Repeat survey of kākahi (freshwater mussels) in the Ō Tū Wharekai Lakes

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Executive summary

Kākahi (freshwater mussels) are considered an important component of New Zealand lake ecosystems. A baseline survey of kākahi abundance and population structure was carried out by NIWA in eleven Ō Tū Wharekai lakes in late November 2012. In February 2021, the Department of Conservation (DOC) commissioned NIWA to undertake a repeat survey of the kākahi in eight of these lakes: Camp, Clearwater, Denny, Emily, Emma, Heron, Māori East, and Māori West.

Methods as similar as possible to those used in 2012 were repeated. In each of the lakes, kākahi were collected from five quadrats (0.33 m^2 each) at LakeSPI sites in zones where they were most abundant (aggregations), focussing on the shallow edge of the littoral zone and beyond the depth limit of vegetation in deeper lakes. Kākahi were counted and the shell length of all, or subsets of individuals, were recorded for each quadrat. Additional observations were made of the depth distribution of kākahi outside of the sampled zones.

Kākahi were present in all eight of the Ō Tū Wharekai lakes resurveyed in 2021 with the overall littoral distribution of aggregations, their density, and population size structure having increased or remained similar for most of the lakes over the eight-year period (2012 to 2021). There was a concerning decrease in the density of kākahi aggregations in Lake Emily (c. 60 % decline) and Māori Lake West (17 % decline). A poor shell condition was noted for individuals in Lake Clearwater; however, the density of aggregates had increased at the one site in this lake where kākahi were found. Densities of aggregations also increased for the remaining four lakes.

The maximum recorded density for sampled quadrats was 396 per m^2 in 2021 compared to 321 per m^2 in 2012, both recorded from Lake Camp. Mean densities at sampled sites in the eight lakes ranged from 0.6 – 381 per m^2 density in 2021 compared to <1 – 266 per m^2 in 2012. Mean densities for aggregations in each lake ranged from 4.2 – 298.5 per m^2 in 2021 and <1 – 195 in 2012. These densities are lower than maximum densities that have been recorded for aggregations in other lakes such as Lake Rotorua and the Waikato hydrolakes.

Changes in the size distribution of kākahi populations in the Ō Tū Wharekai Lakes between the 2012 and 2021 surveys were minimal with mean length remaining within 6 mm of previous values over this eight-year period. Juvenile kākahi (≤37 mm length) numbered only nine individuals in 2021 compared to five in 2012. However, 81 small (≤ 50 mm length) individuals were recorded in 2021, mostly from Lake Heron, with no small kākahi detected in Lakes Emma and Denny. Lakes Denny, Emma and Māori East recorded kākahi with the greatest mean lengths (77, 81 and 82 mm respectively).

The absence of smaller kākahi in the lakes is concerning and likely indicates that recruitment has been impacted for many years. We recommend further investigation of the possible reasons for the absence of young cohorts of kākahi, such as confirmation of kākahi breeding status or availability of host fish populations for the parasitic larval stage of their life-cycle. Further confirmation of the age-structure of populations might be obtained by thin shell section analysis from different populations.

We continue to recommend that kākahi be resurveyed after five years, or earlier if degrading trends in lake water quality have not been halted or reversed (especially at lakes Clearwater and Heron). Lake-specific surveys should also be conducted if there is cause for concern (e.g., large numbers of empty shells washed up, cyanobacterial blooms, aquatic plant/macrophyte die-off events, etc.,) or if there is evidence of a kākahi recruitment event.

1 Background

Ō Tū Wharekai, an inter-montane wetland system incorporating lakes of the Ashburton Basin, is one of five sites making up the national Arawai Kākāriki wetland restoration programme – the Department of Conservation's (DOC) flagship wetland programme. As part of this programme, DOC seeks to monitor the ecological condition of these lakes in response to changing land use pressures and interagency actions to protect the ecological integrity of the area from declining water quality. The Ō Tū Wharekai lakes (Figure 1) are located at an altitude of 600 – 700 m asl in the basin of the South Ashburton River and are glacial in origin. Catchment land cover varies between lakes, with the ratio of tussock grassland to improved pasture being much lower in the more developed catchments (Kelly et al. 2020). Wetland areas are associated with many of the lakes.

A baseline assessment of kākahi (freshwater mussels, *Echyridella menziesii*) was undertaken in eleven Ō Tū Wharekai lakes in 2012 (de Winton et al. 2013). To provide updated information on the health of these populations, DOC commissioned NIWA to undertake a repeat survey of the kākahi in eight Ō Tū Wharekai lakes. Estimates of kākahi density (count per unit area), spatial distributions and size (age) composition was undertaken in Lakes Camp, Clearwater, Denny, Emily, Emma, Heron, Māori East, and Māori West in February 2021. Surveys were not repeated in Lake Roundabout (which is a very small lake where mussels were present in 2012), or in Lake Donne, and the Spider Lakes where no mussels were found in 2012.

Kākahi are considered an important component of New Zealand lake and river ecosystems, and there is evidence that populations are declining as a result of anthropogenic impacts. Elsewhere, declines in bivalve populations have been linked to declining water quality, creating concern for the future of kākahi populations in many freshwater systems in New Zealand. There is also interest in the filter-feeding capacity of kākahi to help protect water quality.

Kākahi are known from lakes and waterways of Ō Tū Wharekai, and baseline data on populations in several streams was first investigated in 2010 (Clucas, undated). In 2012, DOC commissioned NIWA to survey the abundance and population structure of the kākahi (de Winton et al. 2013) at sites established for LakeSPI (Lake Submerged Plant Indicators) monitoring. A NIWA client report (de Winton et al. 2013) presented the results of monitoring and recommended resurveying at five-yearly intervals, or more frequently if there is evidence of a recruitment event, or a specific concern (e.g., rapid change of land/water use in the region). A mass die-off of kākahi in Lake Camp in summer 2013 was linked to strong thermal stratification and almost no measurable dissolved oxygen below 12 m depth (Beech 2013; Sutherland 2013). Resurvey of deeper kākahi populations in the lake in May 2013 suggested about a 50% reduction in live animals at 16.2 m and approximately a 30% reduction in numbers at 14.5 m (Sutherland 2013).

This report describes the main changes in the kākahi populations between the 2012 (de Winton et al. 2013) and 2021 surveys in the eight Ō Tū Wharekai lakes. Raw data was supplied to DOC as a Microsoft.xls spread sheet ('RawData2021_Jan_2022').

Figure 1: **Location of surveyed lakes within the Ō Tū Wharekai area**

2 Methods

NIWA repeated the kākahi assessment protocols used in the Ō Tū Wharekai lakes in 2012 (de Winton et al. 2013) as closely as possible (same sites and depths) to obtain comparable data (Appendix A).

Kākahi sampling was undertaken at baseline LakeSPI survey sites (Appendix A). For the deeper lakes (> 5 m depth, Heron, Camp, Clearwater), divers sampled the shallow lake edge (≤ 2 m depth), and a deep zone (within 5 to 10 m distance beyond the bottom limit of submerged vegetation). Sampled zones were within 10 m either side of the LakeSPI transect. Within this area, sampling was made at a depth (shallow and deep zone) where kākahi presence was subjectively assessed as being the greatest.

In the remaining lakes, which are shallow (i.e., < 3m depth) and completely vegetated, the sampled shallow lake edge was ≤1 m deep. The deep zone was at the maximum depth of the LakeSPI transect (approximately the maximum lake depth).

In each of the sampled areas, divers collected all live kākahi from each of five randomly positioned quadrats of 0.33 m^2 area (0.575 x 0.575 m) (Figure 2). Larger detectable individuals were removed first, before the top 2 – 3 cm of surficial sediment was excavated (shovel or hands) and passed through a 4mm aperture sieve to collect any smaller animals. Sieving was not possible where the substrate was predominantly stony. Quadrats were not deployed if kākahi were distributed at <1 animal per m^2 area (as estimated by divers visual and tactile search of the site), but notes were made on presence and depth distribution. In addition, divers recorded the depth range of mussels that were outside of the sampling zones but were detected along the LakeSPI transect (2 m width). Dead animals (entire empty shells but not fragments) were counted separately but not included in the final counts or in the size distribution analysis (i.e., numbers are reported separately). It is useful to track numbers of dead animals in case mass die-off events occur in the future.

On shore, kākahi were counted and the shell length of all, or subsets of kākahi were measured (± 1 mm) and recorded against site details. All small individuals (≤50 mm) were measured. When time and resources permitted, shell width and height were also measured and shell erosion was scored (Appendix B). Kākahi were then released at a suitable depth and over suitable substrate close to the point of collection within the lake of origin. Histograms of kākahi shell lengths were constructed from counts within size bins of 5 mm (i.e., sizes 45 – 50 mm plotted in the 50 mm bin) and compared with data from 2012.

An accompanying .xlsx file (‘RawData2021_Jan_2022’) provided to DOC contains raw quadrat data, while a summary of average shell lengths and kākahi density per m^2 is provided for each lake in this report.

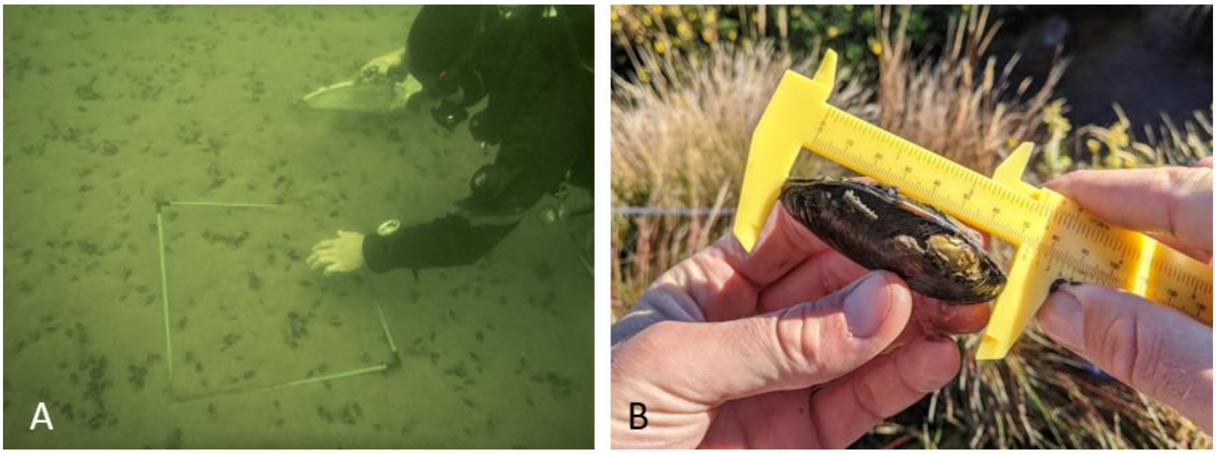


Figure 2: **A) diver collecting kākahi from within a 0.33 m^2 quadrat, B) callipers were used to measure shell length.**

3 Results

3.1 Lake Camp

3.1.1 2021 result

Two sites were resampled for the deep zone in 2021. No kākahi were observed in shallow water (<2 m depth) where the shoreline was armoured with large stones and boulders. The lake basin, beyond the maximum extent of vegetation (native charophyte meadows extended down to a depth of c. 12 m), was observed to support dense concentrations of kākahi at both sites (Figure 4). Kākahi were densest (maximum average density 381 m^2) at depths of 14.5 m but extended across the lake bottom at lower abundances to at least 17.3 m depth (maximum basin depth is 19 m). A total of 995 individual kākahi were collected from sites 1 and 2 for density data and 160 were processed for size data (Table 1). Shell lengths ranged from 45 – 71 mm with most kākahi falling into the 55 – 60 mm size range (Figure 3).

Bottom sediments in the basin were observed to be soft and clay like (c. 8 cm thick) over a firm sandy base. Kākahi appeared to be in good condition with minimal erosion evident on shells (Figure 4). A total of 198 dead kākahi were collected from the lake (from 10 quadrats) but not included in the analysis.

Table 1: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Camp in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	1	16.2	216 (24.8)	56 (3)
	2	14.5	381 (78.9)	58 (5)
	Lake		298.5 (103)	57 (4)

3.1.2 Comparison between 2012 and 2021

During both survey years, aggregations of kākahi were located at depths beyond the limit of submerged vegetation at the two sampled sites. There was a 53 % increase in kākahi densities measured at the survey sites between the 2012 and 2021 surveys (eight-year period) with the average density of kākahi increasing from 195 per m^2 to 298.5 per m^2 (Table 2).

Table 2: Comparison between 2012 and 2021 kākahi densities and lengths in Lake Camp. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Deep	195 (82.4)	54 (4)
February 2021	Deep	298.5 (103)	57 (4)

Average kākahi lengths were similar between surveys with a mean length of 54 mm in 2012 and 57 mm in 2021 (3 mm difference) (Table 2). Most kākahi continued to fall within the 50 – 60 mm size range (Figure 3).

