LAKES ŌKATAINA AND ROTOMĀ

ROTORUA TE ARAWA LAKES KŌURA MONITORING PROGRAMME 2019

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Ian Kusabs & Associates Ltd

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Cover image

Ian Kusabs, Joe Butterworth and kaitiaki from Ngāti Tarāwhai and tauira from Wharekura ō Ngāti Rongomai, kōura wānanga Lake Ōkataina, 28 August 2019.

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EXECUTIVE SUMMARY

Kōura are considered a taonga species by Te Arawa iwi and are an important ecological component in the Rotorua Te Arawa lakes where they are present. The purpose of this study was to monitor kōura populations in lakes Ōkataina and Rotomā as part of the Rotorua Te Arawa Lakes kōura monitoring programme. This report provides an analysis of monitoring data for kōura in the two lakes and a comparison with kōura data collected from the 13 other Rotorua Te Arawa lakes.

The Lake Ōkataina and Rotomā kōura populations were sampled using the tau kōura, a traditional Māori method of harvesting kōura in the Rotorua Te Arawa and Taupō lakes. Two tau kōura were located in each lake with each tau kōura composed of 10 whakaweku (bracken fern bundles). This was the first tau kōura survey carried out in Lake Ōkataina and the third in Lake Rotomā, with previous surveys carried out in April, July, November 2009 and November 2013.

Lakes Ōkataina and Rotomā support abundant populations of koura with a mean CPUE of 15.4 kōura whakaweku^{-1} recorded in Lake Ōkataina and 25.8 kōura whakaweku^{-1} in Lake Rotomā. Lake Rotomā ranked first in terms of mean CPUE and second in mean BPUE in the 15 Rotorua Te Arawa lakes where kōura monitoring has been undertaken. Whereas, Lake Ōkataina ranked third in both mean CPUE and mean BPUE.

The size structure of kōura in both lakes was well-balanced with kōura ranging in size from 3 to 52 mm OCL in Lake Rotomā and 6 to 45 mm OCL in Lake Ōkataina. The presence of small juvenile kōura (<10 mm) at depths >20 m reflects the excellent water quality (oligotrophic) in the two lakes and the absence of catfish. In terms of mean kōura size, Lake Rotomā was ranked fifth (25.6 mm OCL) and Lake Ōkataina sixth (24.2 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded.

In Lake Rotomā, kōura abundance and biomass were lower in 2019 compared to the 2009 baseline surveys. Mean CPUE has decreased by 21% and mean BPUE by 50%, the majority of this decline has occurred at one sampling site. The reasons for this are unknown but it could be due to localised customary kōura harvesting.

The capture of recently fledged juvenile kōura at water depths >30 m in Lake Rotomā is evidence that female kōura do not need to release their juveniles into the littoral zone to complete their lifecycles. This suggests that improving and maintaining water quality to ensure that the bottom waters remain well oxygenated, and kōura can complete their lifecycles at depth, may be the best means of maintaining abundant kōura populations in lakes with (and without) catfish.

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INTRODUCTION

The Bay of Plenty Regional Council (BOPRC) is leading the restoration and protection programme for the Rotorua Te Arawa lakes. Monitoring is an essential component of this programme and the BOPRC carry out both monthly and continuous monitoring (University of Waikato operated monitoring buoys) of algae, water quality (temperature, dissolved oxygen, nutrients), sediments and zooplankton. In 2016, the BOPRC committed to regular monitoring of kōura (freshwater crayfish, *Paranephrops planifrons*) in the Rotorua Te Arawa lakes henceforth known as the Rotorua Te Arawa lakes kōura monitoring programme.

Kōura are the largest bottom living crustacean and an important ecological component of the Rotorua Te Arawa lakes. They are also an important mahinga kai species for Te Arawa iwi (Hiroa 1921; Stafford 1996, Kusabs et al. 2015a) supporting customary fisheries in lakes Rotoiti, Rotomā and Tarawera. Freshwater crayfish are considered a keystone species in many freshwater ecosystems acting as predators, shredders, and detritivores (Nyström 2002). In addition, crayfish increasingly feature as indicator species because of their important role in aquatic ecosystem food webs and their iconic and heritage values (Reynolds and Souty-Grosset 2012).

Until recently, there was a lack of quantitative information on kōura abundance and ecology which made it difficult for iwi and government agencies to manage kōura populations in New Zealand lakes. However, the recent development and use of the tau kōura, a traditional Māori harvesting method (Fig. 1), for monitoring (Kusabs and Quinn 2009) and research purposes (Parkyn et al. 2011; Clearwater et al. 2012; Wood et al. 2012) has greatly increased understanding of kōura populations in the Rotorua Te Arawa lakes. Kusabs et al. (2015b) found that kōura abundance and distribution in seven Rotorua Te Arawa lakes was influenced by the combined effects of lake-bed sediments, lake morphology, and hypolimnetic deoxygenation. Furthermore, (Kusabs et al. 2015a) examined biological traits of kōura in eight lakes and used this data to determine fisheries regulations as part of the sustainable management of kōura in the Rotorua Te Arawa lakes.

Regular monitoring of kōura is important because it can answer conservation questions such as 'How are kōura populations changing within the lakes?' 'What are the changes over time?' 'How are kōura populations responding to lake restoration initiatives' and 'Where are the most important lakes and areas for kōura?' Long-term monitoring of kōura populations, using the tau kōura, is currently undertaken in three lakes – lakes Rotoiti (Kusabs 2019a), Rotoehu (Kusabs 2019b; and Rotorua (Kusabs 2018c). The purpose of the Rotorua Te Arawa lakes kōura monitoring programme is to carry out regular monitoring (on a 5-year rotation i.e., 2 lakes per year) in the remaining nine Rotorua Te Arawa lakes i.e., lakes Ōkāreka, Ōkaro, Ōkataina, Rerewhakaaitu, Rotokakahi, Rotomā, Rotomahana, Tarawera and Tikitapu.

Objectives

The aim of this study was to carry out monitoring of kōura populations in lakes Ōkataina and Rotomā as part of the Rotorua Te Arawa Lakes kōura monitoring programme.

METHODS

Study area

Lakes Ōkataina and Rotomā are in the Central North Island of New Zealand within the Taupo Volcanic Zone (Fig. 2).

