LAKE ROTORUA

KŌURA AND KĀKAHI MONITORING PROGRAMME 2020

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Cover image

Anthony Waiomio with a large kōura collected from the tau kōura deployed off Mokoia Island. 17 November 2020. Photo: I. Kusabs).

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EXECUTIVE SUMMARY

Lake Rotorua is a eutrophic lake that has suffered from water quality issues since the 1960s. The Bay of Plenty Regional Council is leading the restoration and protection programme for the lake and have implemented a number of in lake treatments and nutrient management strategies in the catchment to improve water quality.

Kōura (freshwater crayfish) and kākahi (freshwater mussels) are considered taonga (treasured) species by Te Arawa iwi. Freshwater crayfish are also widely recognised as an important ecological component of freshwater ecosystems as they have a dominating influence on community structure. Freshwater mussels are important to aquatic ecosystems as their filter-feeding ability enables them to improve water quality by filtering organic matter, bacteria, algae and pollutants, as well as stabilising suspended sediments.

The principal aims of this monitoring programme is to determine trends in kōura population characteristics and kākahi abundance in Lake Rotorua. This report provides an in-depth analysis of Lake Rotorua kōura and kākahi monitoring data for 2020 and a comparison with previous surveys carried out in 2009, 2010, 2011, 2016, 2017, 2018 and 2019.

The Lake Rotorua kōura population was sampled using the tau kōura a traditional Māori method of harvesting kōura in Te Arawa and Taupō lakes. Two tau kōura were located on the western side of Mokoia Island each composed of 10 whakaweku (bracken fern bundles). The kākahi monitoring methodology developed by NIWA specifically for community and iwi groups, was used to determine kākahi densities at seven sites in the shallow (< 1 m) littoral zone around the Lake Rotorua shoreline.

Results of data analysed show that kōura abundance (-21%) and biomass (-15%) in Lake Rotorua were lower in 2020 than 2019. Furthermore, kōura mean CPUE has decreased by -85% and mean BPUE by -59%, since the 2009 baseline surveys. Length frequency analysis of kōura data shows that this is due to a decline in the numbers of small-sized kōura (<22 mm) OCL recorded.

The decrease in the Lake Rotorua kōura population has coincided with the establishment of brown bullhead catfish (*Ameiurus nebulosus*) and an improvement in water quality. Catfish, are well known predators of kōura and were officially recorded in Lake Rotorua in December 2018, however, it is highly probable that they had been present for quite some time but at densities too low to be detected using standard trapping methods. In Lake Rotorua the trophic level index (TLI) has decreased from 5.0 in 2004/05 to 4.1 in 2019/20. This has resulted in a decrease in algae production and an increase in water clarity. The reduced primary production may have resulted in a decrease in food supply for kōura (and therefore kōura abundance), while increased water clarity may have led

to an increase in the growth (and extent) of introduced macrophytes which could have decreased available habitat for kōura.

Kākahi were abundant in the littoral zone with mean densities (range 1.0 to 12.1 kākahi m^{-2}) similar to those recorded in neighbouring Lake Rotoiti. Kākahi were least abundant at Waikawau (Holden’s Bay) and Te Ruapeka (Ohinemutu), both influenced by geothermal inputs. Kākahi abundance has remained relatively stable at most sites since surveys began in January 2017, with the exception of Waerenga where kākahi abundance has declined, and at Ruapeka, where kākahi numbers have increased.

It is recommended that kōura and kākahi monitoring surveys continue in Lake Rotorua given the ecological and cultural importance of these taonga species. Monitoring of the kōura population in Lake Rotorua is particularly important given the continued decline in kōura abundance and biomass.

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INTRODUCTION

The Bay of Plenty Regional Council (BOPRC) is leading the restoration and protection programme for Lake Rotorua. Monitoring is an essential component of this programme and the BOPRC monitor; algae, aquatic plants (LAKESPI), water quality (temperature, dissolved oxygen, nutrients), sediments and zooplankton. In 2016, the BOPRC committed to regular monitoring of kōura (freshwater crayfish, *Paranephrops planifrons*) and kākahi (freshwater mussel, *Echyridella menziesii*) due to their cultural and ecological importance.

Kōura are a taonga and mahinga kai species for Te Arawa iwi and an important ecological component of Lake Rotorua where large numbers are present (Kusabs et al. 2015a). Kōura abundance and distribution in Lake Rotorua is known to be influenced by benthic substrate composition, fish predation (Kusabs, et al. 2015b) and hypolimnetic deoxygenation (Kusabs and Butterworth 2011). Kākahi have important cultural, ecological and conservation values. In pre-European times, kākahi were a highly valued food source (Hiroa 1921). Freshwater mussels are important to aquatic ecosystems as their filter-feeding ability enables them to improve water quality by filtering organic matter, bacteria, algae and pollutants, as well as stabilising suspended sediments. Furthermore, freshwater mussels are under threat and are declining, both in New Zealand and worldwide therefore they have significant conservation values (Walker et al. 2001). Little is known about kākahi in Lake Rotorua, the only source of published information is from conventional benthic macroinvertebrates studies that did not specifically target kākahi.

Background and Objectives

Lake Rotorua

Lake Rotorua is a large (80.9 km^2), relatively shallow polymictic lake with an average depth of 10 m. The lake has pressures from urban and rural landuses. Since the 1960's, Lake Rotorua has experienced water quality problems associated with eutrophication. Recent management interventions to improve the water quality of Lake Rotorua include: land disposal of the city's wastewater since 1991, sewage reticulation of smaller communities, trial of nitrogen removal of water from Tikitere geothermal field (2011), alum dosing to lock phosphorus from Utuhina Stream (2006) and Puarenga Stream (2010), and regional rules to cap land-based inputs (Rule 11).

Aims and Objectives

The principal aim of this study is to to determine trends in kōura population characteristics and kākahi abundance in Lake Rotorua. The objectives were to carry out the fourth year of seasonal kōura and kākahi monitoring (2020) and to compare the results with previous surveys carried out in 2009, 2010, 2011, 2016, 2017, 2018 and 2019.

METHODS

Tau kōura construction and use

The Lake Rotorua kōura population was sampled using the tau kōura (Fig. 1), a traditional Māori method of harvesting kōura in Te Arawa and Taupō lakes (Hiroa 1921; Kusabs and Quinn 2009). The two tau kōura were located on the western side of Mokoia Island (Table 1, Fig. 2). Each tau kōura was comprised of 10 whakaweku each with c. 10 bracken fern (*Pteridium esculentum*) fronds per bundle. The fronds were bound together using 250 mm length industrial strength cable ties and were attached using twine (~ 2.5 m long) to a 450 m length of sinking anchor rope. One end of the bottom line was attached to a large boulder near Mokoia Island while the lake-end was anchored to the lake bottom using a concrete-filled car tyre. Whakaweku were deployed at water depths ranging from 3 to 15 m.