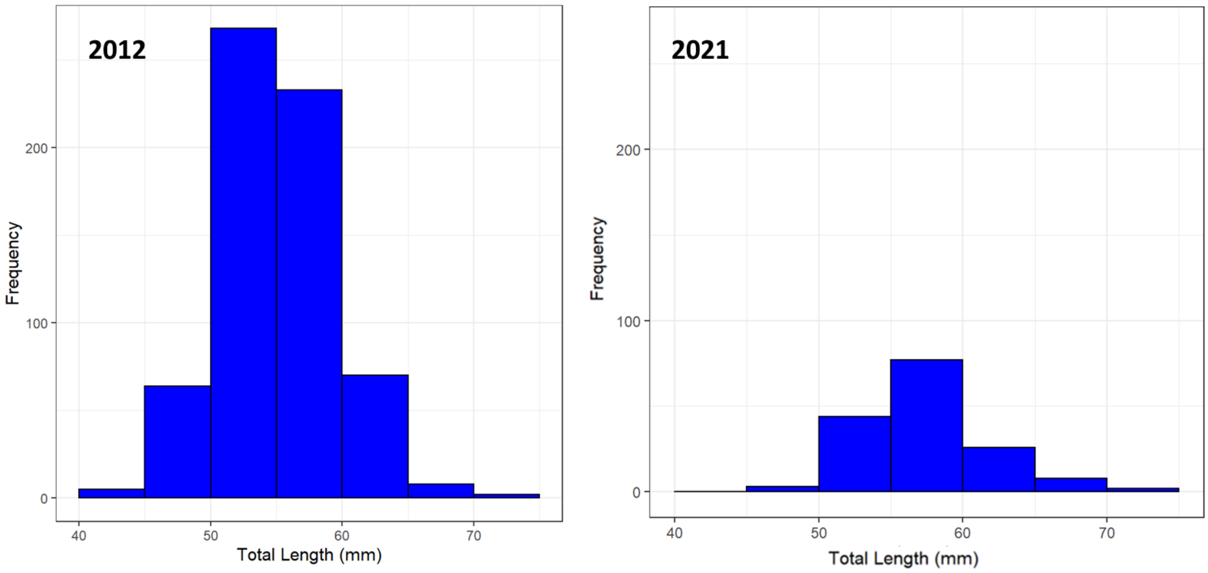


Figure 3: Frequency distribution of kākahi length (5 mm intervals) from Lake Camp populations in 2012 and 2021. Note: density cannot be extrapolated from this plot as not all of the individuals counted were measured for length in 2021. For accurate density information refer to Table 2.

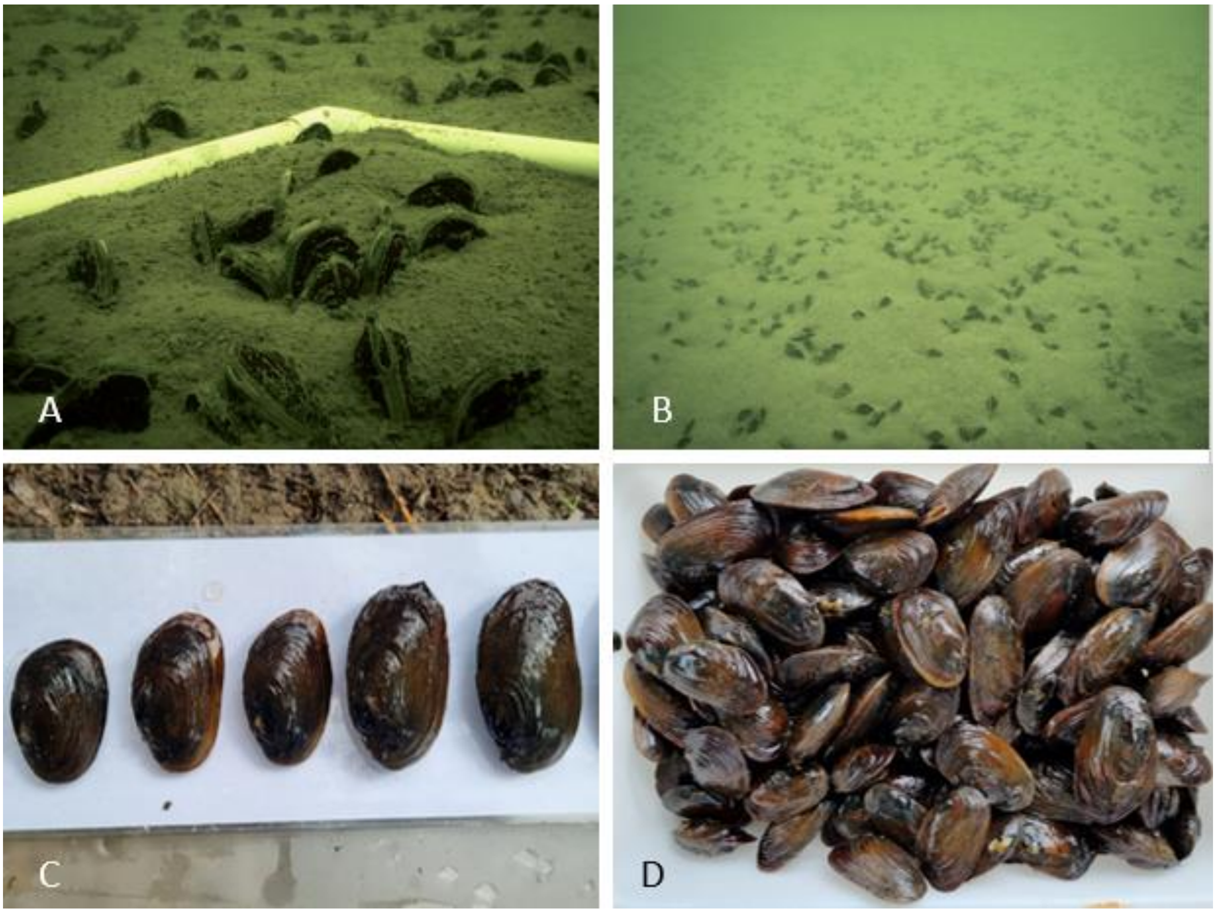


Figure 4: **Lake Camp 2021.** A and B) kākahi observed over lake bottom, C) kākahi showed little evidence of shell erosion or deformities, D) kākahi collected from one of the transects.

3.2 Lake Clearwater

3.2.1 2021 Result

Very poor water clarity (Figure 6) limited sampling to diver's tactile searches at Lake Clearwater in 2021, even at the three shallow sites. Sampling was not possible at the deep-water sites (within the basin of up to 18 m maximum depth) due to zero visibility. No kākahi were detected under poor visibility conditions at shallow sites 1 or 2. Kākahi were sampled from shallow water (<1 m depth) at only one site (Site 3) in the western arm of the lake. Here, 142 kākahi were collected from very soft, flocculent sediments for density and size data (Table 3). Twelve dead kākahi were also collected from the five quadrats but not included in the analysis. Kākahi were densest at a depth of c. 0.8 m with a mean density of 85.2 per m^2. Lengths ranged from 46 – 70 mm and most kākahi fell within the 55 – 60 mm size bin (Figure 5).

All kākahi collected were highly deformed, irregular, and rounded in shape (see Appendix B, Shell height and width), with obvious flaking and thickening evident on shells (Figure 6).

Table 3: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Clearwater in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
15/02/2021	3	0.8	85.2 (16.1)	58 (5)

3.2.2 Comparison between 2012 and 2021

As was the case in 2012, kākahi were only detected from one site (Site 3) in the western arm of Lake Clearwater in 2021. However, the absence of kākahi within the deeper lake basin (5.5 – 6 m) in 2012 could not be reconfirmed in 2021 due to unfavourable conditions for diving. At Site 3 there was a 141 % increase in the average density of kākahi, increasing from 35.4 per m^2 in 2012 to 85.2 per m^2 in 2021 (Table 4).

Overall kākahi mean length remained similar at 58 mm in 2021 to 59 mm in 2012 (Table 4), and most individuals still fell within the 55 – 60 size range (Figure 5).

Table 4: Comparison of 2012 and 2021 kākahi densities and lengths in Lake Clearwater. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	35.4 (8.3)	59 (7)
February 2021	Shallow	85.2 (16.1)	58 (5)

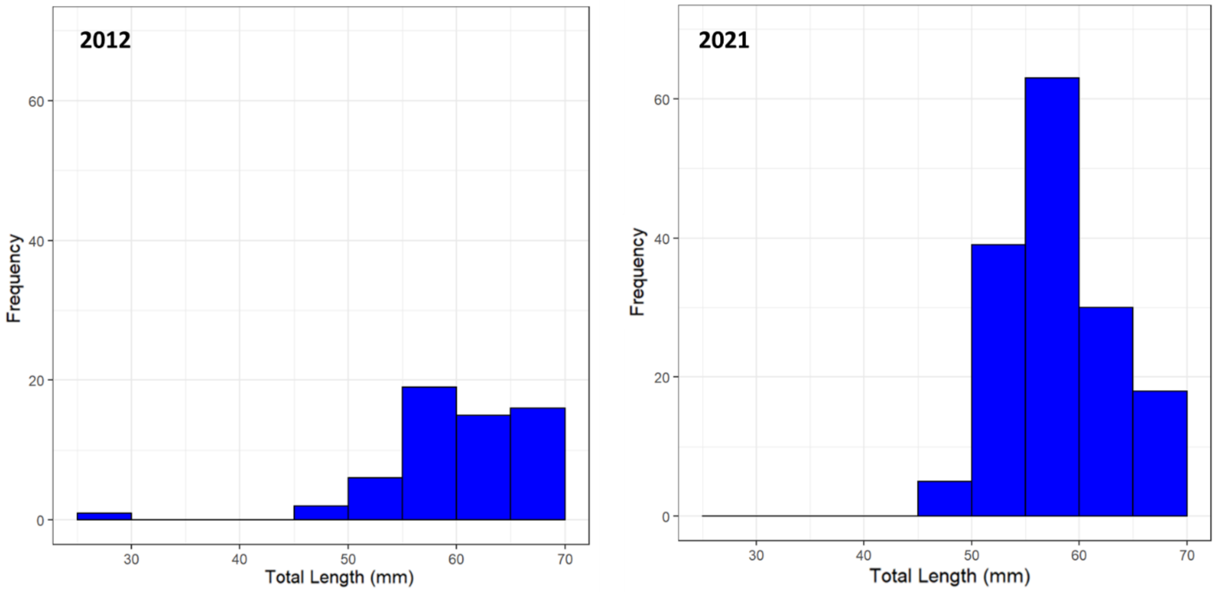


Figure 5: **Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Clearwater populations in 2012 and 2021.**

Figure 6: **Lake Clearwater 2021.** A) sample of kākahi showing shell deformities, B) Divers collecting kākahi under zero visibility conditions in the western arm, C) DOC crew (and others) assessing kākahi on shore.

3.3 Lake Denny

3.3.1 2021 result

Four sites were resurveyed in 2021 with aggregations of kākahi present along all surveyed shorelines in shallow water (0.5 – 0.6 m depth). A total of 646 kākahi were collected from the four sites for density data and 186 kākahi were processed for size data (Table 5). Sites 1 and 4 were located on the south-eastern shore, adjacent to a steep, scree slope. At these shorelines, average densities of up to 109 kākahi per m^2 were concentrated into a narrow band between the rocky lake edge and dense vegetation (*Elodea canadensis*) that began at c. 0.8 m. Kākahi were observed between gaps in the stones and boulders (Figure 8b), which precluded the sieving of sediment at these sites. By contrast, at Sites 2 and 3 on eastern shore, the slope was flat, and the substrate was silty (Figure 8a). Here kākahi were more diffusely distributed over a wider, shallower littoral area with a maximum average density of 227.4 individuals per m^2. Most kākahi were between 80 – 85 mm in length, with the size distribution (Figure 7) skewed to larger animals up to 97 mm in length. No kākahi were observed amongst dense *Elodea canadensis* across the deeper lake to the c. 2 m maximum lake depth.

Most kākahi were noted as having 'thickened' shells with some erosion (Appendix B). Five dead kākahi were collected from the lake (from 20 quadrats) but not included in this analysis.

Table 5: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Denny in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	1	0.6	28.8 (18.6)	76 (4)
	2	0.5	22.8 (7.8)	85 (4)
	3	0.5	227.4 (33.2)	83 (4)
	4	0.6	108.6 (11.9)	67 (5)
	Lake		96.9 (86.8)	77 (8)

3.3.2 Comparison between 2012 and 2021

Aggregations of kākahi were present at the shallow shorelines of all surveyed sites in 2012 and 2021. There was a 39 % increase in kākahi densities at the survey sites between 2012 and 2021 with the average density of kākahi increasing from 69.9 per m^2 in 2012 to 96.9 per m^2 in 2021 (Table 6). This was despite three of the four sites (Sites 1, 2 and 4) showing a decrease in numbers compared to the 2012 data (de Winton et al. 2013). There was an increase in average kākahi density at site 3 from 15.6 per m^2 in 2012 to 227.4 per m^2 in 2021.

