Kākahi (Freshwater Mussel) Monitoring in Christchurch City

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EXECUTIVE SUMMARY

The native freshwater mussel *Echyridella menziesii* (kākahi) is an At Risk species that is also valued mahinga kai. This report presents new kākahi survey data and updates kākahi distribution records for the Christchurch district. The report also describes results of rapid and quantitative monitoring methods and makes recommendations for long term monitoring of kākahi in the district. Lastly, the report describes results of follow-up surveys, where kākahi had been relocated prior to dredging and bank works in Cashmere Stream, Pūharakekenui / Styx River, and Ōpāwaho / Heathcote River.

Rapid kākahi surveys have now been completed in every major catchment in Christchurch. Kākahi have been found to be abundant in the Pūharakekenui, Waikākāriki / Horseshoe Lake, and Cashmere Stream. While kākahi have been recorded in the Ōtākaro / Avon River and the Ōpāwaho, they are patchy and sparse. Despite considerable search efforts, kākahi have not been recorded in the Ōtūkaikino catchment, nor in the Huritini / Halswell River, within the Christchurch district.

Quantitative surveys revealed a sparse kākahi population in the Ōtākaro, averaging 0.08 kākahi per m², compared with 17.51 kākahi per m² in Cashmere Stream. Both populations were extremely patchy in their distribution, which explained the high levels of error around previous density estimates in Cashmere Stream. Through simulations of varying sample sizes using 0.25 m² quadrats, it was estimated that approximately 200 quadrats must be sampled to detect a 30% population change in the Cashmere Stream population. This level of sampling effort was estimated to take 40 person-hours in the field.

Follow-up surveys of relocated kākahi revealed recolonisation of impacted sites is slow and may be hindered by habitat modifications associated with construction or dredging activities. Survivorship rates of relocated kākahi are unclear, however, circumstantial evidence suggests low survivorship of relocated kākahi, or movement of individuals away from relocation sites.

Key recommendations include: two-yearly quantitative sampling of the Cashmere Stream population; two to five-yearly rapid (timed count) sampling of the Ōtākaro population; rapid surveys to better delineate the Pūharakekenui kākahi population; rapid surveys in the Huritini catchment to confirm whether kākahi are present within the Christchurch district; continued monitoring of relocated kākahi in the Pūharakekenui; avoid kākahi relocations when possible; when relocation is unavoidable, include a robust before and after monitoring design.

1. INTRODUCTION

The native freshwater mussel *Echyridella menziesii* (kākahi) is found in a range of New Zealand freshwater environments, including lakes, rivers, and water races. Unlike the familiar marine mussel *Perna canaliculus* (kuku), kākahi do not attach themselves to the substrate. Instead, they tend to be found partially or completely submerged amongst both fine-grained and stony sediments. Kākahi are of conservation interest, due to their At Risk – Declining status (Grainger *et al.* 2018), plus they are also valued mahinga kai. However, kākahi are often not detected using standard sampling methods for invertebrates or fish, due to their partially submerged habit and a typically patchy distribution. Therefore, dedicated surveys for kākahi are required to determine their distribution and population status.

Historic and recent surveys for Christchurch City Council (CCC) indicate that kākahi are abundant in Cashmere Stream and the Styx River / Pūharakekenui, and present in lower numbers in the Heathcote River / Ōpāwaho and Avon River / Ōtākaro catchments (Burdon and McMurtrie 2009; Marshall 2018; Instream Consulting 2020a; Instream Consulting 2020b). These recent surveys included recommendations for additional surveys of kākahi, to better understand their distribution and abundance in the Christchurch district, regular monitoring of kākahi populations, and follow-up surveys of kākahi that were relocated prior to river works.

This report presents new kākahi survey data and updates kākahi distribution records for the Christchurch district. The report also describes results of quantitative monitoring methods and makes recommendations for long term monitoring of kākahi in the district. Lastly, the report describes results of follow-up surveys, where kākahi had been relocated prior to dredging and bank works in Cashmere Stream, Pūharakekenui, and Ōpāwaho.

2. METHODS

Three survey methods were employed in the current study, with each tailored to addressing specific objectives. These methods included rapid surveys, quantitative surveys, and relocation follow-up surveys. A total of 34 rapid surveys were carried in the Ōtūkaikino, Ōpāwaho, and Halswell / Huritini catchments, between 26 November 2020 and 31 March 2021, to delineate kākahi populations and to identify potential long-term monitoring sites. Two quantitative surveys were carried out in the Ōtākaro and Cashmere Stream on 14–15 April 2021 to better describe kākahi populations and gain insights on monitoring requirements. Finally, two follow-up surveys were carried out in Cashmere Stream and the Ōpāwaho on 6 April 2021 to determine the fate of kākahi that had previously been relocated prior to dredging or construction activities. Additional follow-up surveys carried out by NIWA divers during May 2018, May 2019, and April–May 2021 in the Pūharakekenui are reported on to provide the first published follow-up analysis since the baseline survey in November 2017 (Marshall 2018).

Each survey method is described in detail below, with locations presented in Figure 1.

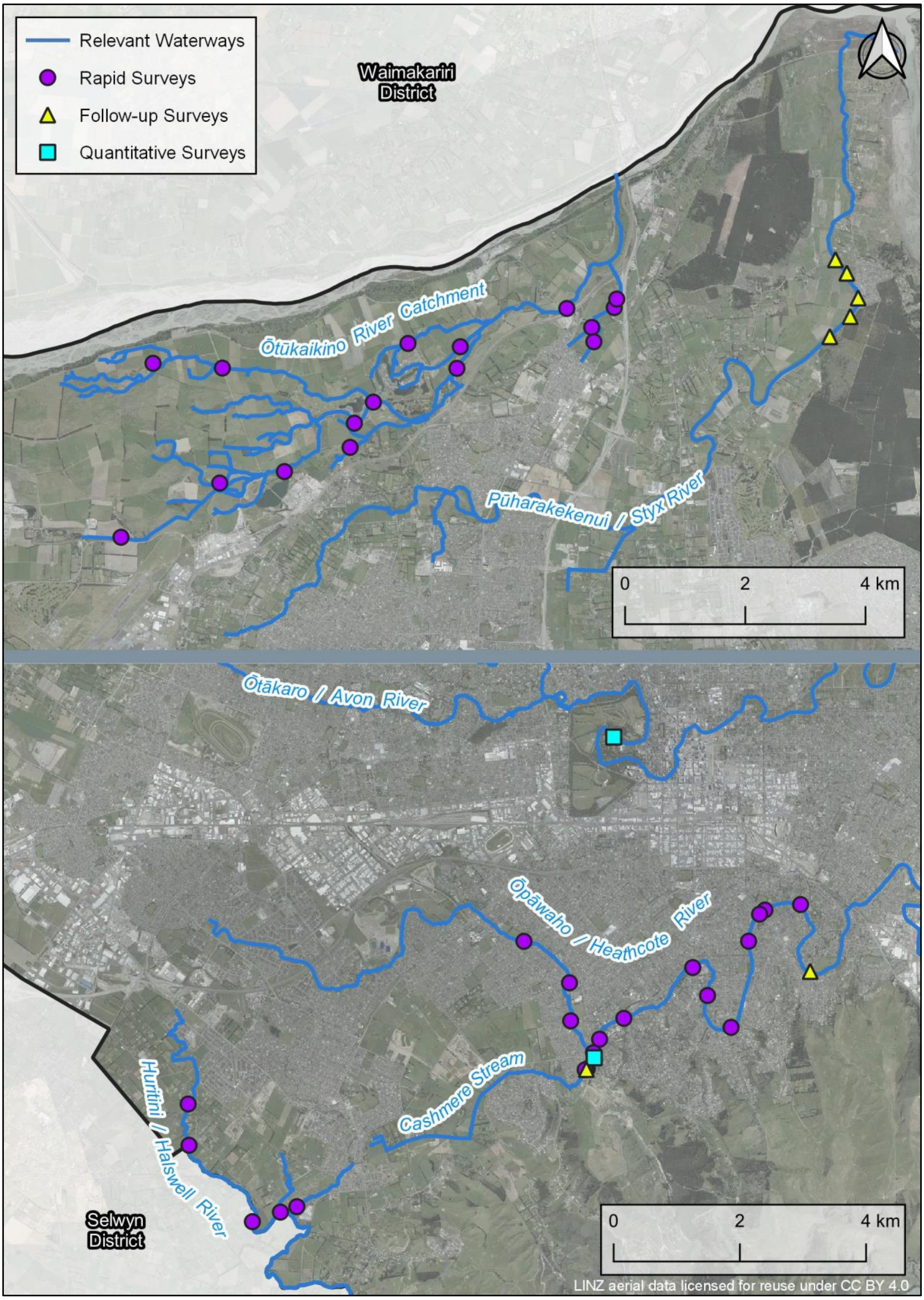


Figure 1: Locations and methods for all surveys completed during the current survey round, as well as the Pūharakekenui follow-up survey locations.

2.1. Rapid Surveys

Rapid surveys were carried out at a total of 34 locations across the Ōtūkaikino, Ōpāwaho, and Huritini / Halswell River catchments within the Christchurch district (Figure 1). Sites were selected to provide good spatial coverage by supplementing previous CCC surveys and including catchments where kākahi have been previously reported. Beyond this, sites were selected to be located near CCC ecological monitoring sites where possible, and accessibility was also considered.

Survey methodology was adapted from Instream Consulting (2020a). Briefly, this involved two surveyors carrying out a 15-minute timed search (i.e., 30 minutes total effort), visually observing the full width of stream bed through bathyscopes, moving in an upstream direction. Surveys were carried out at baseflow and, when possible, shortly after macrophyte removal, to enhance search efficiency. Any factors identified by surveyors that may impact search efficiency were recorded. Once a kākahi was located, the position was recorded via GPS, and the elapsed search time was noted. Unlike the previous rapid surveys completed for CCC (Instream Consulting 2020a), the searches then resumed for any remaining time. All kākahi observed over the 15-minute search were counted. Using this method resulted in a semi-quantitative measure of kākahi abundance (i.e., number of kākahi per 30-minute search), rather than just presence/absence data. All rapid kākahi surveys were accompanied by a rapid habitat assessment (Clapcott 2015).