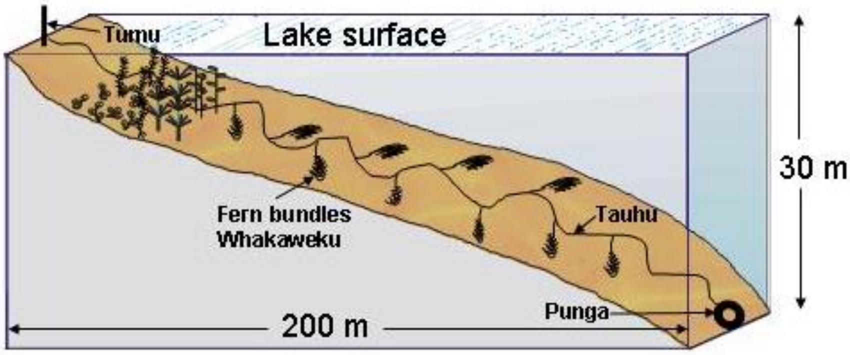

Figure 1 Schematic diagram of the tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

The two tau kōura in Lake Rotorua were retrieved on 12 February, 22 May, 13 August and 17 November 2020. Owing to fern decomposition, whakaweku were replaced (with fresh bracken fern) on 13 August 2020.

Sampling was achieved by lifting the shore end of the rope and successively raising each whakaweku while moving along the tauhu (bottom line) in a boat. A kōrapa (landing net) was placed beneath the whakaweku before it was lifted out of the water. The whakaweku was then shaken to dislodge all kōura from the fern into the kōrapa. The whakaweku were then returned to the water. The kōura were then collected and placed into labelled (2 litre) plastic containers to keep kōura shaded before processing.

Table 1 Sampling site and grid reference of kōura monitoring sites, Lake Rotorua.

Sampling site	Site description	Grid reference (WGS84)
Kōura A	Mokoia Island	38° 04′ 66″S 176° 16′ 79″ E
Kōura B	Mokoia Island	38° 04′ 88″S 176° 16′ 78″ E

Figure 2 Approximate locations of Lake Rotorua kōura (A &B) and kākahi (1 -7) monitoring sites.

Kōura measurements

Kōura were assessed for size, sex, reproductive state (presence of eggs or young) and shell softness (soft or hard). Orbit-carapace length (OCL, mm) of each kōura was measured using Vernier callipers (± 0.5 mm) and the sex of kōura (OCL >12 mm) assessed. A power regression equation (previously determined by B. Hicks and P. Riordan, University of Waikato) was used to estimate kōura wet weight:

$$W(\text{g}) = 0.000648\ \text{L(mm)}^{3.0743}$$

where *W* is wet weight in g and L is OCL in mm.

After processing, all kōura were returned live to the water in close proximity to the tau kōura. Total sample handling time for two people to retrieve and process the samples from each tau was typically 2-3 hours. Catch Per Unit Effort (CPUE) was defined as the number of kōura per whakaweku and Biomass Per Unit Effort (BPUE) as estimated wet weight (g) of kōura per whakaweku.

Comparison of kōura data with previous surveys in Lake Rotorua

Kōura population data for this study were compared with surveys carried out in 2009, 2010, 2011, 2016, 2017, 2018 and 2019 (Table 2).

Table 2 Survey year/month(s) sampled and source of kōura data for surveys carried out in Lake Rotorua from 2009 to 2020.

Year/Month sampled	Purpose & source
April, July, November 2009	PhD study; Kusabs *et al.* (2015b)
December 2010	Alum study; Kusabs & Butterworth (2012)
December 2011	Alum study; Kusabs & Butterworth (2012)
June 2016	Iwi liaison; Ian Kusabs; unpub. data
March, July & November 2017	Kusabs (2018)
February, May, August & November 2018	Kusabs (2019)
February, May, August & November 2019	Kusabs (2020)
February, May, August & November 2020	This report

Kākahi surveys

The kākahi monitoring methodology developed by NIWA specifically for community and iwi groups was used in this study to determine kākahi densities. Transects were located at seven sites in Lake Rotorua (Table 3, Fig. 2). At each site 40 m transects, 0.5 m wide, and perpendicular to the shore, were inspected out into the lake from standard points to a depth where the water was regularly wadeable. All kākahi in an area of 0.5 m wide running parallel to and up-current from a weighted survey line were counted using an underwater viewer. An “L” shaped measuring device constructed of 25 mm PVC pipe (1.2 m high x 0.5 wide) was used to measure water depth (to the nearest 1 cm) and to maintain the 0.5 m distance from the survey line. Counts were summed for each 1 m interval.

Sediment type was visually assessed along the transect lines as mud, mud-sand, clean sand, gravely sand etc. Where possible, surveys were carried out when weather conditions and water clarity allowed good visual observations to be made. In some instances, two days were required to complete surveys at all seven sites. Kākahi surveys were carried out on 10 February, 28 April, 4 August and 12/20 November 2020.

Table 3 Sampling site, description and grid reference of kākahi monitoring sites, Lake Rotorua.

Sampling site	Site name	Location	Grid reference (WGS 84)
Kākahi 1	Waikawau	Holden's Bay	38° 06′ 46″ S 176° 18′ 28″ E
Kākahi 2	Te Pohue	Park Cliff Road	38° 04′ 08″ S 176° 19′ 33″ E
Kākahi 3	Waerenga	Mission Bay	38° 02′ 14″ S 176° 18′ 35″ E
Kākahi 4	Kaikaitahuna	Hamurana	38° 02′ 04″ S 176 ° 15′ 21″ E
Kākahi 5	Waimihia	Keith Road	38° 03′ 29″ S 176° 13′ 00″ E
Kākahi 6	Parawai	Ngongotaha	38° 05′ 37″ S 176° 13′ 27″ E
Kākahi 7	Te Ruapeka	Whittaker Road	38° 07′ 27″ S 176° 14′ 36″ E

Dissolved oxygen

A HOBO dissolved oxygen data logger (model: U26-001) was deployed at the Rotorua A site to determine dissolved oxygen (DO) concentrations and water temperatures from the period 12 February to 22 May 2020. The logger was attached to the tau kōura approximately 3 m past the last, and deepest, whakaweku at a depth of 12.4 m. Net floats were used to ensure that the sensor end of the logger was suspended above the lake bed.

Data analysis

Linear regression was used to determine trends in kōura population parameters (CPUE, BPUE and OCL) and kākahi density data. ANOVA with post hoc Bonferroni-Holm comparisons were used to determine whether there were any statistically significant differences between mean kākahi densities at the seven survey sites.

The Kolmogorov-Smirnov test for normality was used to determine whether the variables were normally distributed. Where necessary, data were transformed (log_{10} or square root) to approximate the normal distribution. Data analysis and visualization was performed using Daniel's XL Toolbox add in for Excel, version 7.3.2 (Kraus, 2014).