Table 6: Comparison of 2012 and 2021 kākahi densities and lengths in Lake Denny. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	69.9 (76.9)	71 (8)
February 2021	Shallow	96.9 (86.8)	77 (8)

On average kākahi were 6 mm larger in 2021 compared to those measured in 2012 (Table 6). Most kākahi fell within the 80 – 85 mm size range in 2021 compared to 65 – 75 mm size range recorded in 2012 (Figure 7).

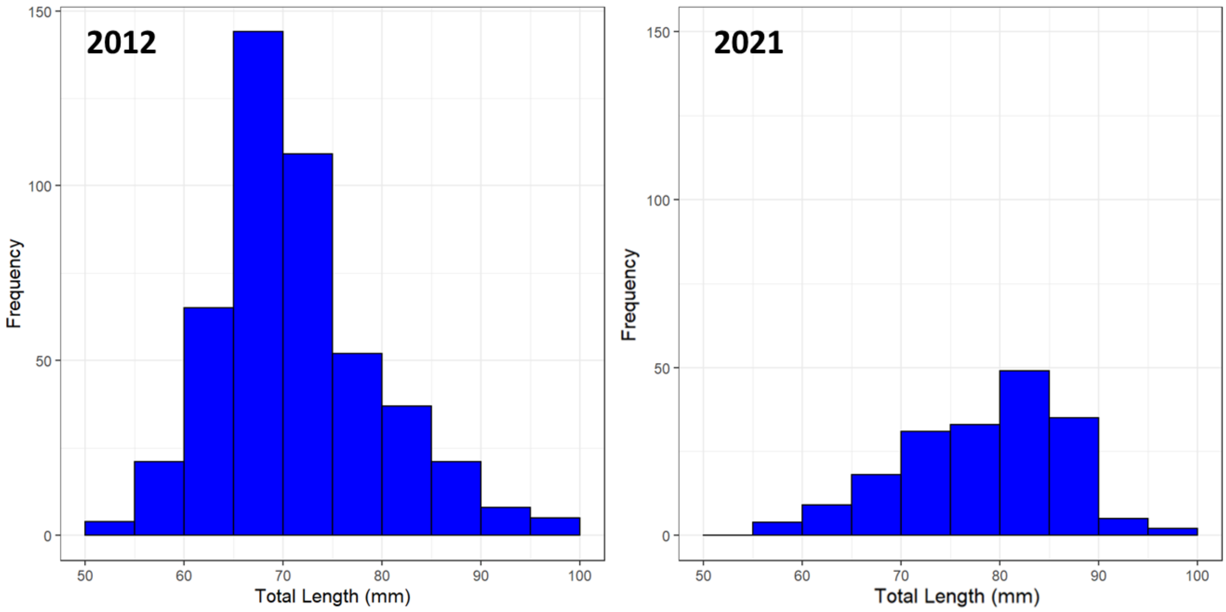


Figure 7: Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Denny populations in 2012 and 2021. Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. For accurate density information refer to Table 6.

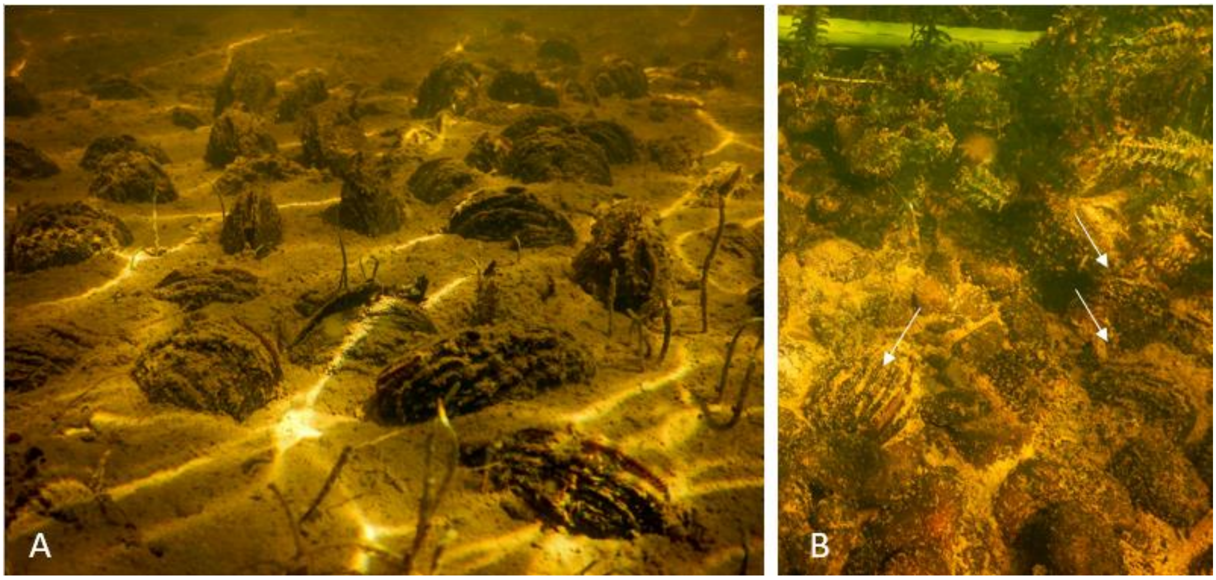


Figure 8: **Lake Denny 2021.** A) Kākahi on eastern shore in soft sediments, B) kākahi on the western shore growing amongst stones.

3.4 Lake Emily

3.4.1 2021 result

Two sites (Sites 2 and 3) out of the four 2012 sites were resurveyed in 2021, as time did not allow for all sites to be surveyed (Table 7). Kākahi were present at both sites in gravel/stone substrates in the shallow margins (≤ 0.5 m depth) (Figure 10). Higher numbers were present at Site 3 on the southern shoreline where the average density was 40.8 per m^2. In total 106 kākahi were collected (from 10 quadrats) for density data and 92 were processed for size data. Kākahi ranged in length from 27 – 69 mm with the majority falling in the 55 – 60 mm size class (Figure 9). No kākahi were observed through the tall dense beds of *Elodea canadensis* which grew across the lake bottom to a depth of at least 2 m (maximum recorded lake depth c. 2.3 m).

Most kākahi were described as having thickened shells with some level of mild deformity and/or erosion (Appendix B). A total of 40 dead kākahi (from 10 quadrats) were collected but not included in the analysis.

Table 7: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Emily in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	2	0.5	22.8 (11.7)	56 (9)
	3	0.5	40.8 (48.2)	56 (5)
	Lake		31.8 (34.4)	56 (7)

3.4.2 Comparison between 2012 and 2021

Overall comparisons of density between survey years were limited as only two sites of the four 2012 sites could be resampled in 2021. However, the average density of kākahi for these two sites decreased c. 60% from 78 per m^2 in 2012 to 31.8 per m^2 in 2021 (Table 8).

Kākahi lengths were very similar between surveys of the two sites with a mean length of 56 to 57 mm in both years. Most kākahi continued to fall within the 55 – 60 mm size class (Figure 9).

Table 8: Comparison of 2012 and 2021 kākahi densities (Sites 2 and 3 only) and lengths in Lake Emily. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	78 (30)	57 (5)
February 2021	Shallow	31.8 (34.4)	56 (7)

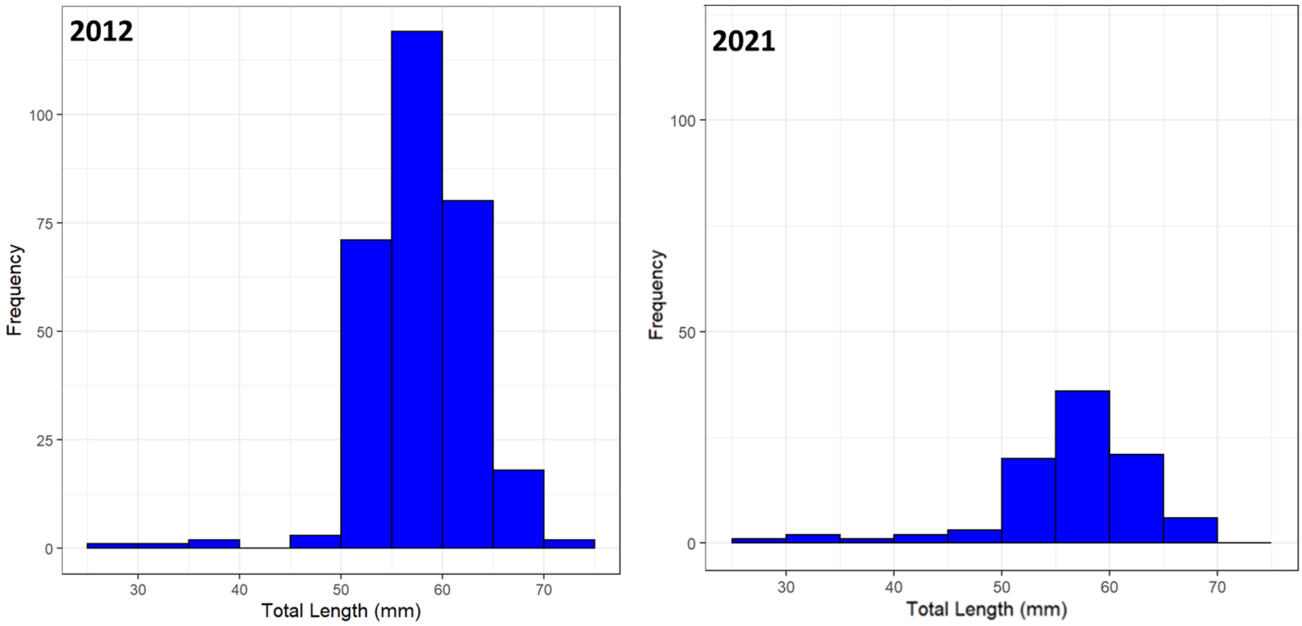


Figure 9: Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Emily populations in 2012 and 2021. Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. Only two of the sites surveyed in 2012 were resurveyed in 2021. For accurate density information refer to Table 8.

Figure 10: Lake Emily 2021. Tussock lands surround the lake with shallow sediments consisting of gravel and stones.

3.5 Lake Emma

3.5.1 2021 result

Four sites were surveyed. Kākahi were present at low densities (≤ 10.2 per m^2) from all sites (Table 9). Generally, they were encountered in shallow water (0.3 – 1.5 m depth) at the interface between the mostly rocky lake margin (Figure 12) and dense beds of vegetation (*Elodea canadensis*) that extended over much of the lake bottom. In total there were 28 live kākahi collected for density and 32 for size data. Six kākahi at site 3, where density was < 1 per m^2, were collected for size data only. At site 4 (northern shoreline), four kākahi (< 1 per m^2) were also found beyond the vegetation at a depth of c. 2 m. However, the sediment at this depth was very soft and jelly-like with kākahi only detected by feeling c. 8 cm below the sediment surface. Elsewhere, kākahi were not observed in depths of 2.3 to 2.4 m within this c. 2.7 m deep lake.

Individual shell lengths ranged from 57 – 96 mm (Table 10) with most falling into the 80 – 85 size class (Figure 11). Kākahi were noted to have minimal deformities and/or erosion evident on their shells (Appendix B). There were 30 dead individuals collected from the lake (from 20 quadrats). Dead kākahi were not used in the size or density analysis.

Table 9: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Emma in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	1	0.6	0.6 (1.3)	96 (-)
	2	0.7 – 1	6 (3.7)	85 (7)
	4	1.5	10.2 (4.5)	78 (8)
	Lake		4.2 (5.1)	81 (8*)

*Includes Site 3 measurements

3.5.2 Comparison between 2012 and 2021

A direct comparison of densities and size composition between the surveys was limited by the low numbers of kākahi recorded in 2012, which did not exceed 1 per m^2 at any of the four sites. There was an increase in the density recorded for Lake Emma in 2021, but values were still low at an average of 4.2 kākahi per m^2 (Table 10).

The 16 kākahi recovered in 2012 had lengths ranging from 24 – 95 mm (average 76 mm). However, as kākahi were not able to be assessed using quadrats in 2012, frequency distribution data is not shown on the histogram below (Figure 11). Shell lengths were 5 mm larger on average in 2021, with most individuals falling within the 80 – 85 size class (Figure 11).

