the final loss of individuals from the system (Tilman et al. 1994). It is therefore important to measure the age structure of

mussel populations and thus enable examination of recent recruitment to fully understand the potential longevity of localised populations.

As part of the restoration work at Lake Horowhenua, NIWA has undertaken aquatic macrophyte (aquatic plant) surveys at the lake since 2014. For the present study NIWA was engaged by HRC to survey the abundance, population structure and breeding status of kākahi at the lake in a project combined with a macrophyte survey to mitigate costs. NIWA was required to provide a survey report that:

- described the monitoring methodology in sufficient detail for follow-up surveys;
- included the raw survey data;
- provided an analysis of the data and a summary of the results; and
- provides a discussion of the findings of the survey and conclusions about juvenile kākahi recruitment.

3 Methods

3.1 Transect positioning and dive survey methods

Diving was conducted on the 14 November 2017. Six transects of 100 m length were pre-planned and mapped using GIS software. The locations were selected on the basis of information provided by, a) Rob Warrington and other iwi members about the position of past and probable current mussel beds, and b) from NIWA staff (A. Taumoepeau) about lake substrate types and aquatic plant (weed) beds. The predetermined transect positions were located and laid using R.V Rahope and the onboard GPS system (Figure 3-1). We laid a 100 m weighted line, anchored at either end and provided with surface floats to mark the ends (Figure 3-2). A cable tie at 10 m intervals gave the diver an indication of progress along the transect. Each transect was searched by a single diver using underwater communications and towing a progress float to allow for monitoring by boating staff. Visibility was virtually nil so a tactile (i.e., by touch) method of searching was employed following a method previously developed by one of the authors of the present study (S. Clearwater) and used in Lake Waahi (Baker et al. 2014). The diver carried a 0.5 m x 0.5 m quadrat, a catchbag and a slate.

At the weight, and at each 10 m marker, the diver held on to the transect line with one hand and searched the sediment by hand along a line perpendicular to the transect with the other hand out to the length of their arm span (1.5 to 1.7 m), then back into the transect line so that every 10 m an area approximately 0.3 m by 1.5 m (0.45 m^2) was searched intensively (Figure 3-2). The diver then rapidly searched the sediment by hand to a depth of approximately 5 cm as she or he swam along the transect to the next 10 m marker, where the intensive sediment search perpendicular to the transect line was repeated. As a result, once the transect is complete, an area of sediment >6 m^2 has been intensively searched by the diver (i.e., (11 x 0.45 m^2) + (0.15 m x 0.7 m x 10) = 6.35 m^2). The divers noted sediment types, vegetation, any fish and other features along each transect, and searched the sediment to a depth of approximately 5 cm. Each diver was monitored from a boat tracking the surface buoy, with a standby diver ready to provide assistance. Transect and dive information was recorded on "Site Characteristics" datasheets (Appendix A).

Figure 3-1: Lake Horowhenua dive transects searched 14th November 2017.

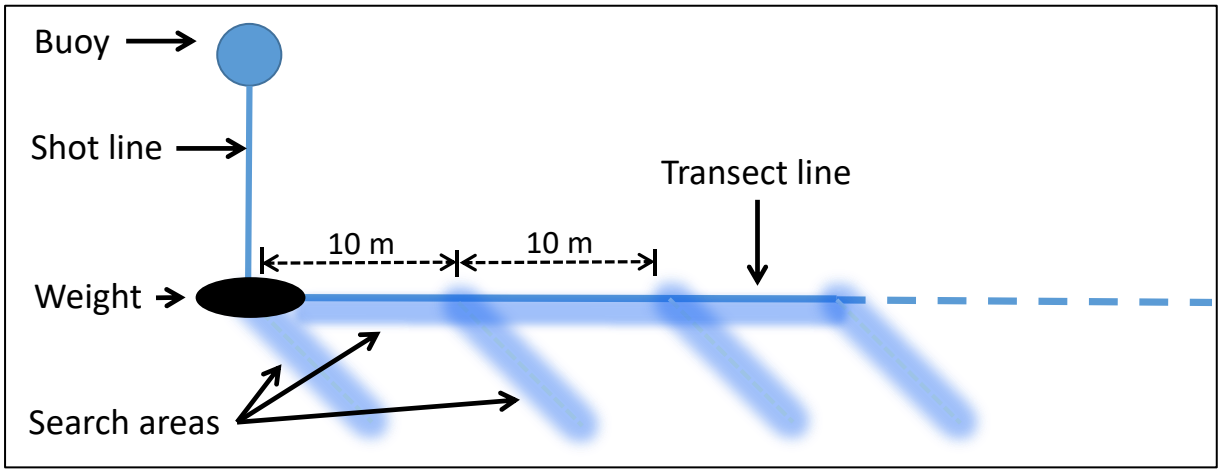

Figure 3-2: Diagram of dive transect in Lake Horowhenua and areas searched by the tactile method (not to scale).

The diver also completed quadrat counts, aiming for 5 quadrats "inside mussel patches" and 5 quadrats "outside mussel patches". To do this, the diver noted the location on the transect where mussels were first detected. If, for example no mussels were found in the first 20 m, the diver randomly placed the quadrat either to the left or right of the transect several times at some point in the first 20 m, and intensively searched the quadrat for mussels to a depth of 10 cm (i.e., finger depth) and recorded the number found. Divers took particular care to search the substrate for

juvenile mussels to a minimum length of 10 mm. The approximate position of each quadrat was noted (e.g., 11 m). These counts were considered "outside the mussel patch". Once a "mussel patch" was encountered, the diver noted its position and extent (e.g., 22 m to 35 m), and quadrat counts in the region were considered "inside the mussel patch". If the dense mussel patch "ended" before the diver had made 5 quadrat counts, the diver back-tracked and completed sampling inside the patch, taking care to place quadrats in positions that had not previously been sampled. The same principle applied for quadrats to be taken "outside the patch". In this manner we measured mussel densities inside and outside "mussel patches".

The criteria for "inside" and "outside" a mussel patch could be subjective if mussels were present at very low densities. In our experience however, mussels tend to be truly patchy, making it easy for a diver to allocate quadrats to inside/outside a "patch".

Divers also collected the first 100 live mussels encountered during the quadrat counts for shell measurements. Some mussels were collected by backtracking along the transect after all quadrat counts had been completed, and some were collected while returning to the boat in order to characterise the size distribution of the mussels.