Results of rapid kākahi surveys were collated with existing survey data in MS Excel to create a database of the known distribution of kākahi in Christchurch city, which was then mapped. All existing survey data was from the year 2019 or later.

2.2. Quantitative Surveys

Quantitative surveys were carried out two sites, one in the Ōtākaro at the Botanical Gardens and one in Cashmere Stream at Worsleys Reserve (Figure 1). Sites were selected due to the previously established high kākahi densities, relative to their respective waterways (Instream Consulting 2020a). With the exception of follow-up monitoring in Pūharakekenui, quantitative sampling was not undertaken at any other locations, due to low kākahi densities. Quantitative sampling was carried out using the method of systematic sampling with multiple random starts described by Strayer & Smith (2003), and previously carried out in Cashmere Stream by Burdon and McMurtrie (2009). This method was selected as it is efficient at sampling clustered populations (Christman 2000; Strayer and Smith 2003).

Systematic sampling with multiple random starts involves surveying populations with quadrats placed at predetermined locations. Quadrats of 0.25 m^2 were selected as smaller (0.1 m^2) quadrats have been found to produce high levels or error around density estimates in Cashmere Stream (Instream Consulting 2020b). Following the methodology of Strayer and Smith (2003), the locations of the first three quadrats were selected at random from within a small starting area, using a random number generator. Each of these quadrats represents the beginning of a sampling unit called a ‘chain’. Quadrats were then sampled at 4 m intervals from the initial three quadrats, filling the entirety of the sampling area. The distance between quadrats was determined using the formula of Strayer and Smith (2003), which relates to the size of the sampling area and the number of quadrats intended to be sampled. The sampling pattern for the Cashmere Stream quantitative survey is presented as an example in Figure 2.

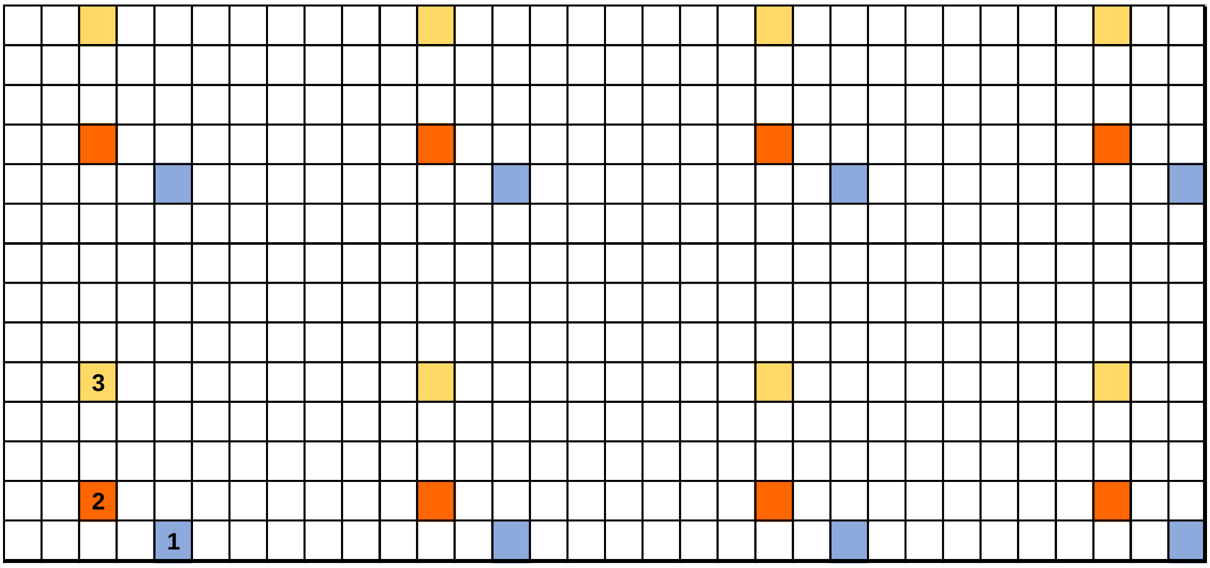


Figure 2: A subset of the systematic sampling design with multiple random starts used at the Cashmere Stream quantitative survey reach. The first three randomly placed quadrats are numbered, with colours indicating quadrats in the same chain. Each square represents 0.5 m x 0.5 m (i.e., the quadrat size) of stream bed.

Using this design, a minimum length of 100 m of waterway was surveyed at each of the locations. This involved sampling a total of 246 quadrats over 100 m in the Ōtākaro, and 156 quadrats over 102 m in Cashmere stream. Differences in the number of quadrats at each location relate to the relative widths of the waterways. The predetermined quadrat locations were found in the field by running a tape the full length of the survey area and a tape across the waterway (Figure 3).

Figure 3: Surveyors sampling quadrats at predetermined locations across the Ōtākaro (left). Quadrats were 0.25 m² with kākahi and sediments excavated into 5 mm sieves (right).

Each quadrat was sampled by collecting all kākahi observed on the bed and placing them in a 5 mm sieve (Figure 3). If the bed consisted of fines, sediment was then excavated by hand to a depth of approximately 10 cm and put through the sieve. The total number of live kākahi and dead kākahi shells was then recorded. Lengths were also recorded for all live kākahi using digital vernier callipers. After measurement, all kākahi were placed hinge down on the bed at the quadrat location in which they were found.

Habitat measurements were taken over each of the quantitative sampling reaches, including:

- Wetted width: 10 equidistant transects.
- Depth and velocity: five points across the waterway at five equidistant transects. Velocity was measured at 40 % of the water depth, mid-channel using a Hach FH950 velocity meter.
- Percent shade (using a spherical densiometer), macrophyte cover, and composition, and fine sediment cover at five equidistant transects.
- Substrate composition: 10 particles measured at each of five equidistant transects, giving a total of 50 particles.

A rapid kākahi survey was also carried out over each of the quantitative sampling reaches to allow for comparison between the methods.

2.3. Kākahi Relocation Follow-up Surveys

Follow-up surveys were carried out during the current survey round in Cashmere Stream and the Ōpāwaho (Figure 1). Both surveys took place on 6 April 2021. The Cashmere Stream follow-up survey was carried on out to investigate the fate of 1,345 kākahi that were moved in April 2019 to allow for the renewal of 18 m of retaining wall along the bank of Cashmere Stream. The Ōpāwaho follow-up survey was carried out to investigate the fate of 36 kākahi that were relocated from approximately 300 m of waterway prior to dredging in July 2020. In both instances, the surveys involved timed counts surveys over the sites where the kākahi were originally salvaged from, and where they were relocated to. Searches were carried out by a single person, using a combination of an underwater viewer and a dive mask. All kākahi were counted and survey time recorded. Baseline surveys were not completed prior to kākahi relocation in Cashmere Stream, presumably because the high number of kākahi encountered was unexpected. Baseline data was also not collected prior to the Ōpāwaho relocation as live kākahi had not previously been recorded in the river. Therefore, only the number of relocated kākahi were available for follow-up comparison.

In addition to the follow-up surveys described above, this report also presents the results of follow-up surveys in the Pūharakekenui. These surveys follow a baseline study that was completed in 2017, prior to dredging of the lower Pūharakekenui (Marshall 2018). Follow-up surveys were periodically carried out by NIWA divers at five locations, including: two impact sites, where kākahi were salvaged prior to dredging; one unimpacted control site, located upstream of the dredging; one downstream site, located downstream of dredging but not directly impacted by activities; and one relocation site, where salvaged kākahi were shifted to. Follow-up surveys were carried out at intervals 0.5-, 1.5-, and 3.5-years post-dredging. All sites had been previously surveyed during the baseline, except for the relocation site. Surveys involved either three or six transects, each containing seven quadrats measuring 0.2 m x 0.2 m (0.04 m^2) for the baseline survey and 0.25 m x 0.25 m (0.0625 m^2) for the follow-up surveys. Kākahi counts were converted to kākahi per m^2 prior to plotting, to account for inconsistencies in the sampling effort among sites and years. In-depth analysis of these data is beyond the scope of the current report. More detailed analysis will be included in a scientific paper that is currently being written.

2.4. Mapping and Data Analysis

Kākahi rapid survey data from the current study was collated with existing rapid survey data to create a database of known kākahi locations. The known distribution of kākahi in Christchurch city was then mapped using QGIS (QGIS Development Team 2016). All other analysis was carried out, and with relevant figures produced, in R (R Core Team 2013).

Kākahi density estimates were calculated for the quantitative sampling reaches, with 90% confidence intervals generated using standard error bootstrapping, simulating 100,000 samples (Efron 1979). As freshwater mussel populations are often naturally patchy, sample distributions are intrinsically non-normal. Bootstrapping provides a method of confidence interval calculation that does not make assumptions about the underlying distribution of the data, and has been widely used in various forms for the estimation of population level statistics in studies of freshwater mussels, as well as other patchy taxa (Smith and van Belle 1984; McCarthy and Snowden 1985; Christman 2000; Christman and Pontius 2000; Sun *et al.* 2019).

To allow for visual assessment of the distribution of kākahi at the quantitative sites, spatial interpolation was used (Akima R Package; Akima 1978). This method allows for the prediction of values (i.e., kākahi density), among irregularly distributed points with known values (i.e., sampled quadrats). Using these values, complete heatmaps of the quantitative survey reaches were produced.

The relationship between sampling effort and precision of density estimates was assessed following a bootstrap approach. Briefly, this involved simulating various sample sizes by randomly selecting quadrats from our real data, with replacement (i.e., previously selected quadrats were not removed from the pool of potential quadrats for future selection). The number of quadrats (n) in each sample ranged between 10–200, increasing in intervals of 10 (i.e., n = 10, 20, …, 200). Each n sized sample was simulated 1,000 times, for which the mean and standard error was calculated. The ratio of standard error to mean was used as the measure of precision. These simulated values were then plotted to demonstrate the relationship between sampling effort and precision of density estimates.

