Submission on the Future of Lake Clearwater and Lake Camp

2 *How often do you visit?*
Four times a year averaging 10 days each visit. Average occupancy 2.5 adults/day

3 Where do you stay?
Own a bach

4 *What do you value the most about the area?*
The wide open golden tussock vistas with alpine backdrops; the clean air and once-upon-a-time crystal clear lakes and streams; the roaring wind and velvet silence; the community and active caring for the environment; the night sky; friendships; frigid winters and frozen lakes; walking, biking, tramping, mountaineering, swimming, skating, fishing, photography, art and hunting. Seeing ghekos and skinks, grebes, herons, waterfowl and native flora.

The absence of dogs, their barking, menace, poop, discarded plastic bags of poop and the intrusive shouts of owners trying to control them.

Up until recently the light hand of the ADC when it came to regulation and its tacit acknowledgement of the need for innovative solutions for baches on tiny sections in an extreme environment.

It is my turangawaewae where my family have been coming for many generations. It has been the hinterland escape from commercial stresses for my family which settled in Timaru in the 1870s.

5 *What does a thriving future at Lake Camp and Lake Clearwater look like to you? What do you see for the density and character of future development (if any) of the area?*

Without the lakes few visitors would spend time in the area, and so lake health is of prime importance. The village and community are already “thriving” and do not need to thrive more.

In peak times (Xmas, Easter, Labour and show weekend) congestion is approaching uncomfortable levels with more and bigger vehicles and ever-larger groups trying to squeeze into small sections and tiny baches. Other popular scenic areas like Tekapo, Mt Cook, Queenstown, Akaroa etc. are wrestling with congestion and starting to introduce park-and-walk or park-and-bus schemes for visitors. Voluntary restraints on vehicle use, bach extensions and visitor/family numbers by hutholders might go some way to alleviating the need for heavy regulation.

The camping areas are terrific and popular and demand for sites will only grow to the point of becoming uncomfortable for campers and hutholders. But campers’ tolerance of squalor (because they can drive away from it) to the distaste of bach owners needs to be managed. **Charging realistic fees (for high, shoulder and low season use) will modify demand.**

Future development should be limited to upgrades of baches, roading and community facilities with no industry, commercial accommodation or excessive stocking or development of surrounding land (the soil is too poor). Plantation or carbon sequestration forestry should <u>not</u> be permitted.

Any attempt by investors, outside interests, iwi or overseas funds to take ownership of such land in the Ashburton Lakes for commercial, forestry or farm development should be resisted because of fire hazard and loss of biodiversity and amenity.

Convoys of big buses should be dissuaded from driving on the settlement streets because of road damage and congestion (or at least charged a fee for road maintenance). Perhaps DoC could allow a

viewing area with road access from the east end of Lake Camp (paid for by the tourist companies) to the top of the hill above Lovers Rock. Or, concrete could be laid on the steeper streets.

6 *What do you think is holding us back from this?*

Degenerating water quality in all the Ashburton lakes because of farm development is the main threat to the future of the Lake Clearwater settlement and the Ashburton Basin for most activities. Farming and its downstream effects are also a threat to biodiversity.

In view of the eutrophic condition of Lakes Clearwater, Emma, Denny and Roundabout, and the deteriorating condition of Lakes Heron and Camp and the Maori Lakes I believe that the only action that will return the lakes to their former health and clarity is to severely limit the amount of artificial fertiliser and lime applied to farmland in the lakes' catchments.

Specifically, with regard to Lake Clearwater and Lake Camp I would like to see an immediate and drastic reduction in the application of artificial fertilisers and lime to their catchments.

By way of background, the water quality in Lake Clearwater was clear and pure (oligotrophic) up until the tenure review in 2005. Extensive freshwater mussel beds and swamps easily filtered and cleaned any water run-off from the surrounding land. After 2005, intensive farm development on the Potts Face south of the inlet swamp, and application of artificial fertiliser, has overwhelmed the natural systems, and the lake water is now turbid and subject to algal blooms. The graphs tracking the increase in nitrate, phosphate and trophic level index (TLI) levels that mirror land development can be found on p.6 of the report: *CLUES Nutrient Load Predictions for the Ashburton Basin Lakes 2021 Cawthron report Supplementary Memorandum* (see attachments).

In January 2022 ECan Councillor and farmer Mr Ian Mackenzie addressed the LCHHA AGM saying no one knew why the water quality in Lake Camp was clear compared to Lake Clearwater. He was being disingenuous, the answer is in plain sight. The two lakes have different catchments: Camp's is undeveloped with no top-dressing; Clearwater's is developed and subject to intense fertiliser application (3 full days of aerial topdressing in spring 2021 with scores of short flights dropping 1.9 tonnes of superphosphate each). The boundary between the catchments is clearly visible east of Whisky Stream.

The green pasture shows the limit of top dressing (land development) on the east boundary of the Lake Clearwater catchment 27/10/2021.

In the future, if the farmer decides to develop the Lake Camp catchment the result will be eutrophication of that lake similar to what has happened at Lakes Emma, Denny and Clearwater.

The ADC plan should include regular communication with the landowner by council staff and hutholders calling for restrained and sensitive farm management practises in the catchments.

For ADC to concentrate its plan only on the areas in the map over which it has direct jurisdiction is to deny the global interconnectedness of all systems. For example, 20 years ago there were extensive mussel beds in the shallows at the western end of Lake Clearwater, and bullies were plentiful. This summer I checked and there were no mussels, and a 150mm layer of silt on the lake bed. It is years since I have seen bullies in the lake – they are host fish in the mussel lifecycle. A single mussel can filter more than a litre of lake water an hour, and, along with the inlet swamps was sufficient to maintain the oligotrophic status of the lake. In Lake Camp the mussel population is healthy at 300/sq measured at test sites (see attachments).

The residual mussels in Lake Clearwater are now sick with poor reproduction rates — efforts are urgently needed to nurture and bolster them in the effort to restore lake health.

The ADC has attempted to deal with the cause of eutrophication in Lake Clearwater by ordering the closure of village long-drops, yet there are no baches or long-drops in the catchments of Lake Emma (flipped twice), Lake Denny (pea green eutrophic) and Lake Roundabout (choked with weed after top-dressing), but all are surrounded by farm development. To be consistent the ADC needs to proactively apply the same standards to the local farmer who regularly drives stock through the village (see photos p.4).

2700 sheep were driven up Hakatere Potts Rd to the Lake Clearwater catchment in spring 2021. Photos taken 25/10/2021 also show more than 100 cattle on Potts Face.

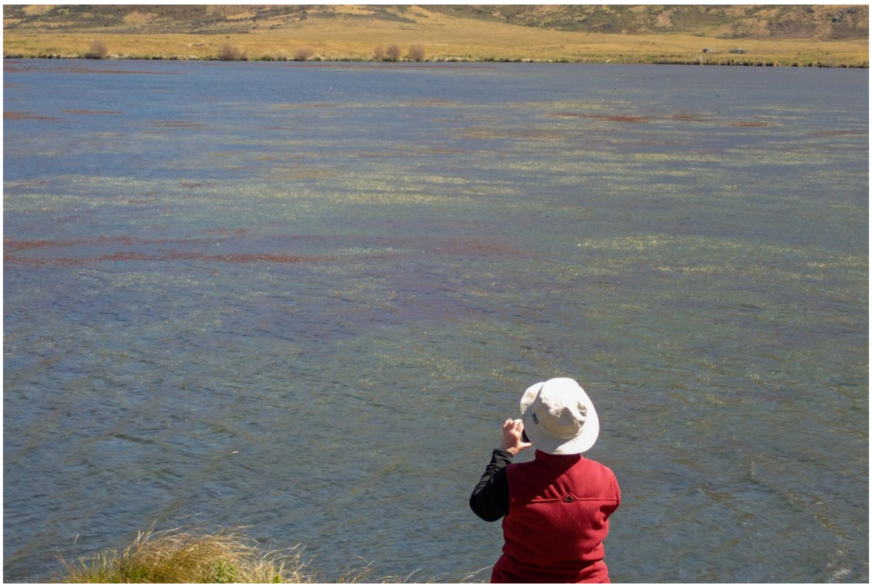
1400 sheep on Haketere Potts Rd en route to the Potts Face through the village 20.01.2021

Mt Possession St, Lake Clearwater Huts, January 15, 2019. Sheep outnumbered people 200 to 1 – council needs to be consistent in its edicts to limit faecal contamination and more vigilant in policing poor farming practice where it impinges on the wider community.

By way of illustrating poor farming practise that affect lake health in the area, clouds of airborne lime drifted over Lake Roundabout many times during top dressing of paddocks adjacent to it and Lake Emma in 2019. This prompted prolific growth of weed. In a northerly wind this drift would be across Lake Emma.

A south-easterly wind blows clouds of lime across Lake Roundabout (out of sight under the cloud, top right) not the tiny lake in the foreground 23/07/2019

The lime cloud drifting towards Lake Roundabout 23/07/2019



Excessive weed growth in Lake Roundabout 28/12/2020

A scientific paper comparing the botany of the Lake Clearwater inlet swamp with that of the village "baches" swamp, by Dr Peter Williams, presented evidence that nutrient run-off from farmland, and not the bach village, was the most likely cause of the lake eutrophication. *Comparing Changes in Plant Composition of Two Swamps Draining into Lake Clearwater 2021* (see attachments):

> "The composition of the "baches swamp" has remained essentially unchanged over at least the last 45 years in the author's experience. There is no evidence from the vegetation that this area receives more nutrients other than would be expected in that environment.
>
> "CONCLUSION Judging from the vegetation and the historical changes in adjacent land use it is likely the nutrient levels in water from the "inlet swamp" have increased over time, especially in the last couple of decades. There is no evidence from the vegetation to suggest nutrient levels in the water flowing from the "baches swamp" has similarly increased."

7 Do you have any other comments? (feel free to attach additional pages to your submission)

The former Hakatere Station land purchased by the Nature Heritage Fund in 2007 that is currently parked as Stewardship Land and appears on the map as Hakatere Conservation Area should be fully integrated into the Hakatere Conservation Park asap.

The programme by ADC and Bert Hofmans to remove invasive plants should be supported and continue.

The current status of Lake camp for motorboats and Lake Clearwater for non-motorised craft should be retained.

The sediment plume (below) washed into Lake Clearwater from the Potts Face farmland will have contained nitrates, phosphates and animal excrement. It is a threat to the community 31/05/2021.

8 I understand that all submissions are public documents and will be made available on the Council’s website with the names of the submitters included. Yes.

9 Do you wish to speak in support of your submission? Yes (pending travel arrangements)

Attachments

Comparing Changes in Plant Composition of Two Swamps Draining into Lake Clearwater 2021.

CLUES Nutrient Load Predictions for the Ashburton Basin Lakes – 2021 Cawthron report – Supplementary Memorandum.

Repeat survey of kākahi (freshwater mussels) in the Ō Tū Wharekai Lakes Prepared for Department of Conservation January 2022.

Alan Knowles

Comparing Changes in Plant Composition of Two Swamps Draining into Lake Clearwater

P.A.Williams, Nelson, April 27, 2021

PREFACE

For 15 years the deteriorating condition of Lake Clearwater (and other Ashburton lakes) has caused increasing concern among the 180 hutholders and visitors to the area. They have blamed the local runholder who has developed land and applied superphosphate and lime to the Whisky Stream catchment that drains into the inlet swamp. The farming community has responded by blaming the hutholders for their long-drop toilets. However, over that time the hutholders have been progressively replacing their long-drops with holding tanks, and the presence of tanker trucks pumping out these holding tanks has become a common sight in the settlement. [A report commissioned by the Ashburton District Council describes wastwater disposal in the settlement. Of the huts that could be investigated, 76% had holding tanks (WSP 2021). The report provides no direct evidence of contamination of Lake Clearwater by settlement blackwater.]
The turbid condition of the lake (fig.1) and the excessive weed growth had reached such alarming levels that the Lake Clearwater Hutholders Association decided on December 8, 2020, to write a letter of concern to ECan (Envronment Canterbury). Before this letter could be sent ECan and the Canterbury District Health Board issued a warning on December 21 about the presence of possibly toxic cyanobacteria in the lake. The letter of concern was subsequently sent on December 24.