RESULTS

Water quality

An examination of data from the dissolved oxygen logger deployed at the Rotorua A site, from 12 February to 22 May 2020, showed that dissolved oxygen (DO) concentrations consistently fell below 5 mg l^{-1} on 17, 21 and 22 February 2020. The lowest DO concentration recorded was 1.3 mg l^{-1}at 1200 hrs on 21 February 2020. Water temperatures ranged from 13.5 to 22.7°C.

Kōura

Kōura abundance and biomass

A total of 760 kōura were captured in 2020 at a mean CPUE of 9.5 (SD 9.2) kōura whakaweku^{-1} and an estimated mean BPUE of 330.7 g (SD 392.2) koura whakaweku^{-1}. Relative abundance and biomass were highly variable between sites and seasons with mean CPUE ranging from 3.8 to 22.8 kōura whakaweku^{-1} and mean BPUE from 120.4 to 703.5 g kōura (Table 4). Kōura abundance and biomass were lower in 2020 compared to the 2019 survey. Mean CPUE decreased by -20.8% from 12 kōura whakaweku^{-1} (2019) to 9.5 kōura whakaweku^{-1} (2020) (p = .49) (Fig. 3a). While mean BPUE decreased by 15.4% from 331 g kōura whakaweku^{-1} (2019) to 280.1g kōura whakaweku^{-1} (2020) (p = .99) (Fig. 3b).

Table 4 Survey date, sampling site, mean catch per unit effort (mean CPUE (± SD) and estimated mean biomass per unit effort (BPUE) of kōura collected from two tau kōura each composed of 10 whakaweku, deployed in Lake Rotorua and retrieved from 12 February 2020 to 17 November 2020.

Survey date	Mean CPUE (n; SD)		Mean BPUE (g; SD)	
	Rotorua A	Rotorua B	Rotorua A	Rotorua B
12 February 2020	16.1 (12.5)	22.8 (12.5)	440.3 (394.1)	703.5 (393.4)
22 May 2020	5.4 (5.0)	7.9 (3.1)	212.2 (228.0)	252.2 (120.3)
13 August 2020	4.8 (2.9)	3.8 (1.6)	143.8 (108.3)	120.4 (88.6)
17 November 2020	8.8 (5.7)	6.4 (3.4)	199.3 (143.5)	169.2 (118.7)

Kōura abundance and biomass - comparison with previous surveys

Monitoring data recorded from 2009 to 2020 shows that there have been significant declines in kōura mean CPUE (p < .01) and estimated mean kōura BPUE (p < .01) in Lake Rotorua (Figs. 4 a & b; Appendix A1). Mean CPUE has declined by -84.9% from 63 kōura whakaweku^{-1} in 2009) to 9.5 kōura whakaweku^{-1} in 2020 (p < .01) (Fig. 4a). While mean BPUE has declined by 59% from 683 g kōura whakaweku^{-1} in 2009 to 280.1 g kōura whakaweku^{-1} in 2020 (p < .001) (Fig. 4b).

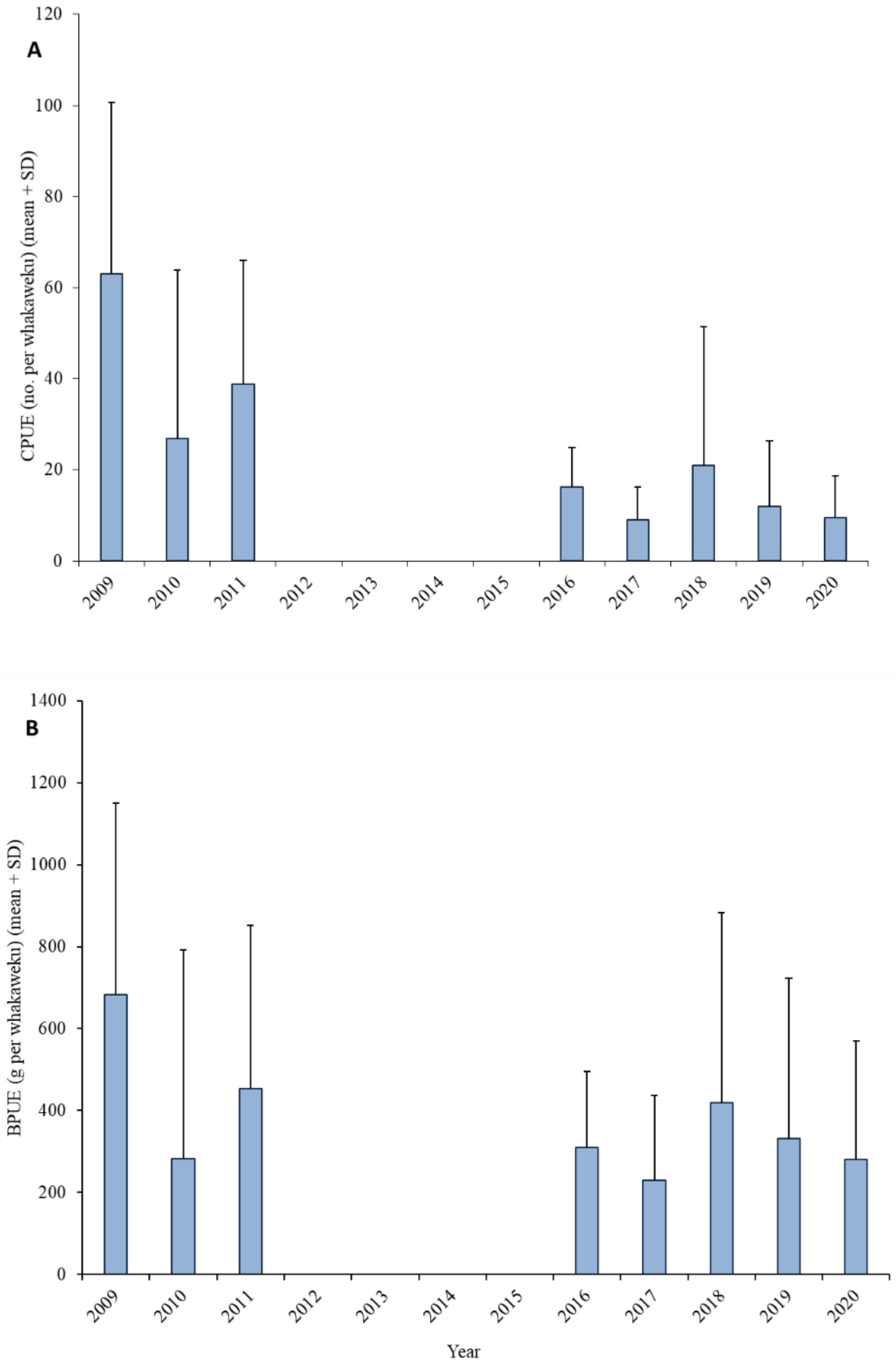

Figure 3 (A) Catch per unit effort (mean number + SD) and (B) estimated biomass per unit effort (mean grams + SD) of kōura captured on tau kōura (composed of 10 to 20 whakaweku at two sites) deployed in Lake Rotorua in 2009, 2010[1], 2011, 2016, 2017, 2018, 2019, 2020.