Table 10: Comparison of 2012 and 2021 kākahi densities and lengths in Lake Emma. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	<1	76 (18)
February 2021	Shallow	4.2 (5.1)	81 (8)

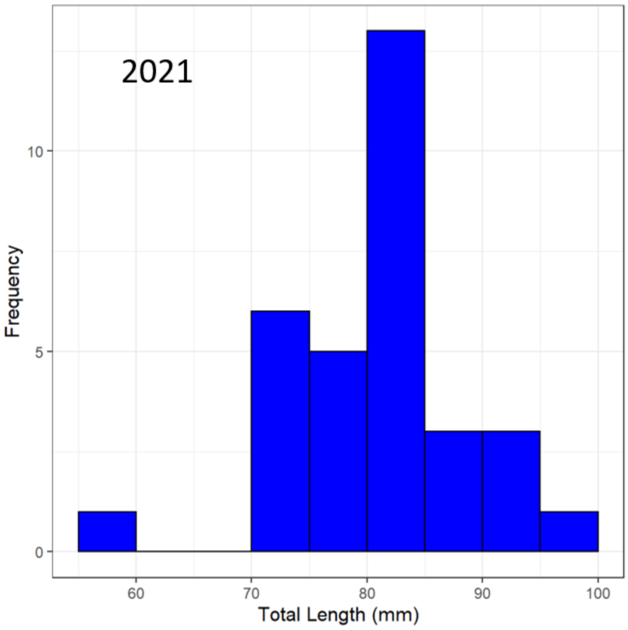


Figure 11: Frequency distribution of kākahi length (5 mm intervals) in collections from the 2021 Lake Emma population. (Note: frequency distribution is not included for 2012 due to the very low population numbers).

Figure 12: Lake Emma 2021. Diver collecting kākahi in the shallows along rocky margin of Site 4.

3.6 Lake Heron

3.6.1 2021 result

Five sites were surveyed. Kākahi populations were variable between sites and sampling depths (shallow and deep). Bands of kākahi were sampled in the shallows (<1.1 m depth) from three sites (Figure 14c, d) and in deeper water (7 – 8.5 m depth) (Figure 14a, b) at four of the five sites (Table 11). In total 605 live kākahi were collected for density data and 298 were processed for size data. The densest aggregations were sampled beyond the depth of vegetation at Site 5 on the southern shoreline where average densities of 177.6 per m^2 were recorded. Kākahi were collected in both the shallow and deeper zones at Site 2 and 3. Outside of the zones of aggregation, kākahi were frequently observed at densities <1 per m^2 across the remainder of the vegetated dive transects, except they were absent where vegetation was densest (*Elodea canadensis* or turfs of *Isoetes alpina*), or in the shallows where the shore was armoured with large boulders at Sites 4 and 5.

Individuals ranged from 31 – 84 mm in length, with most being 50 – 60 mm (Figure 13). Kākahi collected from shallow zones tended to be slightly bigger (mean 62 mm) than those from the deeper zones (mean 54 mm) (Table 11, Figure 13).

Most kākahi were in good condition (Figure 14e, f) with varying degrees of erosion noted on the shells (Appendix B). In total 131 dead kākahi (from 35 quadrats) were also observed but are not included in this analysis.

Table 11: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Lake Heron in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
16/02/2021	1	1 (shallow)	13.2 (5.4)	76 (6)
	2	1.3 (shallow)	7.2 (5.0)	60 (6)
	2	7 – 8 (deep)	55.2 (15.5)	55 (4)
	3	1 (shallow)	37.2 (12.1)	57 (9)
	3	7.6 (deep)	8.4 (4.9)	53 (5)
	4	8.2 (deep)	64.2 (8.6)	55 (3)
	5	8.5 (deep)	177.6 (27.4)	54 (4)
	Lake		51.9 (57.7)	57 (8)

3.6.2 Comparison between 2012 and 2021

In 2021, kākahi aggregations were sampled from shallow depths at Site 1, but earlier in 2012 kākahi were not observed at densities >1 m^2 at this site and therefore were not sampled. Kākahi aggregations in 2021 were otherwise re-recorded at the same sites and depth zones as in 2012.

The average density of kākahi from the samples in 2021 at 51.9 per m^2 was very similar to the value of 52.4 per m^2 recorded in 2012 (Table 12).

Kākahi lengths were slightly higher on average for the 2021 survey, with a mean length of 56 mm recorded in 2012 and 57 mm in 2021. Most kākahi continued to fall within the 50 – 60 mm size class in 2021 and kākahi again were slightly larger at the shallow sites (Figure 13).

Table 12: Comparison of 2012 and 2021 kākahi densities and lengths in Lake Heron. Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Lake	52.4 (53.0)	56 (6)
February 2021	Lake	51.9 (57.7)	57 (8)

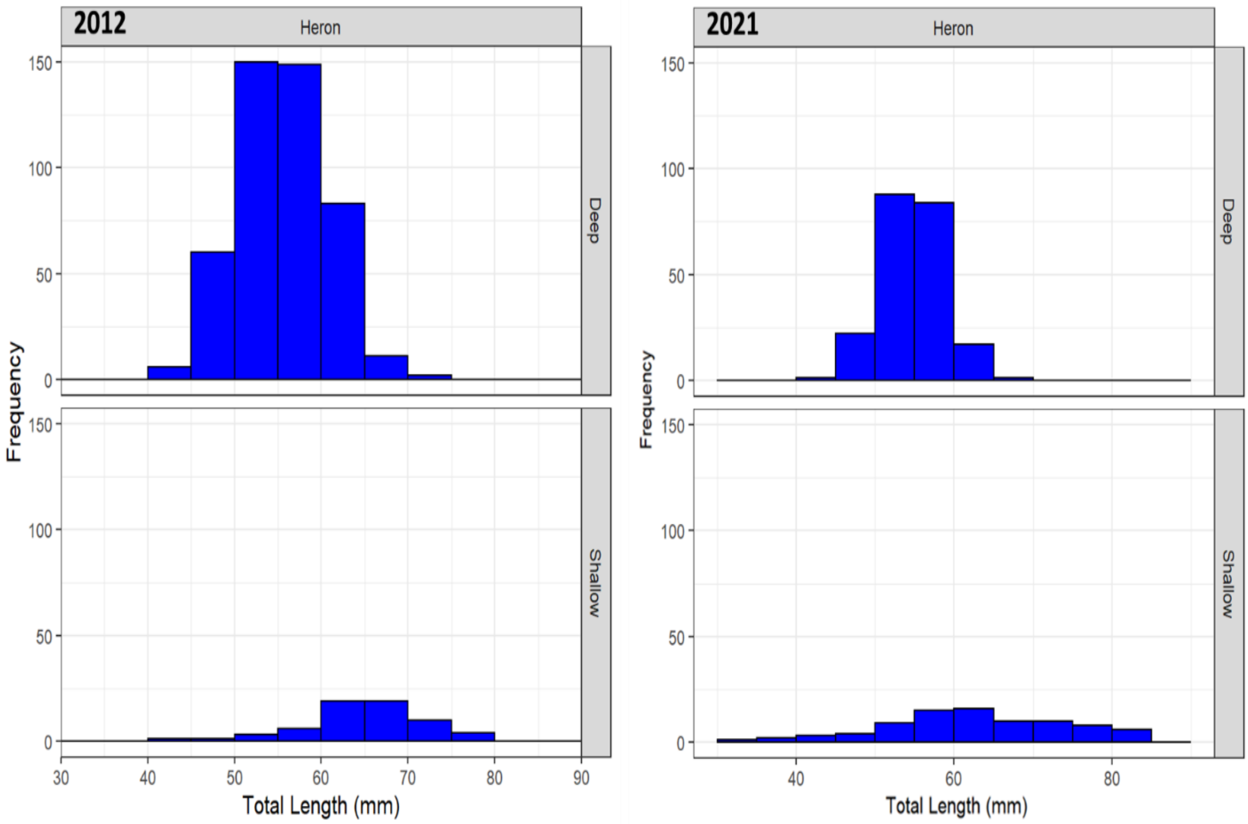


Figure 13: Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Heron in 2012 and 2021 comparing deep and shallow populations. Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. For accurate density information refer to Table 12.

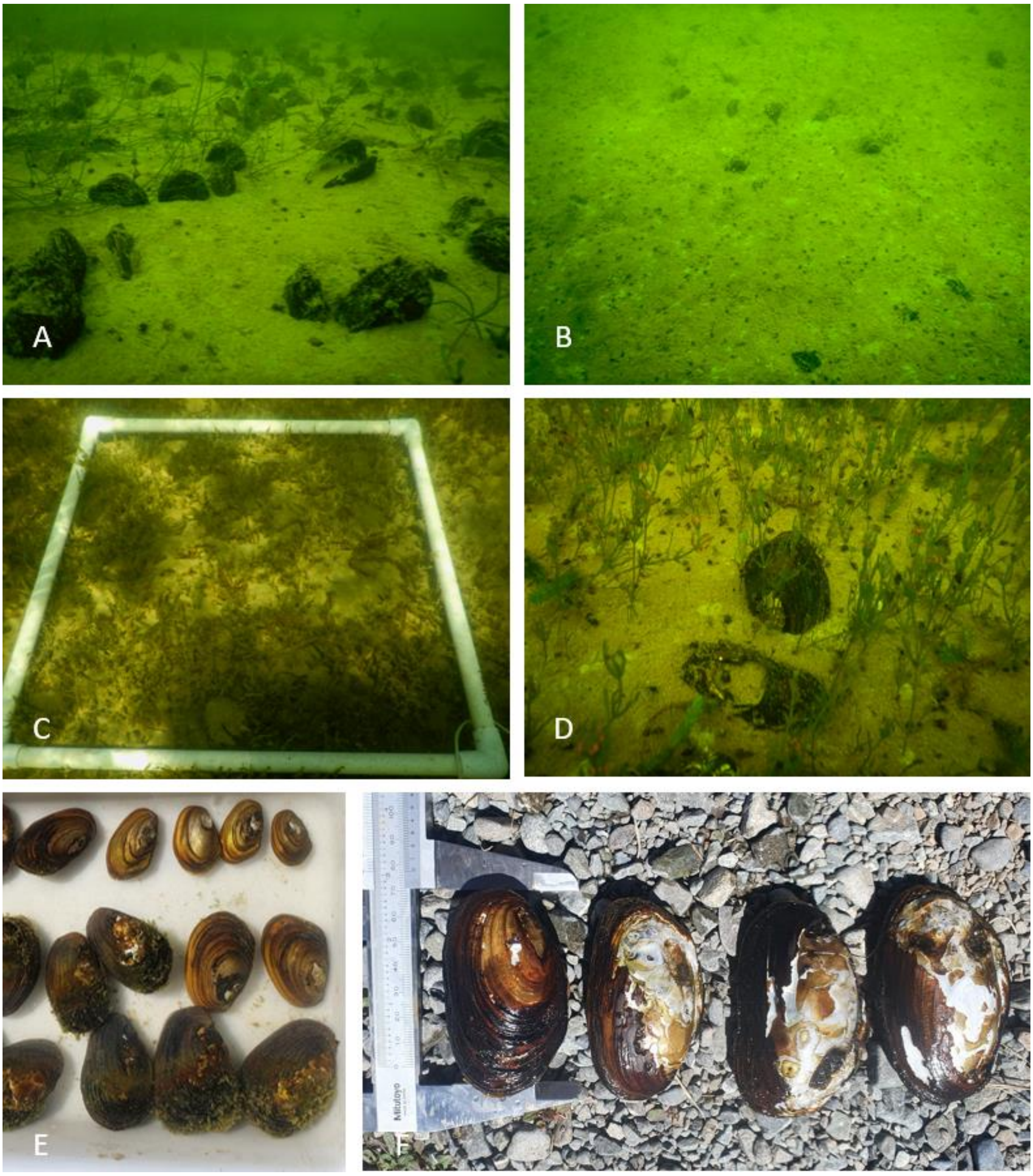


Figure 14: **Lake Heron 2021.** A and B) kākahi across bottom at depth c. 14.5 m, C) quadrat placed in shallows zone amongst low growing turf plants, D) kākahi amongst native charophytes, E and F) kākahi samples showing range in size and various degrees of shell erosion.

3.7 Māori Lake (East)

3.7.1 2021 result

Two sites were surveyed but kākahi were only found from Site 1 (Appendix A, Figure 16). Here low numbers of kākahi (33 from five quadrats) were collected from shallow water (0.6 m depth) on a gravel substrate (sieving was not possible at this site). The average density was 19.8 per m^2 (Table 13). The population ranged from 60 – 95 mm in length except for one individual that was 47 mm. Kākahi were skewed towards larger individuals that fell within the 85 – 95 mm size class (Figure 15). No kākahi were observed across the mostly un-vegetated lake basin (c. 1.2 m depth), or from Site 2 where the shoreline was dominated by raupō (*Typha orientalis*).

Kākahi were observed to be in good condition (no shell deformities) (Figure 16, Appendix B) and no dead individuals were observed in samples.

Table 13: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Māori Lake (East) in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	1	0.6	19.8 (5.4)	82 (12)

3.7.2 Comparison between 2012 and 2021

As in 2012, kākahi aggregations were only recorded at the shallow shoreline of Site 1 (Table 14). There was a 50 % increase in average kākahi densities at Site 1 from 13.2 m^{-2} in 2012 to 19.8 m^2 in 2021 (Table 14). Kākahi sizes decreased slightly (mean decrease in length of 4 mm) between the surveys with a mean length of 86 mm in 2012 and 82 mm in 2021. This was due to recording more individuals <75 mm in 2021 (Figure 15). Most individuals in 2021 continued to fall into the larger size class with lengths 85 – 90 mm (Figure 15).