> On February 10, 2021 Dr Adrian Meredith, Principal Surface Water Scientist, Environment Canterbury, wrote: "From our current data and understanding, the issues to address at Lake Clearwater are broadly increasing nutrient loads (both phosphorus and nitrogen) and resulting increase in biomass of all algal communities in the lake generating the cloudy/turbid water that is both the primary source of complaints, and the most pressing management issue to address to prevent long term degradation of the lake ecosystem."

INTRODUCTION

There are several possible causes for the deterioration of Lake Clearwater, including increased sediment from recent high rains, high water temperatures, increased nutrients in run off from farm development at the western end, and nutrients from the baches at the southern side of the lake.
As a general rule the vegetation of a wetland reflects the ground water conditions, including its nutrient status and that of the subsequent outflow or seepage from such wetland. This study describes the vegetation of the "inlet swamp", through which the farm development drains, and the vegetation of the "baches swamp" through which ground water from the Lake Clearwater baches drains, as likely indicators of the nutrient status of their respective outflows
The wetlands in the Upper Ashburton have been described (Johnson 1979) and more recently in a report prepared for the tenure review process (DOC 2003).

METHOD

Photographic surveys of the swamps were undertaken by photographer Alan Knowles at a panoramic landscape scale and close ups of vegetation. Alan Knowles photographed the inlet swamp (January 8, 2021) while approaching from the north-east, crossing the boardwalk, progressing along the path in an easterly direction on the south side and up to the carpark on the Hakatere Potts Road. He re-entered the swamp (January 25, 2021) from the south-east and photographed within 20m of the lagoon edge towards the inlet stream and exited to the south-west.

At the “baches swamp” he carried out a panoramic photographic survey (January 22, 2021) of the entire swamp; and then photographed on a transect straight through the swamp from the campground moving east, and then around the lakeshore in front of the swamp.

These photographs were examined by the author. He also drew on his long association with the area in several roles (see Appendix).

Google Earth was examined in a search for landscape scale changes in land use or condition and two images saved.

GEOGRAPHY

The “inlet swamp” occupies an area 3km x 1km at the western end of the lake. It is fed mainly from small streams off the Dogs Range and also from several small feeder streams, Whisky Creek being the largest, that drain the hill country to the south. This area is known locally as the Potts Face. These drain under the Hakatere Potts Road and hence into the “inlet swamp”.

The small “baches swamp” is directly below the bach settlement and covers an area about 300m x 50m. This swamp is fed partly by a subterranean stream from Lake Camp at a higher elevation. This drains along a shallow depression through the centre of the settlement and enters the swamp and thence the lake below the baches. This receives surface flow and presumably ground water emanating from the vicinity of the baches.

RESULTS

Google earth

A comparison of Google Earth aerial photographs (figs. 2, 3) shows land was developed south of Lake Clearwater between 2006 and 2018. This area drains into the “inlet swamp”. Other changes at a landscape scale either at the inlet or the baches could not be interpreted from Google earth.

Vegetation

Inlet Swamp

The vegetation of the “inlet swamp” draining into Lake Clearwater has small areas of native tall tussock (*Chionochloa rubra*) and *C.rigida* (and their hybrids) or hard tussock (*Festuca novae zelandiae*) on drier ground (fig.4). These are conspicuously scattered over a cover of predominantly exotic pasture grasses with lesser amounts of tall native makura (*Carex secta*) and bog rush (*Schoenus pauciflorus*). The pasture grasses are predominantly Yorkshire fog (*Holcus lanatus*), sweet vernal (*Anthoxanthum odorarum*), brown top (*Agrostis capillaris*), chewing fesque (*Festuca rubra*), and timothy (*Phleum pratense*). Large areas dominated by timothy are a characteristically bluish colour in the photographs (figs.5,6). Other exotic herbaceous plants include chick weeds (*Cerastium* spp),

Hieracium species and thistles, mainly Californian thistle (*Cirsium arvense*) and species of Juncus. The native Maori onion (*Bulbinella hookeri*) was seen in the photos.
Swamp vegetation extends a short way along the southern side of the lake to the east, some distance from the true right bank of the main stream entering the lake. This wetland is fed by two small streams to the east of Whisky Stream and its adjacent unnamed creek mentioned above. These appear to drain undeveloped land. This vegetation has a higher proportion of native species and less pasture species (fig.7) than the area fed by Whisky Stream and its associates draining developed land.

Baches Swamp
Vegetation of the "Baches swamp" (fig.8) has some residual tall tussock and also some toi toi (*Cortederia* sp.) (planted?), scattered native shrubs and a few Scotch broom (*Cytisus scoparius*). Shrubs are more common on the slightly steeper upper slopes away from the lake margin. The herbaceous layer is a finely intermingled assemblage of native Carex species, bog rush, and pasture grasses. The pasture grasses are dominated by Yorkshire fog, sweet vernal, and tall fesque (*Festuca arundinacea*). Timothy and chewings fesque are of very minor importance. Other herbs photographed include monkey musk (*Mimulus guttatus*), red clover (*Trifolium repens*) and Maori onion. Similar vegetation covers small wetland areas further around the lakeshore to the east and contiguous with the "baches swamp".
The foreshore herbfield at the outlet of the "Bach drain" consists of small native and exotic herbs (figs.9) and appears similar to that looking east and west along the lake shore.

DISCUSSION
50 years ago much of the "inlet swamp" and surrounding area was tussock-like plants: *C.rigida* on the drier ground with hard tussock and *C.rubra* and several *Carex* species in the wetter places. Judging from the accompanying photos much of this vegetation has been replaced by introduced pasture species: mainly sweet vernal, chewings fescue, Yorkshire fog, and timothy.
The latter is noteworthy as being a relatively high nutrient demanding pasture plant that thrives on fertile, heavy soils (Levy 1951). Swards such as those at Lake Clearwater are unusual in wetlands, and timothy was not mentioned in a comprehensive account of wetland plants in New Zealand (Johnson and Brooke 1989) nor an account of wetland types in NZ (Johnson and Gerbeaux 2004).
From the author's memory of high country management in the 1980s, the impact of cattle grazing in wetlands was widely recognised as a problem because they broke up the organic soils which could lead to localised erosion. At least some cattle were present in the wetlands upstream of Lake Clearwater at that time. This would have resulted in sediments entering the lake.
The collective evidence of these photographs is that much of the "inlet swamp" now has only remnant tall tussocks and tall Carex species. Much of it is now dominated by shorter native species and a dense sward of pasture species, one in particular with relatively higher nutrient requirements. It is likely this process of species replacement occurred initially via cattle grazing then oversowing with or without fertilising. The fact that pasture species are now so well established over a wide area suggests the change did not take place merely over the last couple of years. At some time unknown to the author it may have been top-dressed with superphosphate. That a large area of the "inlet swamp" remained in private

ownership following the tenure review process resulting in the Hakatere Conservation Park (fig 10) further would suggest it may have indeed been subject to some form of agricultural modification relatively recently.

Run-off from the development on the Potts Face between 2006 and 2018 may also have contributed to raising the nutrient levels which would have favoured exotic grasses over native species.

The composition of the “baches swamp” has remained essentially unchanged over at least the last 45 years in the author’s experience. There is no evidence from the vegetation that this area receives more nutrients other than would be expected in that environment.

CONCLUSION

Judging from the vegetation and the historical changes in adjacent land use it is likely the nutrient levels in water from the “inlet swamp” have increased over time, especially in the last couple of decades. There is no evidence from the vegetation to suggest nutrient levels in the water flowing from the “baches swamp” has similarly increased.

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FIGURES

Fig 1. The deteriorated quality of Lake Clearwater.

Fig 2. The western end of Lake Clearwater and the absence of land development in the vicinity of Whisky Creek (Google Earth, 2006)

Fig 3. The western end of Lake Clearwater showing land development on hills draining into Lake Clearwater primarily via Whisky Creek (Google Earth, 2018).

Fig 4. Swampland feeding the main inlet stream to Lake Clearwater. The glaucous areas in the distance are timothy.

Fig 5. Dense stands of timothy grass on the margins of Lake Clearwater.

Fig. 6. The dense stands of timothy that are visible in the distance in Fig.4.

Fig 7. Swampland east of that shown in Fig. 4 and away from the main inlet stream is dominated by tussocklike native species and low fertility exotics. Timothy is rare.

Fig 8 The Baches swamp is dominated by tussocklike native species and mainly low fertility exotic herbs and grasses.

Fig 9. The lake edge vegetation in the vicinity of the outlet to the drain running through the settlement is dominated by native herbs and low fertility exotic grasses.

Fig 10. Freehold land to the west and south of Lake Clearwater bounded in red (https://propertysearch.canterburymaps.govt.nz). Coincidently, the property reference point indicates the dense area of timothy grass.

APPENDIX

Dr Peter A. Williams
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In the early 1970s Peter Williams was based in the Tussock Grasslands and Mountain lands Institute, Lincoln College when he studied soils and tussock grassland nutrient cycling in Paddle Hill Creek and Dogs Range immediately north of Lake Clearwater. He was later employed as a plant ecologist by Botany Division DSIR. He was their representative on the South Canterbury Catchment Board for several years in the 1980s. He participated in the survey of the lakes in the Ashburton Basin in 1979 (Johnson 1979). He also visited the lake often from the early 1970s, although less frequently in the last 20 years.
For this account he did not visit the area but studied dozens of the photographs identified the plants where possible, and commented on the vegetation changes over time based on his experience of the area.

CLUES Nutrient Load Predictions for the Ashburton Basin Lakes – 2021 Cawthron report – Supplementary Memorandum

By Tina Bayer, Adrian Meredith, Tom Drinan & Hugh Robertson June 2021

Introduction

The purpose of this supplementary memorandum is to:

i) Provide a simplified summary of the findings of the CLUES Cawthron report.
ii) Outline the implications of the report to lake management.
iii) Supply additional technical information to help interpretation of the report including the most recent lake water quality data.

Summary of Cawthron report

The purpose of the modelling report (Kelly et al 2021[i]) was to:

(i) Update previous (2014[ii]) catchment nutrient load modeling.
(ii) Estimate the catchment load reductions (for Total Nitrogen and Total Phosphorus) needed to meet the Canterbury Land and Water Regional Plan (LWRP) objectives for lakes in the Ō Tū Wharekai (OTW, Ashburton Lakes) basin and Upper Waimakariri catchment.
(iii) Provide updated bird contributions to total nutrient loads in the Ashburton Lakes basin.

Key findings:

The Cawthron report provides an estimated reduction in **both in-lake nutrient concentrations and catchment nutrient loads** (detailed in Table 5 of Kelly et al 2021). In-lake nutrient concentrations reflect current conditions in the lakes and can be assessed against LWRP objectives. External catchment loads of nutrients contribute to in-lake nutrient concentrations, but do not translate 1:1 to in-lake concentrations due to nutrient attenuation (i.e., the reduction of nutrients by processes other than dilution – e.g., plant/algal uptake) and processing. The load reductions were determined from both monitoring data and the relationship between lake water quality and catchment loads from the CLUES model[1]:

All monitored lakes in the **Ashburton Lakes basin** need **reductions in algal biomass** and in-lake **Total Nitrogen concentrations** to meet the LWRP objectives (outcomes) and limits. Four out of 8 lakes need reductions in in-lake **Total Phosphorus concentrations** to meet the plan limits.