3.2 Mussel measurements and evaluation

After collection, live kākahi were taken to shore in buckets of lake water (labelled by transect) where shell length, height and inflation were measured using plastic Vernier callipers by HRC staff and a Muaūpoko iwi member (Appendix B for datasheets). The measurements were taken following the method of Fenwick and Marshall (2006) and were recorded for each transect. Briefly, length was the maximum length of each shell measured perpendicular to the height measurements, and inflation is the width (or 'fatness' of the mussel). Note that "height measurements" were taken on a line that always extended through the umbo (origin) of the shell and was perpendicular to the length measurements[1].

Additional information such as sex and state of brood pouch, was also collected along with percentage of shell erosion averaged across the two shell valves.

Brood pouches were evaluated non-destructively by using a smooth-edged, blunt but thin "butter knife" to gently prise open the two shells approximately 5-8 mm (without breaking the kākahi's adductor muscles) and view the gills. Three brood pouch features were noted, present or absent (Yes/No), size (none [0] small [S], fat [F] and very fat [VF], and colour (pale yellow [PY], yellow [Y], orange [O]).

The presence or absence of shell damage by the chironomid fly *Xenochironomus canterburyensis* (Forsyth and McCallum 1978) (that can have dramatic effects on shell length in kākahi) was also graded 1 (none) to 5 (severe) based on a simplified field version of the "Kākahi Shell Deformity Index Version 1" (Phillips 2007) which uses internal as well as external shell features to grade shells (Appendix C). The field version of the index uses only external features on live mussels.

While the mussels were held onshore, care was taken to keep mussels shaded by the bucket lids and water was exchanged frequently to keep water temperatures equal to those in the lake. Once measurements were completed, the mussels were returned to the water in the area of the mussel patch on each transect (as indicated by the onboard GPS system).

[1] It is possible to also measure "wing height" which is the maximum height of the shell, and is often found posterior to the umbo, but this measurement was not recorded in this survey.

4 Results

4.1 Dive surveys

Divers encountered mud or soft mud (from 3 to 70 cm deep) along all transects, but the distribution of macrophytes was variable (). Two out of the six transects completed had kākahi present.

Transect 1 in the northeastern corner of the lake was characterised by soft mud and some sparse, small patches of macrophytes, that were not surface-reaching. Mussels were found embedded in the substrate but emergent (i.e., the posterior end of the mussel extends above the substrate) – and the majority of the dead mussels retrieved were found dead *in situ* (i.e., they appeared to be embedded and intact, rather than broken or empty shells on the substrate surface). There was an obvious "patch" of mussels found on the transect that extended approximately 5 m along the transect (from 80-85 m) and areas either side of this had virtually no mussels (the occasional mussel was found). Five quadrats (0.5 m x 0.5 m) were searched within the patch (counts were 3, 3, 3, 1, 6) and mussel densities were 12.8 ± 7.2 mussels/m^2. After the mussel patch (from 85-100 m) the substrate was mostly hard bedrock interspersed with areas of soft mud. Five more quadrats were searched outside the patch at either end of the transect and no mussels were found.

On Transect 2 on the eastern shore of the lake, and north of the public boat ramp, mussels were found the length of the transect at similar densities throughout. As on Transect 1 live mussels were embedded and emergent, and the dead mussels were found *in situ.* Approximately 50-60% of the mussels in each quadrat were dead. All mussels collected were relatively large, although divers did search for smaller mussels. Five quadrats were searched (counts were 4, 4, 5, 6, 1) and mussel densities were 16.0 ± 7.5 mussels/m^2.

The initial quadrat counts for Transect 1 were completed prior to the team recognising the extent of the issue of "mud-filled" shells that appeared to be live – so the live mussel densities are probably overestimated on Transect 1. No mussels were found on Transects 3 to 6. Transect 4 was positioned in a relatively dense surface-reaching macrophyte bed that made surveying difficult. Future surveys should avoid this area.

Inshore land use was similar around the lake consisting mostly of pasture farming, some swamp/scrub and a narrow riparian band of mostly native vegetation (raupo, flax) and some exotic species (e.g., willow, gorse, pines). There was exotic forest inshore of Transect 3 as well as farming, and some urban landuse inshore of Transect 4.

Table 4-1: Detailed information collected on the dive survey of Lake Horowhenua. Divers examined the right side of the transect line (as they swam along it). Diver (SC = Sue Clearwater; MF = Mark Fenwick). Rob Stewart recorded data and took all other water quality measurements. Q = quadrat.

Transect	Location	Inshore or lake end	Northing	Easting	Secchi depth (m)	Maunsell colour	Tempera-ture (°C)	Water depth (m)	Distance along transect (m)	Substrate	Kākahi	Diver	Comments
1	NE end of lake.	Inshore	-	-	0.85 On bottom	7.6	18.6 - 19.2	0.6 - 0.9	0-80 [135-55]	Soft deep mud (0.30 m deep) over hard bedrock.	None	SC	Transect started at 135 m on tape measure and worked toward 0. Three "outside patch" quadrats with 0 mussels.
1	"	-	-	-	"	"	"	"	80-85 [55-50]	Fine mud 0.05 m deep.	Common	SC	Five quadrats "inside patch" (3,3,3,1,6 mussels/quadrat).
1	"	-	40.59878[A]	175.26199[A]	"	"	"	"	85-100 [50-35]	Occasional macrophytes, not dense, patches of mud and bedrock.	Occasional	SC	Two quadrats "outside patch" both 0 mussels. 26 mussels collected for measurement onshore by backtracking after completing quadrats.
2	Eastern shore north of boat ramp.	Inshore	40.60588[A]	175.26619[A]	1.1	7.6	19.2 - 19.3	0.8 - 1.1	0-100	Fine mud 0.03 m over bedrock, patches of small macrophytes.	Mussels found ~ common along transect	SC	Five quadrats "inside patch" (4,4,5,6,1) live mussels/quadrat. Discovered that 50% of the mussels in each quadrat were dead *in situ.* This is accounted for in the numbers reported above. 100 mussels collected afterwards for measurement (many of these were later found to be dead – see measurement datasheet for details).