Table 14: Comparison of 2012 and 2021 kākahi densities and lengths in Māori Lake (East). Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	13.2 (13.0)	86 (5)
February 2021	Shallow	19.8 (5.4)	82 (12)

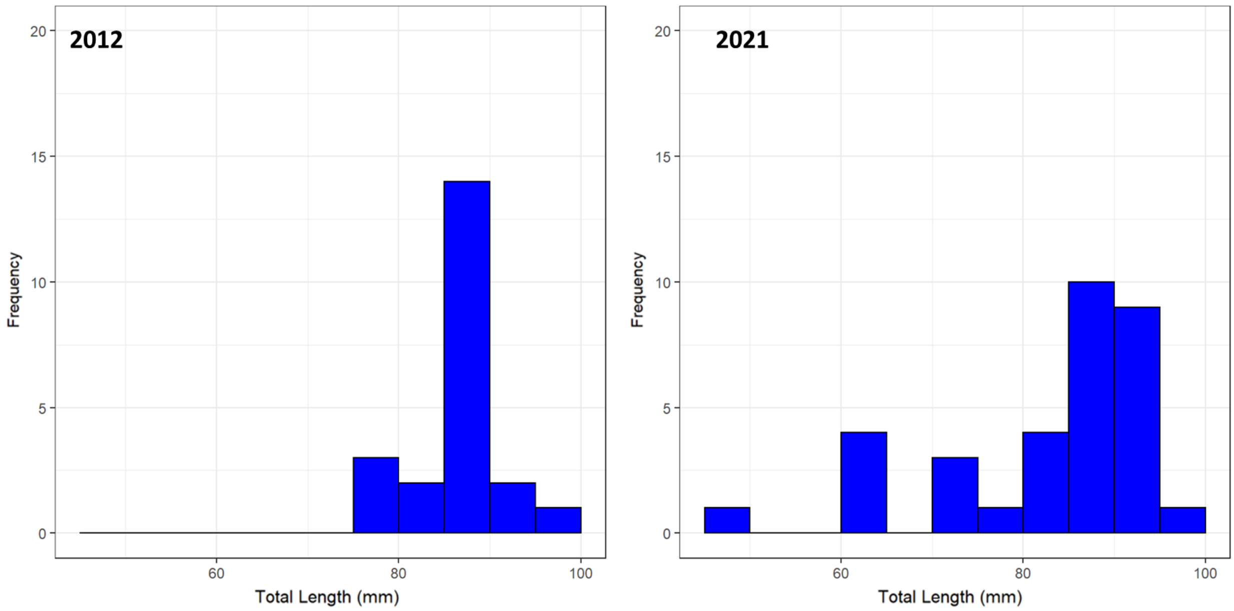


Figure 15: **Frequency distribution of kākahi length (5 mm intervals) in collections from Māori Lake East populations in 2012 and 2021.**

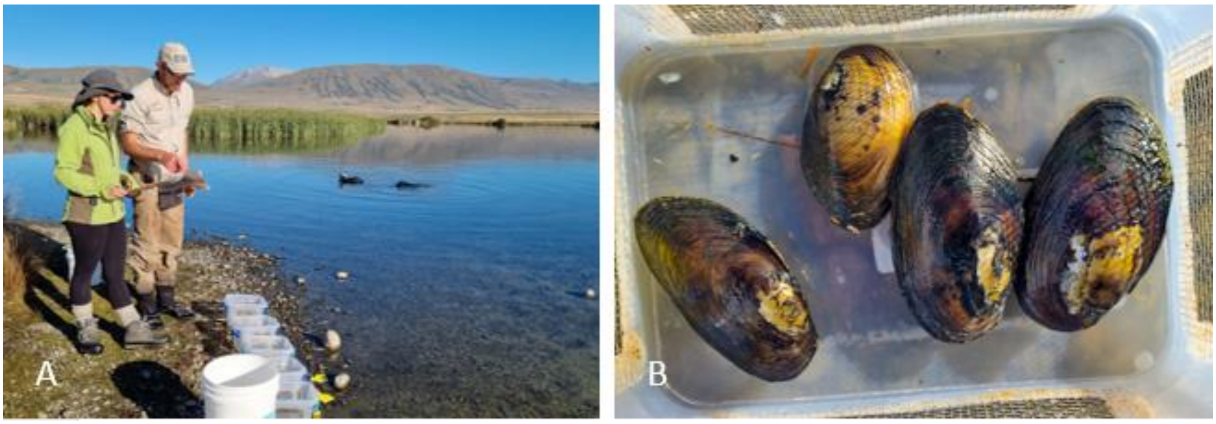


Figure 16: **Māori Lake East 2021.** A) DOC staff awaiting kākahi for onshore measurements – diver in background, B) sample of kākahi from one quadrat.

3.8 Māori Lake (West)

3.8.1 2021 result

Three sites were surveyed. Kākahi were concentrated in a narrow band along the shoreline of Site 1 (average 65.4 per m^2) (Table 15), but elsewhere were absent from the shallow areas, where raupō dominated the silty shoreline (Site 3) or formed a floating raft over shallow water to 1.2 m depth (Site 2). Dense submerged vegetation extended over the deeper basin to 2.1 m depth without any kākahi being observed. At Site 1 (Figure 18), kākahi were wedged between stones into pockets within a spongy, fibrous peat that appeared to be the remains of wetland vegetation. This substrate could not be sieved for juvenile animals, but stones and soft material were retrieved and sieved, and no further mussels were collected beyond those detected by eye (minimum 24 mm length). In total 109 kākahi were collected for density and size data. Kākahi ranged in length from 24 – 86 mm with most individuals falling within the 65 – 75 mm length size class (Figure 17, Table 15).

Kākahi were observed to be in good condition with few deformities and/or erosion visible on their shells (Appendix B). Only one dead individual was observed from the five quadrats.

Table 15: Summary of kākahi density per m^2 (based on five quadrats per site) and length of sampled individuals from Māori Lake (West) in zones where kākahi were most abundant, with standard deviation in parentheses.

Date	Site	Sampling depth (m)	Mean density m^2 (1 SD)	Mean length mm (1 SD)
16/02/2021	1	0.8	65.4 (9.6)	66 (11)

3.8.2 Comparison between 2012 and 2021

There has been an 17 % decline in kākahi densities at Site 1 with the average density of kākahi decreasing from 78.6 per m^2 to 65.4 per m^2 in 2021 (Table 16).

Kākahi lengths had decreased slightly with a mean length of 69 mm in 2012 and 66 mm in 2021 (3 mm mean difference). Most kākahi continued to fall within the 70 – 75 mm size class (Figure 17).

Table 16: Comparison of 2012 and 2021 kākahi densities and lengths in Māori Lake (West). Standard deviation in parentheses.

Date	Depth zone	Mean density m^{-2} (1 SD)	Mean length mm (1 SD)
November 2012	Shallow	78.6 (61.7)	69 (5)
February 2021	Shallow	65.4 (9.6)	66 (11)

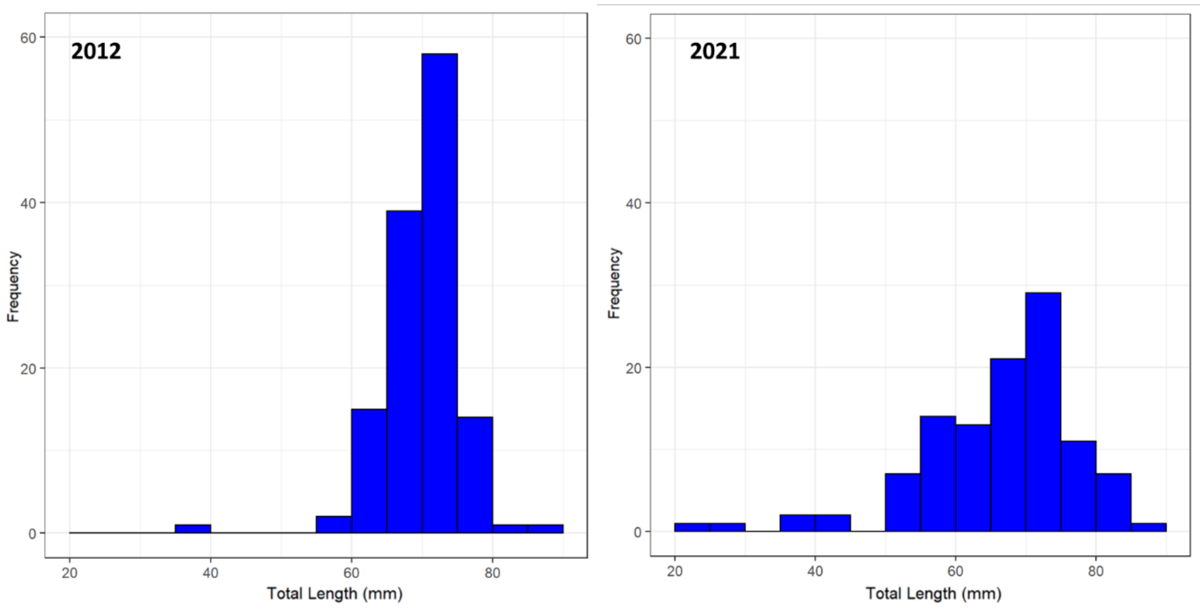


Figure 17: Frequency distribution of kākahi length (5 mm intervals) in collections from Māori Lake West populations in 2012 and 2021.

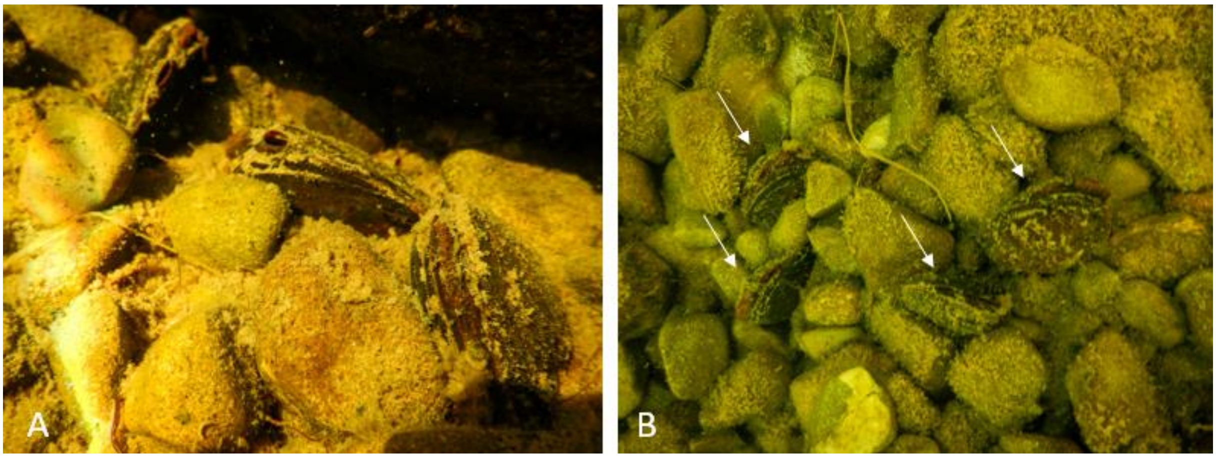


Figure 18: Māori Lake West 2021. A & B) kākahi were wedged between stones and a fibrous peat material at Site 1.

4 Discussion

4.1 Kākahi distribution

Kākahi were found in all eight of the lakes resurveyed in 2021. In most cases the distribution of aggregations of kākahi within the lakes was very similar to those observations made in 2012 (Appendix A) and is likely related to vegetation cover and depth, as well as factors such as substrate type or related wave exposure. Population sources for lake kākahi may also be present in inflowing streams. For instance, the sole site sampled for kākahi aggregations in Lake Clearwater was in the western arm proximal to the stream where kākahi were found approximately 500 m upstream of the lake in 2021 (S. Clearwater, DOC, Pers. Comm. 15/11/2021).

Kākahi continued to be excluded from littoral areas with dense plant growth, both native (e.g., *Isoetes*) and exotic (e.g., *Elodea canadensis*). In lakes elsewhere, the presence of dense submerged vegetation is known to limit the availability of habitat for freshwater bivalves (James 1985, Burlakova and Karatayev 2007), possibly directly through occupation of the lake bed, by modifying water currents and food availability, creating diurnal fluctuations in oxygen and pH, or modifying sediments. Consequently, the depth distribution of kākahi aggregations in the Ō Tū Wharekai lakes frequently reflected vegetation development, with a band present above the shallow margin of the vegetation, and beyond the maximum extent of vegetation in the deeper lakes. This pattern of distinct density peaks for kākahi in very shallow water (≤1 m depth) and also below thick macrophyte beds has been described elsewhere for the glacial South Island Lake Matiri (Cyr et al. 2017).