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[1] Loads were calculated from the reductions in in-lake concentrations required to meet plan limits which were then translated into an estimated load reduction via the regression models built with CLUES catchment loads estimates and the monitoring data (Vollenweider model). Load reductions estimates are not a direct output of the CLUES model.

Most of the Ashburton Lakes require major reductions in **catchment nutrient loads to** meet the LWRP plan objectives and limits. Of the lakes evaluated[2]

- 80% of lakes require large **Nitrogen load** reductions.
- 33% of lakes require large or moderate **Phosphorus load** reductions.
- 100% of lakes need **significant reductions in nutrient loads to meet algal biomass** (chlorophyll a) plan objectives.

Similarly, many of the **Waimakariri lakes** also require moderate or large nutrient load reductions to meet plan objectives. Lake nutrient load reductions are therefore not unique to the Ashburton lakes, and may be needed in many high-country lakes across Canterbury.

The **nutrient load reductions are described for entire lake catchments** (catchment-scale), and not for individual farms or sub-catchments, and do not account for fine-scale land cover (e.g. location of winter fodder crops, location of high production areas [e.g. legumes such as lucerne], or other small scale, high-impact activities or areas).

Lakes Emily and Emma have the highest contribution of **bird sources to total nutrient loads**. All other lakes have low bird contributions to total nutrient loads, accounting for less than 9% (of total lake loads) for Total Phosphorus and less than 2% for Total Nitrogen.

Implications for lake management

The Cawthron report provides additional evidence that **significant catchment nutrient load reductions** are needed in all monitored lakes in the Ō Tū Wharekai area and for many of the Waimakariri Lakes. The report also provides an estimate of the magnitude of load reductions required for each lake.

The need for significant nutrient load reductions in the Ashburton Lakes basin is also evident from the Department of Conservation's and Environment Canterbury's stream and lake monitoring data. These monitoring data show:

- increasing trends of total nutrient concentrations and algal biomass in many lakes in the basin (Table 1) along with increasing nutrient concentrations in streams.
- that LWRP objectives are consistently not being met for nutrient concentrations and algal biomass outcomes in the lakes.

As both Nitrogen and Phosphorus availability is likely to control algae, **both Total Nitrogen and Total Phosphorus catchment loads** will need to be co-managed to avoid further increases in algal biomass and failure to achieve the overall algal biomass outcome.

Lakes are often accumulators of nutrients and legacy issues can persist for years after external nutrient loads are reduced. Degradation is not readily reversible; especially once lakes have

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[2] Some lakes were excluded from the load assessment based on poor catchment model fit. These lakes are likely to have additional factors driving nutrient dynamics and algal biomass (beside catchment land cover, soil type, land topography and climate) that were difficult to model. These additional factors may include internal loading processes within a lake and unquantified additional external nutrient sources. The following lakes were removed from load reduction estimates: Lakes Emma, Denny, Clearwater, and Hawdon. **Their removal does not indicate they do not also require significant nutrient load reductions.**

reached their 'tipping points'. Climate change is likely to further increase the lakes vulnerability. These considerations highlight the need for substantial and urgent action to prevent the Ashburton lakes from entering into (or remaining in) persistent, degraded states.

Supplementary technical information and updated lake water quality data

The Cawthron report does not include the 2020/2021 seasons data or recent (post 2018) land use mapping. As nutrient and chlorophyll a concentrations are continuing to increase in most lakes, even higher nutrient load reductions than indicated in the CLUES modelling report will be required to meet the LWRP objectives and targets.

Table 2 presents an overview of required reductions of in-lake nutrient concentrations and catchment loads needed to meet the LWRP objectives. The data presented in this table uses the load reduction estimates from the Cawthron report, but in-lake concentration reductions are based on 2017-2021 monitoring information and are therefore more up to date than what is shown in the Cawthron report (2015-2020). Updated Trophic Level Index and NPS-FM attribute grades are shown in Table 3.

Specifically, recent monitoring highlighted:

- None of the lakes monitored in the Ashburton basin now meet the plan objectives for the Trophic Level Index in the period between 2017 and 2021 (based on 5-year averages, Table 3).
- Most lakes in the Ashburton basin continue to have increasing trends in in-lake Total Nitrogen concentrations and/or algal biomass (Table 1), and the frequency and magnitude of exceedance of LWRP objectives is increasing.
- There have been recent large increases in algal biomass in Lakes Clearwater and Heron alongside increasing nutrient trends (Figure 1 and 2, Table 1):
    - Lake Heron no longer meets the LWRP Total Nitrogen concentration limit based on the latest 5-year averages (2017-2021)
    - The Lake Heron Total Phosphorus concentration limit was exceeded in the past 2 years, and the Total Nitrogen concentration limit exceeded in the past 4 years.
    - **Lake Heron and Lake Clearwater did not meet the NPS-FM national bottom line for algal biomass in 2020/2021.**
    - Conditions below the national bottom line indicate that lake ecosystems have undergone, or are at high risk of, a shift to a persistent, degraded state.
- Urgent action is needed for Lake Clearwater in particular as there are indications that the lake may be 'tipping' (i.e. transitioning from a clear macrophyte dominated state to a turbid algae dominated state).

In terms of land use:

- The report used land use data available from LCDB5 that is based on land use data up until to 2018; therefore, it may not detect more recent land use changes. It also uses broad categories and does not account for differences in farming practices.

Additional information for interpretation:

Overall, the catchment model performed reasonably well in predicting lake water quality from catchment land uses for most lakes. However, the Cawthron report clearly states that given the complexity of models and lake ecosystems there are some areas of uncertainty.

The report and our memo have considered land use responses from a water quality limits approach, and have not directly considered the relevance or appropriateness of these (plan) targets and limits to cultural values and Mātauranga measures of the lakes.

Below are notes to assist in interpretation of the report's findings:

- The relationship between in-lake nutrient concentrations and catchment nutrient loads is not linear, so catchment **load** reductions needed are higher % reductions than measured in-lake total nutrient concentrations.
- For the lakes that could not be effectively modelled, significant nutrient load reductions are still likely to be required given their currently degraded water quality status.
- The community of algae present can vary from lake to lake and over time, which can influence lake trophic status and nutrient sensitivity. These relationships may need to be considered when developing individual lake catchment management strategies.
- Investigations into different forms of nutrients (dissolved organic, dissolved inorganic, and particulate) are ongoing for the monitored Ashburton lakes. Preliminary results indicate that the proportion of nutrients that are immediately bioavailable varies markedly between the lakes. This variability could help explain some differences in algal biomass responses to total nutrient concentrations and loads, and poor model fit for some lakes.
- For Lake Heron where a large proportion of Total Nitrogen load is delivered as bioavailable nitrate in some areas, having catchment load limits for Total Phosphorus, Total Nitrogen **and nitrate** may be a more effective management strategy than relying on total nutrient load limits alone.
- While nutrient concentrations are useful indicators of eutrophication, algal biomass indicates the overall ecosystem response. It is the increase in algal biomass above reference conditions that compromises the ecological, cultural, recreation and amenity values. All Ashburton Lakes need higher reductions of algal biomass than nutrient concentrations (both based on current in-lake concentrations and modelling results), which suggests that the current limits for Total Nitrogen and Total Phosphorus are not necessarily conservative enough to achieve the chlorophyll a objectives.
- Because the contribution of birds was excluded from the load reductions, the estimates of Total Phosphorus load reduction required from some lakes (Emma, Emily) may be lower than what is currently estimated, given the recent management of bird populations.
- There is a mismatch between LWRP Schedule 8 and Table 1a in terms of TLI objectives vs. plan limits for Lake Emily and the Maori Lakes. In the report this was resolved by using the plan objectives (TLI of 4 and chlorophyll a of 5 µg/L), and the TP and TN concentrations (350 µg/L TN and 20 µg/L of TP) that correspond to a TLI of 4. This mismatch needs to be resolved in future plan changes.

Table 1: Long-term trends for the Ashburton Lakes (2007-2021)

Lake	Total Nitrogen	Total Phosphorus	Chlorophyll a
Heron	Very likely increasing		Very likely increasing
Maori-Front	Very likely increasing	Likely decreasing	
Maori-Back	Likely increasing		Very likely increasing
Emily		Very likely increasing	Likely increasing
Clearwater	Very likely increasing	Very likely increasing	Very likely increasing
Camp	Very likely increasing		Very likely increasing
Emma	Likely increasing	Likely increasing	Very likely increasing
Denny	Likely decreasing		

Very likely >90% likelihood; likely 67-90%

Table 2: Reductions of in-lake concentrations (based on 2017-2021 averages) and catchment loads needed to meet LWRP objectives

Lake	TN in-lake reduction needed	TP in-lake reduction needed	Chla in-lake reduction needed	Estimated TN Load reduction*	Estimated TP Load reduction*
Heron	9%		81%	0-33%*	
Maori Front	45%		54%	>66%*	
Maori Back	34%	13%	63%	>66%*	
Emily	25%	29%	40%	>66%*	33-66%*
Clearwater	74%	55%	80%	ND* likely >66%**	>66%*
Camp	52%		37%	>66%*	
Emma	76%	70%	87%	ND*	
Denny	75%	91%	83%	ND* likely >66%**	

Kelly et al 2021, ND = not determined as outside regression model
** estimated based on 2017-2021 in-lake data only. Lakes Clearwater, Emma and Denny fall outside the regression model. Lake Emma is likely to be affected by internal loading processes. Lakes Clearwater and Denny likely have additional sources of nutrients in their catchments.

Table 3: Updated lake water quality assessments of the Ashburton lakes

Lake	TLI 2020/ 2021	LWRP assessment (ø 2017-2021)			NPS-FM Attribute State (2017-2021) (in µg/L)				Frequency of NPS-FM D-bands in all years 2017-2021			
		TLI (ø2017-2021)	Grade	LWRP met?	TN - MED	TP - MED	Chla - MED	Chla - MAX	TN	TP	Chla - MED	Chla - MAX
Heron	3.9	3.6	mesotrophic	NO	150	7	6.1	38			1	
Maori-Front	3.8	4.3	eutrophic	NO	620	8	1.8	137				2
Maori-Back	4.8	4.5	eutrophic	NO	410	16	4.3	80			1	1
Emily	4.1	4.4	eutrophic	NO	410	23	3.5	50				
Clearwater	5.4	4.3	eutrophic	NO	510	14	4.3	40	1		1	
Camp	3.6	3.4	mesotrophic	NO	330	7	2.8	6.6				
Emma	5.3	4.8	eutrophic	NO	620	26	10.8	48	1		3	
Denny	4.5	5.0	supertrophic	NO	530	49	8	140		3		

TLI = Trophic Level Index, TP = Total Phosphorus, TN = Total Nitrogen, Chla = chlorophyll a, MED = median, MAX = maximum. NPS band colour coding: Blue = A-band, Green = B-band, Orange = C-band, Red = D-band.

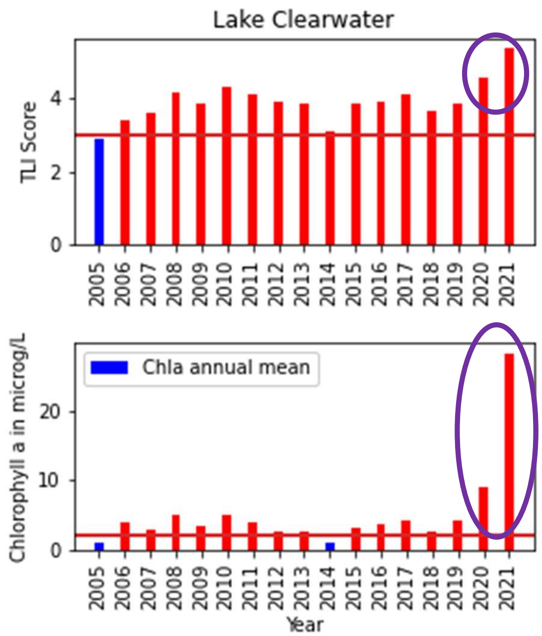

Figure 1: Trophic Level Index, Total Nitrogen, Total Phosphorus and chlorophyll a annual means in Lake Clearwater, 2005-2021. Red line is the LWRP objective/limit. Circle highlights notable recent (2020 2021) increases.