Transect	Location	Inshore or lake end	Northing	Easting	Secchi depth (m)	Maunsell colour	Tempera-ture (°C)	Water depth (m)	Distance along transect (m)	Substrate	Kākahi	Diver	Comments
3	Western shore mid lake.	Inshore	40.60570	175.2549	1.1	7.6	19.5	1.1 - 1.4	0	Soft mud approx. 0.70 m deep, & rooted macrophytes (*Potamogeton*?).	None	SC	No mussels found on transect. Quadrat 1@10 m, 0 mussels; Q2@18 m, 0 mussels; Q 3 to 5, 0 mussels.
3	"	Lake	40.60633	175.25611	"	"	"	"	100	"	None	SC	"
4	SE shore of lake in weed bed.	Inshore	40.61815	175.24918	"	"	19.9	0.8 - 1.6	0	0.50 m deep mud covered with heavy weed mat – surface reaching.	None	MF	No mussels, start of transect. Five quadrats searched, no mussels.
4	"	Lake	40.6178	175.24887	"	"	"	"	100	"	None	MF	No mussels found on the second half of the transect. One mussel found outside the transect (L = 77, H = 39, I = 11 mm; Erosion 10%, Fly 1 (no thickening); no Brood Pouch.
5	SW shore of lake just south of outlet.	Inshore	40.61318	175.24145	0.6	7.6	19.9 - 20.0	0.9 – 1.3	0	Mud	None	MF	One eel seen/felt by diver, Q1@40 m, 0 mussels; Q2-Q5, 0 mussels.
5	"	Lake	40.61322	175.24332	"	"	"	"	100	"	None	MF	No mussels.

Transect	Location	Inshore or lake end	Northing	Easting	Secchi depth (m)	Maunsell colour	Tempera-ture (°C)	Water depth (m)	Distance along transect (m)	Substrate	Kākahi	Diver	Comments
6	Northern shore of lake outlet.	Inshore	40.60725	175.24083	0.75	7.6	20.5	0.7 – 1.1	0	Mud	None	MF	Transect at lake outlet. No mussels found on transect or in 5 quadrats searched along the transect. After completing transect included an extensive search mainly around an inshore area of raupo on the northern side of the outlet, but no mussels found.
6	"	Lake	40.60789	175.24164	"	"	"	"	100	"	None	MF	"

[A]Latitude and Longitude for other end of the transect appears to be incorrect.

4.2 Mussel measurements

In the vicinity of Transect 1 in the north-western section of the lake, 22 live kākahi and 3 dead kākahi were collected for measurement and in the vicinity of Transect 2 in the north-eastern section of the lake 81 live kākahi and 19 dead kākahi were collected for measurement. The 22 dead kākahi shells (pairs) collected for measurement were mistakenly thought to be alive until brood pouch inspection revealed that the shells were full of mud. Their shell measurements were not included in this analysis. The diver was sometimes able to detect these dead mussels prior to collection, so an even greater proportion of mussels present in the substrate were dead "*in situ*". Raw measurements, shell and brood pouch scores are provided in Appendix B.

All mussels were identified as *Echyridella menziesii* (MCF or SJC) by examining external shell morphology. Shell measurements were combined because mean length between transects only varied by 1.5 mm. Live kākahi shell measurements (n = 103) were mean length (± standard deviation) 90 ± 7 mm (range 69 – 105 mm), mean height 51 ± 5 mm (range 40 mm – 63 mm), and mean inflation 31 ± 4 mm (range 21 – 39 mm). A size-class frequency plot indicates that 34% of the mussels were 81-90 mm long and 54% of the mussels were >91 mm long (Figure 4-1). Average shell erosion was 14 ± 10% (range 2-50%), and average "fly" score (i.e., external shell thickening) was 1.9 ± 0.9 (range 1 to 4). Dead kākahi shell measurements (n = 22) were very similar with mean lengths of 88 ± 8, mean height, 51 ± 5, and mean inflation of 31 ± 3, mean shell erosion of 16 ± 9% and mean "fly score" of 1.2 ± 0.5.

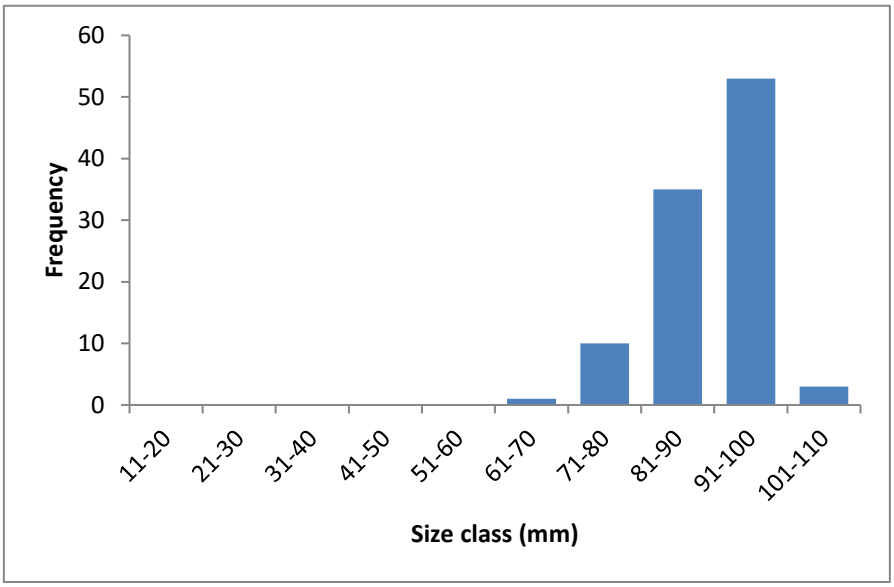

Figure 4-1: Size distribution of kākahi collected from two northern sites (n = 103).

Brood pouch evaluations were completed for the 22 mussels from the vicinity of Transect 1, and 45 of the mussels from Transect 2. Due to logistical difficulties we were unable to provide good training in this technique, therefore the results should be interpreted with caution. A total of 67 mussels were evaluated for brood pouches and 30% had none, while 70% had at least a small brood pouch. Considering the total length of the mussels, and the time of year, the individuals without brood

pouches are likely to be males (see discussion for further details). Two of the mussels had white brood pouches and were therefore also likely to be males. The remainder (67%), had pale yellow to orange brood pouches and were therefore likely to be female. *Echyridella menziesii* with orange (or orange/brown) brood pouches contain ripe glochidia, while pale yellow and yellow brood pouches generally contain oocytes/eggs and immature glochidia. The size of the brood pouch indicates the quantity of eggs or larvae. Our data therefore suggest that approximately 43% of the mussels were females brooding ripe glochidia, while 24% of the mussels were females at an earlier stage of egg or larval development.