Lake Ōkataina (Te moana-i-kataina-ā-Te Rangitakaroro) is an important place for Ngāti Tarāwhai. It is a medium sized (10.9 km^2) with an average depth of 39 m and maximum depth of 79 m. Lake Ōkataina is an oligotrophic lake, with the trophic level index (TLI) fluctuating between 2.5 and 3 in the last two decades (LAWA 2019a). The target TLI for the lake is 2.6. Lake Ōkataina has no surface outlet, instead draining southward by seepage towards Lake Tarawera. Because the level of Lake Ōkataina is not controlled by overflow, water levels fluctuate dramatically, depending on rainfall. A rise of 10 m has occurred in the last 100 years or so. Geothermal springs exist on the eastern shore of the lake. Lake Ōkataina has a moderately sized catchment of about 60 km^2, which is comprised mainly of native forest and scrub (80%), while the other predominant land uses are dry-stock farming (10%) and exotic forestry (8%) (LAWA 2019a).

Lake Rotomā is the cleanest of all the Rotorua Te Arawa lakes, with water clarity of around 11 m and a 3-year average TLI of 2.3 (LAWA 2019b). The lake has total area of 1.11 km^2 and a catchment area of 28.1 km^2. The catchment comprises native bush, livestock farming and areas of exotic plantation forests. The average depth of the lake is 37 m and the deepest point of the lake is 83 m (LAWA 2019b). The lake has no surface outflow and water levels fluctuate dramatically, depending on rainfall. Ngāti Pikiao, Ngāti Awa and Ngāti Tūwharetoa ki Kawerau affiliate to Lake Rotomā and its catchment.

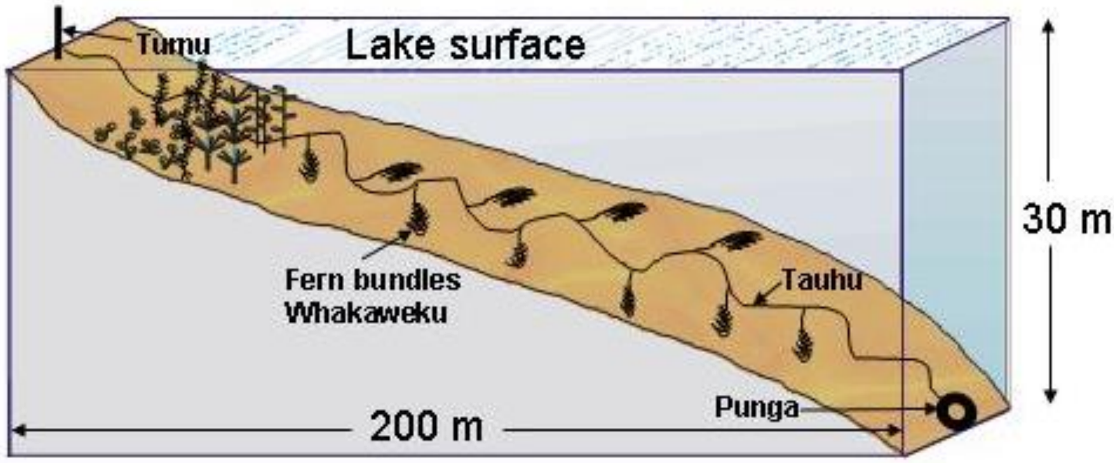

Figure 1 Schematic diagram of the tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

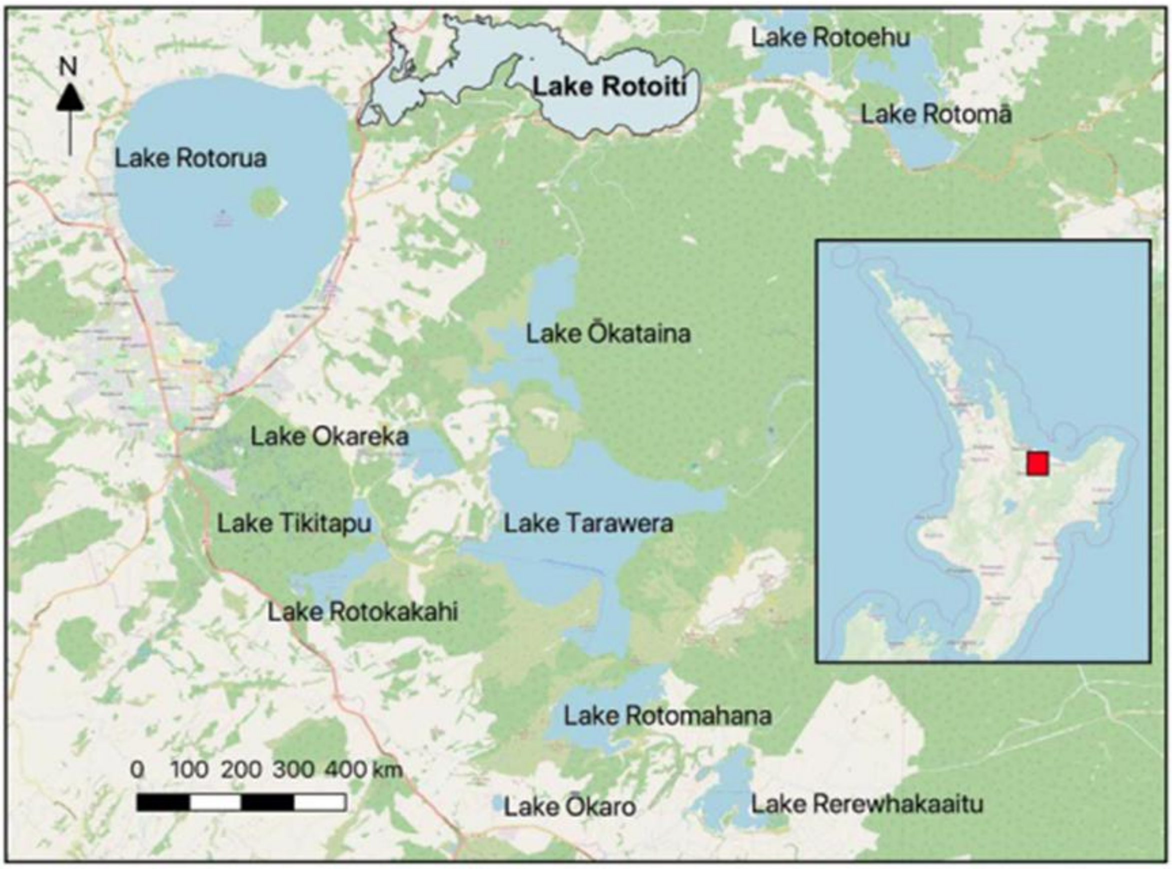

Figure 2 Map of the Rotorua Te Arawa Lakes showing the location of lakes Ōkataina and Rotomā.