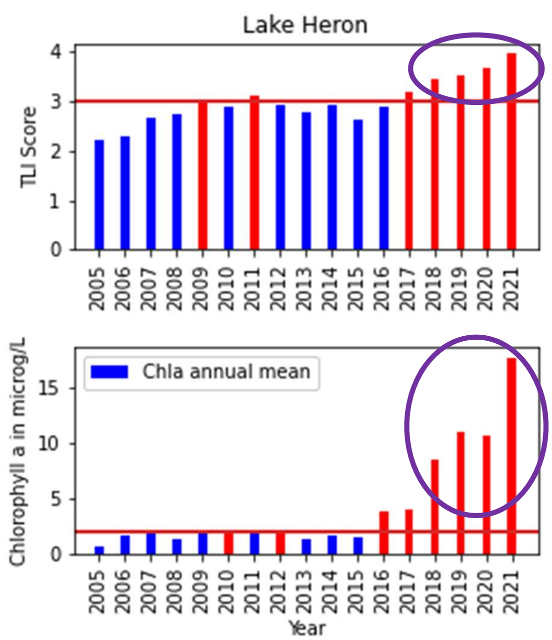

Figure 2: Trophic Level Index, Total Nitrogen, Total Phosphorus and chlorophyll a annual means in Lake Heron, 2005-2021. Red line is the LWRP objective/limit. Circle highlights notable recent (2018 to 2021) increases.

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[i] Kelly, D, Floerl, L, & P Cassanovas (2021). Updating CLUES nutrient load predictions for Ashburton Basin and Waimakariri high-country lakes. Prepared for Department of Conservation & Environment Canterbury. Cawthron Report NO 3589

[ii] Kelly, D, Robertson, H, & C Allen (2014). Nutrient loading to Canterbury high- country lakes for sustaining ecological values. Prepared for Department of Conservation and Environment Canterbury. Cawthron Report NO. 2557

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

Prepared for Department of Conservation

January 2022

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Contents

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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.

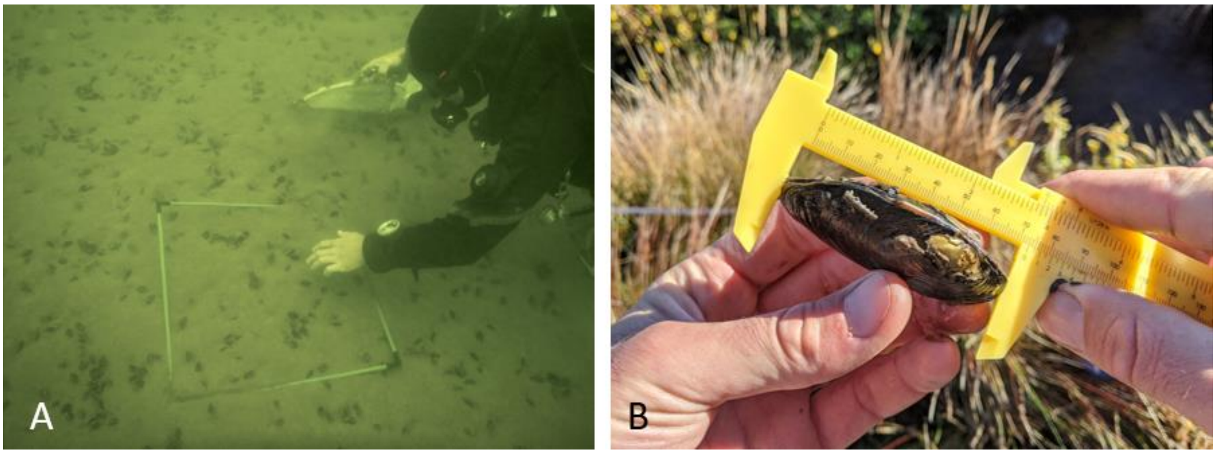


Figure 2: A) diver collecting kākahi from within a 0.33 m^2 quadrat, B) callipers were used to measure shell length.

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)
	1	16.2	216 (24.8)	56 (3)
16/02/2021	2	14.5	381 (78.9)	58 (5)
	Lake		298.5 (103)	57 (4)

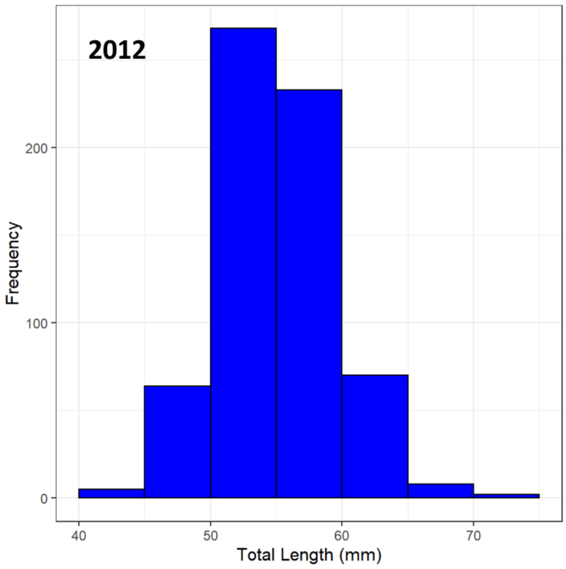
3.1.2 Comparison between 2012 and 2021

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).



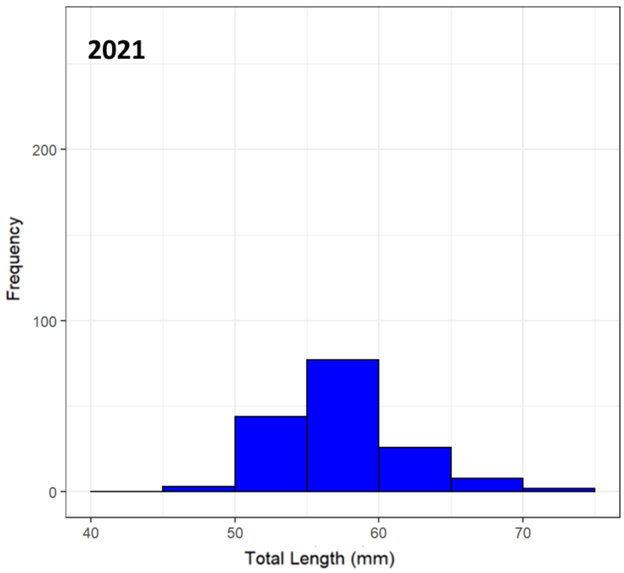


Figure 3: Frequency distribution of kākahi length (5 mm intervals) from Lake Camp populations in 2012 and 2021. Note: density cannot be extrapolated from this plot as not all of the individuals counted were measured for length in 2021. For accurate density information refer to Table 2.

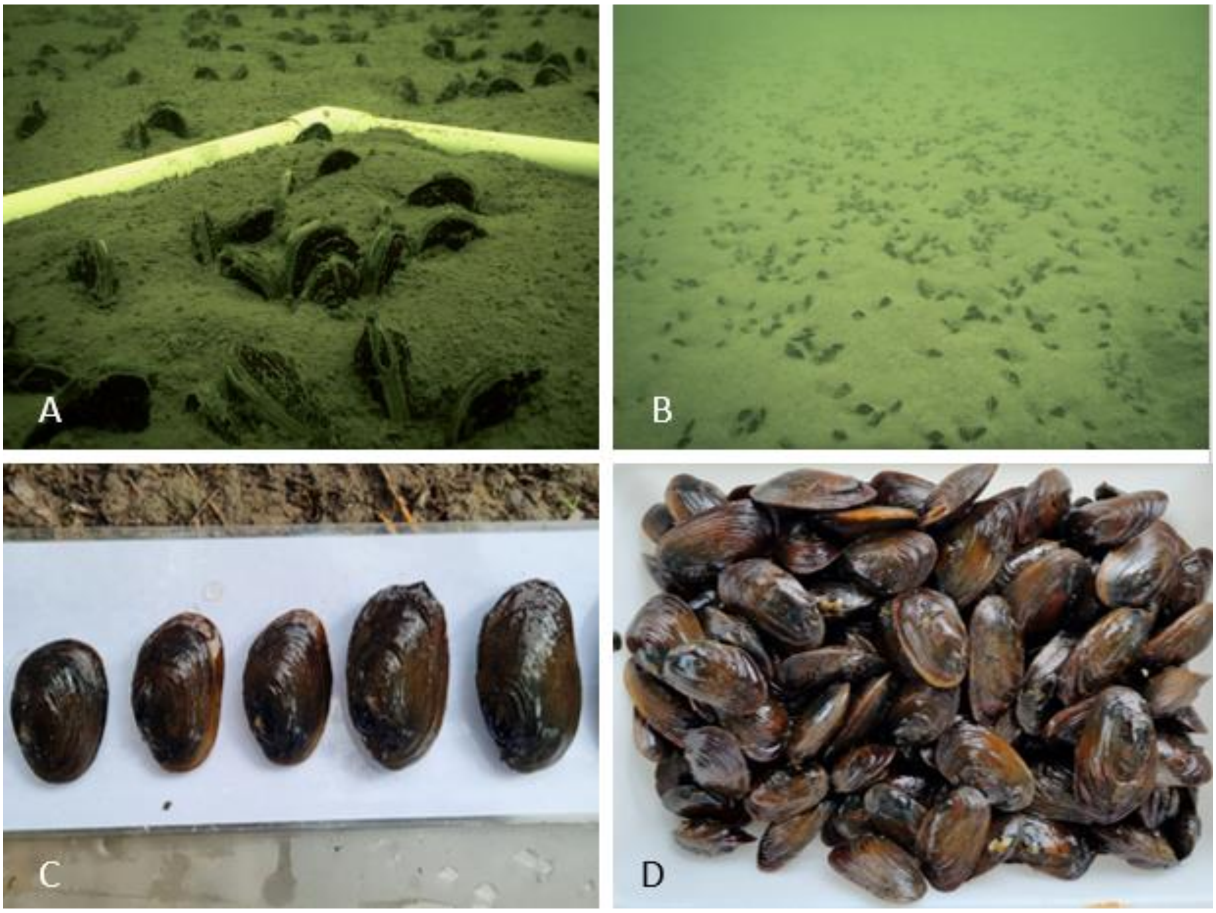


Figure 4: **Lake Camp 2021.** A and B) kākahi observed over lake bottom, C) kākahi showed little evidence of shell erosion or deformities, D) kākahi collected from one of the transects.