We used the precision estimates to determine how large a change in kākahi density would need to be, to be identified as statistically significant, given the variance of the sample population. For instance, a 30% reduction in kākahi density between years would not be detected if the standard error bars around each year's density estimates overlap (Cumming *et al.* 2007). Therefore, if the standard error is greater than 15% of the mean in both years, a 30% decline is unlikely to be detected, as 15% below the mean in year one would be approximately equal to 15% above the mean in year two (i.e., overlapping standard error bars). Thus, the approximate statistical precision required to detect a 30% decline in kākahi density is achieved when the standard error is less than 15% of the mean kākahi density.

3. RESULTS AND DISCUSSION

3.1. Rapid Surveys

A total of 117 rapid kākahi surveys in Christchurch city were collated, including 34 surveys from the current sampling round. Of these surveys, 44 recorded the presence of kākahi (Table 1, Figure 4). Surveys have now been carried out in every major catchment in the city, including a range of habitats. Rapid habitat assessments of the surveyed sites generally produced low to moderate habitat scores, with a median score of 50 out of 100 (Figure 5). The exception being three sites in the Ōtūkaikino catchment near the Groynes, which scored 72–86. Surveyed sites scored especially low in the categories of Deposited Sediment (due to predominantly fine sediments), Hydraulic Heterogeneity (due to a dominance of uniform run habitat), and Invertebrate Habitat Abundance (due to a lack of diverse substrates for colonisation, Figure 5). Separating the rapid habitat assessments into sites with and sites without kākahi revealed few clear trends, with most sites being comparable over the habitat assessment categories (Figure 5). Kākahi were found on average more often at sites with lower deposited sediment scores (i.e., higher deposited sediment cover), however, a permutation test revealed this pattern was not statistically significant ($z = 1.83$, $p = 0.07$). Other habitat differences were unsubstantial, or unlikely to be biologically meaningful.

Table 1: The number of surveyed locations and the number of locations where kākahi have been recorded in Christchurch city, by catchment. These data are the collation of rapid surveys in the current study with existing rapid survey data. Cashmere Stream has been separated from the greater Ōpāwaho catchment to provide better understanding of the sampling effort over each waterway. Distances were totalled for surveys with search length data available, thus Distance Searched is a minimum for each catchment.

Catchment	Survey Locations (Current)	Survey Locations (Existing)	Total Locations	Locations with Kākahi	Distance Searched (km)
Ōtūkaikino River	16	3	19	0	3.72
Pūharakekenui	0	13	13	7	0.90
Ōtākaro	0	41	41	21	4.03
Ōpāwaho	13	5	18	6	2.43
Cashmere Stream	0	20	20	10	0.88[1]
Huritini	5	0	5	0	1.41
Totals	**34**	**82**	**116**	**44**	**11.59**

Notes: [1] Under the old survey methodology, rapid surveys were completed as soon as the first kākahi was located. As a result, despite Instream completing 20 surveys in Cashmere Stream, the distance searched is relatively low as kākahi were usually located within a short distance.

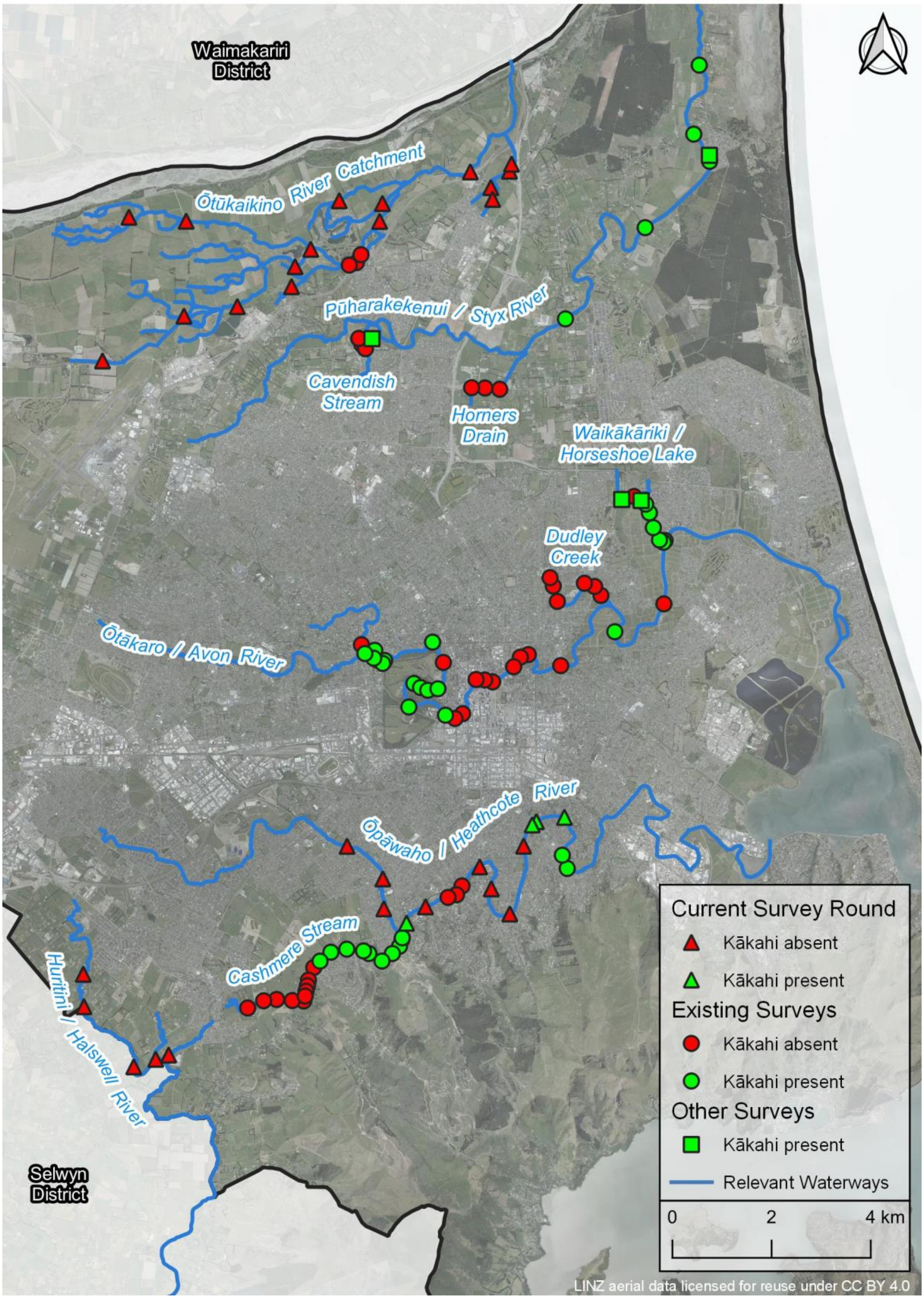


Figure 4: The locations and results of dedicated rapid kākahi surveys completed to date in Christchurch city. Surveys include those completed by Instream that have not previously been reported on (Current Survey Round), those completed by Instream that have been previously reported (Existing Surveys), and selected other surveys not completed by Instream (Other Surveys). Some points have been slightly offset for visibility.

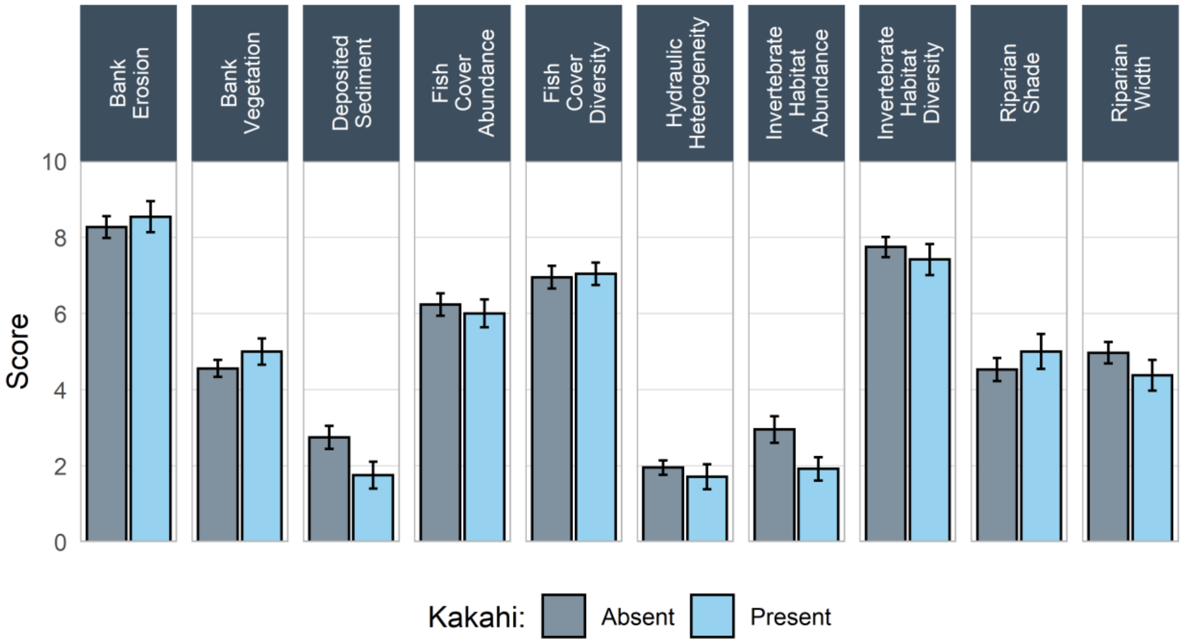


Figure 5: Results of the rapid habitat assessments categorised by sites where kākahi were either present or absent. Data includes all CCC rapid surveys in Christchurch city to date (Figure 5), for which associated rapid habitat assessments were available. Data are means (±1 SE, absent n = 63, present n = 24).