Kākahi were found on sediments ranging from fine organic silt, gravel, and stones through to fibrous peat, but were absent from shorelines armoured by large stones and boulders. Sediment type and stability is suggested to be a key physical factor influencing the density of kākahi (James 1985, James et al. 1998, Cyr et al. 2017), with soft sediment, generally sand or silt required by kākahi for burial. Lake shore slope, and an interplay with sediment stability, are also thought to be determinants of the depths at which density peaks of kākahi are found (Cyr et al. 201). On the other hand, excessively deep, soft silt has been found to be unsuitable due to the potential for clogging of filtering mechanisms (James 1985 and 1987), with potential for kākahi to sink and suffocate on low density substrates. Interplay between substrate type and wave energy means that these factors may not be clearly distinguished, but areas of regular wave action are thought unlikely to support settlement of juvenile kākahi and possibly also even adults (James 1985), especially if sediments are readily mobilised by wave action. Accordingly, physical forces (surface waves and currents) were suggested to limit the upper distribution of kākahi (Cyr et al. 2017). Although large lakes like Taupō and Rotorua have considerable wave action, kākahi can still form dense populations on compacted sandy sediment in shallow water (authors pers. obs.).

Elsewhere, for instance in the Rotorua lakes, kākahi have been shown to be excluded from the deeper areas of lakes due to low dissolved oxygen concentrations developing in bottom waters during thermal stratification (Butterworth 2008, Cyr et al. 2017). As a general guide, James et al. (1998) suggested a threshold dissolved oxygen concentration above 5 mg/L was required for long term viability of mussel beds. Kākahi are known to survive acute periods of low oxygen (e.g., <2 mg/L, approx. 24 hours) with their tolerance increased at lower temperatures, but chronic exposure (e.g., several days) will eventually be lethal (S J. Clearwater, DOC unpublished data). Oxygen depletion due to thermal stratification was attributed as the cause of a mussel die-off event in Lake Camp in Summer 2013 (Beech 2013, Sutherland 2013). Resampling of the deeper kākahi population in this lake within three months of the low oxygen event suggested a 44 % reduction in density of the aggregates (Sutherland 2013), yet by 2021 kākahi densities were 53 % higher than recorded prior to the event in 2012. A mass mortality event for kākahi in Lake Camp is reported for 2015 in Bayer and Meredith (2020), but it is possibly referring to the event in 2013.

In Lake Clearwater, water quality was very poor during the 2021 survey and zero visibility conditions meant that divers were unable to recheck the deeper lake basin. However, this area was described by de Winton et. al. (2013) as having vegetation-bare areas of silty sediment that appeared suitable for kākahi and yet they were absent (or <1 m^2). It is possible that low dissolved oxygen events limit the suitable habitat available for kākahi in the small, deep basin of Lake Clearwater, but available profile data measured in February 2017, February 2021, and September 2021 did not show levels ≤5 mg/L below 5.5 m depth (Tina Bayer, Environment Canterbury, pers. comm. 17/09/2021).

With the exception of where oxygen limitation or sediment degradation may occur, kākahi are expected to be more abundant in lakes with higher trophic status due to greater plankton food available for filter feeders (Phillips et al. 2007). However, it is likely that at higher trophic status in shallow lakes particularly, nutrient enrichment to supertrophic and hypertrophic levels will produce combinations of water and sediment conditions that prevent juvenile recruitment, and eventually becomes lethal to adult mussels (which are generally long-lived and highly tolerant of adverse conditions).

Detrital food sources are also thought to be important, with high kākahi densities in lakes associated with the fine, detritus rich sediments found under the macrophyte beds and below the macrophyte zone (Weatherhead and James 2001).

Other factors suggested to be of importance for kākahi distribution, such as bed slope, and temperature (James 1985, James et al. 1998) could not be discerned for the Ō Tū Wharekai lakes based on this 2021 or the 2012 survey.

Observations of low kākahi numbers (density < 1 m^2) in Lake Emma in 2012, despite the presence of apparently suitable habitat, was suggested by de Winton (2013) to be related to significant blooms of cyanobacteria (*Anabaena*) recorded in the years prior to the 2012 survey (Sullivan et al. 2012). Increased mortality of juvenile kākahi is known to occur under toxin concentrations typical of a severe cyanobacteria (*Microcystis*) bloom (Clearwater et al. 2012).

4.2 Kākahi densities

Between the 2012 and 2021 surveys (eight-year period), densities of kākahi aggregations at the survey sites increased on average in five of the eight lakes (Camp, Clearwater, Denny, Emma, Māori Lake East) declined in two lakes (Emily, Māori Lake West), and stayed approximately the same in Lake Heron. Maximum densities of aggregations recorded in individual quadrats sampled in the lakes in 2021 ranged from 0 – 396 per m^2 compared to <1 – 321 per m^2 in 2012. Mean density at sampled sites ranged from 0.6 – 381 per m^2 density in 2021 compared to <1 – 266 per m^2 in 2012. Mean densities for aggregates in each lake ranged from 4.2 – 298.5 per m^2 in 2021 and <1 – 195 in 2012 (Figure 19).

Lake Camp recorded the highest density for kākahi aggregations of the eight lakes in both 2012 and 2021 with an increase of 53 % from the lake average of 195 per m^2 in 2012 to 298.5 per m^2 in 2021 (Figure 19). The next highest average densities of kākahi were recorded from lakes Denny (average 96.9 per m^2), Clearwater (average 85.2 per m^2), and Māori West (average 65.4 per m^2). Despite an increase in kākahi numbers recorded for Lake Clearwater in 2021, increasing from 35.4 per m^2 in

2012 to 85.2 per m^2 in 2021, kākahi were again found at only one shallow site out of three sites checked (note absence from deep sites could not be reconfirmed in 2021).

Lake Emma (average 4.2 kākahi per m^2) and Māori Lake East (average 19.8 per m^2) had the lowest recorded densities for aggregations of the eight lakes in 2021 (Figure 19). Kākahi in these lakes were restricted to a narrow band in shallow water (generally <1 m depth).

The only lakes to show a large decrease in kākahi numbers over the eight-year period (2012 – 2021) were Lake Emily (60 % decrease for two resurveyed sites) and Māori Lake West (17% decrease). Kākahi numbers in Lake Emily showed the greatest decrease with average numbers declining from 78 per m^2 in 2012 to 31.8 per m^2 for the two sites that were resurveyed in 2021 (Figure 19).

As discussed in the report for the 2012 survey (de Winton et al. 2013), maximum densities in the Ō Tū Wharekai lakes have not approached reports of dense beds exceeding 600 individuals per m^2 in some other lakes (James 1985 and 1987, Weatherhead and James 2001). Wells and Clayton (1996) found kākahi in Lake Rotorua with densities of up to 550 per m^2, while lake and river sites in the Waikato River system have had densities of up to several hundred per m^2 (Roper and Hickey 1994). Happy (2006) also undertook kākahi surveys across the depth gradient in four Rotorua lakes and recorded maximum kākahi densities ranging from 43.3 to 322.5 per m^2. By these comparisons the Ō Tū Wharekai lakes appear to have similar to slightly lower kākahi densities than other sampled lakes in New Zealand.

Kākahi are known to have highly patchy distributions, and in both the 2012 and 2021 surveys, areas of dense aggregation were targeted at a small number of sites in each lake. Although the results indicate the general littoral distribution patterns for kākahi, the recorded densities for aggregations may not be representative of the lake as a whole.

Changes in the density of kākahi aggregations in the Ō Tū Wharekai lakes may relate to changing habitat availability or quality in lakes generally, but also might reflect local kākahi movement and migration. For instance, kākahi are known to migrate over distances of 1 m or more in the space of a few days and can also be moved by physical disturbances in lakes. Physical forces (surface waves and currents) are known to limit the upper range of peak kākahi density distribution in lakes (Cyr et al. 2017). Therefore, factors such as water level fluctuations or storms might disperse or concentrate kākahi in shallow zones of the lakes. Kākahi may also congregate above a low oxygen zone at depth in lakes and this driver is likely to be prominent in lakes of higher trophic status (Cyr et al. 2017).

Eutrophication is a concern for the Ō Tū Wharekai lakes, with recent upticks in Trophic Level Index indicating increased enrichment for six out of eight of the surveyed lakes (T. Drinan, DOC, pers. comm. 19/08/2021). Lakes Denny, Clearwater, and Heron were identified as 'of concern' in an update on water quality, due to trends of high or increasing trophic status, with impacts of an agricultural catchment also suspected for the Māori Lakes (Bayer and Meredith 2020). A number of the lakes are relatively shallow, so increasing trophic status may fail to provide kākahi with suitable habitat (e.g., on warm still, summer days hypoxic conditions may occur, even in shallow lakes).

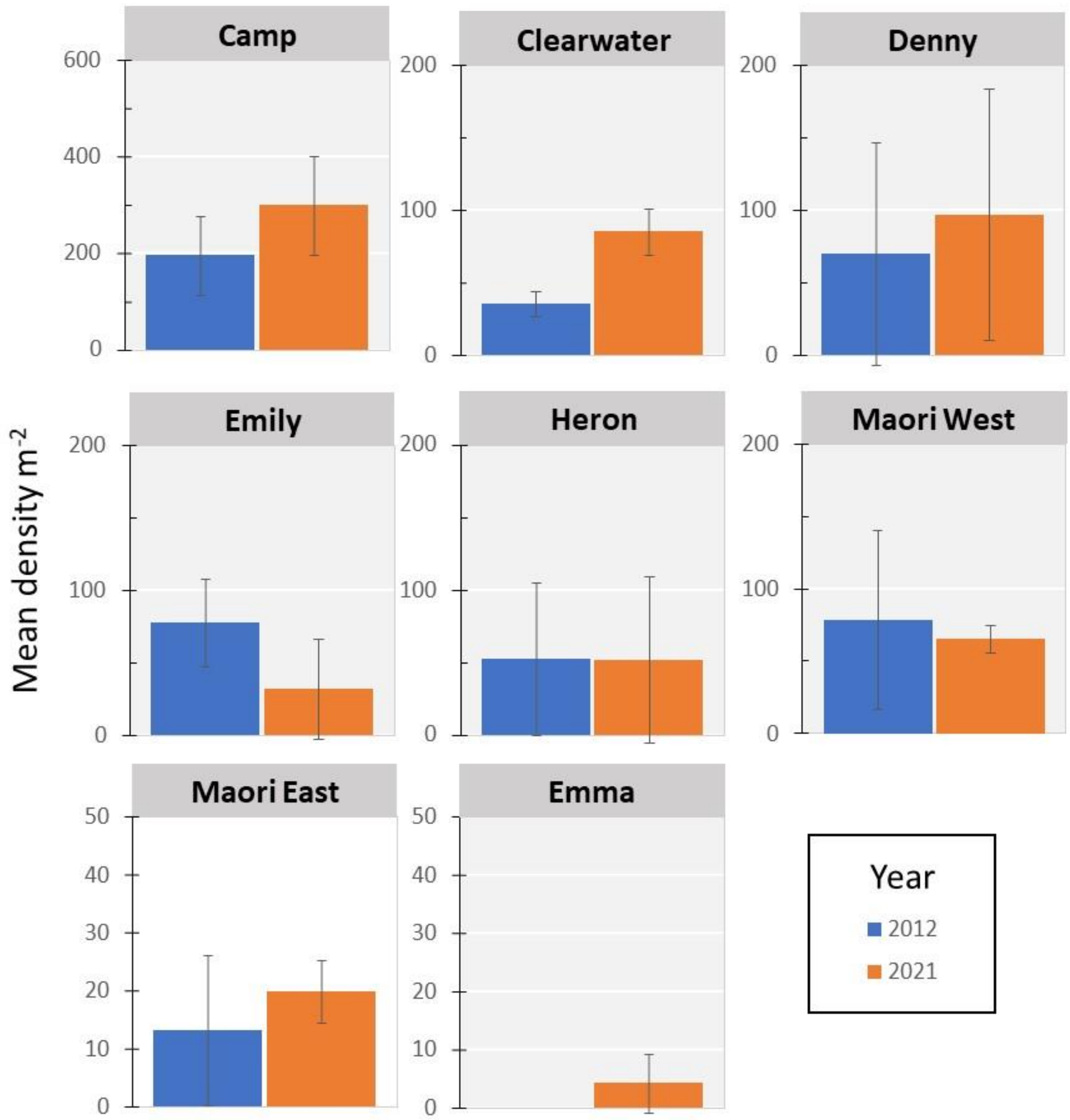


Figure 19: Kākahi average densities (per m^2, ±1 SD) for all quadrats sampled in the Ō Tū Wharekai lakes in 2012 and 2021. Note scale varies between lakes.

4.3 Population size structure

Changes in the size distribution of kākahi in the Ō Tū Wharekai lakes between the 2012 and 2021 surveys were minimal with the mean length recorded for lake populations remaining within 6 mm of the previous values over this eight-year period (Figure 20, Figure 21). Only Lake Denny showed a shift (increase) in the size class for most individuals.