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)

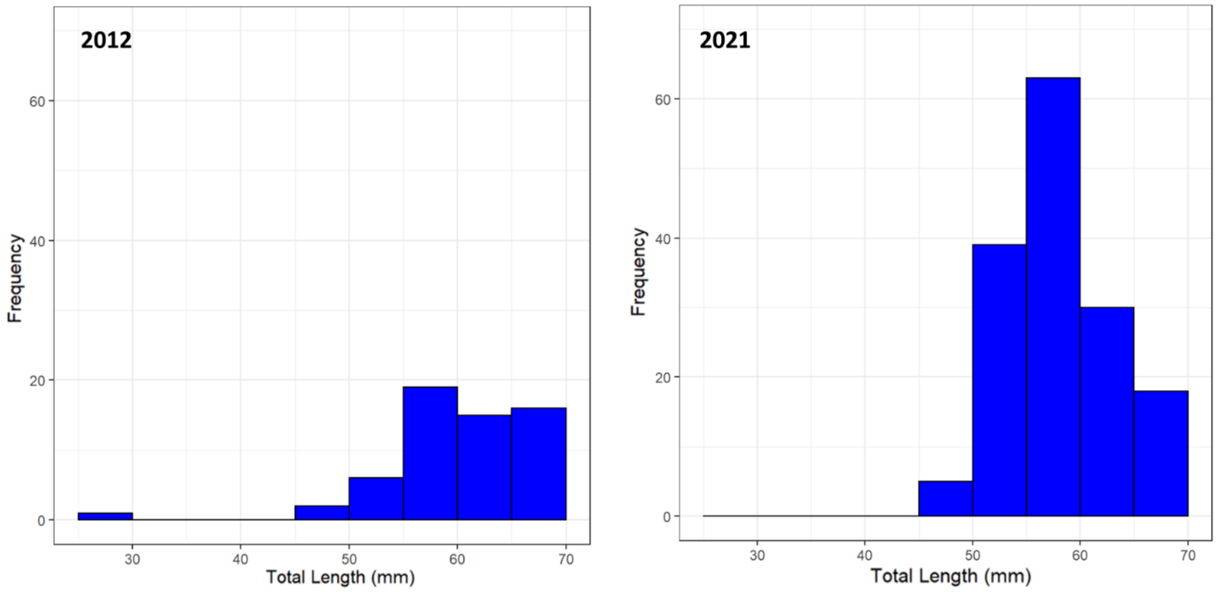


Figure 5: **Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Clearwater populations in 2012 and 2021.**

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).

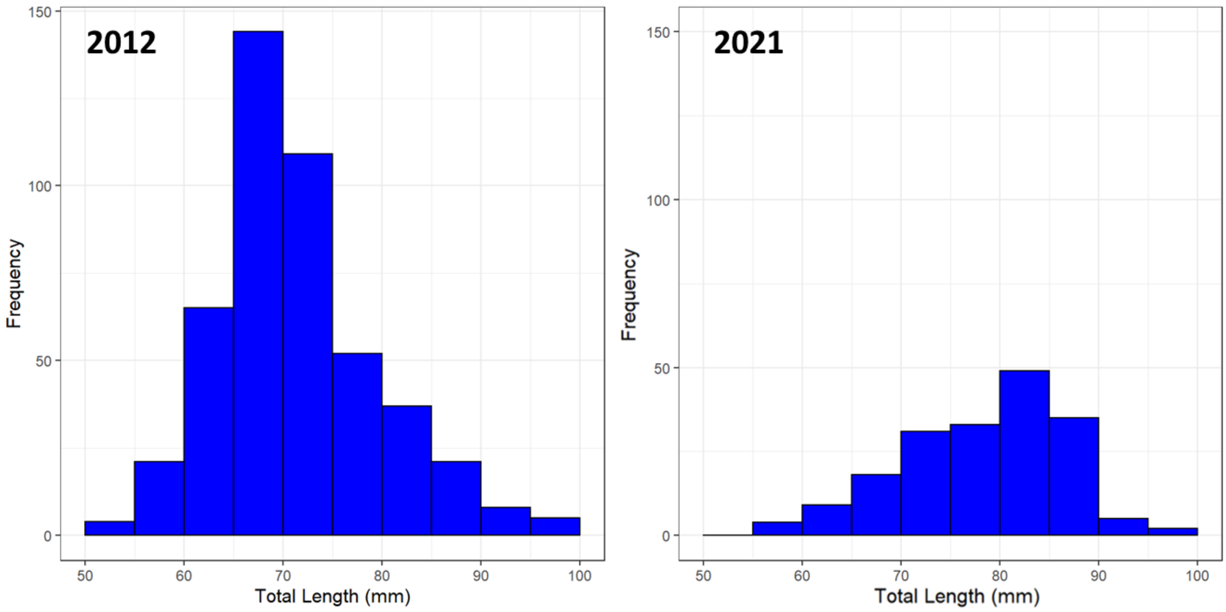


Figure 7: Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Denny populations in 2012 and 2021. Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. For accurate density information refer to Table 6.

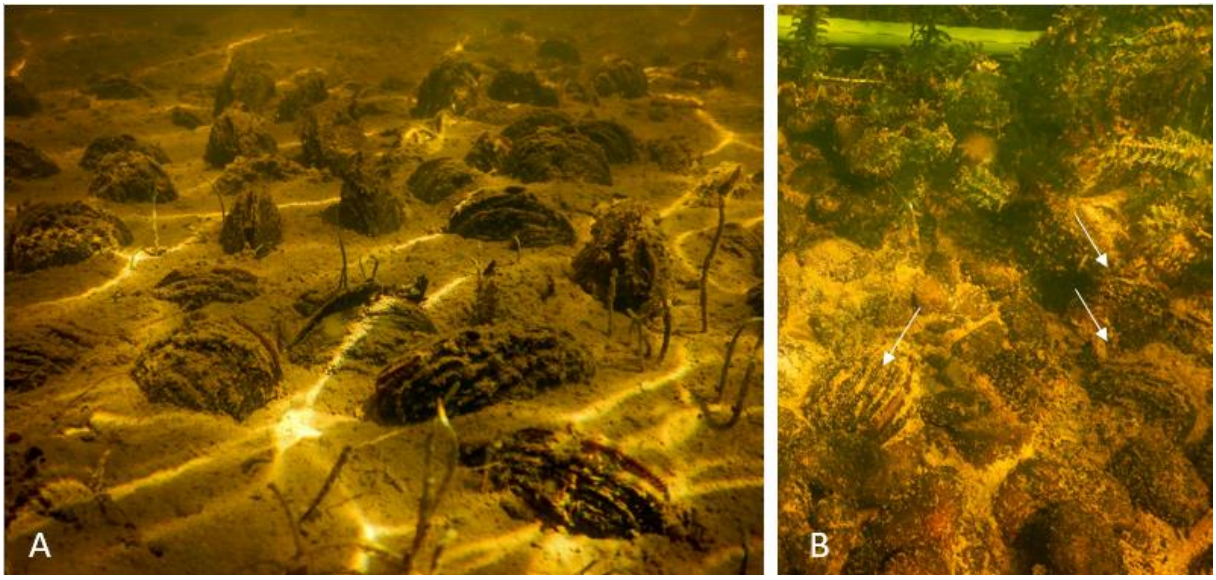


Figure 8: **Lake Denny 2021.** A) Kākahi on eastern shore in soft sediments, B) kākahi on the western shore growing amongst stones.

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)
	2	0.5	22.8 (11.7)	56 (9)
16/02/2021	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)

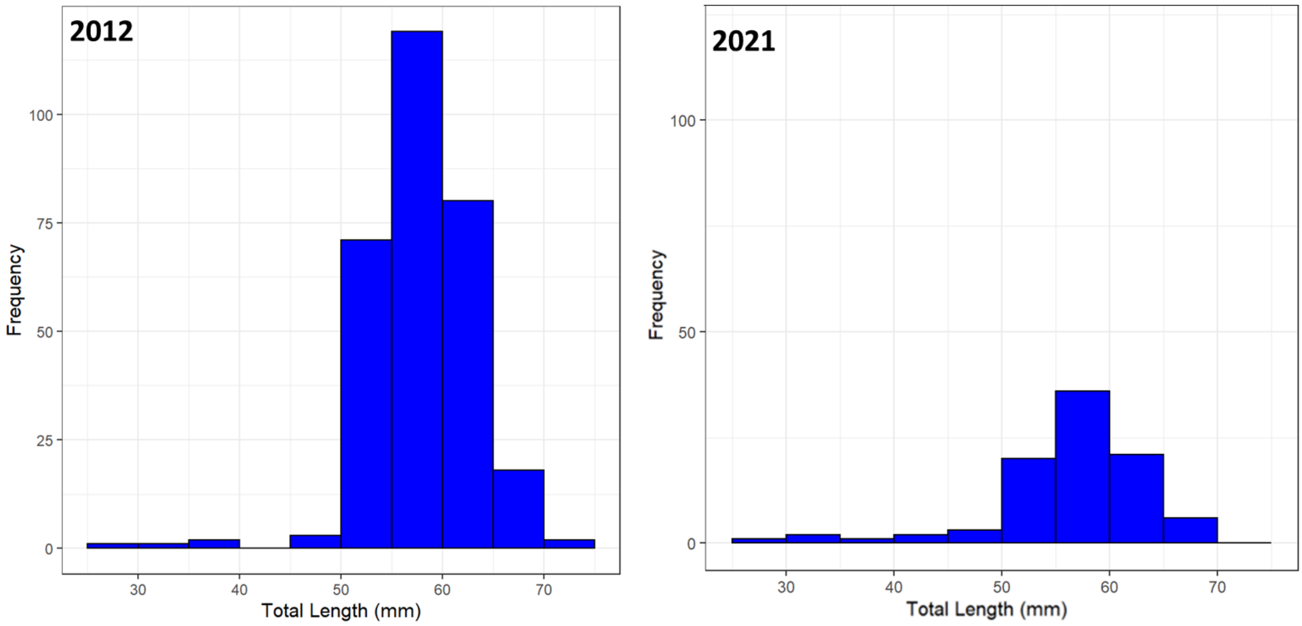


Figure 9: **Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Emily populations in 2012 and 2021.** Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. Only two of the sites surveyed in 2012 were resurveyed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

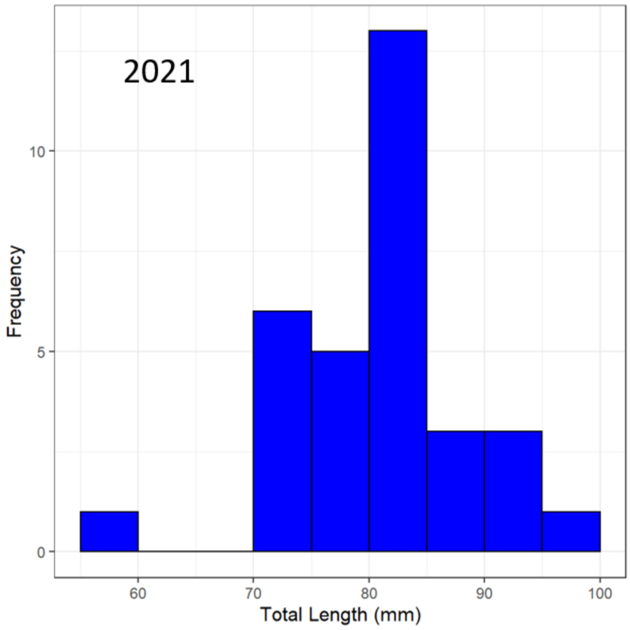


Figure 11: Frequency distribution of kākahi length (5 mm intervals) in collections from the 2021 Lake Emma population. (Note: frequency distribution is not included for 2012 due to the very low population numbers).