Tau kōura construction and use

The kōura populations in lakes Ōkataina and Rotomā were sampled using the tau kōura with two tau kōura deployed in each lake (Table 1; Figs. 3 & 4). Each tau kōura was composed of 10 whakaweku (dried bracken fern; *Pteridium esculentum*, bundles), with c. 10 - 12 fern fronds per bundle, which were attached to a bottom line (a 250-m length of sinking anchor rope) (Fig. 1). In Lake Ōkataina, whakaweku were set in depths ranging from 5 to 28 m and 5 to 33 m in Lake Rotomā (Table 1; Figs. 3 & 4). Tau kōura were deployed in Lake Ōkataina on 21 July 2018 and were left for approximately 15 weeks to allow kōura to colonise the fern before first retrieval on 23 November 2018, they were retrieved again on 13 February 2019. In Lake Rotomā, tau kōura were deployed on 21 July 2018 and were left for approximately 13 weeks to allow kōura to colonise the fern before first retrieval on 25 October 2018, they were retrieved again on 14 March 2019. Owing to decomposition of whakaweku, whakaweku were replaced in both lakes with fresh bracken fern on 14 March 2019 and retrieved again on 23 May 2019 and 16 August 2019.

Table 1 Sampling site, grid reference and approximate location of kōura monitoring sites in lakes Ōkataina and Rotomā, depths recorded on 16 August 2019.

Lake	Sampling site	Latitude Longitude (Decimal degrees)	Water depth (m)
Ōkataina	North	S 38°07.011’ E 176°25.771’	13 - 28
Ōkataina	South	S 38°08.917’ E 176°25.788’	10 - 28
Rotomā	West	S 38°02.246’ E 176°34.313’	7.5 - 28
Rotomā	North	S 38°01.520’ E 176°34.522’	6 - 33

Kōura collection

Harvesting 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 and calm before processing.

Figure 3 Lake Ōkataina showing the approximate locations and direction of the North (A) and South (B) tau kōura sampling sites.

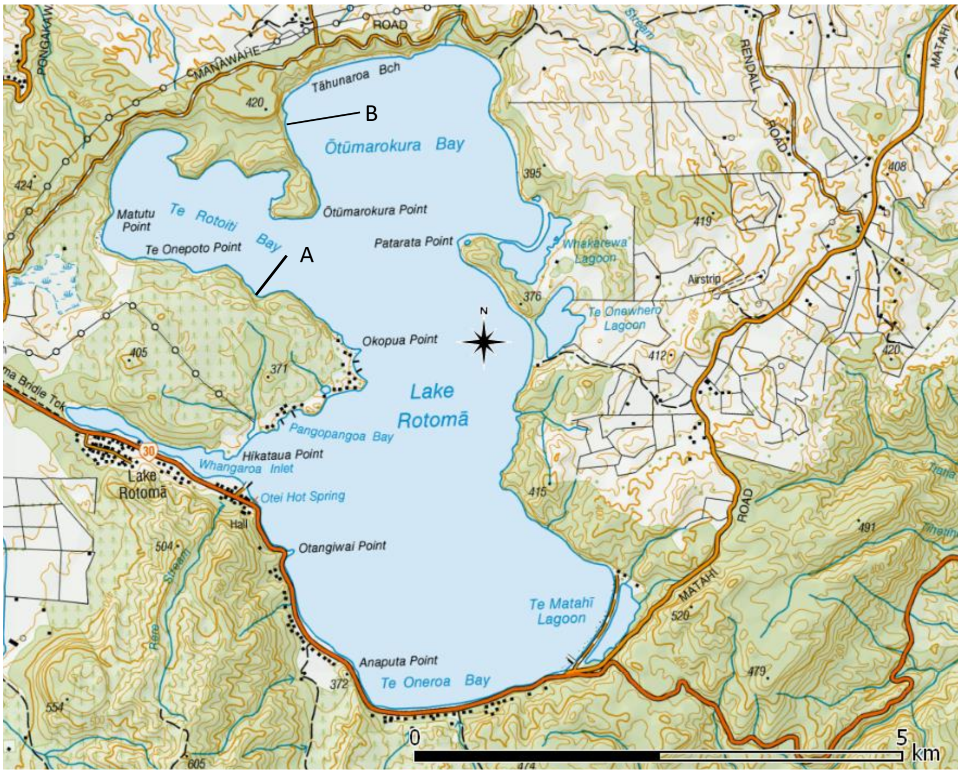

Figure 4 Lake Rotomā showing the approximate locations and direction of the West (A) and North (B) tau kōura sampling sites.

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 determine kōura wet weight (Kusabs *et al.* 2015a). 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. After processing, all kōura were returned live to the water in close proximity to the tau kōura. Total sample handling time for two to three people to retrieve and process the samples from each tau kōura was typically 2 hours.

Comparison of kōura data with other Rotorua Te Arawa lakes

Kōura data from lakes Ōkataina and Rotomā was compared with that collected from 13 other Rotorua Te Arawa lakes. The sources of this data are shown in Table 2.

Table 2 Lake, month/year sampled and source of kōura data for 15 Rotorua Te Arawa lakes.

Lake	Month/year sampled	Source
Ōkāreka	April, July, November 2009	Kusabs et al. (2015b)
Ōkataina	November 2018, February, May and August 2019	This report
Ngāhewa	December 2016	Kusabs (2017a)
Ngāpouri	December 2016	Kusabs (2017a)
Ōkaro	March, June, Nov 2016; February 2017	Kusabs (2017b)
Rerewhakaaitu	March, June, Nov 2016; February 2017	Kusabs (2017b)
Rotoehu	October 2018, March 2019	Kusabs (2019b)
Rotoiti	February, May, August, November 2018	Kusabs (2019a)
Rotokakahi	April, July, November 2009	Kusabs et al. (2015b)
Rotomā	October 2018, March, May and August 2019	This report
Rotomahana	July 2017, October 2017, January 2018, May 2018	Kusabs (2018)
Rotorua	February, May, August, November 2018	Kusabs (2019c)
Tarawera	April, July, November 2009	Kusabs et al. (2015b)
Tikitapu	July 2017, October 2017, January 2018, May 2018	Kusabs (2018)
Tutaeinanga	December 2016	Kusabs (2017a)

Comparison of kōura data previously collected from Lake Rotomā

Kōura population data for this study (2019) were compared with surveys carried out in April, July, November 2009 and November 2013 (Table 3).

Table 3 Survey year/month(s) sampled and source of kōura data for surveys carried out in Lake Rotomā from 2009 to 2019.