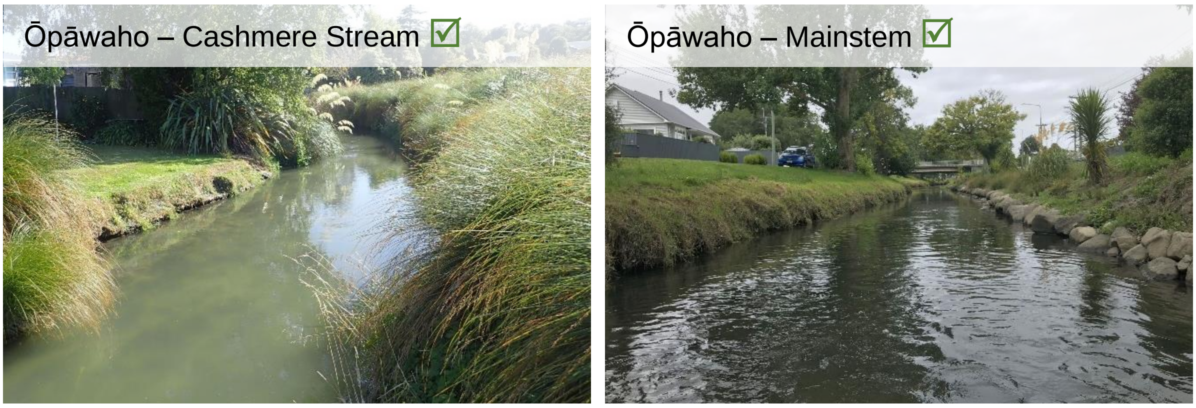
The kākahi population in the Pūharakekenui is the most widespread and dense known population in Christchurch city. Kākahi have been recorded in the mainstem at several locations, spanning from Marshland Road to Earlham Street (Figure 4). However, there have been no surveys in the mainstem outside of these reaches, and the population likely continues in both upstream and downstream directions. Few tributaries of the Pūharakekenui have been surveyed, however, kākahi were reported in Cavendish Stream during a 2019 University of Canterbury survey (Channell Thoms, Pers. Comm., August 2021). While recent surveys for CCC in Cavendish Stream did not locate any kākahi, high macrophyte cover was recorded as reducing search efficiency (Instream Consulting 2020a). Similarly, the recent surveys in Horners Drain also recorded no kākahi but reported high macrophyte cover. Kākahi have been reported in Horners Drain by CCC maintenance contractors and may have been missed during dedicated surveys (Instream Consulting 2020a). Further rapid surveys are required to delineate the extent of the Pūharakekenui mainstem kākahi population, and to identify populations in other associated tributaries. Representative photographs of the Pūharakekenui mainstem and Cavendish Stream are presented in Figure 6.

Figure 6: Representative photographs of some surveyed reaches in the Pūharakekenui and Ōtākaro catchments. Sites with kākahi are indicated by a green tick. The Cavendish Stream photograph was taken during the CCC 2020 survey round, when no kākahi were detected, but kākahi have been reported at a nearby location, during other surveys (Channell Thoms, Pers. Comm., August 2021).

In the Ōtākaro, kākahi have been located as far upstream as Mona Vale, and as far downstream as the Waikākāriki / Horseshoe Lake outlet. Kākahi distributions have been reported as patchy and sparse through these sections of the Ōtākaro mainstem, with the exception of the reaches adjacent to the Botanical Gardens, where kākahi have been reported as common (Figure 4; Instream Consulting 2020a). The Botanical Gardens reach was subject to a quantitative survey in the current survey round and is discussed further in Section 3.2. Kākahi are absent or scarce in the reaches spanning from the Antigua Boatsheds to the Waikākāriki outlet. A substantial population has been reported within the body of Waikākāriki, which has been discussed in previous reports for CCC (Instream Consulting 2020a; Instream Consulting 2021). This population extent includes lower sections of No 2 Drain and Old No 2 Drain, extending through Waikākāriki to the outlet culvert. However, kākahi appear to be absent or in low densities in the northern most sections of Waikākāriki.

Live kākahi were first reported in the Ōpāwaho mainstem during 2020, with surveys recording sparse numbers in the reaches adjacent to Riverlaw Terrace (Instream Consulting 2020a). This population has been further delineated by the current survey, in which kākahi were found up to, and adjacent to, Eastern Terrace (Figure 4, Figure 7). The population through this section remains sparse, with only four kākahi observed over 315 m of surveyed waterway in the current survey round. The only other location kākahi were found in the Ōpāwaho mainstem was immediately downstream of the Ōpāwaho / Cashmere Stream confluence. Kākahi were again found in low abundance over this section, with only five individuals observed over the 70 m sampling reach. However, the water was moderately turbid during the rapid survey, which was noted as reducing search efficiency. This number may therefore underrepresent the density of kākahi present at this location.

The kākahi population in Cashmere Stream (Figure 7) is one of the densest in Christchurch city, and the most well studied, being the subject of two previous quantitative studies (Burdon and McMurtrie 2009; Instream Consulting 2020b). The population extends upstream from the Ōpāwaho confluence for approximately 2 km, with the highest densities occurring in the lower reaches. This population was subject to a quantitative survey in the current survey round and is discussed in detail in Section 3.2.


Ōpāwaho – Cashmere Stream ☑

Ōpāwaho – Mainstem ☑

Figure 7: Representative photographs of some surveyed reaches in the Ōpāwaho catchment. Sites with kākahi are indicated by the green tick.

The Ōtūkaikino and Huritini catchments are the only major catchments in Christchurch city that have been subject to targeted kākahi surveys without detecting kākahi. A total of 19 sites have been searched in the Ōtūkaikino River catchment, covering over 3.7 km of waterway, and including a wide variety of stream habitats (Table 1, Figure 4, Figure 8). While there is a single New Zealand Freshwater Fish Database (NZFFD) record of kākahi located in the Groynes (NZFFD card: 19408), the extensive and unsuccessful sampling efforts to date indicate that kākahi are either absent from the catchment or are present in small, isolated patches. Kākahi are reported to be frequently found in the Huritini mainstem during weed clearance activities. However, these reports are largely centred around the lower reaches near Motukarara, in the Selwyn district (Myke Hyett, Pers. Comm., March 2021). To our knowledge, there have been no reports of kākahi in the Huritini catchment within the Christchurch district. While the results of the rapid surveys indicate that kākahi are likely not present in the upper reaches of the Huritini catchment, a 5.8 km length spanning upstream from the Christchurch district border was not searched during the current survey round. This was due to a combination of water depths exceeding requirements for wading surveys and high macrophyte cover. Further surveys following macrophyte removal are required to determine if there are kākahi in the Huritini mainstem, within the Christchurch district.

The emergence of environmental DNA (eDNA) technology provides another tool that may be useful for detecting small or patchy populations of kākahi in the future. Briefly, this technology identifies the presence of a species in a waterway through DNA analysis of a water sample.

The DNA analysis identifies the concentration of DNA markers, which are released by an organism into the environment via natural processes, which for kākahi may include DNA from tissue, shell material, faeces, and sperm or glochidia (Ferris 2020). Such technologies are still under development, however, the ability to detect kākahi via eDNA (including *E. menziesi*) has already been demonstrated (Ferris 2020). While this method may be useful in identifying the presence of kākahi in locations such as the Ōtukaikino catchment or the upper Huritini, negative results would not definitively exclude kākahi from the systems, as kākahi eDNA levels may be below detectable limits. The relationship between kākahi densities, eDNA concentrations, and detectable downstream distance for water samples is not currently known. Furthermore, extinct populations may provide false positives, through the release of eDNA from dead shells (Stoeckle *et al.* 2016).

Figure 8: Representative photographs from some surveyed reaches in the Ōtūkaikino and Huritini catchments. No kākahi have been recorded within the Christchurch district during recent surveys in these catchments.

3.2. Quantitative Surveys

The quantitative survey reaches in the Ōtākaro and Cashmere Stream were located in council reserves and parks, with natural vegetated banks (Figure 9). The canopy at the Ōtākaro site was much more open, averaging only 30% channel shading, compared with 79% shade recorded at the Cashmere Stream site (Table 2). Both survey reaches were wide, shallow, and straight, with slow water velocities. It was noted by surveyors that Cashmere Stream appeared to be in a state of very low flow at the time of the survey. Macrophytes were more abundant at the Ōtākaro site, averaging 25% cover, compared to <1% at the Cashmere Stream site. The most notable difference between the sites was the dominant bed sediments. The Ōtākaro was stony, consisting mostly of gravels and averaging 15% fine sediment cover (<2 mm diameter), whereas the bed of Cashmere Stream consisted almost entirely of fine sediment.

Figure 9: The quantitative sampling reaches in the Ōtākaro (left) and Cashmere Stream (right).

Table 2: Select habitat parameters for each of the quantitative sampling sites. Data are site means.

Site	Shade (%)	Width (m)	Depth (m)	Velocity (m/s)	Substrate Size (mm)
Ōtākaro	30	12.6	0.19	0.20	22
Cashmere Stream	79	7.5	0.19	0.08	1

A total of 683 live kākahi were recorded at the Cashmere Stream quantitative site and five were recorded at the Ōtākaro quantitative site (Table 3). This equated to an average of 17.5 kākahi per m² at the Cashmere Stream site, and <0.1 kākahi per m² at the Ōtākaro site. The density estimate in Cashmere Stream is higher than the 12.4 kākahi per m² recently reported for a nearby site, however, given the very high level of error around the previous estimate, this difference is unlikely to be biologically meaningful (Site 1; Instream Consulting 2020b). The 683 kākahi recorded at the Cashmere Stream site, from surveying just 39 m² of stream bed, also indicates that the Cashmere Stream population is likely well in excess of previous population estimates. A 2007 survey of the Cashmere Stream population estimated the total number of kākahi in the waterway to be just 3,500, although there was, again, a high level of error around this estimate (Burdon and McMurtrie 2009).

Table 3: The total number of kākahi recorded, respective sampling efforts, and estimated kākahi densities at each of the quantitative survey sites. Confidence Intervals (C.I. = 90%) around density estimates included. Note that this interval is likely to be highly inaccurate at the Ōtākaro site, due to the low number of kākahi found.