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)

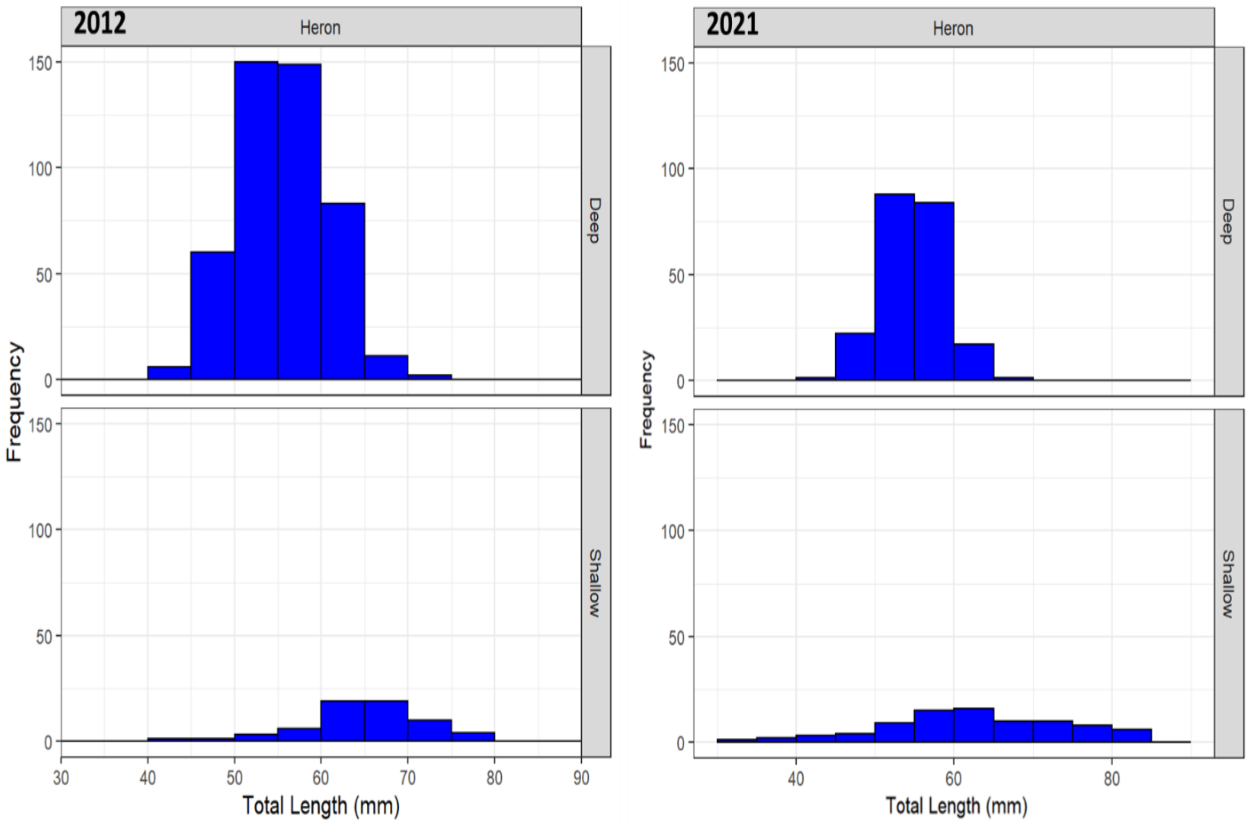


Figure 13: Frequency distribution of kākahi length (5 mm intervals) in collections from Lake Heron in 2012 and 2021 comparing deep and shallow populations. Note: density cannot be extrapolated from this plot as not all of the counted individuals were measured for length in 2021. For accurate density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

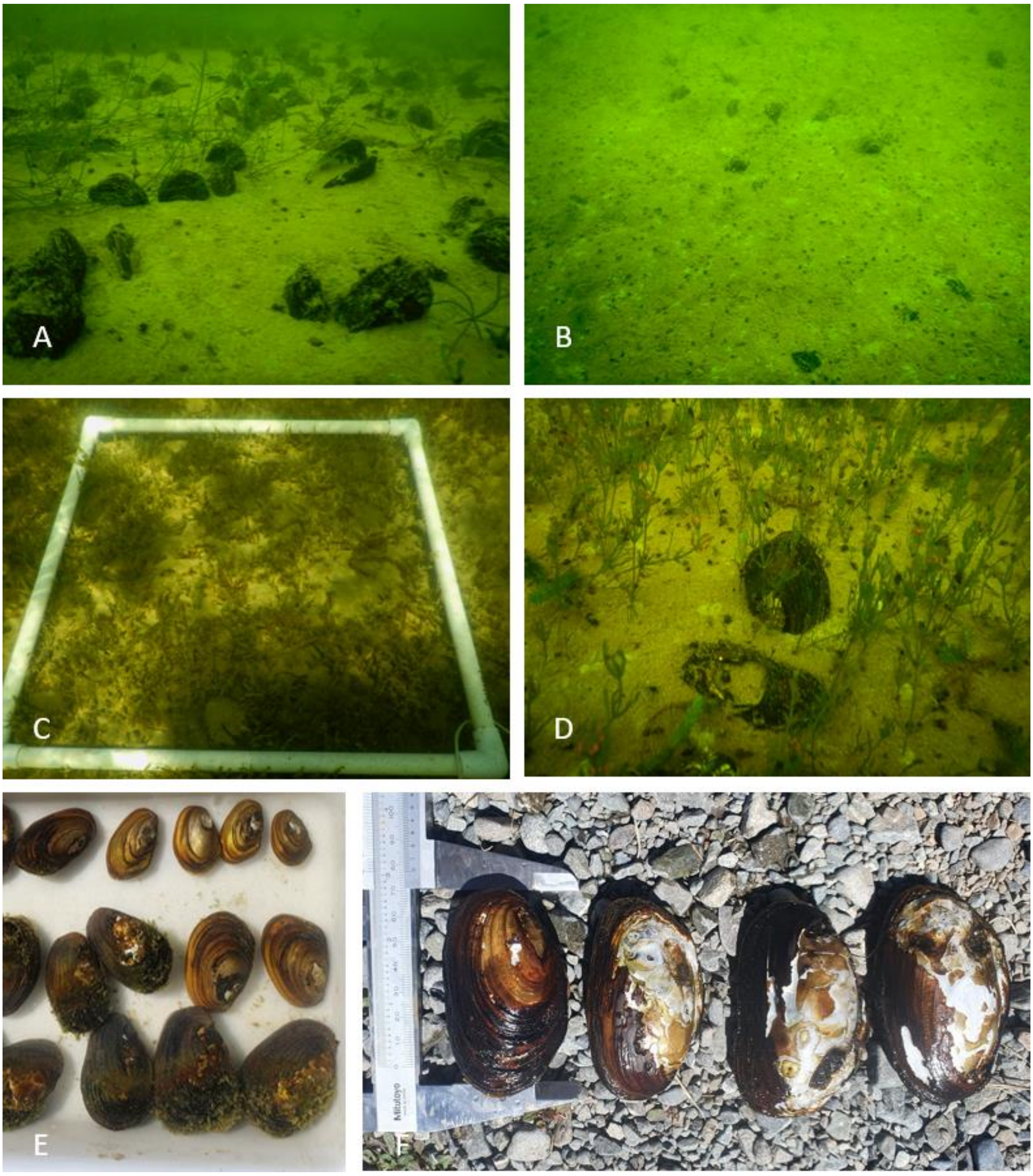


Figure 14: **Lake Heron 2021.** A and B) kākahi across bottom at depth c. 14.5 m, C) quadrat placed in shallows zone amongst low growing turf plants, D) kākahi amongst native charophytes, E and F) kākahi samples showing range in size and various degrees of shell erosion.

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)

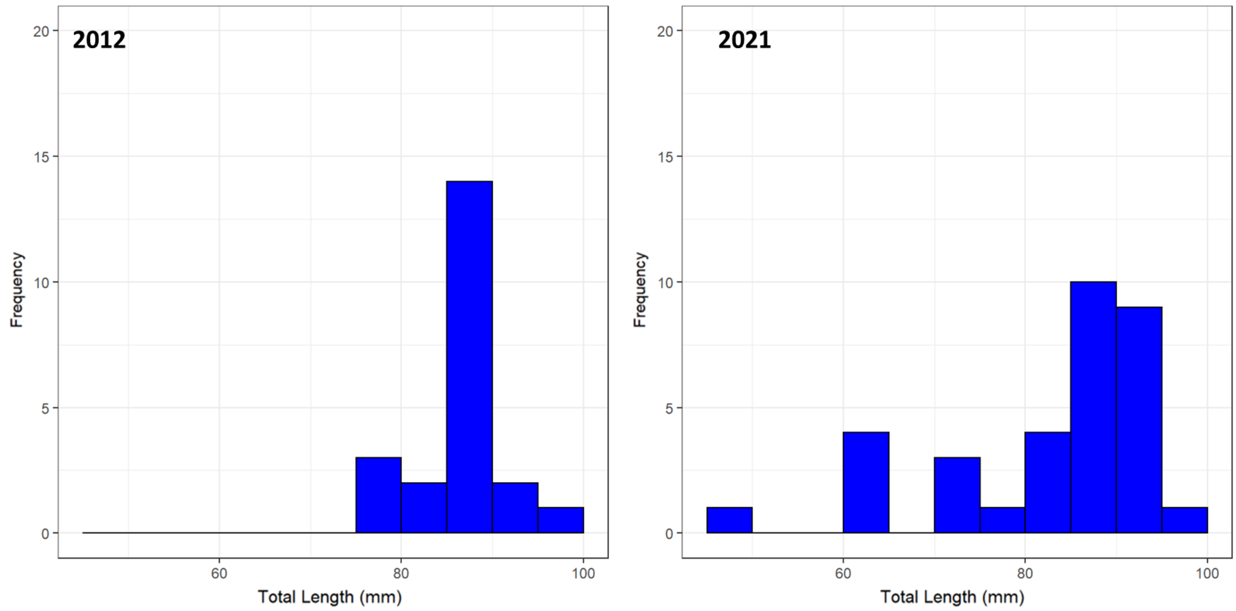


Figure 15: Frequency distribution of kākahi length (5 mm intervals) in collections from Māori Lake East populations in 2012 and 2021.

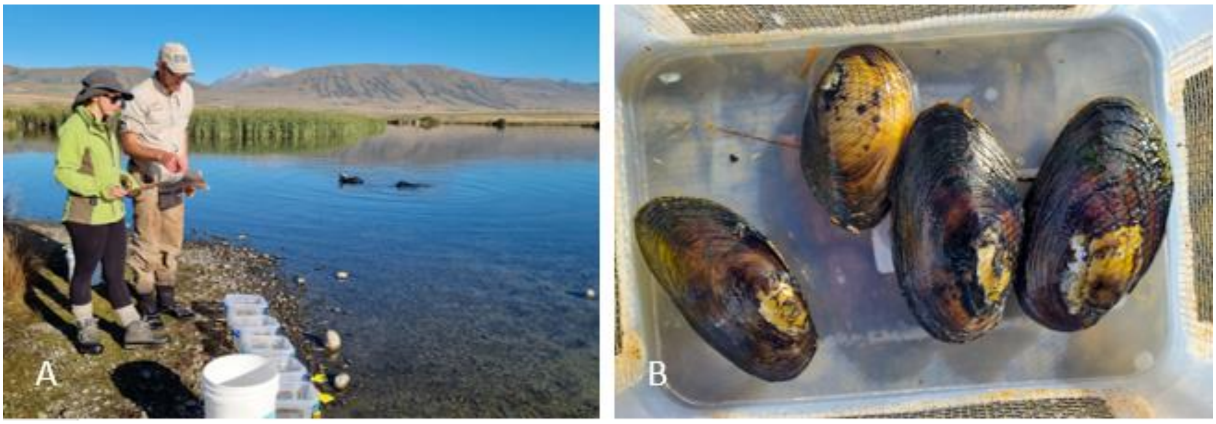


Figure 16: Māori Lake East 2021. A) DOC staff awaiting kākahi for onshore measurements – diver in background, B) sample of kākahi from one quadrat.