[1] Only single surveys were carried out in 2010 and 2011 (both in December). The kōura catch in 2010 was affected by lake stratification which occurred during November-December 2010.

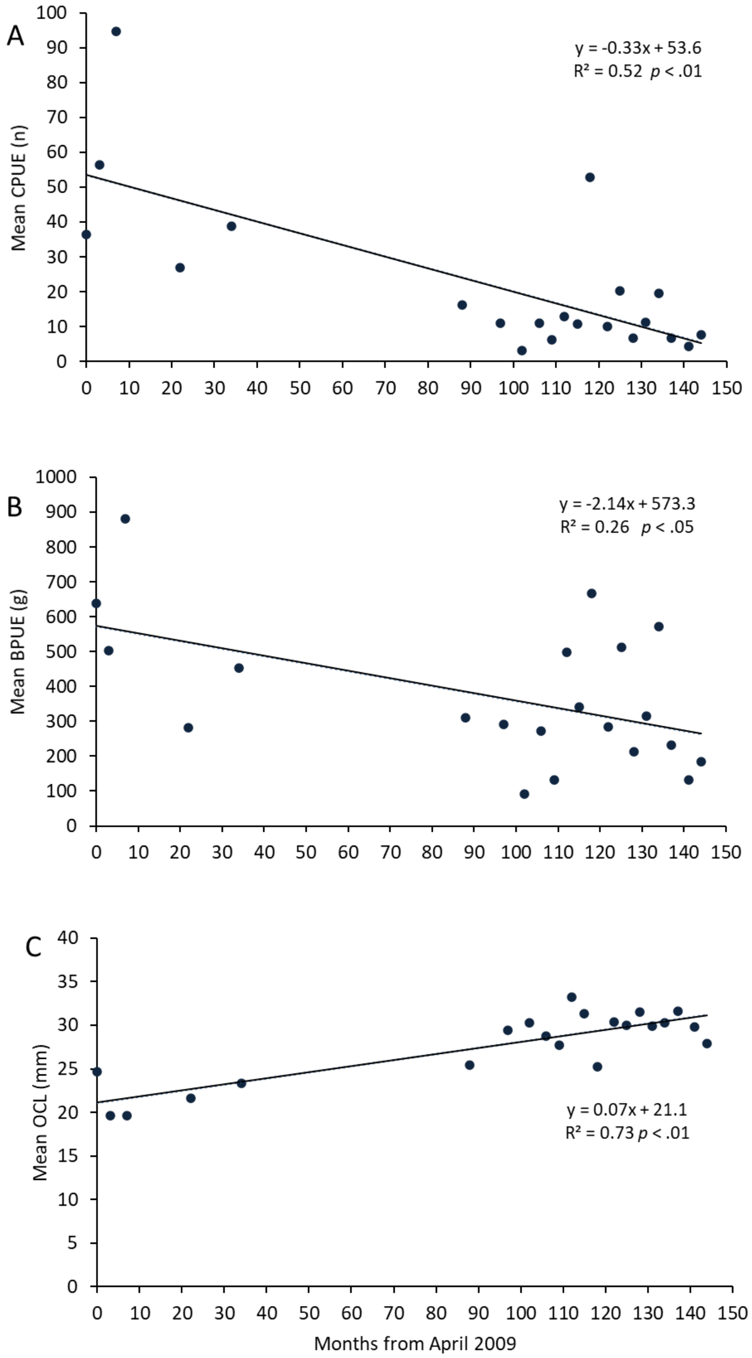

Figure 4 Relationship between (A) Catch per unit effort (mean CPUE) (B) estimated biomass per unit effort (mean BPUE) and (C) orbit carapace length (mean OCL) of kōura captured on tau kōura (composed of 10 to 20 whakaweku at two sites) deployed in Lake Rotorua in 2009, 2010[2], 2011, 2016, 2017, 2018, 2019, 2020.

[2] Only single surveys were carried out in 2010 and 2011 (both in December). The kōura catch in 2010 was affected by lake stratification which occurred during November-December 2010.

Kōura size

Kōura mean size ranged from 29.4 to 31.7 mm OCL in the 2020 survey period with mean sizes varying little between the four seasons (Table 5). The smallest kōura recorded was 9 mm OCL and the largest 55 mm OCL (Table 6).

Table 5 Survey date, sampling site, mean orbit carapace length (OCL; mm) of kōura sampled from two tau kōura each composed of 10 to 20 whakaweku deployed in Lake Rotorua and retrieved from 12 February 2020 to 17 November 2020.

Date	Mean size (OCL; mm)	
2020	Rotorua A	Rotorua B
12 February	29.4 (8.6)	31.0 (8.4)
22 May	32.4 (10.9)	31.0 (9.2)
13 August	29.1 (10.7)	30.5 (9.7)
17 November	27.4 (8.6)	28.6 (9.3)

Kōura size - comparison with previous surveys

Monitoring data recorded from 2009 to 2020 shows that there has been a significant increase ($p < .01$) in kōura mean size since baseline surveys were carried out in 2009 (Fig. 4c; Appendix A2). Kōura mean OCL has increased by 47% from 20.4 mm OCL in 2009 (April, July, November) to 30.0 mm OCL in 2020 (February, May, August, November) (Table 6; Fig. 5). Length frequency analysis of the April 2009 and May 2020 kōura samples show that this increase is mainly due to the reduction in small-sized kōura <~22 mm OCL (Fig. 6).

Table 6 Maximum, minimum, mean (SD = standard deviation), first (Q_1), second (median; Q_2) and third (Q_3) quartile values for orbit carapace length (mm) of kōura collected from Lake Rotorua from 2009 to 2020.

	2009	2010	2011	2016	2017	2018	2019	2020
Minimum	7	11	11	12	16	14	10	9
Q1	15	16	17	17	23	23	25	23
Median	18	20	21	25	27	28	30	28
Q3	25	26	29	30	34	35	35	30
Maximum	51	49	50	54	53	56	56	55
Mean (SD)	20.4 (8.0)	21.6 (6.8)	23.3 (7.9)	25.4 (9.2)	29.1 (7.9)	29.4 (8.5)	30.3 (8.3)	30.0 (9.1)