5 Discussion

Lake Horowhenua is hypertrophic with high turbidity, and may at times present a risk to humans because of the presence of cyanobacterial blooms that can sometimes produce toxins (Gibbs 2011). The lake is shallow, being less than two metres deep. SCUBA diving with full face-masks was determined to be the most appropriate way to mitigate risk arising from contact with potentially contaminated water. SCUBA diving also makes it easy to evaluate mussel habitat, excavate quadrats and other equipment in water depths >1 m.

All kākahi collected during the survey were identified as *Echyridella menziesii* (MCF or SJC); the same species found by Fenwick and Clark during a wading search in April 2005. We re-examined the specimens collected in 2005 that were archived at the Museum of New Zealand Te Papa Tongarewa, and measured them for comparison with those collected during the current survey. The 2005 specimens (n = 20) had mean length (± standard deviation) of 90 ± 6 mm (ranged 76 mm – 102 mm), mean height 49 ± 4 mm (range 40 mm-55 mm), and mean inflation 32 ± 3 mm (range 25 mm-38 mm). These data indicate that the mean size of mussels present in the lake has remained the same since 2005. It is possible that because we did not sieve the sediments, we missed collecting some mussels however it is relatively easy to detect mussels down to 10 mm total length particularly in the fine mud sediment we encountered at Lake Horowhenua. We are therefore relatively confident that the mussels we collected are representative of the population currently present at the search locations within Lake Horowhenua – although sediments would need to be sieved to exclude the possibility that mussels <10 mm length are present.

The average and maximum length of the Lake Horowhenua mussels is noticeably larger than those reported in most other studies in New Zealand, which have however tended to examine mussel populations in the central North Island around the Waikato or the Te Arawa lakes (Rotorua). For example the size range of *E. menziesii* was 10-70 mm in Lake Taupo, and 20-90 mm at six sites along the Waikato River with median lengths from 48 mm at Taupo to 65 mm in Lake Maraetai (on the Waikato) (James 1985; Roper and Hickey 1994). The few published studies of *E. menziesii* populations from South Island locations suggest that longer shell lengths are more common. For example *E. menziesii* at Lake Tuakitoto (70 km south of Dunedin) were 30-105 mm length (Ogilvie and Mitchell 1995), at Lake Waihola (35 km south of Dunedin) they were 10-110 mm long, with the majority in the 80-100 mm range (Grimmond 1968) and at Ō Tū Wharekai (Ashburton Lakes) (110 km west of Christchurch) the largest size range was in Lake Roundabout at 16-110 mm length (de Winton et al. 2013).

In *E. menziesii* shell length does appear to be related to mussel age, but ages estimated from annular rings within the shells are highly variable (Grimmond 1968; James 1985; Roper and Hickey 1994). A recent study of the microgeochemistry of *E. menziesii* shells from Lake Rotorua as a proxy for climate records supports the contention that dark rings are indeed formed annually, but growth rates decrease markedly as the mussels age (Herath et al. 2017). The longest shell examined by James (1985) from Lake Taupō was 60 mm length and had 12 annular rings. The longest shells examined by Roper and Hickey (1994) from the Waikato River were 80-83 mm long and had approximately 12-33 annular rings. Grimmond (1968) provides the most comprehensive study of *E. menziesii* annular rings and estimated the ages of 81-90, 91-100, and 103-106 mm long mussels at 21-30, 31-50 and 51-55 years old respectively. It seems likely therefore that 88% of the mussels that we examined from Lake Horowhenua are >20 years old, 56% are >30 years old and 3% are >50 years

old. The smallest mussel collected in Lake Horowhenua was 68 mm long and according to Grimmond (1968) would be approximately 16 years old.

On the present survey mussels were found in two patches located in the north and eastern end of the lake. The northerly patch extended only 5 m along Transect 1 and the density was estimated at 13 ± 7 mussels/m^2 - although this is probably an overestimate because some of the sampled mussels may have been dead *in situ*, but were counted as live by the diver. The mussel patch at Transect 2 extended the entire length of the 100 m transect and appeared to extend at least 1.7 m (a diver's arm span) in one direction (at least) from the transect and the mussel density was 16 ± 8 mussels/m^2 (excluding dead mussels *in situ*). The mussels were found in 0.03-0.05 m deep soft mud and were sometimes associated with small, sparse macrophytes. No mussels were found on Transect 3 to 5 where there was either deeper mud and/or dense stands of surface-reaching macrophytes. Mussel densities of 0.1 to 814 mussels/m^2 have been recorded in Lakes Rotokawau, Rotokākahi and Taupō (James 1985; James 1987; Butterworth 2008).

In general, the shells of the live mussels were found to be in relatively good condition, with relatively low rates of deformity and average erosion rates of 14 ± 10% compared to 16 ± 9% erosion in the few dead shells that were also evaluated. Thickening due to chironomid (fly) infestation was not prevalent. The team did note that dead mussels had extremely thick, sturdy shells when compared to those found at most other locations in New Zealand. This observation prompted Rob Warrington's recollection that in the 1960's children played with "pearls" from the mussels. Rob clarified that the pearls were not even and spherical. Given the number of dead mussels found *in situ* it seems likely that adult mussel survival is also decreasing in recent years. Alternatively, they are simply reaching the end of their life span. Adult freshwater mussels are considered markedly more tolerant of environmental stressors than the early life stages, however water quality in the lake is considered to be significantly degraded (see below for details).

As noted in the methods, due to logistical constraints at the site, the NIWA team was unable to provide thorough training for HRC staff in brood pouch evaluation therefore these survey results must be considered preliminary. The data suggests that there may be a 67:33 ratio of female: male mussels in the lake and that approximately 43% of the female mussels were brooding glochidia with the remainder in an earlier stage of development. These results align with the only study of the reproductive seasonality of *E. menziesii* (at Lake Taupō) and unpublished data from other locations in the North Island, particularly Lake Karāpiro (Waikato) (Clearwater et al. Unpublished Data) where for the last five years, ripe female mussels brooding glochidia have been routinely collected from November to March to support laboratory-based research on early life stages of mussels (Clearwater et al. 2014; Clearwater et al. 2017; Clearwater et al. in prep). The Lake Taupō study suggested that *E. menziesii* is reproductively mature at shell lengths >37 mm, therefore all the mussels collected in the present study (minimum length 68 mm) could potentially produce gametes.