Site	Kākahi Sampled	Number of Quadrats	Total Area Sampled (m²)	Kākahi Density per m² (90% C.I.)
Ōtākaro	5	246	61.5	0.08 (0.00–0.17)
Cashmere Stream	683	156	39.0	17.51 (12.34–23.44)

Kākahi found at the Ōtākaro site were on average 80.5 mm long, which is larger than those found at the Cashmere Stream site, where they averaged 74.9 mm (Table 4, Figure 10). However, given the low number of kākahi measured from the Ōtākaro site, there is little that can be concluded with confidence about their size distribution. Kākahi sizes at the Cashmere Stream site were comparable with the results from a nearby site from the 2020 survey, where 31 kākahi were measured, averaging 70.5 mm, with a range of 46.4–90.7 mm (Site 1; Instream Consulting 2020b). While the range of sizes was larger in the current survey round, this likely reflects the much greater sample size.

Table 4: Summary statistics of kākahi lengths recorded at each of the quantitative sites.

Site	Mean (mm)	Median (mm)	Minimum (mm)	Maximum (mm)	Standard Deviation (mm)
Ōtākaro	80.5	81.9	67.0	91.7	11.0
Cashmere Stream	74.9	74.1	13.8	103.8	11.62

Figure 10: Examples of the kākahi size ranges recorded during the quantitative surveys, including the smallest kākahi (left) and a more typical size (right). Both individuals are from Cashmere Stream.

The distribution of size classes for the kākahi recorded in the Cashmere Stream quantitative survey was slightly bimodal (Figure 11), consistent with previous surveys (Burdon and McMurtrie 2009; Instream Consulting 2020b). Bimodality of the size structure in this population may indicate recruitment pulses, potentially due to natural variability of favourable reproductive conditions or disturbance events (Payne and Miller 2000). Alternatively, sexual dimorphism in shell length (i.e., differences in mature sizes between males and females) has been suggested as a mechanism that may create bimodal size structures in studies of freshwater mussels overseas (Payne and Miller 2000). While there is little information available on physiological differences among sexes for kākahi, Roper and Hickey (1994) described size structures of kākahi from seven populations, finding size classes followed approximately normal distributions. This would seem to indicate that the mechanism driving the bimodal size structure of the population in Cashmere Stream is system specific, unrelated to differences in size between sexes, and possibly a reflection of past environmental conditions. Therefore, the two peaks in the size distribution of kākahi in Cashmere Stream may represent two periods of greater than normal reproductive conditions, or alternatively, the trough between the peaks could reflect a disturbance (or period of disturbances) among normal reproductive conditions.

Following the kākahi size-age relationship of Ogilvie (1993), the two shell length peaks correspond to kākahi ages of approximately 18 and 30 years. This would seem to indicate a gap in recruitment during 1991–2003. However, preliminary results of a study of the kākahi population in Cashmere Stream indicates that growth rates in this waterway may well exceed the rates predicted by the Ogilvie (1993) formula (Channell Thoms, Pers. Comm., April 2020). Therefore, this recruitment gap may have occurred much more recently than predicted by the Ogilvie (1993) formula. However, without a comprehensive study of kākahi growth rates within the Cashmere Stream population, it not possible to say confidently what years the peaks in the kākahi size distribution align with.

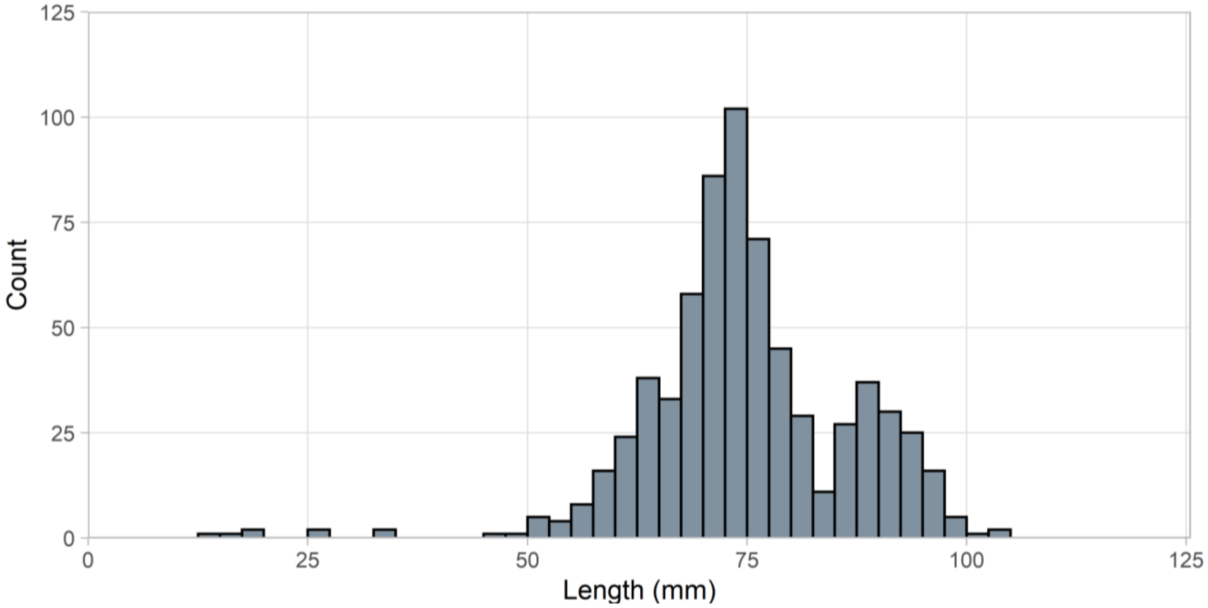


Figure 11: The distribution of kākahi sizes in Cashmere Stream.

The size structure of the Cashmere Stream population was highly skewed towards larger adults, with few individuals measuring under 50 mm in length (Figure 11). This pattern has been reported during both the previous surveys in Cashmere Stream, as well as studies of other kākahi populations around New Zealand (James 1985; Roper and Hickey 1994; Burdon and McMurtrie 2009; Instream Consulting 2020b; Moore and Clearwater 2021). Relatively low numbers of juveniles observed in the population may indicate low recruitment (or even recruitment failure), or that juveniles occur in different habitats, migrating to adult habitats as they mature (Phillips *et al.* 2007; Moore and Clearwater 2021). If similar to overseas species of freshwater mussel, juvenile kākahi habitats may include being buried deeper in the soft sediments (Cyr 2009). While small kākahi may be easily missed with visual surveys, our method of processing excavated sediments through a 5 mm sieve is likely to have a high detection rate for juvenile kākahi, if they were relatively abundant at the depths we excavated to (c. 10 cm).Given that kākahi populations are declining nationally, kākahi monitoring must be sufficiently accurate and precise to detect population changes. Creating a sampling design that reduces error around estimates of kākahi density is integral to this, as sampling error affects our ability to detect a given effect size (i.e., subtle population changes may only be detected with low error). However, previous kākahi surveys in Cashmere Stream have reported large error around density estimates. This relates to the small site-wise sample sizes employed in the previous surveys and the patchy nature of the kākahi distributions.

Interpolating the kākahi data from all quadrats at each quantitative survey reach provides greater understanding of the natural local-scale patchiness of these populations (Figure 12). The five kākahi recorded at the Ōtākaro sampling reach were distributed over three discrete patches. The distribution of kākahi at the Cashmere Stream sampling reach was much more complex. The kākahi distribution was highly patchy in Cashmere Stream, with densities ranging from 0–68 kākahi per quadrat (Figure 12), equivalent to 0–272 kākahi per m². A large proportion of the sampled quadrats in Cashmere Stream did not contain any kākahi, with empty quadrats accounting for 86 out of the 156 (55%) quadrats surveyed. Patterns of aggregation were visible both across the width and length of the survey reach. Two substantial patches occurred along the length of sampled area, with one occurring at each end of the sampling reach (Figure 12). The upstream cluster coincided with a deeper scour pool. Between these two patches, kākahi were intermittent and recorded in low density. Across the channel, kākahi were substantially denser towards the centre, and no kākahi were recorded within 1.5 m or beyond 7.0 m from the true left bank. The patchiness visualised in these heatmaps explains the high levels of error reported around density estimates produced by the previous CCC surveys in Cashmere Stream, where only 2.5 m² of stream bed was sampled per site (Burdon and McMurtrie 2009; Instream Consulting 2020a). Monitoring of kākahi populations must therefore involve adequate sampling effort to account for this patchiness, reducing the error around density estimates to a level that allows for the detection of changes in density over time.