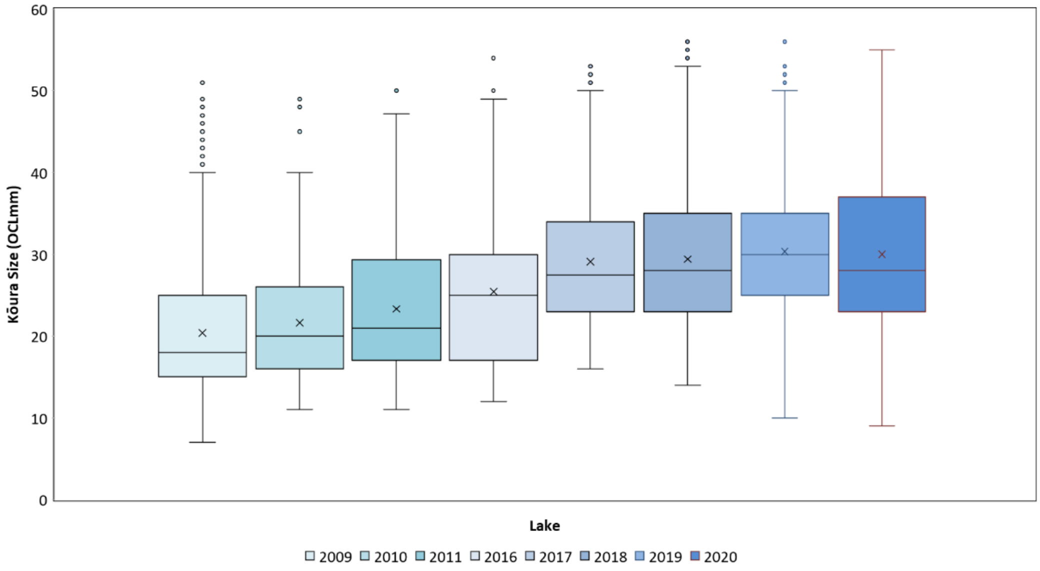

Figure 5 Box-and-whisker plot showing mean (x), median (horizontal line), interquartile range (box), distance from upper and lower quartiles times 1.5 interquartile range (whiskers), outliers (>1.5× upper or lower quartile) of kōura captured on tau kōura (composed of 10 to 20 whakaweku x two sites) deployed in Lake Rotorua in 2009, 2010, 2011, 2016, 2017, 2018, 2019, 2020.

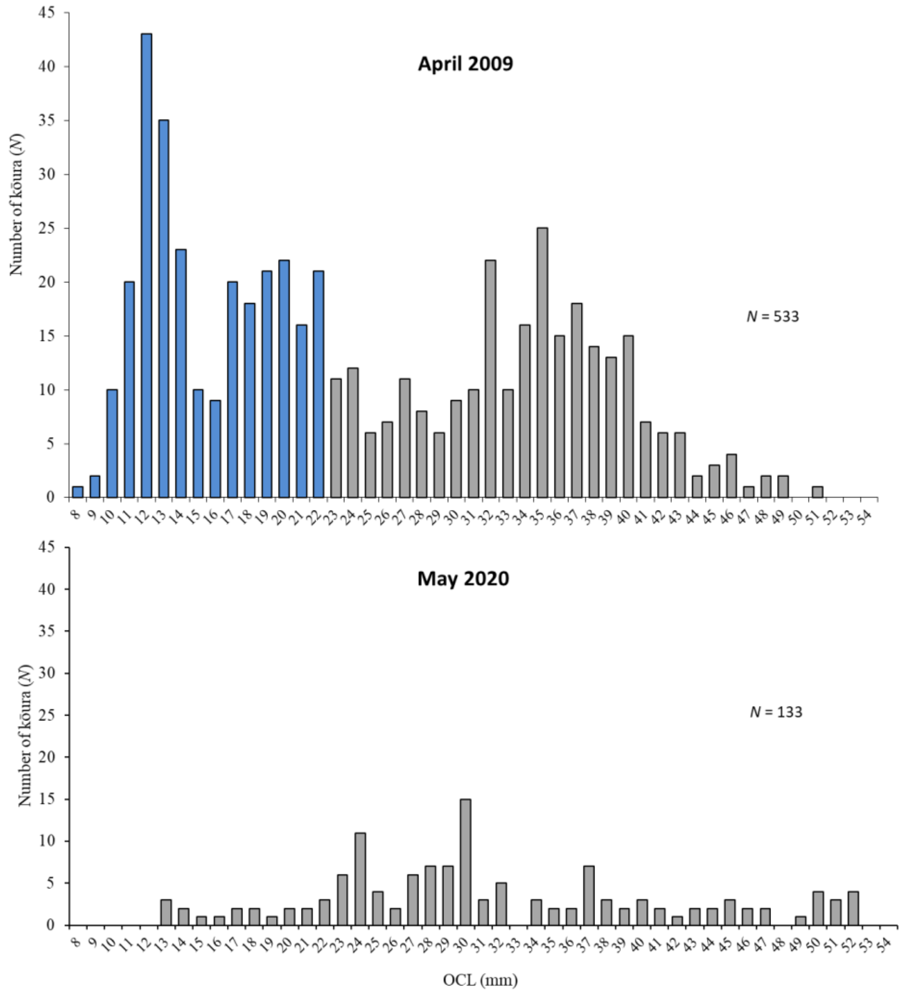

Figure 6 Length-frequency distributions of kōura collected from two tau kōura each composed of 10 whakaweku set in Lake Rotorua and retrieved on 14 April 2009 and 23 May 2020. OCL = orbit carapace length. Bars coloured blue show kōura <22 mm OCL.

Percentage females, breeding kōura and soft shells

Female kōura comprised 47% of the population over the 2020 survey period, ranging from 41 to 53% (Table 7). The ratio of female to male kōura was consistent throughout the year (Table 7). Breeding sized females with eggs or hatchlings were present in May, August and November with none recorded in February (Table 7). The proportion of kōura with soft shells ranged from 9 to 23% (Table 7). This shows that kōura continue to grow throughout the year.

Table 7 Sampling site, sampling date, number of kōura sampled, mean percentage of females, mean percentage of breeding size females with eggs, young or spermatophores (defined as >21 mm OCL) and mean percentage of kōura with soft shells, in subsamples taken from 2 tau kōura comprised of 10 whakaweku (fern bundles) in Lake Rotorua, 2020.

Date	Number of kōura sampled		% Female		% Breeding size females with eggs		% Soft shells	
2020	Rotorua A	Rotorua B	Rotorua A	Rotorua B	Rotorua A	Rotorua B	Rotorua A	Rotorua B
12 February	162	227	47.2	45.8	0.0	0.0	14.2	10.6
22 May	54	79	46.3	46.8	43.5	48.5	18.5	22.8
13 August	48	38	41.7	47.4	45.5	20.0	16.7	18.4
17 November	88	64	53.4	40.6	13.9	41.2	22.7	9.4

Percentage females, breeding kōura, soft shells - comparison with previous surveys

Female kōura comprised 51% of the samples collected over the 10-year sampling period with the highest proportions most often recorded in autumn (Table 8). The percentage of breeding size females was lowest in summer and highest in autumn and winter (Table 8).

Interestingly, there appears to have been a decrease in the percentage of breeding size females collected in spring, from 67% in 2009 to 23% in 2020 (Table 8). There has also been a corresponding increase in the minimum breeding size over the sampling period, particularly in winter (21 to 29 mm OCL) and spring (21 to 32 mm OCL) (Table 8).

The percentage of kōura with soft shells was always highest in summer, with most of these being male kōura (Table 8).