The transition from juvenile to reproductive adult kākahi is considered to occur at 37 mm shell length (S. Clearwater, DOC, pers. comm., 20/09/2021). Only five juveniles were recorded in 2012 and nine in 2021 across all lakes. In 2021, the smallest individuals were recorded from Māori Lake West (four individuals, 24 to 36 mm in length), Lake Emily (four individuals, 27 to 35 mm in length) and Lake Heron (one individual, 31 mm in length). However, 81 individuals in 2021 were small (≤ 50 mm shell length) with over half of these recorded from Lake Heron. No small (≤ 50 mm) kākahi were recorded from Lakes Emma and Denny and 10 individuals or fewer were recorded from each of the other five lakes in 2021.

Lakes Denny, Emma and Māori East recorded the highest mean lengths in 2021, being 77, 81 and 82 mm respectively (Figure 20). The maximum recorded length of an individual kākahi was 97 mm in Lake Denny. Previously in 2012, the largest kākahi was recorded at 111 mm in Lake Roundabout, but this lake was not resurveyed in 2021.

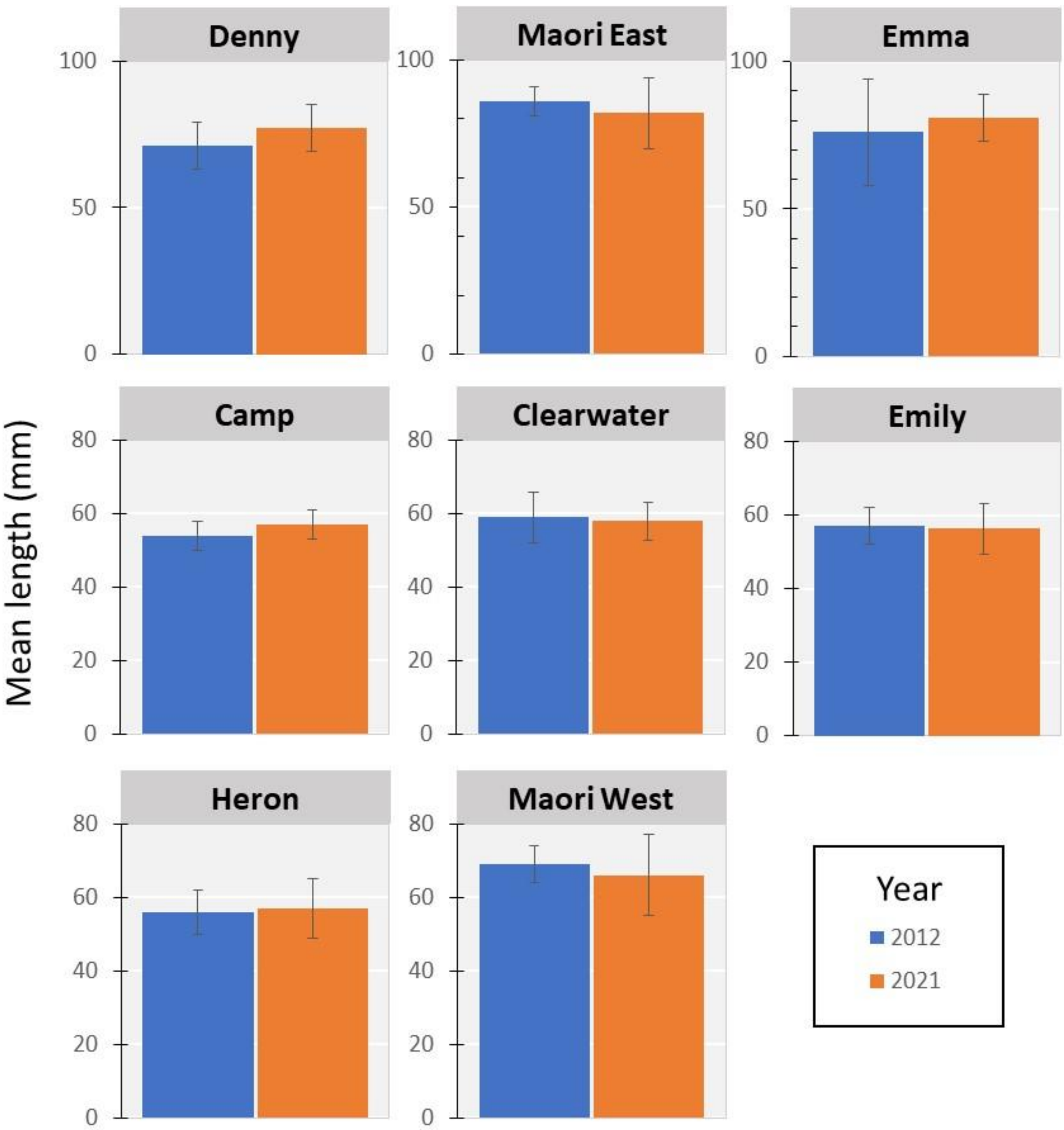
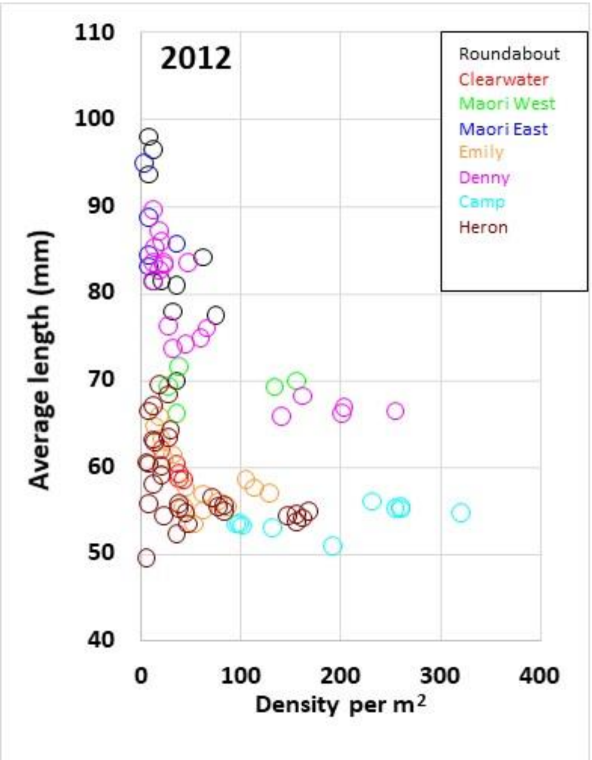


Figure 20: Kākahi average lengths (mm) for all quadrats sampled in the Ō Tū Wharekai lakes in 2012 and 2021. Note scale is either 100 mm (top row) or 80 mm.

Overall, the size structure in all eight lakes showed that kākahi aggregations tended to comprise larger individuals and were unimodal without evidence of younger cohorts and with limited juvenile recruitment. A healthy population of kākahi would be expected to have a range of sizes from small (10 mm) to large (c. 100 mm) individuals (James 2006). The absence of juvenile kākahi in many of the lakes is concerning and may indicate that recruitment has been impacted for many years. This could be due to a variety of reasons with the most likely factors including changes in water quality, increased sedimentation and declines in dispersal vectors (e.g., declines in host fish populations). However, we also recognise that recruitment of juveniles may not be concentrated in the same areas that aggregations of adults are found, as were targeted in this survey.

The condition of kākahi shells varied amongst the lakes in 2021 and influenced morphological data for some lakes. Out of the surveyed lakes, Lake Clearwater kākahi had the greatest proportion of shells with high levels of erosion (≥50%), with Lake Denny kākahi also having generally poor shell condition (see Appendix B for shell erosion). Kākahi shells from Lake Clearwater were distorted and had greater average width than other measured lake populations (see Appendix B for shell heights and widths). The likely reason for this is infestation from the parasitic fly larvae (*Xenochironomus canterburyensis*). Roper and Hickey (2004) attributed shell abnormalities in Lakes Taupo and Ohakuri to chironomid infestations. In 2016, kākahi with highly deformed shells were found in a relatively abundant population (several hundred readily observed) in the shallows near the Lake Clearwater outlet at the eastern end of the lake (S. Clearwater, DOC, pers. comm. 21/09/2021).



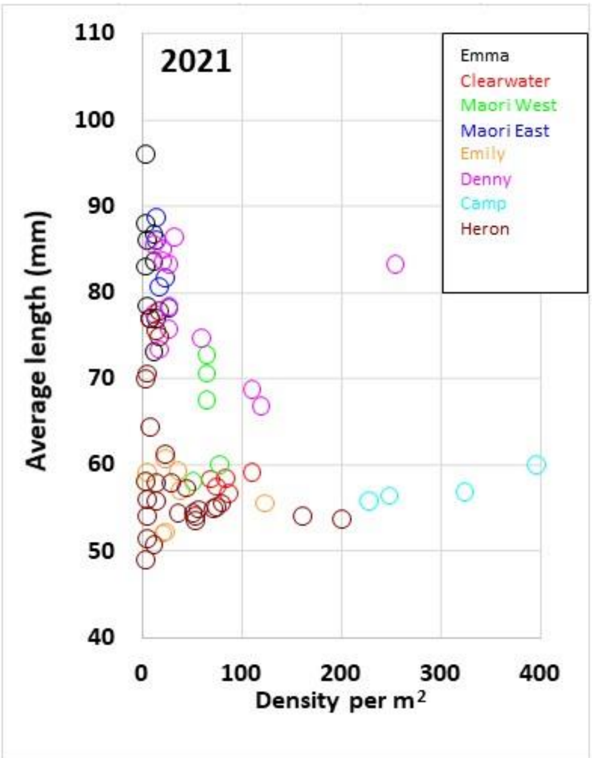


Figure 21: Average length of kākahi (mm) for each quadrat plotted against density per m^2. See legend for lake symbol. Note Lake Roundabout was sampled in 2012 and Lake Emma in 2021 (black markers). Not all quadrats were assessed for kākahi length in Lakes Camp, Denny, Emily and Heron in 2021 and so cannot be plotted.

5 Conclusion and recommendations

Overall, the littoral distribution of kākahi aggregations, their density and population size structure in Ō Tū Wharekai lakes have remained relatively similar for most lakes over the eight-year period between the 2012 and 2021 surveys. There was a concerning decrease in kākahi densities at Lakes Emily and Māori Lake West. Although kākahi densities increased at the one recorded site in Lake Clearwater, the poor condition of the adult mussels and declining water quality at this lake suggests that this population may be at risk. Five other lakes also underwent increases in the density of kākahi aggregations compared to 2012.

The ongoing low numbers of juvenile and small kākahi in many lakes is concerning and likely indicates that recruitment has been impacted for many years. This could be due to a variety of reasons with the most likely factors including changes in water quality and contaminants, increased sedimentation and declines in dispersal vectors (e.g., declines in host fish populations). Nevertheless, we cannot rule out the possibility that recruitment is happening in areas other than where the main aggregations of adults were sampled.

Confirmation of the age structure of populations by the analysis of a selection of shells from different populations by thin sections (e.g., Neves and Moyer 1988) would be useful. It would also be worthwhile to consider the reasons for the absence of young cohorts of kākahi, such as confirmation of kākahi breeding status (gonad development in summer) or the availability of host fish populations for the parasitic larval stage (e.g., assessment of host fisheries).

We continue to recommend that kākahi be resurveyed after five years, or earlier if degrading trends in lake water quality have not been halted or reversed (especially at lakes Clearwater and Heron). Lake-specific surveys should also be conducted if there is cause for concern (e.g., large numbers of empty shells washed up, cyanobacterial blooms, aquatic plant/macrophyte die-off events, etc.,) or if there is evidence of a recruitment event.

6 Acknowledgements

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Appendix A Survey sites

Lake Camp

Appendix A Table 1: Summary comparison of 2012 and 2021 surveys for Lake Camp showing where kākahi aggregates (>1m^2) were present. *NS* indicates site and depth were not sampled.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°36'43.77"S 171° 3'7.69"E	No	Yes	No	Yes
2	43°36'47.04"S 171° 3'21.76"E	No	Yes	No	Yes
3	43°36'49.77"S 171° 3'33.43"E	No	*NS*	No	*NS*
4	43°37'1.33"S 171° 3'25.40"E	No*	*NS*	No	*NS*
5	43°36'57.07"S 171° 3'8.28"E	No	*NS*	No	*NS*

*Kākahi observed at <1 m^2.

Appendix A Figure 1: Lake Camp showing the shoreline location of five survey sites.

Lake Clearwater

Appendix A Table 2: Summary comparison of 2012 and 2021 surveys for Lake Clearwater showing where kākahi aggregates (>1m^2) were present. *NS* indicates site and depth were not sampled.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°36'27.59"S 171° 2'43.80"E	Yes	No	Yes	*NS*
2	43°36'7.52"S 171° 2'54.48"E	No	No	No	*NS*
3	43°35'56.45"S 171° 1'26.53"E	No	No	No	*NS*

Appendix A Figure 2: Lake Clearwater showing the shoreline location of three survey sites.