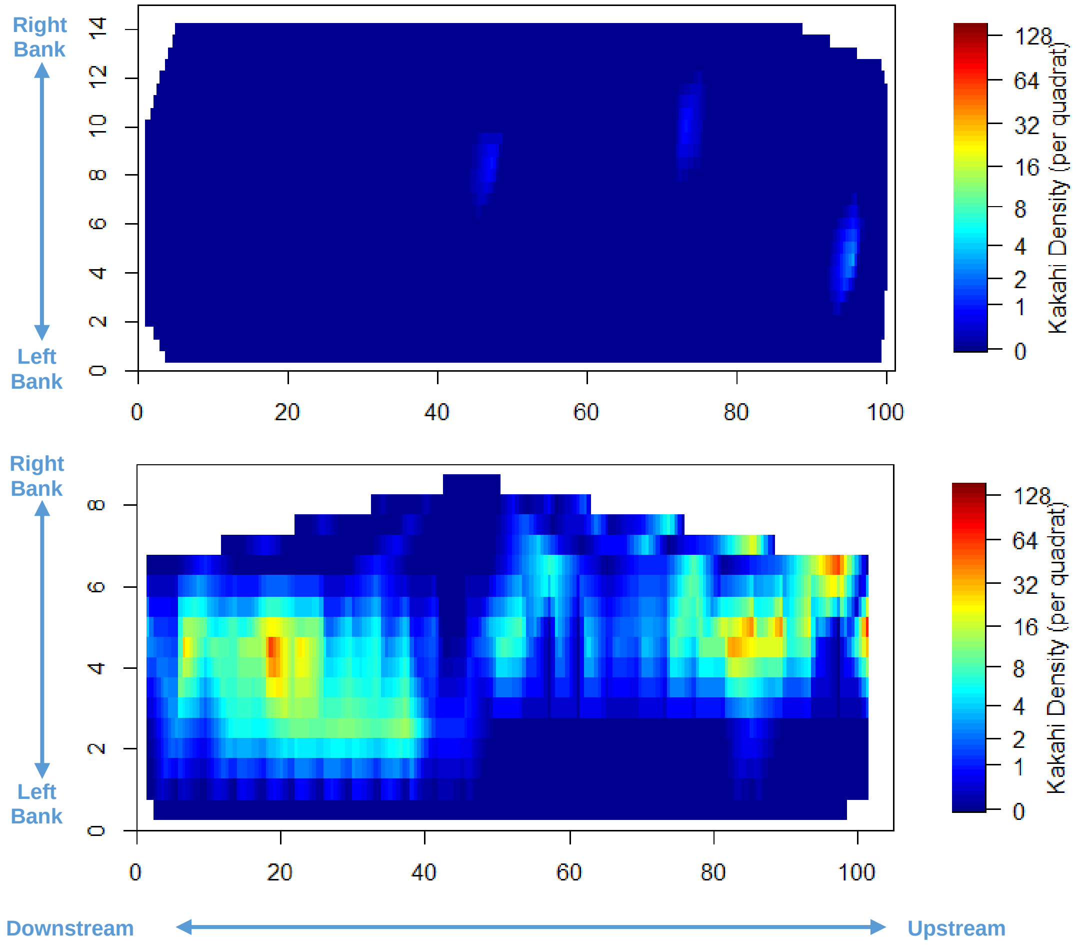


Figure 12: Heatmaps showing kākahi density distributions over the Ōtākaro (top) and Cashmere Stream (bottom) quantitative survey reaches. Axis units are meters. Note that the colour ramp is a log scale

As noted in Section 2.4, a precision value of 15% or less is needed to detect a 30% change in kākahi density, where precision is standard error divided by the mean. The value of 30% change in density is considered biologically meaningful, and 15% precision may be practical to achieve, depending on kākahi density and patchiness. Following the current sampling design, 15% precision for the Cashmere Stream kākahi density estimate is unlikely to be achieved until more than 200 quadrats are sampled (‘All Quadrats’; Figure 13). However, using the knowledge that kākahi are aggregated around the centre of the channel at the Cashmere Stream quantitative site (Figure 12), we may choose to exclude the edges from future sampling. This is consistent with recommendations from the literature to reduce sample variance (Christman 2000). Simulating this on our current data, by excluding quadrats within 1.5 m and beyond 7.0 m from the true left bank, results in precision values reducing more rapidly with increasing sample size, requiring fewer quadrats to achieve greater precision (Figure 13). When the edge quadrats were excluded and sample sizes were simulated to be 180 quadrats, 95.8% of simulations were below the 15% error to mean ratio. This increased to 99.3% of simulations below the 15% error to mean ratio when sample sizes were increased to 200. Considering this information, we recommend future quantitative surveys predetermine edge areas for exclusion with a visual survey, and then sample at least 200 quadrats, with each quadrat measuring 0.25 m^2.

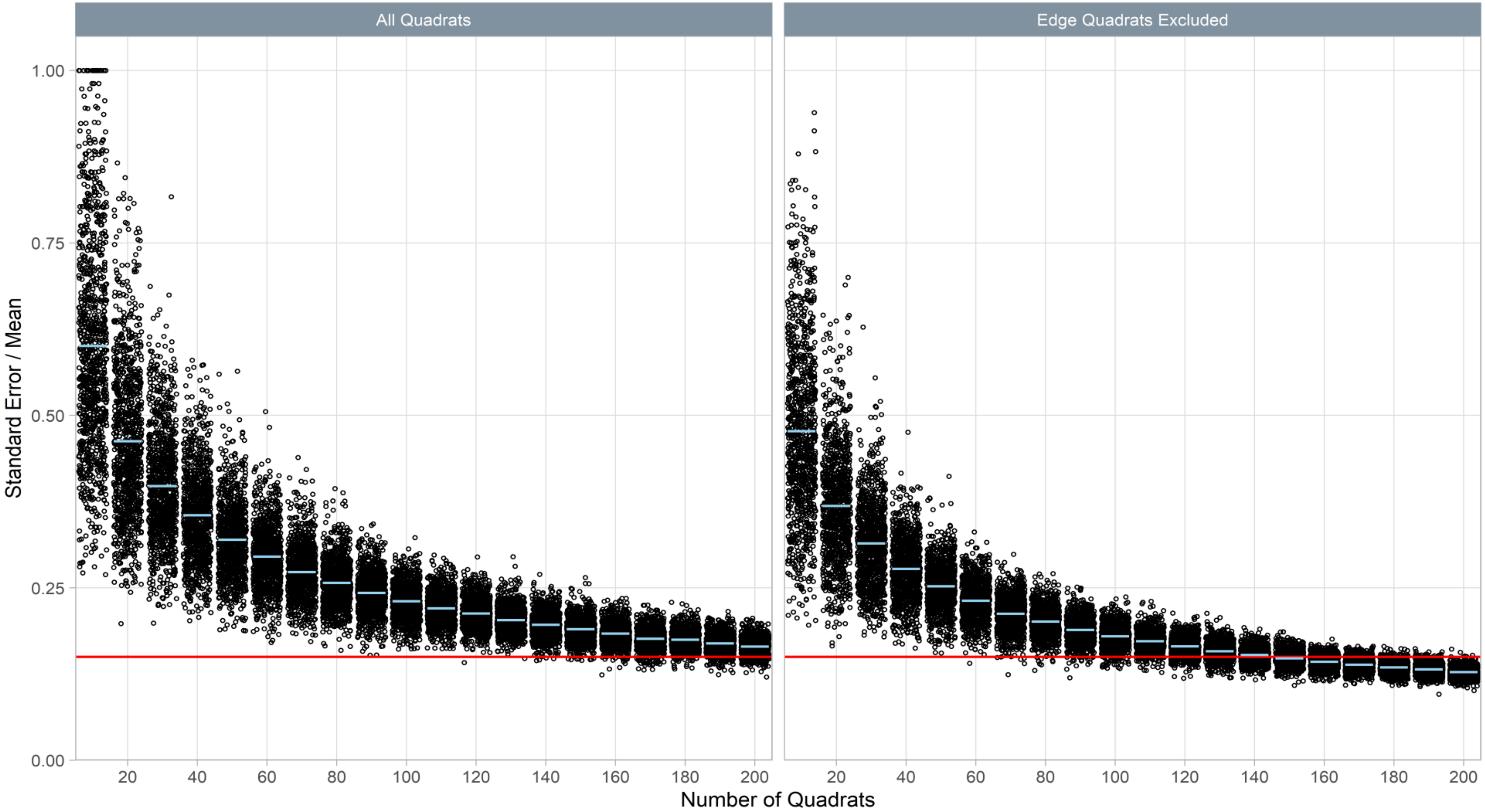


Figure 13: Simulations of precision (the ratio of the standard error to the mean), created by subsampling different numbers of quadrats (in increments of 10) from data collected at the Cashmere Stream quantitative site. For each 10 quadrat increment 1,000 samples were simulated (i.e., each data band contains 1,000 points). The mean value of each quadrat increments is indicated by the blue lines. The red line indicates a standard error to mean ratio of 0.15 (15%).

3.3. Kākahi Relocation Follow-up Surveys

Follow-up surveys found no kākahi at locations they had previously been relocated away from in the Ōpāwaho and Cashmere Stream (Table 5). This indicates that there have been very low rates of recolonisation since completion of the works. The Ōpāwaho reach in question was dredged nine months prior to our follow-up survey, and given the low kākahi densities observed prior to relocation, any recolonisation of the removal site will be very slow. However, the bank works and associated kākahi relocation in Cashmere Stream occurred 24 months prior to the follow-up survey, and the site is in a reach known to have high densities of kākahi. Lack of recolonisation at this location may therefore reflect both low recolonisation rates and negative impacts of habitat modification associated with the retaining wall renewal. During construction of the new retaining wall, ballast (small angular rocks) was installed along the foot of the wall (Figure 14). This ballast covered the existing soft substrates in which the kākahi were originally found, as well as substantially reducing the water depth. Ballast is a preferred substrate for bank protection works, because its angular structure binds the substrate together more tightly than natural, rounded stones. Unfortunately, this feature makes ballast a poor substrate for benthic species such as kākahi, as it may restrict their ability to burrow into the bed.

While kākahi were detected at the relocation site during the follow-up survey in Cashmere Stream, the numbers were low relative to the number of kākahi relocated prior to the instream works (Table 5). Previous quantitative CCC surveys upstream and downstream of this location recorded an average of 6.4 kākahi per m^2 (Instream Consulting 2020b). Given that the follow-up survey in Cashmere Stream covered an area of approximately 49 m x 5 m (245 m^2), it could be reasonably expected that there would be in the order of 1,500 kākahi in this search area. While we are aware that visual searches are appreciably less efficient than quantitative surveys, the 200 kākahi recorded at the relocation site does not appear to be largely above background levels. Given that an additional 1,345 kākahi were relocated to this site in 2019, this would seem to indicate that there was either low survivorship among relocated kākahi, or, relocated kākahi have since moved outside of the relocation area. A meta-analysis of freshwater mussel relocations in North America reported an average mortality rate of 49% in relocated mussels (Cope and Waller 1995). Cope and Waller (1995) summarised the potential stressors associated with mussel relocation that may result in mortality. Briefly, these factors related to aspects of handling (e.g., aerial exposure, air temperature, holding and transport, relative humidity, tagging, and positioning) and differences in the receiving habitat, including placement depth, as well as differences in microhabitat features. Strong monitoring designs, including baseline surveys of relocation sites, are required to determine the success of kākahi relocation projects.