Year/Month sampled	Purpose & source
April, July, November 2009	PhD study; Kusabs et al. (2015b)
November 2013	University of Waikato study, Kusabs unpub. data;
October 2018, March, May & August 2019	This report (Kusabs 2019)

Data Analysis

The one-way analysis of variance (ANOVA) was used to determine whether there were any statistically significant differences in mean kōura CPUE and BPUE between the 2 sites in each lake. ANOVA was also used to compare differences in mean kōura CPUE and BPUE recorded in November 2018, May and August 2019 with baseline surveys carried out in April, July and November 2009. In addition, ANOVA with post-hoc Bonferroni-Holm comparisons were used to determine differences in mean CPUE and BPUE in November 2009, November 2013 and October 2019 in Lake Rotomā.

The Mann-Whitney U Test was used to determine differences in kōura OCL in the two lakes. Mann-Whitney is a non-parametric test of the null hypothesis that it is equally likely that a randomly selected value from one sample will be less than or greater than a randomly selected value from a second sample.

The Kolmogorov-Smirnov test for normality was used to determine whether the variables were normally distributed. Levene's test was used to test for equal variance. Where necessary, data was log transformed 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) and R version 3.3.3.

RESULTS

Lake Ōkataina

Kōura abundance and biomass

A total of 1295 kōura were captured in Lake Ōkataina with a mean CPUE of 15.4 ± 10.3 mm (± 1 SD) kōura whakaweku^{-1} and a mean BPUE of 245.7 g ± 251.6 mm (±1 SD) kōura whakaweku^{-1}. The highest mean CPUE (29.5 kōura whakaweku^{-1}) and mean BPUE (654.4 g kōura whakaweku^{-1}) were both recorded in May at the South site (Table 4). ANOVA showed that there were no significant differences in mean CPUE (p = 0.63), or mean BPUE (p = 0.20), between the two sites over the sampling period. The mean CPUE was 15.9 ± 10.1 (±1 SD) kōura whakaweku^{-1} for the North site compared to 14.9 ± 10.6 (±SD) kōura whakaweku^{-1} for the South site, while the mean BPUE was 211.6 g ± 230.3 (± 1 SD) kōura whakaweku^{-1} for the North site compared to 283.1 g ± 271.2 (± 1 SD) kōura whakaweku^{-1} for the South site (Table 4).

Table 4 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 whakaweku, set at two sites in Lake Ōkataina and retrieved from November 2018 to August 2019. (Standard deviation).

Date	Mean CPUE (n ± 1 SD)		Mean BPUE (g ± 1 SD)	
	North	South	North	South
23 November 2018	24.6 (12.3)	8.9 (2.6)	480.3 (345.4)	65.0 (26.3)
13 February 2019	19.0 (9.0)	10.5 (8.9)	165.1 (83.1)	171.7 (135.6)
23 May 2019	11.9 (5.9)	29.5 (8.4)	130.3 (105.7)	654.4 (240.6)
16 August 2019	9.9 (6.7)	10.5 (3.7)	103.3 (70.7)	241.2 (141.0)
Mean	15.9 (10.1)	14.9 (10.6)	211.6 (230.3)	283.1 (271.2)

Kōura size

The mean OCL of all kōura collected in Lake Ōkataina was 24.2 ± 6.9 mm (± 1 SD) with individuals ranging from 6 to 45 mm OCL (Table 5; Fig. 5). Female kōura were significantly (p <0.01) larger than male kōura, with a mean size of 25.5 mm ± 6.8 mm (± 1 SD) for females, compared to 23.5± 6.4 mm (± 1 SD) for males.

Three size classes were identified as cohorts in Lake Ōkataina from the May 2019 samples (Fig. 5). The young-of-the-year (YOY) cohort ranged from 6 to ~14 mm, the age 1-year class was ~15 to 21 mm, and the age 2-year class from ~20 to 25 mm. The likelihood of overlap was too high to reliably determine year classes above these ages.

Table 5 Mean OCL (n ± SD) and range (mm) and percentage of females for kōura captured in two tau kōura (each composed of 10 whakaweku) set at two sites in Lake Ōkataina and retrieved from November 2018 to August 2019. (n) = number of kōura sexed.

Date	Mean OCL (n ±SD)		OCL Range (mm)		Female to male % (n)	
	North	South	North	South	North	South
23 November 2018	27.7 (7.1)	19.3 (5.3)	10 - 45	6 - 38	33.8 (151)	55.4 (89)
13 February 2019	21.0 (5.3)	25.8 (5.0)	9 - 36	16 - 38	51.4 (185)	46.1 (102)
23 May 2019	21.6 (6.7)	29.1 (5.1)	6 - 41	14 - 45	46.3 (160)	59.8 (291)
16 August 2019	20.6 (7.4)	29.1 (6.6)	6 - 43	16 - 45	43.6 (99)	65.3 (101)

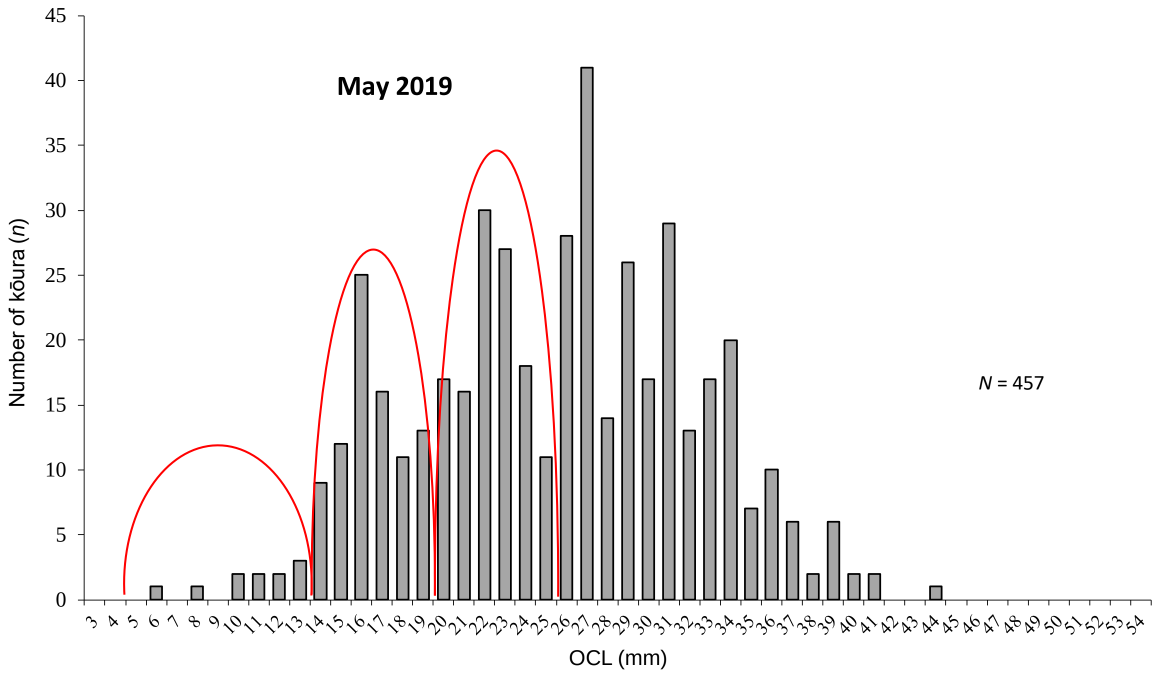

Figure 5 Length frequency distribution of kōura captured on two tau kōura (each composed of 10 whakaweku) set in Lake Ōkataina, sample collected 23 May 2019. The young-of-the-year (YOY) cohort and the age 1 and 2-year classes are outlined in red.