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)

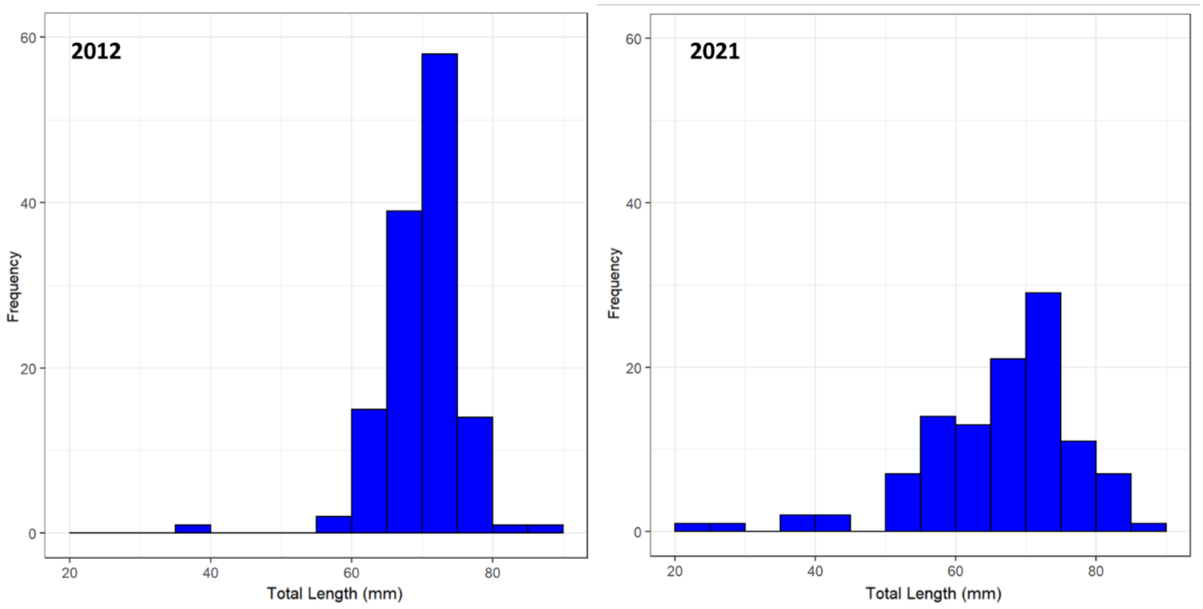


Figure 17: Frequency distribution of kākahi length (5 mm intervals) in collections from Māori Lake West populations in 2012 and 2021.

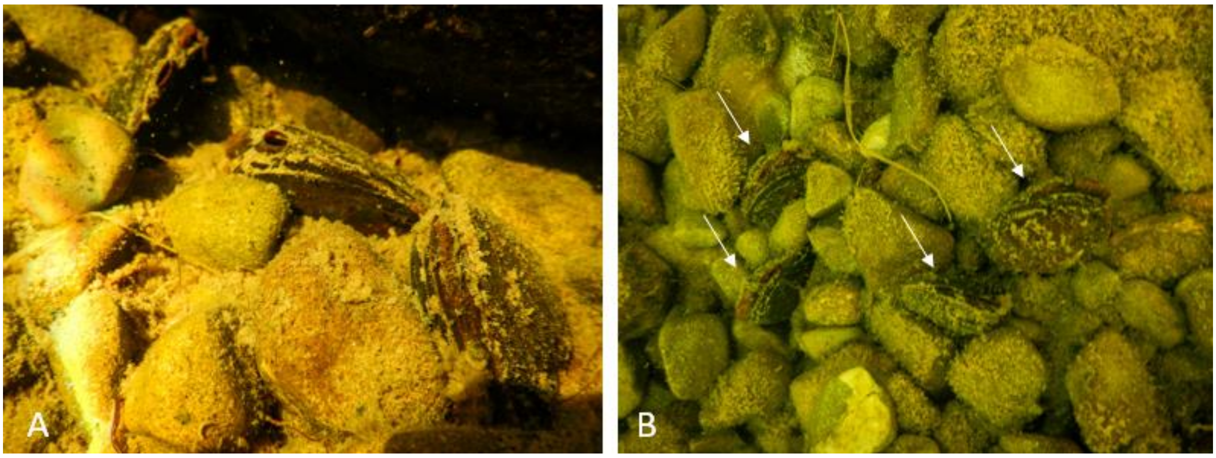


Figure 18: Māori Lake West 2021. A & B) kākahi were wedged between stones and a fibrous peat material at Site 1.

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).

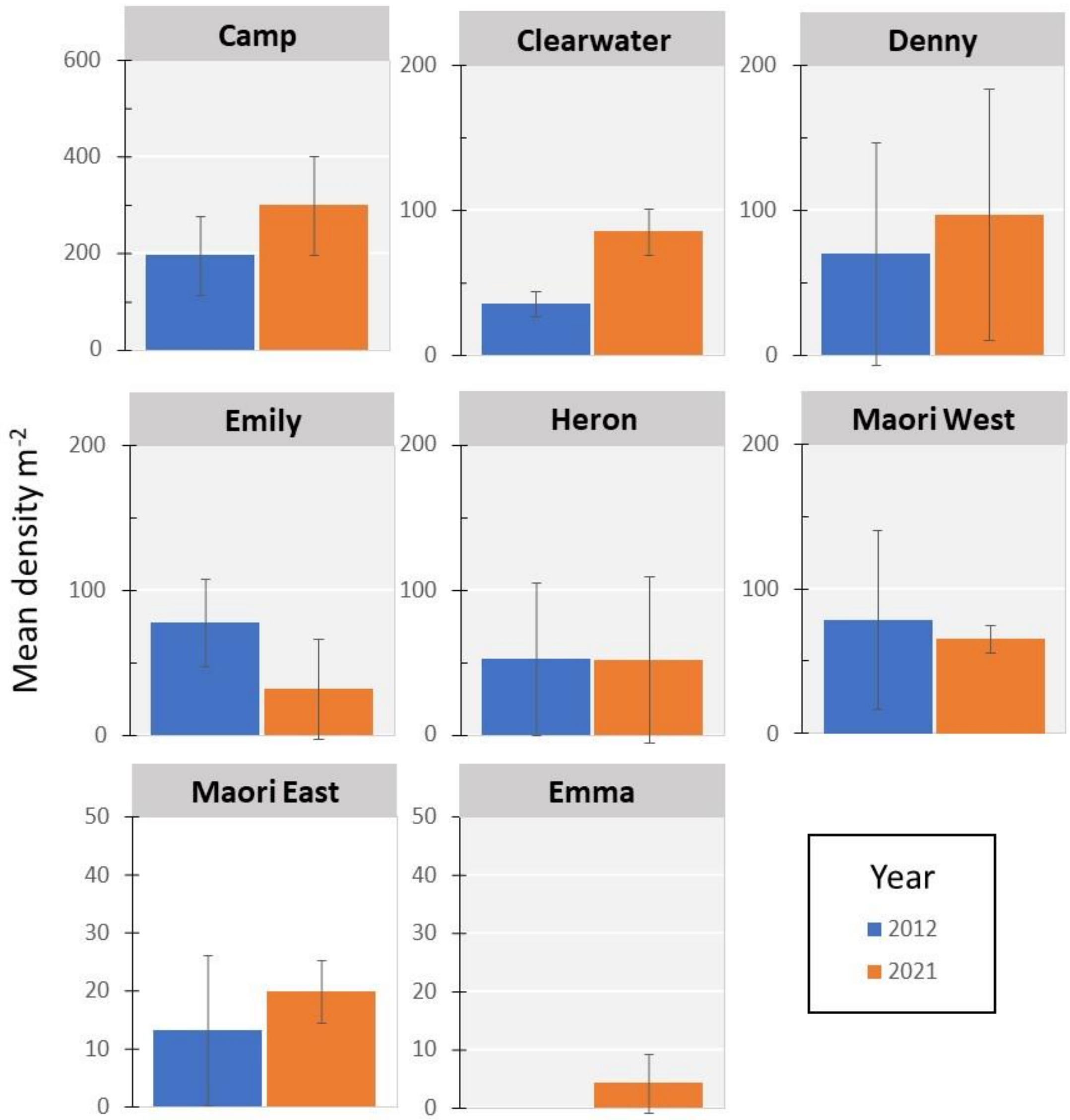


Figure 19: Kākahi average densities (per m², ±1 SD) for all quadrats sampled in the Ō Tū Wharekai lakes in 2012 and 2021. Note scale varies between lakes.

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.

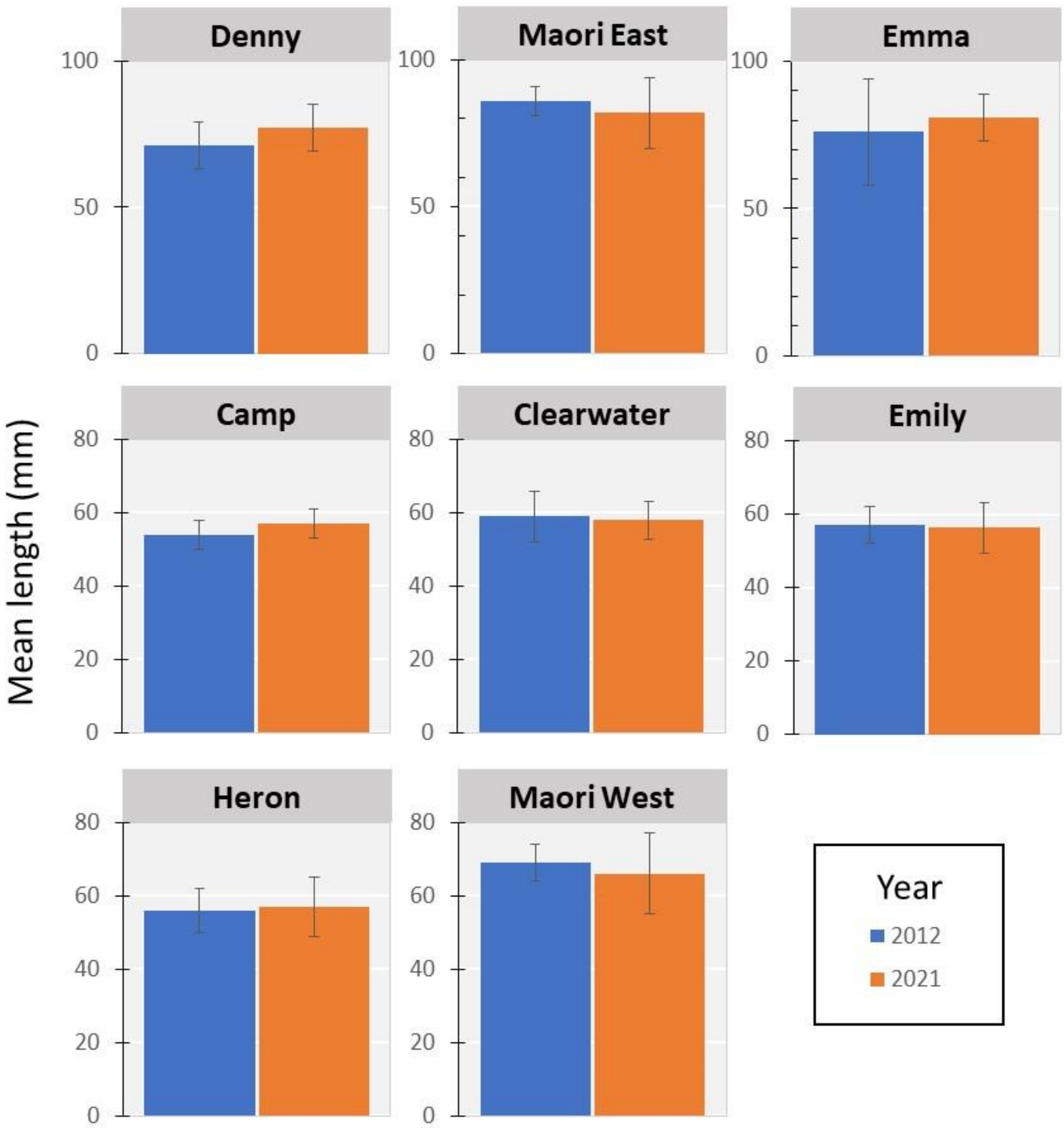


Figure 20: Kākahi average lengths (mm) for all quadrats sampled in the Ō Tū Wharekai lakes in 2012 and 2021. Note scale is either 100 mm (top row) or 80 mm.