Given that no mussels less than 68 mm were found in the present survey, and the youngest mussel is estimated at 16 years of age, it seems likely that there has been no successful recruitment (survival) of juvenile mussels into the adult mussel population at Lake Horowhenua for at least 10-15 years[2]. Clearwater et al. (2014) demonstrated that *E. menziesii* larvae (glochidia) are extremely sensitive to ammonia exposure when compared to other native invertebrate species. This research is supported by an extensive body of research on the larvae and juveniles of multiple North American freshwater mussel species and strongly suggests that *E. menziesii* juveniles are also

[2] Lake sediments would however, have to be sieved to definitively prove that juvenile mussels are not present in the lake.

among the aquatic invertebrate species most sensitive to ammonia exposure. The North American mussel research was undertaken to inform revisions to the United States Environmental Protection Agency's ammonia guidelines (USEPA 2013) and has also been incorporated into New Zealand's National Policy Statement for Freshwater Management (NPS-FM), National Objective Framework as ammonia guidelines (NPS 2017). The ammonia sensitivity of freshwater mussels is highly relevant to Lake Horowhenua because monitoring data indicates that in recent years elevated ammonia and pH concentrations occur during the summer months (Gibbs 2015) (Figure 5-1). Ammonia toxicity in Lake Horowhenua will be increased by the simultaneous high pH that occurs as a result of aquatic plant photosynthesis[3].

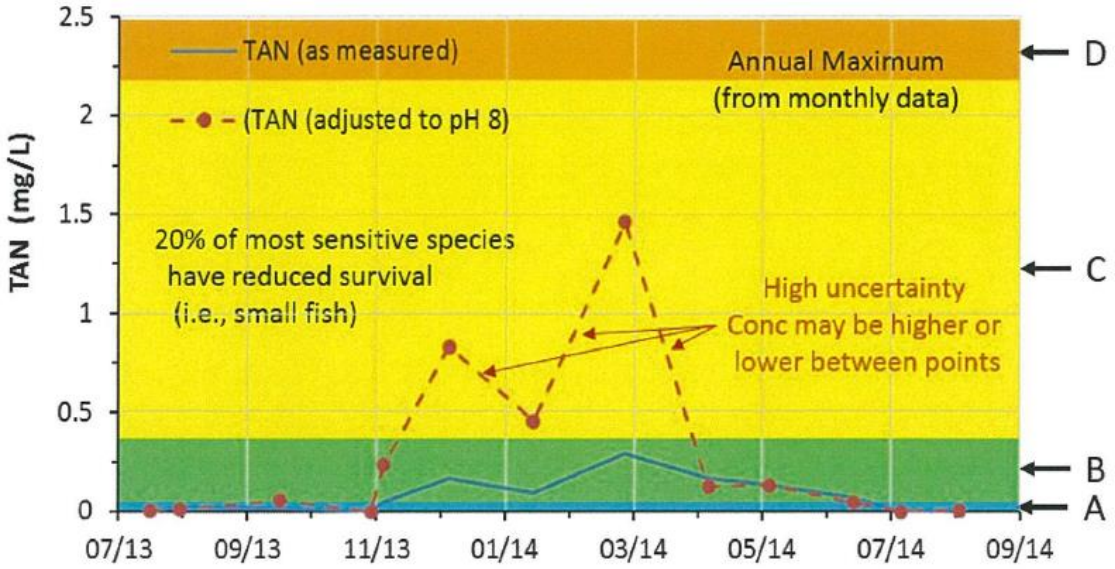

Figure 5-1: Lake Horowhenua total ammoniacal nitrogen (TAN) data from July 2013 to September 2014 (from Gibbs 2015). TAN concentrations have been normalised to the NPS-FM NOF bands (right-hand y-axis) at pH 8 and 20oC water temperature. Dashed lines indicate uncertainty about monthly maximum concentrations.

Echyridella menziesii juveniles are likely to be sensitive to chronic (long-term) exposure to ammonia (TAN) concentrations greater than 0.5 to 0.9 mg TAN/L (pH 8.0) (Clearwater et al. 2014). Ammonia is also toxic to fish and may therefore have decreased populations of host fish in Lake Horowhenua that are required for freshwater mussel larvae to transform into juveniles. Recent research suggests that *E. menziesii* are host generalists and, in the laboratory at least, can transform into juveniles on common bullies *Gobiomorphus cotidianus*, shortfin and longfin eels *Anguilla australis* and *A. dieffenbachii,* kōaro *Galaxias brevipinnis*, banded kōkopu *G. fasciatus*, Canterbury galaxias *G. vulgaris*, and rainbow trout *Oncorhynchus mykiss* (Clearwater et al. 2014; Brown et al. 2017). The presence of any of these fish species in the lake may therefore provide some opportunity for juvenile mussel transformation – a process that requires attachment to a fish for one to two weeks. It seems likely however that high ammonia concentrations, during the summer months when female mussels are producing larvae, will inhibit the survival of juvenile mussels.

[3] High pH changes the chemical form of ammonia (from ionized to un-ionized) and makes it markedly more toxic to aquatic life. This mechanism of toxicity is sufficiently well-understood that water quality guidelines for ammonia are always expressed in terms of pH.

Worldwide, the habitat requirements of freshwater mussel juveniles are poorly understood, but are thought to include well-sorted and well-aerated sediments with high quality pore water and a supply of fine detrital material for food (Yeager et al. 1994; Buddensiek 1995; Geist and Auerswald 2007). Sedimentation is thought to "clog" sediments and reduce survival of juvenile mussels possibly through a combination of decreased dissolved oxygen concentrations and elevated ammonia concentrations – and this is supported by recent research into the rearing of juvenile *E. menziesii* (Clearwater et al. 2017). Host fish are thought to provide transport of mussel larvae to favourable habitat. If tributaries to Lake Horowhenua have higher water quality (than the lake), suitable sediments, and are accessible to host fish species, they may provide both juvenile and adult mussel habitat – and a means to extend the long-term survival of Lake Horowhenua sub-population of *E. menziesii*, until lake restoration efforts take effect.