Percentage females, breeding kōura and soft shells

The overall ratio of female to male kōura in Lake Ōkataina was ~50%, with the percentage of females caught over the sampling period ranging from 33.8 to 65.3% (Table 5). Egg-bearing kōura were recorded in Lake Ōkataina in October, May and August but none were collected in February (Table 6). Female kōura bearing hatchlings or eggs ranged in size from 24 to 42 mm OCL. Kōura in soft shells were present on all four sampling occasions, with the highest percentage recorded in May (15%) (Table 6).

Common bullies

A total of 139 common bullies (*Gobiomorphus cotidianus*) were captured over the sampling period with the highest catch recorded in November (*n* = 81) with the lowest catch in August (*n* = 9).

Table 6 Number of kōura sampled, mean percentage of breeding size females with eggs or young (defined as >21 mm OCL) and mean percentage of kōura with soft shells, in samples collected from two tau kōura (each composed of 10 whakaweku) set at two sites in Lake Ōkataina and retrieved from November 2018 to August 2019. (*n*) = number of kōura sexed.

Survey date	Number of kōura sampled	% Breeding size females with eggs	Range breeding size OCL mm	% Soft shells
23 November 2018	240	18.6 (11)	25 - 41	7.9 (19)
13 February 2019	291	0	-	5.5 (16)
23 May 2019	457	28.3 (212)	24 - 42	14.9 (68)
16 August 2019	200	57.5 (73)	24 - 43	8.0 (16)

Lake Rotomā

Kōura abundance and biomass

Kōura were abundant in Lake Rotomā with a total of 1807 kōura captured at a mean CPUE of 22.6 ± 18.0 (± 1 SD) kōura whakaweku^{-1} and a mean BPUE of 391.9 g ±18.0 (± 1 SD) koura whakaweku^{-1}. The highest mean CPUE (39.2 kōura whakaweku^{-1}) was recorded in May at the North Site, whereas the highest mean BPUE (693.3 g kōura whakaweku^{-1}) was recorded in October, also at the North site (Table 7). There were no significant differences in mean kōura CPUE (p = .25), or mean BPUE (p = .41), between the two sites over the sampling period.

Table 7 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 whakaweku, set at two sites in Lake Rotomā and retrieved from October 2018 to August 2019. (Standard deviation).

Date	Mean CPUE (*n* ± SD)		Mean BPUE (g ±SD)	
	West	North	West	North
25 October 2018	21.3 (12.7)	32.7 (8.9)	461.9 (407.4)	693.3 (172.4)
14 March 2019	12.4 (8.6)	13.8 (10.6)	209.9 (131.9)	240.1 (188.0)
23 May 2019	22.0 (13.8)	39.2 (34.2)	407.4 (321.5)	437.7 (399.0)
16 August 2019	18.6 (9.8)	20.7 (17.6)	339.8 (260.1)	345.0 (339.9)
Mean	18.6 (11.6)	26.6 (22.1)	354.7 (301.4)	429.0 (327.6)

Kōura size

The mean OCL of all kōura collected in Lake Rotomā was 25.6 ± 9.2 mm (± 1 SD) with individuals ranging from 3 to 53 mm OCL (Table 8; Fig. 6). The mean OCL of females was 28.2 ± 7.9 mm (± 1 SD) significantly larger (p <0.01) compared to 25.5 ± 6.9 mm (± 1 SD) for males. Three size classes were identified as cohorts in Lake Rotomā from the May 2019 samples (Fig. 6). The young-of-the-year (YOY) cohort ranged from 3 to ~12 mm, the age 1-year class ~15 to 21 mm, the age 2-year class from ~21 to 26 mm. The likelihood of overlap was too high to reliably determine year classes above these ages.

Table 8 Mean orbit carapace length (OCL), OCL range and female percentage, of kōura captured in two tau kōura (each composed of 10 whakaweku) set at two sites in Lake Rotomā and retrieved from October 2018 to August 2019. (*n*) = number of kōura sexed. (Standard deviation).

Date	Mean OCL (*n* ±SD)		OCL Range (mm)		Female to male % (*n*)	
	West	North	West	North	West	North
25 October 2018	27.0 (9.1)	27.4 (9.1)	7 - 52	8 - 50	66.3 (172)	64.4 (216)
14 March 2019	27.4 (6.7)	24.5 (8.8)	13 - 42	10 - 53	49.0 (104)	62.6 (131)
23 May 2019	25.3 (9.5)	22.0 (10.7)	3 - 46	3 - 48	62.3 (167)	69.0 (129)
16 August 2019	26.0 (8.6)	25.0 (8.4)	6 - 47	5 - 43	65.6 (163)	62.1 (174)