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).

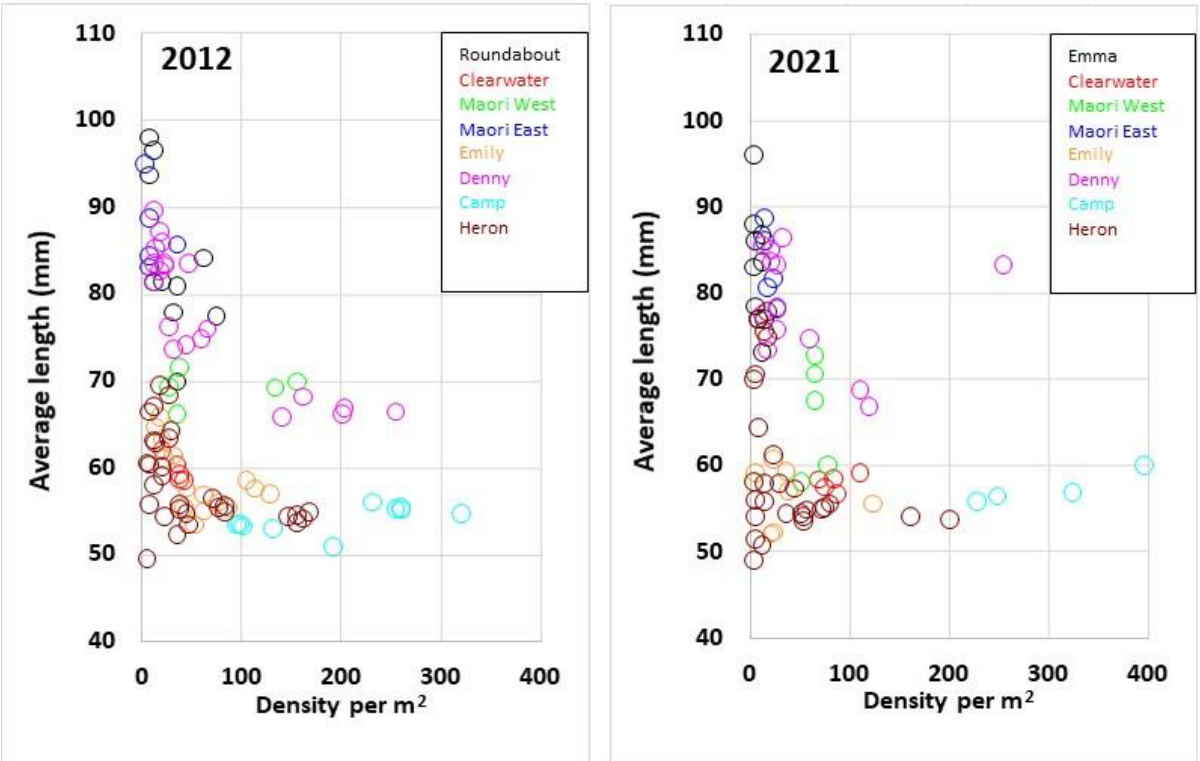


Figure 21: Average length of kākahi (mm) for each quadrat plotted against density per m^2. See legend for lake symbol. Note Lake Roundabout was sampled in 2012 and Lake Emma in 2021 (black markers). Not all quadrats were assessed for kākahi length in Lakes Camp, Denny, Emily and Heron in 2021 and so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

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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 (>1m^2) 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

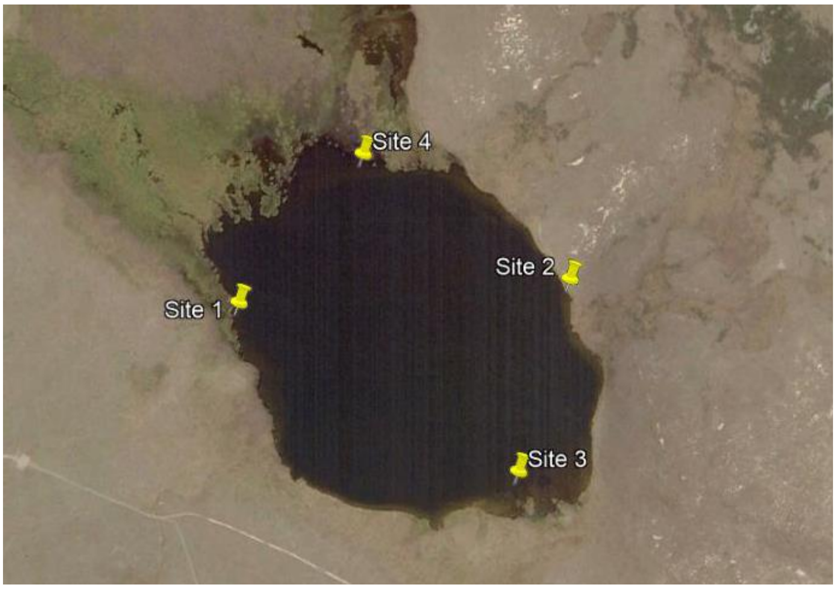
Appendix A Figure 3: Lake Denny showing the shoreline location of four survey sites.

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 (>1m²) 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*

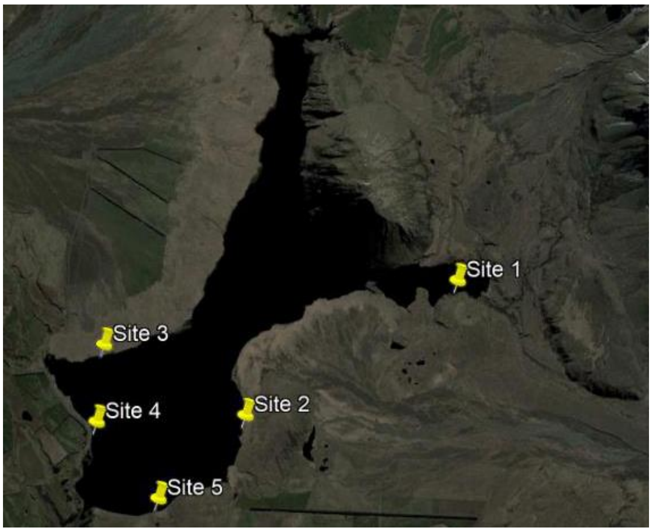
*Kākahi observed at <1 m².

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

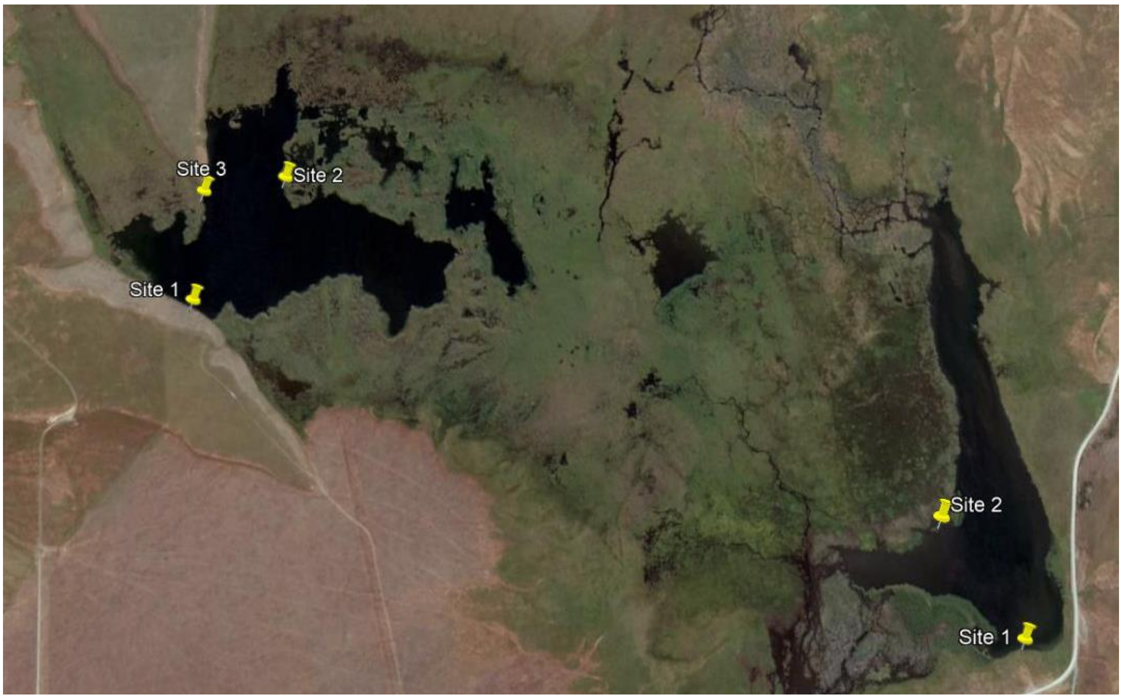


Appendix A Figure 7: **Lake Heron showing the shoreline location of five survey sites.**

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

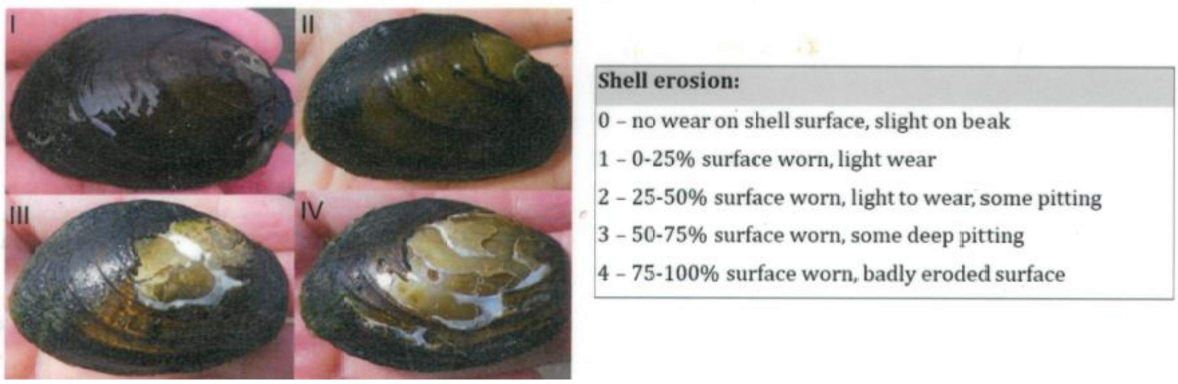


Appendix A Figure 8: **The Māori Lakes showing the shoreline location of survey sites.**

Appendix B Summary tables for other kākahi characteristics

Shell erosion

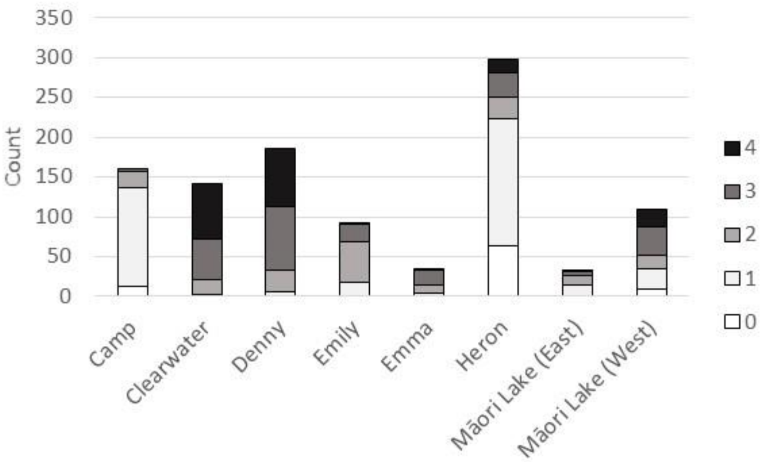
Shells were scored for erosion on a scale of 0 to 4 (Appendix B Figure 9).



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.