Table 8 Sampling month and year, number of kōura sexed, mean percentage of; females, breeding size females[3] with eggs, young or spermatophores and kōura with soft shells. Samples collected from two tau kōura comprised of 10 whakaweku each, set in Lake Rotorua, 2010 to 2020. Shaded areas show the 2020 survey period.

Year	Season	Months sampled	Number kōura sexed	Female %	Breeding size females %	Min breeding size OCL mm	Soft shells %
2010	Summer	December	556	48	2	23	20
2011		December	554	47	5	27	16
2018		February	111	44	0	-	15
2019		February	201	57	0	-	7
2020		February	161	46	0	-	23
2009	Autumn	April	531	72	55	22	1
2017		March	222	56	7	36	14
2018		May	267	57	60	25	7
2019		May	190	51	44	23	6
2020		May	133	47	46	20	21
2009	Winter	July	1118	50	35	21	6
2016		June	283	52	42	23	2
2017		July	58	41	13	24	0
2018		August	216	42	60	28	6
2019		August	126	35	23	27	6
2020		August	86	44	31	29	17
2009	Spring	November	1780	54	67	21	7
2017		November	310	45	25	25	9
2018		November	291	44	28	28	9
2019		November	223	41	21	28	10
2020		November	152	48	23	32	17

Kākahi

Sampling conditions

Water clarity is an important consideration when counting kākahi in the shallow littoral zone of lakes. Rotorua is an exposed lake open to wind from all directions, therefore on some occasions two days (and multiple visits) were required to complete the surveys. However, when conditions were suitable, kākahi were clearly visible in the clean (algae-free), sandy substrates present at the seven sampling sites. Kākahi surveys were carried out on 10 February, 28 April, 4 August and 12/20 November 2020.

Kākahi abundance

Kākahi mean density for the 2020 survey was 4.0 kākahi m^{-2} higher than 2019 (3.9 kākahi m^{-2}), but lower than 2017 (4.2 kākahi m^{-2}) and 2018 (4.4 kākahi m^{-2}). The highest densities of kākahi this year were recorded at Parawai with a mean density 5.6 kākahi m^{-2} and at Kaikaitahuna with a mean density of 5.3 kākahi m^{-2} (Table 9). Kākahi were least abundant at Waikawau with a mean density of 1.5 kākahi m^{-2} (Table 9).

[3] defined as >21 mm OCL.

There were no statistically significant differences in kākahi abundance between the four sampling years (2017 to 2020) ($F(3, 105) = .32$, $p = .81$). However, ANOVA for the 2017 to 2020 kākahi data showed that there were statistically significant differences between the seven sampling sites ($F(6,102) = 21.9$, $p < .001$). As with last year's analysis, a Bonferroni-Holm post hoc test showed that kākahi density at the Waikawau and Te Ruapeka sites were significantly lower ($p < .05$) than at the Kaikaitahuna, Parawai, Te Pohue and Waerenga sites. In addition, kākahi density at Waimihia was significantly ($p < .05$) lower than at Kaikaitahuna and Te Pohue.

Kākahi abundance has remained relatively stable at most sites since surveys began in January 2017, with the exception of Waerenga where there has been a significant decrease ($p < .05$), and Ruapeka where there has been a significant increase ($p < .05$) in kākahi abundance (Fig. 7, Table 9).

Table 9 Mean (± SD) densities of kākahi (m^{-2}) at seven sites (20 m^2) in Lake Rotorua, January 2017 to November 2020. Shaded area shows the 2020 survey period.

Date	Waikawau	Te Pohue	Waerenga	Kaikaitahuna	Waimihia	Parawai	Te Ruapeka	Mean ± SD
January 2017	2.6	6.9	8.2	8.2	3.5	3.3	0.9	4.8 ± 2.9
May 2017				4.1	0.5	4.4	0.9	2.5 ± 2.1
August 2017	1.3	6.3	5.7	7.7	2.1	7.7	3.3	4.9 ± 2.6
November 2018	1.6	4.3	6.9	9.9	4.4	5.5	2.1	5.0 ± 2.8
January 2018	1.6	7	3.7	6.5	5.4	5.5	0.9	4.4 ± 2.4
May 2018	2.2	7.6	2.1	3.1	0.7	3.4	0.9	2.9 ± 2.3
August 2018	1.2	10.8	6.9	9.5	4.2	4.1	0.9	5.4 ± 3.9
November 2018	0.9	4	6.6	12.3	1.9	6.6	0.9	4.2 ± 4.2
February 2019	1.0	3.8	3.2	10	4.7	5.8	0.9	3.2 ± 2.3
May 2019	1.5	7.5	3.2	5.2	1.7	2.2	1.2	3.2 ± 2.3
August 2019	1.2	6.6	4.7	5.0	2.7	5.0	3.3	4.1 ± 1.8
November 2019	2.3	9.4	3.5	6.1	1.8	2.3	2.2	3.9 ± 2.8
February 2020	1.4	2.5	3.0	4.1	3.3	1.9	1.6	2.5 ± 1.0
April 2020	1.6	5.5	4.7	4.9	2.6	2.9	4.8	3.9 ± 1.0
August 2020	1.9	5.8	2.4	3.9	3.0	5.6	3.8	3.8 ± 1.5
November 2020	1.0	5.8	3.6	8.4	4.4	12.1	5.0	5.8 ± 3.6
2020	1.5 ± 0.4	4.9 ± 1.6	3.4 ± 1.0	5.3 ± 0.6	3.3 ± 0.8	5.6 ± 4.6	3.8 ± 1.6	4.0 ± 2.3
2019	1.5 ± 0.6	6.8 ± 2.3	3.7 ± 0.7	6.6 ± 2.3	2.7 ± 1.4	3.8 ± 1.8	1.9 ± 1.1	3.9 ± 2.5
2018	1.5 ± 0.6	7.4 ± 1.4	4.8 ± 2.3	7.9 ± 4.0	3.1 ± 2.1	4.9 ± 1.4	0.9 ± 0	4.3 ± 3.2
2017	1.9 ± 0.5	6.4 ± 1.3	5.3 ± 2.4	6.6 ± 2.6	2.8 ± 2.0	5.0 ± 1.7	1.5 ± 1.0	4.5 ± 2.7