Finally it is also possible now to extract *E. menziesii* larvae from ripe female mussels, transform them *in vitro* without a host fish, then growth them out with a relatively high survival rate until they are approximately two months old (Clearwater et. al 2017; Thompson and Clearwater 2017). Survival declines markedly after this point, however research into improving juvenile mussel grow-out is continuing and may soon offer an opportunity to maintain a captive or translocated population of the mussels unique to Lake Horowhenua until such time that they can be restored to the lake.

6 Conclusions and Recommendations

Our data demonstrates that Lake Horowhenua kākahi are a geriatric population with an average age of 16 to >50 years. The population structure indicates that no, or minimal recruitment of juvenile mussels has occurred for 16 years, and has probably been limited or declining for up to 20 years. Lack of juvenile survival cannot however be definitively excluded until search methods include sediment sieving. Poor water quality, specifically elevated ammonia concentrations and pH >8.0 during November to March coinciding with the mussel larva release season, is a probable cause of the suspected juvenile mussel recruitment failure.

The presence of many dead adult mussels *in situ* in the sediment suggests that adult survival is also decreasing in recent years. It is not known how long *E. menziesii* shells will remain intact in sediments once the mussel has died. Alternatively, the adult mussels may simply be aging and reaching the end of their life span. It would be informative to examine annular rings in the shells of Lake Horowhenua mussels of a range of sizes, to improve our age estimates of the current population.

Two patches of live mussels at densities of <13 to 16 mussels/m^2 were identified in the lake with a minimum extent of 8.5 m^2 at Transect 1 and 170 m^2 at Transect 2, and although our one-day survey targeted potential mussel habitat it is possible that mussels are present in other locations in the lake. The presence of female mussels with orange-coloured brood pouches suggests that adult mussels are continuing to produce larvae but the early life stages are failing to survive in Lake Horowhenua.

Further monitoring of mussels is recommended at Transects 1 and 2 every two to three years, or sooner if any marked changes in water quality occur. Sediment sieving could be included at these locations to try to find juvenile mussels <10 mm. If resources permit additional transect locations could be examined every year to provide a more comprehensive understanding of the mussel population distribution and abundance in the lake.

Mussel surveys in significant tributaries to Lake Horowhenua are recommended to identify any additional mussel populations that may serve as donor populations to the lake should the mussels in the lake die-out before water quality in the lake improves. In terms of maintaining mussel populations, fish access to tributaries should be ensured to allow the dispersal of mussel larvae and juveniles to additional habitat. It is also possible now to grow juvenile *E. menziesii* in the laboratory in large numbers and this may soon offer the opportunity to establish a captive or translocated population of the mussels unique to Lake Horowhenua until such time as they can be re-established in the restored lake.

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Appendix A Site Characteristics Data Sheets

TRANSECT 1

SITE CHARACTERISTICS LAKE HOROWHENUA	S(32) / F(33)		
Transect Number	1 Wpt 32 start 30m N	GPS (Lat and long)	40.61043 / 40.59878 175.26130 / 175.26199
Date	16/11/17	Time	1044 → 1138
Weather conditions	Light airs, sun 18.6 °C	Observer	Sue Clearwater
Water temperature	18.6 on sonde → 19.2	Permanent water (circle one)	yes / no / unknown (yes circled)
Kākahi shells	nil / present / unknown (present circled)	Downstream barrier	yes / no / unknown (unknown circled)
Colour of water	clear / slightly dirty / dirty (dirty circled) Secchi: 0.95	Avg. water depth (m) (estimate)	0.6 → 0.9
Kōura	nil / present / unknown	Avg. stream width (m) (estimate)	
Freshwater shrimps	nil / present / unknown	Measurer	
Sampling method(s) e.g., Timed, measured area	Transect (50 m) Quadrats	Recorder	
Substrate Type	Mud / Muddy sand / Pebbles / Gravel / Stones (Mud circled) hardrock? (*circle all that are at your site)		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / harakeke / raupō / other (harakeke and raupō circled) 90 m away (*circle all that are at your site)		
Surrounding land use	native bush / exotic forest / farming / urban / scrub / swamp / other (farming circled) (*circle main ones)		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other (*circle one) hard to tell - strip of flax, willows		
Measurements	Soft mud (30 cm deep) – substrate hard bedrock 50 → intermittent mud → occasional mud after that. 135 → on line. Mussels in 55 – 50 collection. Record (photographs)  Transect start @ 400 → 0		

Kakahi = n=10 or timed dive — mussel shell
Quadrat = mud 5 cm deep 5 in zone (3, 7, 1, 6)
3 inshore (0, 0, 0)
2 deeper (6, 0)
Munsell colour 7.6

Secchi 0.85 (on bottom)

November 2015

TRANSECT 2

1

SITE CHARACTERISTICS LAKE HOROWHENUA	(S) 34 → (E 35)		
Transcect Number	2 NNE corner	GPS (Lat and long)	40.60637 175.26926 / 40.60558 175.2661
Date	14/11/17	Time	1213 – 1301
Weather conditions	5 kts	Observer	Sue Clearwater
Water temperature	19.2 → 19.3 / Diver temp 19 – 20	Permanent water (circle one)	yes / no / unknown
Kākahi shells	nil / present / unknown	Downstream barrier	yes / no / unknown
Colour of water	clear / slightly dirty / dirty / Secchi 1.1	Avg. water depth (m) (estimate)	0.8 → 1.1 –
Kōura	nil / present / unknown	Avg. stream width (m) (estimate)	
Freshwater shrimps	nil / present / unknown	Measurer	
Sampling method(s) e.g., Timed, measured area	Transect 100 – Quadrat	Recorder	
Substrate Type	Soft Mud / Muddy sand / Pebbles / Gravel / Stones (*circle all that are at your site)		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / harakeke / raupō / other — Cabbage trees Exotic grass (*circle all that are at your site)		
Surrounding land use	native bush / exotic forest / farming / urban / scrub / swamp / other — Riparian strip – then farmland (*circle main ones)		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other — Unknown – Maybe (*circle one)		
Measurements			

Mussel colour 7.6
Secchi 1.1m at wpt 35 (deep end)
(Q1 3cm deep) Qx5 (4, 4, 5, 6, 1) ⇒ 3cm deep mud
Live! small macrophytes
50/50 live + dead in each quadrat

Transect: continuous mussels along 100 m transect

November 2015

TRANSECT 3

s (036) F (037)