Table 5: The results of the follow-up surveys in Cashmere Stream and the Ōpāwaho. The number of kākahi relocated during the original salvage is provided for comparison against the kākahi found in the follow-up survey. The number of kākahi shifted from the Removal Site to the Relocation Site is indicated in the Kākahi Relocated column. No baseline surveys of either relocation site were carried out.

Site	Kākahi Relocated	Kākahi Recorded During Follow-up	Search Time (minutes)
Cashmere Stream			
Removal Site	-	0	8
Relocation Site	1,345	200	30
Ōpāwaho			
Removal Site	-	0	33
Relocation Site	36	0	32

Figure 14: The Cashmere Stream site that kākahi were relocated from, including the new retaining wall (left) and the associated ballast (right).

Monitoring of kākahi within the dredging reaches of the Pūharakekenui revealed strong impacts of kākahi relocation and dredging (Figure 15). Sampling six months after dredging and relocation, kākahi densities at both impact locations were reduced on average to 9% of their pre-dredging levels. Recovery was slow at these locations, with the latest survey, 3.5 years after dredging, recording densities averaging 18% of pre-dredging levels. At the survey location downstream of dredging, densities have remained stable over the survey period, indicating that there were no impacts of sedimentation on kākahi densities downstream of the dredging activities. However, sublethal effects, such as reductions in fecundity as a response to increases in total suspended sediment (Gascho Landis *et al.* 2013), are unlikely to be detected in this survey. Densities at the relocation site showed no clear trend, and without baseline data, it is difficult to determine the survival rate of the relocated kākahi. However, densities at the relocation site were similar to the upstream control and downstream sites over all surveys, despite the addition of 17,810 relocated kākahi, which may indicate low survivorship or movement of relocated kākahi out of the relocation area. A notable increase in kākahi density at the relocation site was recorded during the second round of monitoring, however, the latest round of monitoring recorded densities comparable with those of the first round. This pattern was not observed across the other survey sites, suggesting the factors underlying the observed increased in kākahi density were site specific and temporary. It is unknown what these factors may include, however, the low error around density estimates would suggest that sampling error is unlikely to be one of them.

Prior to dredging in the Pūharakekenui, kākahi lengths were very similar at each of the impact sites (Figure 16), averaging 70 mm, or 90% of the average kākahi length at the upstream control site. Immediately following the dredging (+0.5 years), kākahi lengths were reduced to an average of 66 mm (88% of the average Control length). Kākahi lengths have remained lower at the impact sites, compared to all other sites, in every survey since the dredging. This potential effect is small, but it may be due to divers unintentionally collecting larger, more easily located individuals during the relocation exercise, leaving a larger proportion of smaller individuals at the impacted sites. This potential effect will be examined further as part of additional analyses that are currently underway.

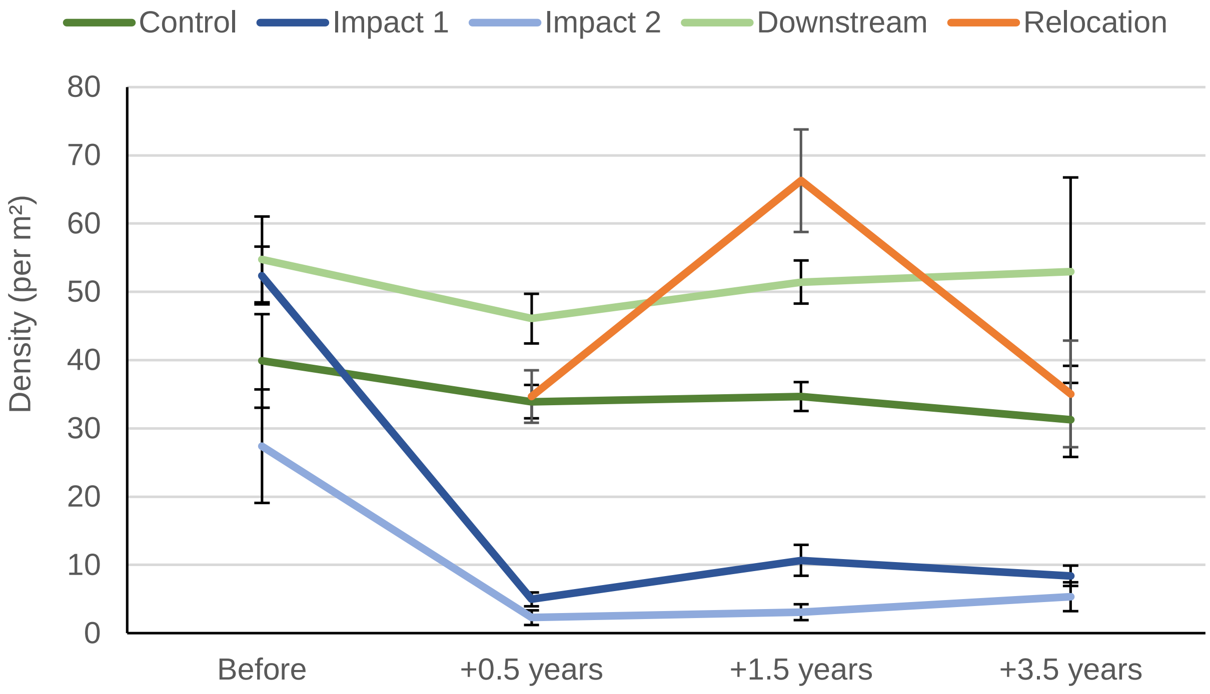


Figure 15: Kākahi densities each of the Pūharakekenui survey sites before and after dredging. Densities presented as mean values, with standard error calculated between transects for each site/year.

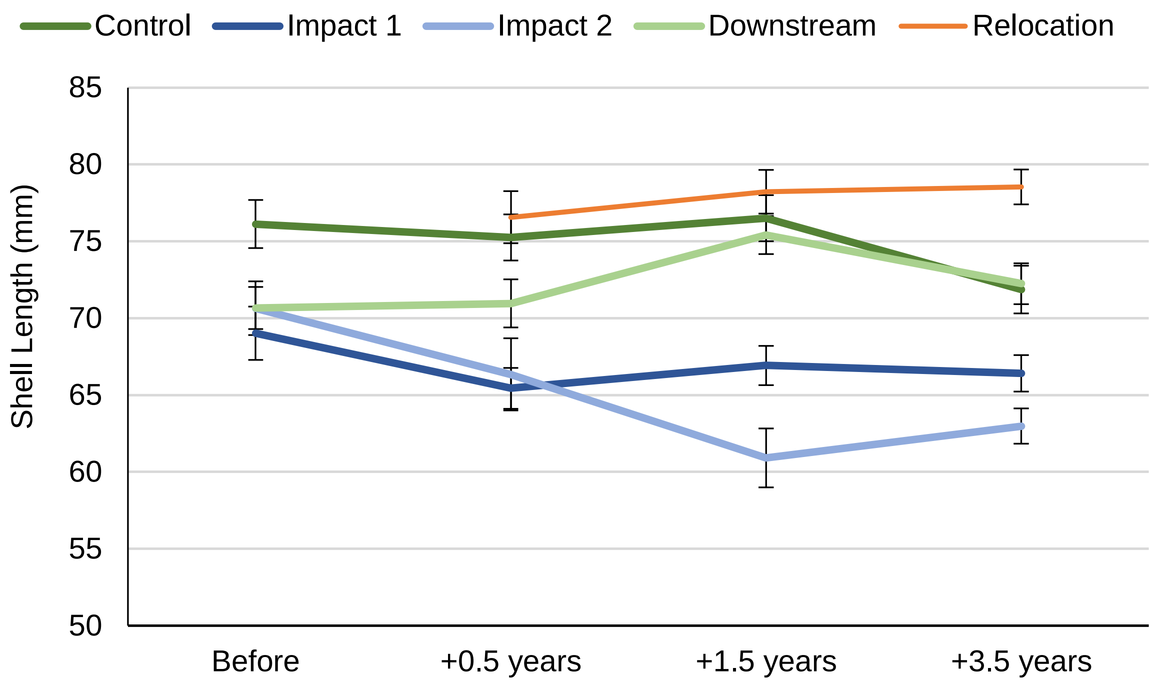


Figure 16: Kākahi lengths at each of the Pūharakekenui survey sites, before and after dredging. Lengths presented as mean values across all individuals, with the standard error of this estimate included. Note that the y-axis scale starts at 50 mm.

3.4. Comparison of Survey Methods

Each survey method described above has different qualities, especially with regards to the level of sampling effort and the depth of information acquired. No one sampling technique is appropriate for all research objectives. The following paragraphs discuss the qualities of each of the rapid, quantitative, and follow-up survey techniques, as well as their appropriateness for meeting research objectives.

The two main survey methodologies used in the current round of sampling were rapid and quantitative surveys. The rapid surveys were an informal sampling design, which require little planning, are easily executed in the field, and are comparatively cheap per site. This allows for many sites to be surveyed, making the rapid survey method well suited to preliminary surveys to identify where kākahi populations are. However, informal designs make it difficult to make inferences about the sampled population (Strayer and Smith 2003).

In contrast, quantitative surveys are a formal sampling design, requiring a greater amount of planning and equipment, as well as taking much longer to complete in the field. For example, the quantitative surveys in the Ōtākaro and Cashmere Stream described above, required approximately 11 and 28 person hours in the field, respectively. These values do not include planning, travel, and habitat measurements. The large difference between the sampling times for the two quantitative surveys are due to the low density of kākahi at the Ōtākaro site. Given that 156 quadrats were surveyed at the Cashmere Stream site in 28 person hours, we estimate that it would require 35–40 person hours (i.e., two days in the field for three people) in the field to complete a survey of the 200 quadrats, the number recommended in Section 3.2. At the Cashmere Stream site, we consider this very good value for the level of data acquired, and the most appropriate method for long term monitoring of this population. However, quantitative sampling at the Ōtākaro site proved to be of little value, as the low densities of kākahi prevented any strong inferences about the population from being made.