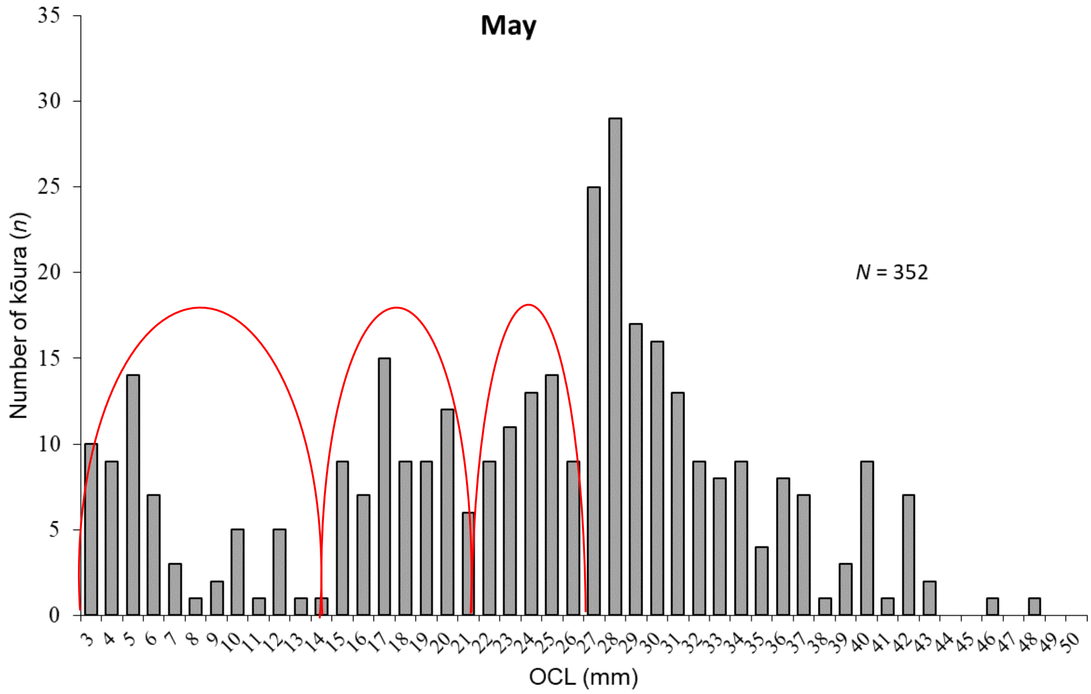

Figure 6 Length frequency distribution of kōura captured on two tau kōura (each composed of 10 whakaweku) deployed in Lake Rotomā, samples collected 23 May 2019. The young-of-the-year (YOY) cohort and the age 1 and 2-year classes are outlined in red.

Percentage females, breeding kōura and soft shells

Female kōura comprised 63% of the samples collected over the four sampling months (Table 8). Egg-bearing kōura were present in Lake Rotomā on all four sampling occasions with the highest proportions recorded in October (61%) and August (48%) and the fewest in March (4%) (Table 9).

Female kōura bearing eggs, hatchlings, or spermatophores ranged in size from 21 to 52 mm OCL. Kōura in soft shells were present on all four sampling occasions with the highest numbers recorded in May (13%) (Table 9).

Table 9 Number of kōura sampled, mean percentage of breeding size females with eggs or young (defined as >21 mm OCL) and mean percentage of kōura with soft shells, in samples collected from two tau kōura (each composed of 10 whakaweku) set in Lake Rotomā and retrieved from October 2018 to August 2019 (*n*) = number of kōura.

Survey date	Number of kōura sampled	% Breeding size females with eggs	Range breeding size OCL mm	% Soft shells
25 October 2018	401	61.4 (129)	21 - 52-	2.0 (8)
14 March 2019	242	4.0 (4)	32 - 41	7.0 (17)
23 May 2019	352	24.2 (37)	27 - 48	13.4 (47)
16 August 2019	376	48.1 (88)	22 - 44	6.4 (24)

Common bullies

A total of 109 common bullies were captured over the sampling period with the highest catches recorded in October (*n* = 51) and August (*n* = 32) with catches dropping off in March (*n* = 8) and May (*n* = 18).

Figure 7 Niwa Nuri and Cyrus Hingston from Ngāti Tarāwhai monitoring kōura, Lake Rotomā, 21 August 2019 (Ian Kusabs).

Lake Rotomā – comparison with previous surveys

Kōura abundance and biomass

Kōura abundance and biomass were lower in 2019 (October 2018, May & August 2019) compared to 2009 (April, July & November 2009) (Table 10). Overall Mean CPUE has decreased by 21% from 32.6 kōura whakaweku^{-1} (2009) to 25.8 kōura whakaweku^{-1} (2019) (p = .08) (Table 10). While, overall mean BPUE has declined significantly (p = .001) by 50% from 749 g kōura whakaweku^{-1} (2009) to 448 g kōura whakaweku-^{1} (2019) (Table 10). Although, mean CPUE and mean BPUE were generally lower in 2019 than in 2009, the only significantly difference (p < .001) was for mean BPUE in autumn (April 2009 vs May 2019) (Table 10).

Table 10 Season, year, mean catch per unit effort (CPUE) and mean biomass per unit effort (BPUE) and significance (ANOVA) of kōura collected from two tau kōura each composed of 10 whakaweku, retrieved from two sites in Lake Rotomā in 2009 and 2019. (Standard deviation).

Season	Mean CPUE (n ± SD)		ANOVA	Mean BPUE (g ± SD)		ANOVA
	2009	2019		2009	2019	
Autumn	41.8 (25.3)	30.6 (26.9)	p = .18	798.6 (508.9)	422.5 (353.0)	p < .001
Winter	30.0 (23.6)	19.7 (13.9)	p = .19	645.7 (673.7)	342.4 (294.6)	p = .07
Spring	26.2 (18.7)	27.0 (12.2)	p = .87	802.1 (672.3)	577.6 (326.8)	p = .19
All	32.6 (23.2)	25.8 (19.1)	p = .08	748.8 (616.9)	447.5 (334.9)	p = .015

Further in-depth analysis showed that the declines in overall mean CPUE and BPUE have occurred primarily at the West site where there has been a 55% decline in mean CPUE (p = .04), and a 60% decline in mean BPUE (p = .03) (Table 11). In contrast, there have been no significant changes in mean CPUE (p = .76) or mean BPUE (p = .27) at the North site over the same period (Table 11). Furthermore, a comparison of mean CPUE and mean BPUE for November 2009, November 2013 and October 2019 also showed no significant changes (p > .20).

Table 11 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 whakaweku, retrieved from two sites in Lake Rotomā in 2009 (May, July, November 2009) and 2019 (October 2018, March & August 2019). (Standard deviation).

Site	Mean CPUE (n ± SD)		Mean BPUE (g ± SD)		Mean OCL (mm ± SD)	
	2009	2019	2009	2019	2009	2019
West	36.2 (25.2)	20.6 (11.9)	751.6 (623.5)	403.0 (327.3)	29.8 (6.8)	26.1 (9.1)
North	29.1 (21.0)	30.9 (23.3)	746.0 (620.8)	492.0 (341.9)	27.3 (8.1)	25.0 (9.6)
Both	32.6 (23.3)	25.8 (19.1)	748.8 (616.9)	447.5 (334.9)	28.3 (7.7)	25.6 (9.4)

Kōura size

Kōura ranged in size from 3 to 52 mm OCl in 2019 (October 2018, May & August 2019) compared to 6 to 51 mm OCL in 2009 (April, July & November 2009). Kōura were significantly smaller in 2019 than in 2009 with a with a mean size of 25.6 mm for kōura collected in 2019 compared to 28.3 mm for those collected in 2009 (Table 12). Length-frequency analysis of kōura size data shows that this is due to a decline in the numbers of kōura in the 24 to 34 mm OCL size class (Fig. 8).