Lake Denny

Appendix A Table 3: Summary comparison of 2012 and 2021 surveys for Lake Denny showing where kākahi aggregates (>1m²) were present.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°40'14.40"S 171° 7'23.32"E	Yes	No	Yes	No
2	43°40'9.84"S 171° 7'18.83"E	Yes	No	Yes	No
3	43°40'11.36"S 171° 7'14.03"E	Yes	No	Yes	No
4	43°40'16.02"S 171° 7'20.64"E	Yes	No	Yes	No

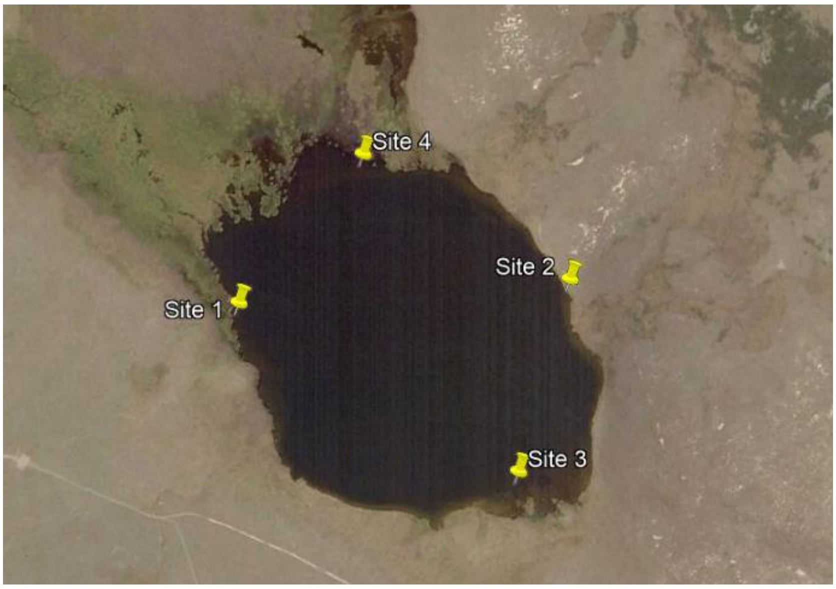
Appendix A Figure 3: **Lake Denny showing the shoreline location of four survey sites.**

Lake Emily

Appendix A Table 4: Summary comparison of 2012 and 2021 surveys for Lake Emily showing where kākahi aggregates (>1m^2) were present. *NS* indicates site and depth were not sampled.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°33'3.78"S 171°13'26.14"E	No*	No	*NS*	*NS*
2	43°33'2.72"S 171°13'46.64"E	Yes	No	Yes	No
3	43°33'11.35"S 171°13'43.46"E	Yes	No	Yes	No
4	43°32'57.11"S 171°13'33.84"E	Yes	No	*NS*	*NS*

*Kākahi observed at <1 m^2.



Appendix A Figure 4: Lake Emily showing the shoreline location of four survey sites.

Lake Emma

Appendix A Figure 5: Summary comparison of 2012 and 2021 surveys for Lake Emma showing where kākahi aggregates (>1m^2) were present.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°38'25.20"S 171° 6'32.98"E	No*	No	Yes	No
2	43°38'32.20"S 171° 6'15.13"E	No*	No	Yes	No
3	43°38'4.22"S 171° 5'59.05"E	No*	No	No*	No
4	43°37'58.26"S 171° 6'40.51"E	No*	No	Yes	No*

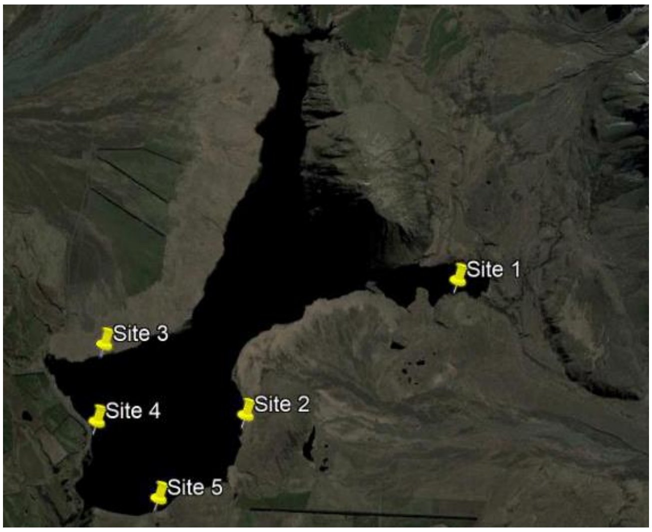
*Kākahi observed at <1 m^2.

Appendix A Figure 6: Lake Emma showing the shoreline location of four survey sites.

Lake Heron

Appendix A Table 5: Summary comparison of 2012 and 2021 surveys for Lake Heron showing where kākahi aggregates (>1m^2) were present.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
1	43°28'13.18"S 171°12'42.28"E	No	No	Yes	No
2	43°29'4.56"S 171°10'50.67"E	Yes	Yes	Yes	Yes
3	43°28'37.63"S 171° 9'36.40"E	Yes	Yes	Yes	Yes
4	43°29'7.06"S 171° 9'32.40"E	No	Yes	No	Yes
5	43°29'36.27"S 171°10'4.90"E	No	Yes	No	Yes

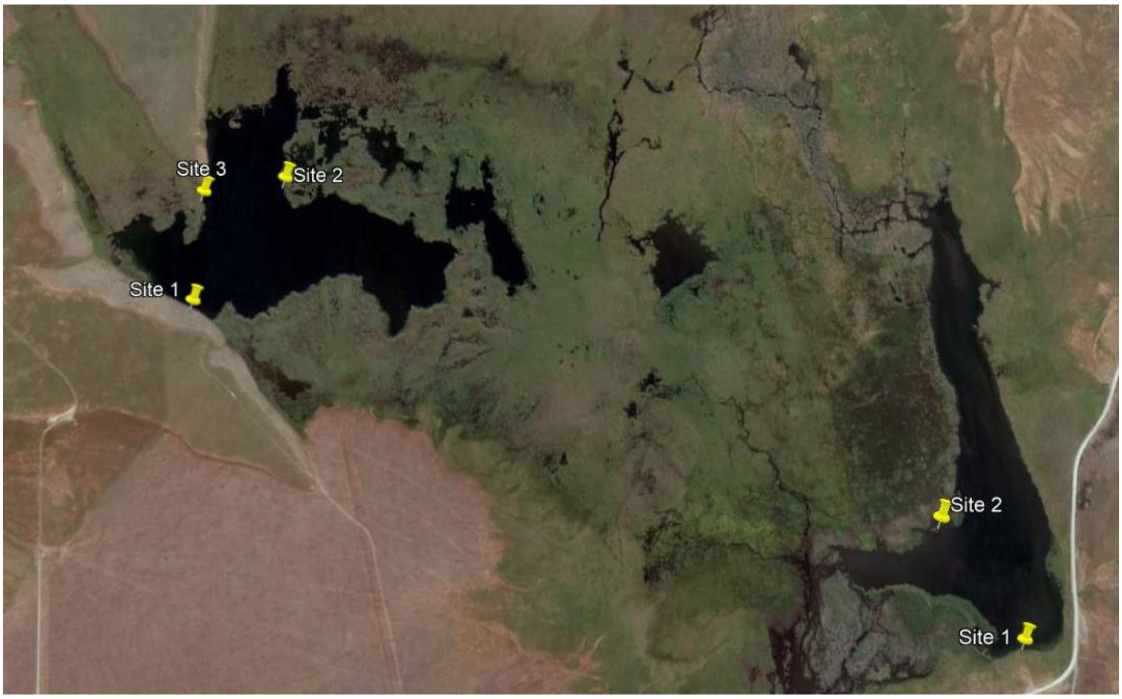


Appendix A Figure 7: Lake Heron showing the shoreline location of five survey sites.

Māori Lakes

Appendix A Table 6: Summary comparison of 2012 and 2021 surveys for the Māori Lakes showing where kākahi aggregates (>1m^2) were present.

Site name	Shore grid reference	2012		2021	
		Shallow	Deep	Shallow	Deep
West 1	43°34'17.60"S 171° 9'59.75"E	Yes	No	Yes	No
West 2	43°34'10.98"S 171°10'6.41"E	No	No	No	No
West 3	43°34'11.59"S 171°10'0.37"E	No	No	No	No
East 1	43°34'36.87"S 171°10'58.46"E	Yes	No	Yes	No
East 2	43°34'30.60"S 171°10'53.23"E	No	No	No	No

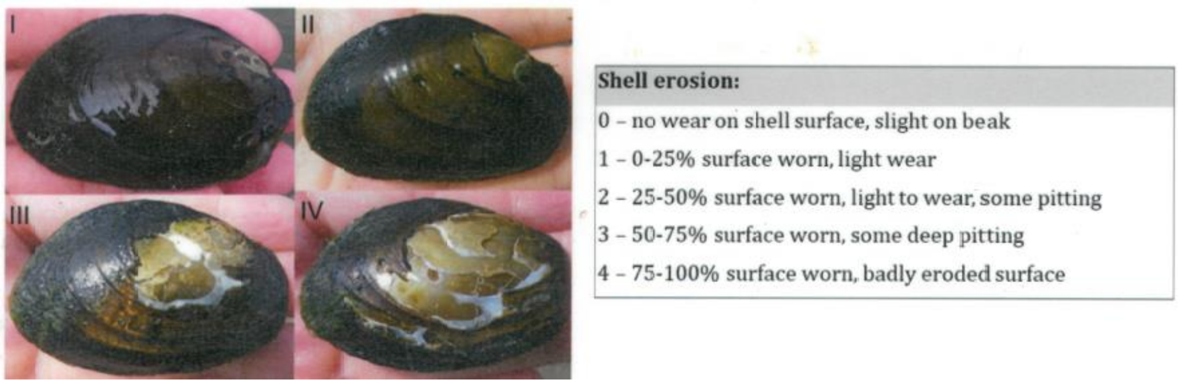


Appendix A Figure 8: **The Māori Lakes showing the shoreline location of survey sites.**

Appendix B Summary tables for other kākahi characteristics

Shell erosion

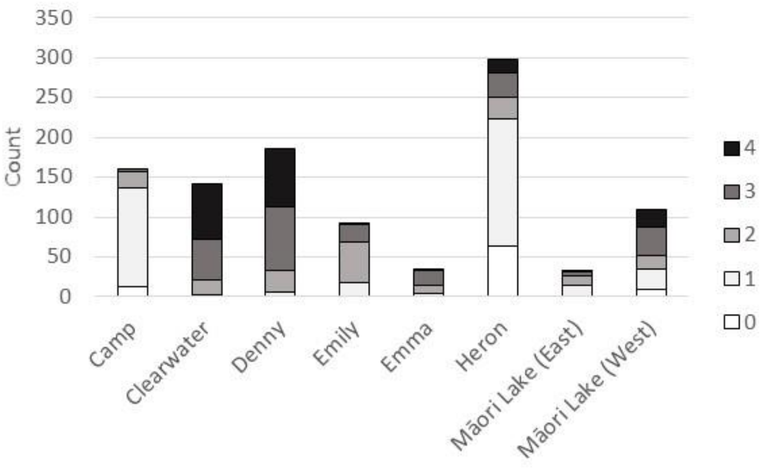
Shells were scored for erosion on a scale of 0 to 4 (Appendix B Figure 9).



Appendix B Figure 9: Scoring system for shell erosion with example photos (provided by S. Clearwater, DOC).

Appendix B Table 7: Summary of shell erosion composition in each lake based on assessed animals. See Figure 1 for erosion scale.

Erosion scale	Lake							
	Camp	Clearwater	Denny	Emily	Emma	Heron	Māori Lake (East)	Māori Lake (West)
0	12	0	0	0	0	64	1	9
1	124	3	6	17	4	159	13	26
2	21	19	27	51	11	28	13	17
3	3	50	79	22	18	30	5	36
4	0	69	74	2	1	17	1	21



Appendix B Figure 10: Plot of shell erosion composition in each lake based on assessed animals. See Figure 1 for erosion scale.

Shell height and width

Subsamples of 20 to 40 kākahi were measured for height, width and wing width.

Appendix B Table 8: Mean and range of measurements for kākahi height, width and wing width (mm) measured for sub-samples collected at Lakes Camp, Heron, Clearwater and Emma. Standard deviation in parentheses.

Lake	Mean height (1 SD), range (mm)	Mean width (1 SD), range (mm)	Mean wing width (1 SD), range (mm)
Camp	30 (3), 25 – 39	18 (2), 14 – 22	33 (6), 9 – 58
Heron	31 (3), 27 – 36	23 (2), 19 – 28	36 (2), 31 – 41
Clearwater	38 (5), 30 – 48	27 (2), 24 – 34	41 (5), 30 – 48
Emma	41 (5), 29 – 53	29 (5), 19 – 46	50 (8), 36 – 87

Brood pouches

Subsets of 28 to 40 kākahi from Lakes Camp, Clearwater and Heron were checked for the presence of female brood pouches. None were detected, as was expected for the timing of sampling.