Completion of the rapid surveys over the quantitative sample reaches allowed for some comparison between these methods. At the Cashmere Stream site, the rapid survey recorded 138 kākahi over 40 m of the quantitative reach. Using this information, we could estimate that there was approximately 345 kākahi over the entire 100 m quantitative reach. However, the results of the quantitative survey prove this to be a vast underestimation, with 683 kākahi recorded from 39 m² of quadrats searched. Differences in kākahi density estimates between the rapid search and quantitative methods are likely due to the difficulty in visually counting many kākahi in a small area, as well as not counting kākahi buried in the sediments. In this scenario the quantitative survey clearly produces more reliable results. However, at the Ōtākaro quantitative reach, the rapid survey recorded 15 kākahi over the entire 100 m reach. As the substrates were hard, and kākahi densities low, we suspect that the rapid search was efficient and that this estimate is reasonably accurate for the reach. Thus, when densities are low and substrates are hard, the rapid survey with a timed count is likely to produce more accurate and efficient results.

The follow-up surveys described above followed independent methodologies. The timed counts used at the Cashmere Stream and Ōpāwaho relocation sites allowed for qualitative or semi-quantitative observations to be made. For instance, the timed counts were efficient at identifying low recolonisation into the salvage sites. However, lack of baseline data in the relocation reaches allowed for only broad inferences about kākahi survivorship to be made. Either timed counts (if densities are low) or quantitative sampling (if densities are high, as per Cashmere Stream) should be carried out at relocation sites when follow-up monitoring is intended. Although timed counts are less accurate than quantitative surveys, this method would allow for substantial relocation effects, such as high or low survivorship, to be detected. Quantitative sampling would provide a more robust and accurate measure of density changes over time. Mark-recapture methods are also recommended, as they provide useful data on growth and survival of relocated individuals (Kurth *et al.* 2007; Hart *et al.* 2021).

The follow-up surveys in the Pūharakekenui were a Before–After–Control–Impact quantitative survey design. Site-wise sampling effort was much lower in the Pūharakekenui, compared to the quantitative surveys completed in Cashmere Stream and the Ōtākaro. Despite this, comparatively low error was achieved around density estimates, allowing for population trends to be described with some confidence. This is due to the high densities of kākahi that are comparatively far less patchy in the Pūharakekenui. In such circumstances where patchiness is relatively low and densities are high, it is therefore appropriate to reduce sampling effort.

Consistent with the Christchurch populations, reported kākahi densities are highly variable across New Zealand. Low densities of 0.3–1.6 kākahi per m², have been reported across three Waikato waterways (Hanrahan 2019). Collating data across 11 New Zealand lakes, Walker *et al.* (2001) reported a mean of 6 kākahi per m², excluding an outlier lake that had a kākahi density of 160 per m². Butterworth (2008) reported consistently high densities in Lake Rotokākahi in the North Island, ranging from 118–210 kākahi per m² across five sites. However, despite high densities, the Lake Rotokākahi population was also highly patchy within sites, with the average within transect (i.e., between quadrat) density range being 116 kākahi per m².

Given the variable nature of New Zealand’s kākahi populations, in terms of density and patchiness, robust monitoring programs are required. Catlin *et al.* (2017) describe three monitoring protocols for kākahi in the Waikato region, including a rapid, timed search for kākahi presence, and two similar quantitative sampling methods. The rapid search method used by Catlin *et al.* (2017) records kākahi presence or absence. However, we found it useful in this survey to count all kākahi encountered during the full 30 minutes of a rapid search, to obtain a qualitative measure of kākahi abundance. This approach was particularly useful in the Ōtākaro, where kākahi densities were low and patchy. For quantitative monitoring, Catlin *et al.* (2017) recommend searching the entire stream bed along a 50 m reach, with the kākahi count kept separate for each of five, 10 m long sub-sections. We considered this approach impractical for Cashmere Stream and the Ōtākaro, which were both considerably wider than the 1 m wide stream Catlin *et al.* (2017) did their pilot study on. Also, we sought to obtain a precise estimate of kākahi density, and it is unlikely the mean of five transects would have achieved reasonable precision in either of the waterways we sampled quantiatively.

Ultimately, the selection of a monitoring method depends on the objectives of the monitoring programme. We consider that the rapid survey method used in this study is suitable for quickly assessing where kākahi are found within a region or district, and for providing indications of their relative abundance in waterways. This information on relative abundance can then be used to determine whether quantitative sampling might be needed (e.g., if there are indications that a location has high densities for the district), and if so, what sampling method to use. We have shown that quantitative monitoring of patchy populations requires highly intensive sampling, to reduce error around density estimates to an appropriate level to detect population changes. Conversely, effort may be reduced when populations display low patchiness. Pilot studies should be used to inform the design of quantitative monitoring programmes, by focussing on establishing the degree of patchiness and relative abundance of the kākahi population.

4. CONCLUSIONS

Dedicated kākahi surveys have now been completed in every major catchment in Christchurch city. Kākahi have been recorded in the Pūharakekenui, Ōtākaro, and Ōpāwaho catchments. The most substantial populations in Christchurch city are in the Pūharakekenui mainstem, Waikākāriki, and Cashmere Stream. While the extents of the Waikākāriki and Cashmere Stream populations are well known, further surveys are required to delineate the extent of the Pūharakekenui population in the mainstem and its tributaries. Despite substantial search effort, kākahi have not been recorded in the Ōtūkaikino catchment in any dedicated survey to date, suggesting that they are either absent, or present in very discrete patches. Kākahi have also not been recorded in the Huritini catchment, within the Christchurch district. However, some reaches of the Huritini mainstem have not yet been surveyed, due to high macrophyte cover and water depths. Kākahi are known to exist in the Huritini mainstem outside of the Christchurch district.

Quantitative sampling in the current survey round was the most sampling intensive site-wise investigation in Christchurch to date. Low kākahi densities in the Ōtākaro allowed few inferences to be made about the population, however, in-depth analysis of the population structure and local distribution was possible at the Cashmere Stream site. Consistent with previous surveys in the district and around New Zealand, the sampled Cashmere Stream population was heavily skewed towards larger individuals. This either indicates that juveniles occur in habitats not currently surveyed, or low recruitment is resulting in an aging population. Detecting a decline in kākahi density in the Cashmere Stream population is only possible by recording precise density estimates, which has not been achieved previously, nor in the current study. The high error around density estimates was explained by visualising the kākahi distribution at this location, revealing a high level of local scale patchiness. Through this process it was also discovered that kākahi do not occur at the margins of the waterway at this location. Exclusion of these margins from analysis was shown to reduce error around density estimates, increasing our ability to detect temporal changes in kākahi density. By simulating sampling with varying levels of effort, it was estimated that approximately 200 quadrats of 0.25 m² area, with stream margins excluded, would be required to reduce the error around density estimates to a level that could detect a 30% change in kākahi density.

Follow-up surveys of kākahi that were relocated out of the way of dredging and construction activities revealed negligible recolonisation rates. There was no direct method of measuring survivorship of relocated kākahi, however, comparison to background densities appear to indicate either low survivorship or kākahi movement away from relocation sites.

Comparison of rapid, quantitative, and follow-up survey techniques highlighted the importance of tailoring survey methodology to the study population. Quantitative surveys were found to be useful when densities were high, with required sampling effort linked to patchiness. Timed counts were useful in delineating population extents, and when densities are low and substrates hard. Pilot surveys are essential prior to making decisions around quantitative survey designs.

5. RECOMMENDATIONS

Based on the conclusions above, we make the following recommendations:

- **Ongoing quantitative monitoring of the Cashmere Stream population.** While the density of this population appears to be greater than previously thought, low numbers of juveniles may be cause for concern. Monitoring should aim to reduce error around density estimates and adequately sample the size class structure, including:
    - Sampling 200, 0.25 m² quadrats per site.
    - Establishing a sampling exclusion zone around the margins where kākahi are not located, prior to sampling.
    - While multiple sampling sites would be preferable, the site discussed in the current study is the highest priority for monitoring. This is because it has the highest kākahi densities in the waterway (i.e., lowest error around density estimates) and it is the most downstream location (i.e., affected by the cumulative effects of urbanisation in the catchment).
    - Quantitative monitoring should occur at least every 2 years, given the rate of development in the Cashmere Stream catchment.
- **Monitoring of the Ōtākaro kākahi population with timed counts.** Comparison of the quantitative and rapid survey techniques showed that there is little value in quadrat-based sampling in the Ōtākaro, due to the low kākahi density. While statistical inferences cannot be made about the population, timed counts would allow for qualitative observations about the density and distribution of the population. Monitoring frequency should reflect the

degree of development anticipated in the catchment, and could occur in the order of every 2–5 years.

- **Further rapid surveys in the Pūharakekenui and Huritini catchments.** The extent of the Pūharakekenui population is not currently well defined, and few tributaries have been surveyed. Further surveys in the Huritini mainstem following macrophyte removal are required to provide confidence that kākahi are not present in this catchment, within the Christchurch district.
- **Continue monitoring relocated kākahi in the Pūharakekenui.** This information will be useful for understanding the recovery of kākahi populations following relocation, and it will help inform future decisions around dredging**.**
- **Avoid relocating kākahi when possible.** There is currently little evidence of successful relocations of kākahi in Christchurch. Avoiding relocation will always be ecologically the preferable option.
- **When relocation of kākahi is unavoidable:**
    - Affected habitats should be made to resemble the surrounding environment as closely as possible. For example, soft substrates should not be covered with ballast in soft bottomed waterways.
    - Baseline and follow-up kākahi surveys should be conducted at both the sites kākahi are removed from and where they are moved to.
    - Timed count methods should be used where densities are expected to be low (e.g., the Ōtākaro or Ōpāwaho) and quantitative methods should be used where densities are expected to be high (Cashmere Stream or Pūharakekenui).
    - The above density measurements should be supplemented with measures of shell length and mark-recapture methods (by tagging shells), to better understand impacts on growth and survival.

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