Table 12 Season, year, orbit carapace length (OCL) mean & range, and significance (Mann- Whitney) of kōura collected from two tau kōura each composed of 10 whakaweku, retrieved from two sites in Lake Rotomā in 2009 (May, July, November 2009) and 2019 (October 2018, May 2019 and August 2019). (Standard deviation).

Season	Mean OCL (mm ± SD)		Mann- Whitney	OCL Range (mm)	
	2009	2019		2009	2019
Autumn	26.7 (6.3)	23.7 (10.2)	*p* < .001	9 - 51	3 -48
Winter	27.4 (7.8)	25.5 (8.5)	*p* = .03	6 - 49	5 - 47
Spring	31.3 (7.2)	27.2 (9.1)	*p* < .001	9 - 50	7 - 52
All	28.3 (7.7)	25.6 (9.4)	*p* < .001	6 - 51	3 - 52

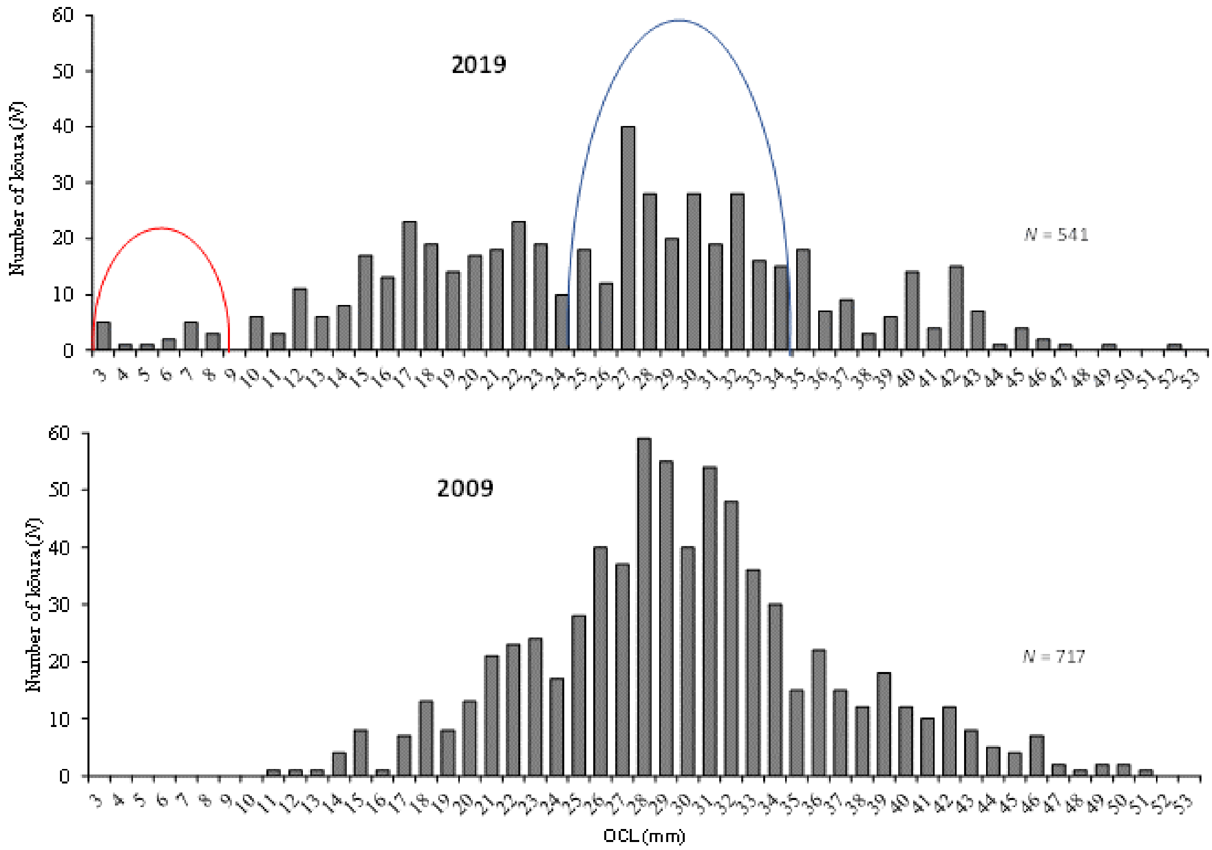

Figure 8 Length-frequency distributions of kōura collected from two tau kōura each composed of 10 whakaweku set in Lake Rotomā and retrieved in 2019 (October 2018, May 2019 and August 2019) and 2009 (April, July and November 2009). OCL = orbit carapace length. The young-of-the-year (YOY) cohort is outlined in red and the blue outline shows the 24 - 34 mm OCL size class, which was much reduced in 2019 *cf*. to 2009.

Kōura population dynamics in relation to other Rotorua Te Arawa Lakes

Kōura abundance and biomass

Lake Rotomā was ranked first in terms of mean CPUE (22.6 kōura whakaweku^{-1}) and second in mean BPUE (392g kōura whakaweku^{-1}) in the 15 Rotorua Te Arawa lakes where kōura monitoring has been undertaken (Fig. 9). Whereas, Lake Ōkataina ranked third in both mean CPUE (15.4 kōura whakaweku^{-1}) and mean BPUE (246 g kōura whakaweku^{-1}) (Figs. 9A & 9B).