SITE CHARACTERISTICS LAKE HOROWHENUA			
Transect Number	3 but #7 in map	GPS (Lat and long)	40.60570 / 40.60633 175.2599 / 175.25611
Date	14/11/17	Time	~~1337~~ → ~~1356~~ 1337 → 1356
Weather conditions	5kt Sw.	Observer	Sue Clearwater
Water temperature	19.5	Permanent water (circle one)	yes / no / unknown
Kākahi shells	nil / present / unknown	Downstream barrier	yes / no / unknown
Colour of water	clear / slightly dirty / dirty	Avg. water depth (m) (estimate)	1.4 → 1.1
Kōura	nil / present / unknown	Avg. stream width (m) (estimate)	
Freshwater shrimps	nil / present / unknown	Measurer	
Sampling method(s) e.g., Timed, measured area	100 m transect Quadrats	Recorder	
Substrate Type	Soft Mud / Muddy sand / Pebbles / Gravel / Stones (*circle all that are at your site) 70 cm deep		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / harakeke / raupō / other (*circle all that are at your site) Pines, gorse		
Surrounding land use	native bush / exotic forest / farming / urban / scrub / swamp / other (*circle main ones) Riparian strip		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other (*circle one) Not Known		
Measurements			

(Q1 - 0 mussels 10 m), (Q2 18m 0 mussels) No mussels

5 Quads

Rooted potamogeton = 0, 0, 0, 0, 0 - Along the line

Maximum 7.6 - Secchi 1.1m

TRANSECT 4

(S38) (F39) 1

SITE CHARACTERISTICS LAKE HOROWHENUA

Transect Number	4 4 on map	**GPS (Lat and long)**	40.61815 / 40.6175 175.24913 / 175.2480
Date	14/11/17	**Time**	1514 → 1529
Weather conditions	5-10 kt Sw	**Observer**	Mark Fenwick
Water temperature	19.7 → 20.0	**Permanent water** (circle one)	yes / no / unknown
Kākahi shells	nil / present / unknown (1 found outside)	**Downstream barrier**	yes / no / unknown
Colour of water	clear / slightly dirty / dirty	**Avg. water depth (m)** (estimate)	0.8 → 1.6
Kōura	nil / present / unknown	**Avg. stream width (m)** (estimate)	
Freshwater shrimps	nil / present / unknown	**Measurer**	
Sampling method(s) e.g., Timed, measured area	Transect Quadrats × 5	**Recorder**	
Substrate Type	50cm deep Mud / Muddy sand / Pebbles / Gravel / Stones (*circle all that are at your site) Covered with weed mat		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / harakeke/ raupō / other (*circle all that are at your site)		
Surrounding land use	native bush / exotic forest / farming / urban / scrub / swamp / other (*circle main ones)		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other (*circle one) Unknown		
Measurements One picked up outside the transect. length 77 mm Height 39 mm width 22 Erosion 10%	→ No thickening, No brood pouch		

Q1 = No mussels Q4 – No mussels
Q2 – No mussel Q5 – No mussel
Q3 = No mussel
edge of weed zone

HEAVY WEED!!

November 2016

TRANSECT 5

(60) (41)

SITE CHARACTERISTICS LAKE HOROWHENUA

Transect Number	5 South transect Line 5 in map	**GPS (Lat and long)**	40.61788 / 40.61322 175.24165 / 175.26332
Date	14/11/17	**Time**	1613 → 1655
Weather conditions	- 5 - kts SE end	**Observer**	Mark Fenwick
Water temperature	20.0 19.9	**Permanent water** (circle one)	yes / no / unknown
Kākahi shells	(nil) / present / unknown	**Downstream barrier**	yes / no / unknown
Colour of water	clear / slightly dirty / (dirty)	**Avg. water depth (m)** (estimate)	0.9 → 1.2
Kōura Ee!	(nil) / present / unknown	**Avg. stream width (m)** (estimate)	
Freshwater shrimps	(nil) / present / unknown	**Measurer**	
Sampling method(s) e.g., Timed, measured area	Transect 100 Quadrats	**Recorder**	
Substrate Type	(Mud) / Muddy sand / Pebbles / Gravel / Stones (*circle all that are at your site)		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / (harakeke) / (raupō) / other (*circle all that are at your site)		
Surrounding land use	native bush / exotic forest / (farming) / urban / scrub / swamp / other (*circle main ones) Riparian strip flax, Raupo		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other (*circle one) Flood to Lake?		
Measurements			

Q1 @ 40m = 0 mussels Q5 = 0 mussels

Secchi: 0.6 m; Maunsell colour 7.6

TRANSECT 6

42

SITE CHARACTERISTICS LAKE HOROWHENUA			
Transect Number	6 6 on map Sw outlet	**GPS (Lat and long)**	40: 60725 / 40 60789 175 26067 / 175 26168
Date	14/11/17	**Time**	1056 → 1719
Weather conditions	25° 31k SW	**Observer**	Mark Fenwick
Water temperature	20-5	**Permanent water** (circle one)	yes / no / unknown
Kākahi shells	(nil) / present / unknown	**Downstream barrier**	yes / no / unknown
Colour of water	clear / slightly dirty / (dirty)	**Avg. water depth (m)** (estimate)	0.7 → 1.0
Kōura	(nil) / present / unknown	**Avg. stream width (m)** (estimate)	
Freshwater shrimps	(nil) / present / unknown	**Measurer**	
Sampling method(s) e.g., Timed, measured area	100 m Transect Riparian strip	**Recorder**	
Substrate Type	Mud / (Mud) / Muddy sand / Pebbles / Gravel / Stones (*circle all that are at your site)		
Common bank vegetation	exposed (none) / native bush / exotic forest / grass (tussock) / scrub / willow / harakeke/ raupō / other 40 m Riparian Strip (*circle all that are at your site)		
Surrounding land use	native bush / exotic forest / farming / urban / scrub / swamp / other (*circle main ones)		
Stock access & fencing	free stock access / one side fenced / both sides fenced / other (*circle one)		
Measurements			

Q1 = 0 Q5 = 0 Munsell 7/6
Q2 = 0 No mussels Secchi 0.75 to bed

November 2015

Appendix B Mussel Measurement Data Sheets and Data

TRANSECT 1.