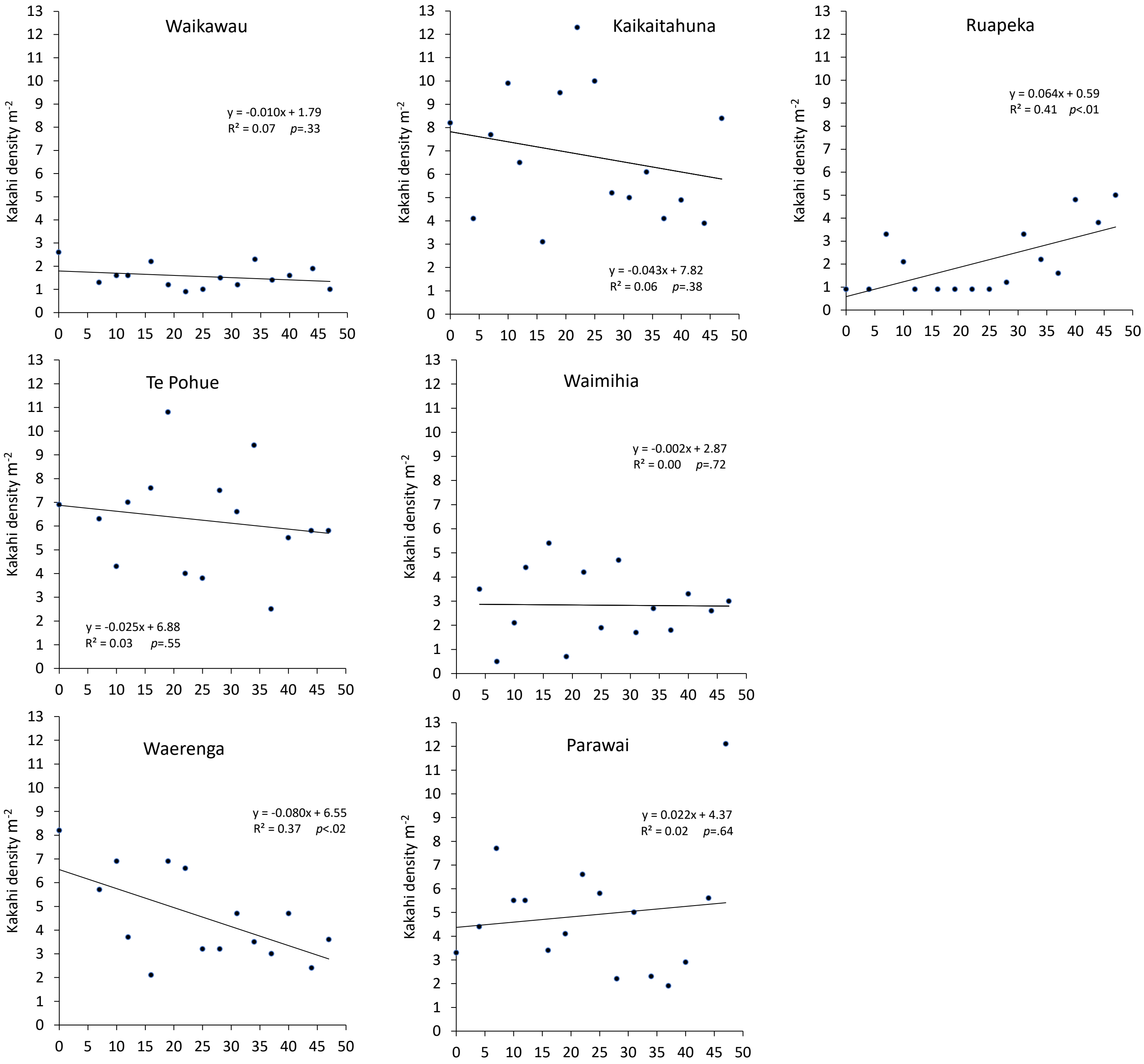

Figure 7 Relationship between kākahi density at seven sites (0.5 m x 40 m transects) situated in Lake Rotorua and time, January 2017 to November 2020.

DISCUSSION

Kōura

Kōura abundance and biomass were lower in 2020 than in 2019 continuing the long-term trend of kōura population decline in Lake Rotorua. Mean CPUE has declined by -84.9% from 63 kōura whakaweku^{-1} in 2009 to 9.5 kōura whakaweku^{-1} in 2020, while mean BPUE has declined by -59% from 683 g kōura whakaweku^{-1} in 2009 to 280 g kōura whakaweku^{-1} in 2020. From 2011 to 2016, there was a sudden shift from a population dominated by small and medium sized kōura to one composed mainly of medium and large sized kōura. Length-frequency analysis of kōura size data shows that this is due to a decline in numbers of kōura <~22 mm OCL.

The reason for the decline in relative abundance is not certain as the kōura population is subjected to multiple stressors in Lake Rotorua including; increased predation by invasive fish, reduced lake productivity and prolific aquatic macrophyte growth. Brown bullhead catfish (*Ameiurus nebulosus*) were officially recorded in Lake Rotorua on 18 December 2018. Catfish have been reported to commonly consume kōura (particularly juvenile kōura) in Lake Taupō and are considered a more effective predator of kōura than trout (Barnes and Hicks 2003).

The drastic reduction in the numbers of kōura <~22 mm OCL in Lake Rotorua, between 2011 and 2016, is most likely due to catfish predation. A corresponding, and similar, decline has also occurred in Lake Rotoiti (Kusabs 2020b) where catfish were officially recorded in March 2016. In comparison, drastic declines in the numbers of small-sized kōura (<~22 mm OCL) have not occurred in those Te Arawa lakes (i.e., Ōkāreka, Rotoehu, Rotokakahi, Rotomā, Tarawera, and Tikitapu) where catfish have not established (Kusabs 2020c).

Nonetheless, the decline in kōura abundance, since 2009 in Lake Rotorua and 2007 in Lake Rotoiti, has also coincided with steadily improving water quality in both lakes. In Lake Rotorua the trophic level index (TLI) has decreased from 5.0 in 2004 to 4.1 in 2019/20 and in Lake Rotoiti from 4.5 in 2004 to 3.7 in 2019/20 (Scholes and Dare 2020). This has resulted in a decrease in algae production and an increase in water clarity. The reduced primary production may have resulted in a decrease in food supply and therefore reduced abundance of kōura in both lakes. Whereas, the increased water clarity may have led to an increase in the growth and extent of introduced macrophytes (e.g., hornwort). Weed proliferation and accumulation of decaying organic matter can markedly degrade the habitat quality of the surrounding lake bed.

An examination of DO data recorded at the Rotorua A site showed that that DO concentrations only fell below 5 mg l^{-1} occasionally (i.e., 17, 21 and 22 February 2020) in summer/autumn 2020. Devcich (1979) found strong correlations between kōura presence and DO concentrations in Lake Rotoiti, with an appreciable decline in abundance when DO fell below 5 mg L^{-1}, with kōura absent when DO levels were below 1.2 mg L^{-1}. This is consistent with other crayfish species which avoid levels below 5 mg L^{-1} (Westman 1985) and are adversely affected at DO levels near 1 – 2 mg L^{-1} (Hobbs and Hall 1974). In the laboratory, studies have shown that *P. planifrons* is tolerant of low oxygen levels with a DO LC_{50} of 0.77 mg L^{-1} (duration 48 hours at 15 °C) (Landman*, et al.* 2005). Dissolved oxygen data suggests that there was sufficient DO for kōura at depths of at least 12.5 m throughout the summer/autumn period.