Kākahi: LENGTH, HEIGHT & INFLATION

Kākahi Number	Quadrate	Species	Length (mm)	Height (mm)	Inflation (%)	Erosion (%)	Fly (1/5)	BP	BP size	BP colour	Comments
Bag 1 1	T1	Em. Es. Eo	550 93	495 55	% 37	% 22	Scale 1/5 2	Y/N Y	0/S/ F/VF F	PY/ Y/O O	
2	T1		101	59	39	15	2				Empty
3	T1		94	57	32	22	1	N	O		
4	T1		94	55	33	17	1	Y	S	O	
5	T1		99	59	37	22	1	Y	F	O	
6	T1		94	57	35	15	2	Y	F	O	
7	T1		76	41	23	5	1	N	O		
8	T1		94	54	32	10	1	Y	F	O	
9	T1		76	42	32	15	2	Y	S	O	
10	T1		94	55	34	15	1	Y	S	O	
11	T1		95	56	35	25	2	N	O		Empty
12	T1		96	57	37	25	2	Y	S	O	
13	T1		84	50	33	5	1	Y	F	O	
14	T1		90	55	26	5	1	Y	S	O	
15	T1		78	51	32	3	1	N	O		
16	T1		86	46	29	30	1	N			Empty
Bag 2 17	T1		101	63	35	15	3	Y	F	O	
18	T1		93	55	30	50	3	Y	VF	O	
19	T1		96	52	33	30	2	Y	S	O	
20	T1		93	51	34	10	2	Y	S	O	
21	T1		94	55	33	8	2	Y	S	O	
22	T1		88	53	27	12	3	Y	F	O	
23	T1		97	53	35	10	1	Y	S	PY	
24	T1		86	49	27	7	1	Y	S	O	
25	T1		91	54	35	15	1	Y	S	PY	
26	T1										
27	T1										

TRANSECT 2 (Page 1 of 2).

Kākahi: LENGTH, HEIGHT & INFLATION

Kākahi Number	Quadrate	Species	Length (mm)	Height (mm)	Inflation (%)	Erosion (%)	Fly (1/5)	BP	BP size	BP colour	Comments
1	1, 2 T2	Em, Ea, Eo	550 880	495 540	% 330	% 20	Scale 1/5 1	Y/N	0/S/ F/VF	PY/ Y/O /W	Empty
2	T2		825	480	295	10	2				Empty
3	T2		960	550	335	10	1				Empty
4	T2		995	560	310	10	1				Empty
5	T2		835	470	305	10	1				Empty
6	T2		900	520	265	20	1				Empty
7	T2		805	495	300	15	1				Empty
8	T2		895	510	290	10	1				Empty
9	T2		950	565	320	5	1				Empty
10	T2		970	530	320	7	2	Y	F	Y	
11	T2		940	565	345	7	2	Y	F	Y	
12	T2		910	470	365	10	2	Y	S	O	
13	T2		890	535	295	35	1	Y	S	Y	
14	T2		950	505	330	10	3	Y	S	PY	
15	T2		820	495	265	10	3	Y	S	Y	
16	T2		850	515	330	10	1	Y	S	O	
17	T2		975	555	295	10	2	Y	S	O	
18	T2		905	510	335	35	2	Y	S	O	
19	T2		865	500	300	20	2				Empty
20	T2		970	590	285	10	2	Y	S	PY	
21	T2		875	480	305	5	1	Y	S	Y	
22	T2		855	510	255	20	2	Y	S	Y	
23	T2		965	535	355	5	2	Y	S	O	
24	T2		970	530	320	10	2	Y	S	Y	
25	T2		865	500	310	15	2				Empty
26	T2		790	455	275	15	1				Empty
27	T2		835	440	300	5	1	Y	S	Y	

TRANSECT 2 (continued, page 2 of 2).

			L	H	Infl.	Erosion	Fly	BP	Size	colour	
28	T2		925	540	345	10	1	Y	S	PY	
29	T2		920	520	295	25	2	Y	F	O	
30	T2		955	565	355	8	1	Y	F	O	
31	T2		865	500	270	5	1	N	O		
32	T2		865	450	275	10	1				Empty
33	T2		955	565	320	40	1				Empty
34	T2		790	430	240	3	1	N	O		
35	T2		820	445	285	5	1	Y	S	O	
36	T2		845	440	315	10	1	Y	S	O	
37	T2		855	475	285	5	1	Y	S	O	
38	T2		785	380	250	35	1				Empty
39	T2		765	445	305	5	3	Y	S	Y	* Correct BP
40	T2		905	458	290	25	2	N	O		
41	T2		950	515	320	10	1	N	O		
42	T2		885	475	320	10	2	N	O		
43	T2		920	550	265	15	2				Empty
44	T2		905	490	365	25	3	N	O		
45	T2		925	570	315	10	2	Y	F	O	
46	T2		945	575	345	25	4	Y	F	W	
47	T2		870	525	305	15	2	N	O		
48	T2		825	475	285	8	2	N	O		
49	T2		825	495	345	35	4	N			
50	T2		850	475	325	10	2	N			

Comments

Appendix C Simplified Shell Thickening Index.

Simplified Shell Thickening Index for use on live mussels adapted from Phillips, N. (2007) Kakahi Shell Deformity Index Version 1 (NIWA) , using a selection of external shell images extracted from Phillips (2007). See more information on original index in the following pages.

Grade 1 LIVE FIELD SYSTEMNo long end thickening

No shell end thickening – similar width both ends

Grade 2 LIVE FIELD SYSTEM Very mild long end thickening

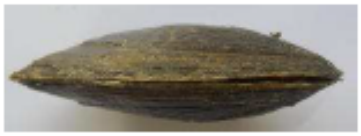
Grade 3 LIVE FIELD SYSTEM obvious, but not severe long end thickening

Grade 4 LIVE FIELD SYSTEM Significant long end thickening

Grade 5 LIVE FIELD SYSTEM Severe long end thickening, often with layering

Phillips (2007) uses internal and external features, therefore external thickening alone isn't a gradual increase.

Grade 1 Phillips (2007) internal/external grading (internal features not shown).



Grade 2 Phillips (2007) internal/external grading (internal features not shown).

Grade 3 Phillips (2007) internal/external grading (internal features not shown).

Grade 4 Phillips (2007) internal/external grading (internal features not shown).

Grade 5 Phillips (2007) internal/external grading (internal features not shown).

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