The percentage of breeding size females was lowest in summer and highest in autumn and winter. There appears to have been a decrease in the percentage of breeding size females collected in spring, from 67% in 2009 to 23% in 2020. It is unclear whether this is due to lower sample sizes or if there has been a shift in kōura breeding times in Lake Rotorua. Future monitoring will reveal if this trend is real or perceived.

Kākahi

This is the fourth year that kākahi monitoring surveys have been carried out in Lake Rotorua. Kākahi were found to be abundant in Lake Rotorua with mean kākahi densities (range 1.0 to 12.1 kākahi m^{-2}) similar to those recorded in Lake Rotoiti (range 0.4 to 18.8 kākahi m^{-2}) (Kusabs 2020b). Kākahi densities varied amongst the sites with kākahi more abundant at Parawai, Kaikaitahuna, Te Pohue, and Waerenga and least abundant at Waimihia, Waikawau and Te Ruapeka, the latter are both influenced by geothermal activity. Kākahi abundance has remained relatively stable at most sites since surveys began in January 2017, with the exception of Waerenga where kākahi abundance has declined and at Ruapeka where kākahi numbers have increased.

CONCLUSIONS AND RECOMMENDATIONS

Kōura abundance and biomass have declined markedly in Lake Rotorua since baseline surveys were carried out in 2009. Length-frequency analysis of kōura data shows that this decline is mainly due to a reduction in the numbers of small-sized kōura <~22 mm OCL. The reasons for this decline are uncertain but could be due to increased predation by brown bullhead catfish, which were officially recorded in Lake Rotorua in December 2018. A similar change in the Lake Rotoiti kōura population has also coincided with the establishment of brown bullhead catfish.

This survey was the fourth year that kākahi abundance has been monitored in Lake Rotorua with mean densities similar to those recorded in Lake Rotoiti. Kākahi were least abundant at Waikawau (Holden's Bay) and Te Ruapeka (Ohinemutu), both influenced by geothermal inputs.

It is recommended that kōura and kākahi monitoring surveys continue given the ecological and cultural importance of these taonga species. Monitoring of the kōura population is particularly important given the declining abundance of kōura in Lake Rotorua.

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APPENDIX

Table A1 Survey date, sampling site, mean catch per unit effort (CPUE) and estimated mean biomass per unit effort (BPUE) of kōura collected from two tau kōura each composed of 10 to 20 whakaweku, deployed in Lake Rotorua and retrieved from 14 April 2009 to 17 November 2020. Highlighted area shows the 2020 survey period. Figures highlighted in red denote the three highest CPUEs and BPUEs recorded over the entire sampling period. SD in brackets.

Survey date	Mean CPUE (n)		Mean estimated BPUE (g)	
	Rotorua A	Rotorua B	Rotorua A	Rotorua B
14 April 2009	34.5(13.2)	41.2 (12.7)	490.4 (288.3)	841.0 (405.3)
10 July 2009	61.3 (45.0)	51.6 (19.6)	571.8 (683.6)	432.8 (262.7)
16 November 2009	99.3 (46.1)	90.0 (23.4)	967.6 (570.0)	796.0 (255.5)
8 December 2010	25.3 (35.2)	28.5 (39.4)	209.8 (301.5)	355.9 (655.5)
3 December 2011	42.0 (26.7)	35.7 (28.2)	439.9 (265.2)	468.4 (390.4)
13 June 2016	16.4 (7.2)	15.9 (10.4)	317.3 (131.6)	301.8 (234.2)
30 March 2017	9.2 (7.1)	13.0 (10.7)	224.2 (196.8)	359.6 (335.8)
11 July 2017	3.9 (3.4)	2.6 (3.0)	97.9 (95.3)	85.1 (124.4)
3 November 2017	9.3 (3.6)	12.1 (6.3)	246.3 (120.7)	286.4 (175.4)
18 February 2018	8.3 (5.7)	4.5 (2.6)	190.2 (165.5)	85.2 (59.5)
17 May 2018	9.0 (5.6)	17.3 (12.9)	309.7 (208.8)	707.8 (814.7)
29 August 2018	11.6 (5.7)	9.7 (10.4)	420.0 (217.0)	263.2 (348.6)
26 November 2018	24.0 (7.6)	81.6 (51.7)	388.1 (107.3)	945.9 (581.3)
28 February 2019	9.2 (6.0)	10.9 (6.4)	276.8 (227.0)	289.7 (194.8)
19 May 2019	5.8 (3.8)	34.5 (26.7)	173.2 (201.4)	850.6 (685.2)
9 August 2019	4.4 (4.2)	8.9 (10.5)	143.2 (83.3)	297.4 (443.9)
7 November 2019	8.0 (4.3)	14.3 (11.1)	224.9 (130.4)	404.0 (361.3)
12 February 2020	16.1 (12.5)	22.8 (12.5)	440.3 (394.1)	703.5 (393.4)
23 May 2020	5.4 (5.0)	7.9 (3.1)	212.2 (228.0)	252.2 (120.3)
13 August 2020	4.8 (2.9)	3.8 (1.6)	143.8 (108.3)	120.4 (88.6)
17 November 2020	8.8 (5.7)	6.4 (3.4)	199.3 (143.5)	169.2 (118.7)

Table A2 Survey date, sampling site, mean orbit carapace length (OCL; mm) of kōura sampled from two tau kōura each composed of 10 to 20 whakaweku deployed in Lake Rotorua and retrieved from 14 April 2009 to 17 November 2020. Highlighted area shows the 2020 survey period.

Date	Mean size (OCL; mm)	
Site	Rotorua A	Rotorua B
14 April 2009	24.4 (10.0)	24.8 (10.7)
10 July 2009	20.1 (6.9)	19.1 (6.9)
16 November 2009	20.1 (7.3)	19.1 (7.4)
8 December 2010	20.9 (6.4)	22.2 (7.0)
3 December 2011	22.6 (7.5)	23.9 (8.1)
13 June 2016	25.8 (9.5)	25.1 (9.1)
30 March 2017	28.7 (7.7)	29.9 (8.0)
11 July 2017	29.9 (6.0)	31 (9.8)
3 November 2017	29.5 (7.9)	28.4 (7.8)
18 February 2018	28.4 (7.0)	26.6 (6.5)
17 May 2018	33.1 (6.7)	33.3 (8.0)
29 August 2018	32.7 (8.8)	29.5 (8.5)
26 November 2018	26.0 (7.6)	24.5 (7.5)
28 February 2019	31.4 (6.8)	29.5 (7.8)
19 May 2019	29.4 (10.8)	30.3 (7.0)
9 August 2019	31.1 (9.4)	31.7 (8.6)
7 November 2019	29.8 (8.7)	30.0 (8.5)
12 February 2020	29.4 (8.6)	31.0 (8.4)
22 May 2020	32.4 (10.9)	31.0 (9.2)
13 August 2020	29.1 (10.7)	30.5 (9.7)
17 November 2020	27.4 (8.6)	28.6 (9.3)