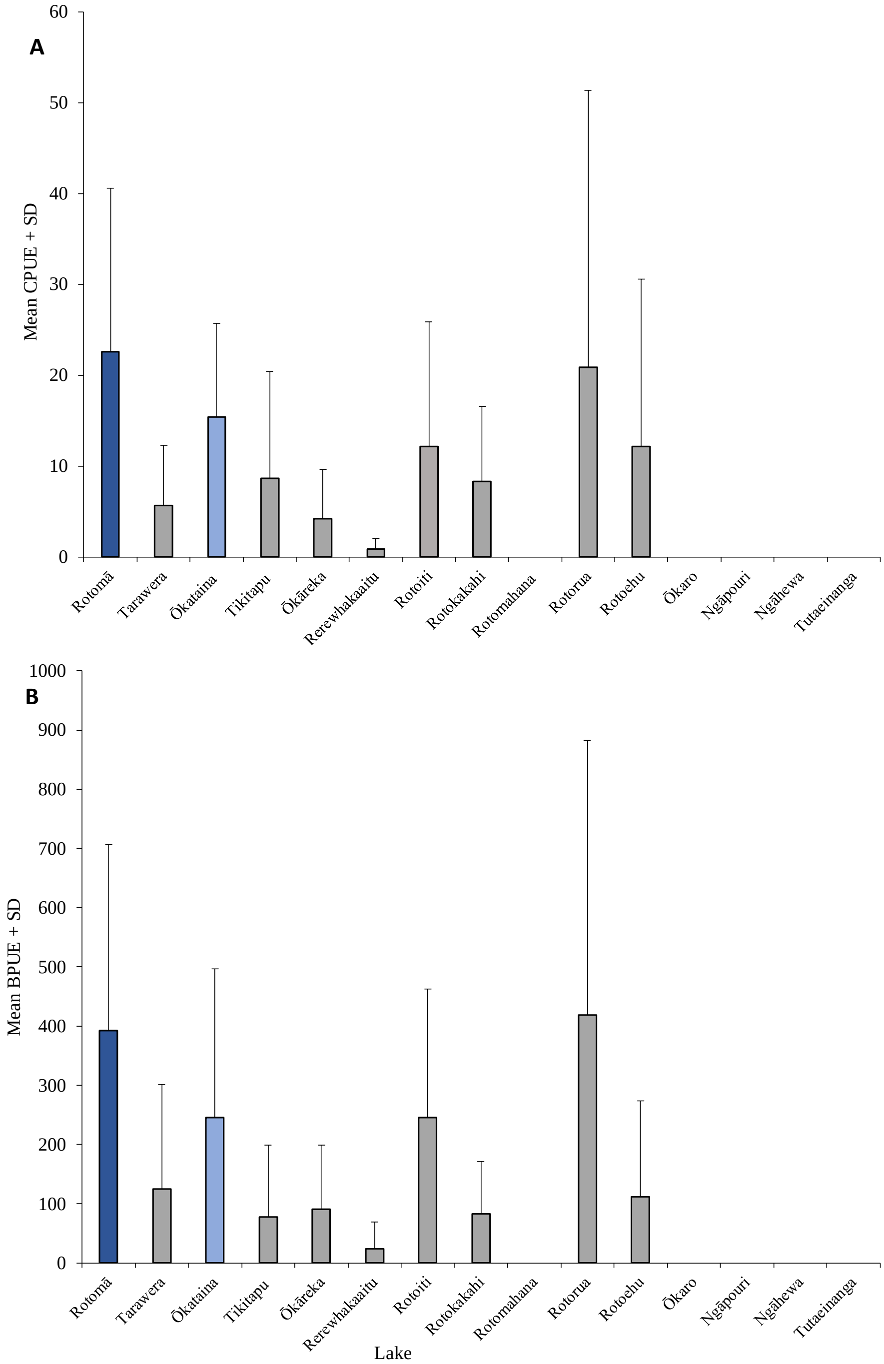

Figure 9 (A) Mean catch-per-unit-effort (CPUE; mm + SD) and (B) mean biomass-per-unit-effort (BPUE; g+ SD) of kōura collected using the tau kōura method in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing Chl-a concentration. Lake Ōkataina is highlighted in light blue and Lake Rotomā in dark blue. Refer Table 2 for details and source of kōura data.

Kōura size

In terms of mean kōura size, Lake Rotomā was ranked fifth (25.6 mm OCL) and Lake Ōkataina sixth (24.2 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded (Fig. 10). Size of kōura in Lake Rotomā ranged from 3 to 52 mm OCL, the greatest size range recorded in any of the Rotorua Te Arawa Lakes. Moreover, the 3 mm kōura collected from Lake Rotomā (at both sites) in the May 2019 survey were the smallest found in any of the Rotorua Te Arawa Lakes to date.

Egg-bearing kōura were present in Lake Rotomā on all four sampling occasions with the highest proportions recorded in spring and winter, compared to autumn and winter in Lake Ōkataina. The smallest female kōura in breeding condition in Lake Rotomā was 21 mm OCL and 24 mm OCL in Lake Ōkataina, consistent with that recorded in the majority of the Rotorua Te Arawa lakes.

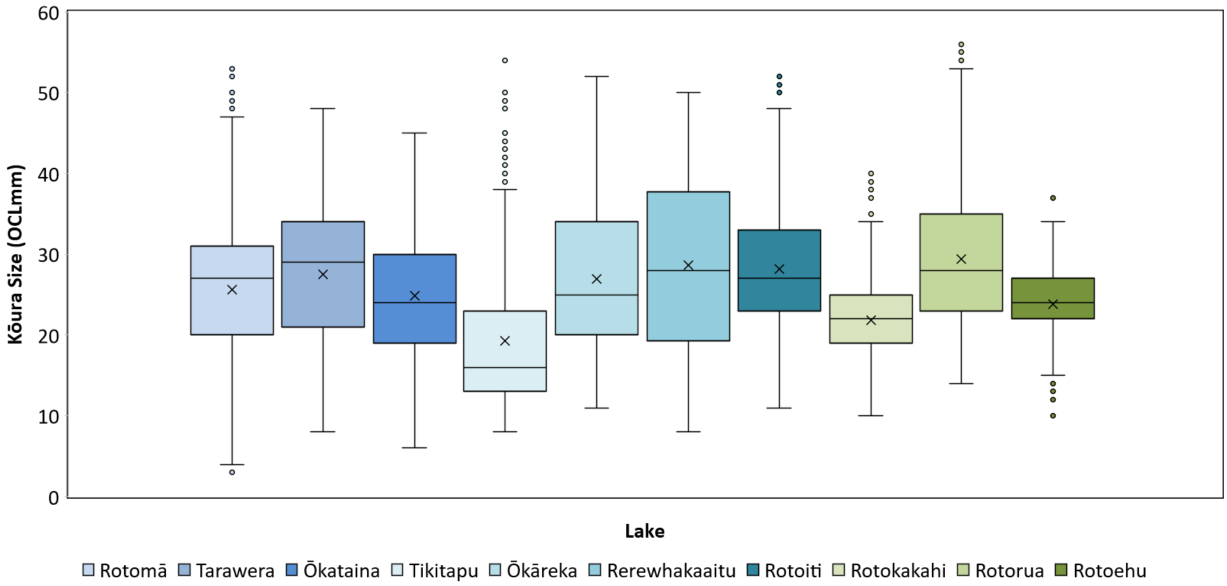

Figure 10 Box-and-whisker plot showing mean (x), median (horizontal line), interquartile range (box), distance from upper and lower quartiles times 1.5 interquartile range (whiskers), outliers (>1.5× upper or lower quartile) for kōura orbit carapace length for kōura collected in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing Chl-a concentration. Refer Table 2 for details and source of kōura data.

DISCUSSION

Lakes Ōkataina and Rotomā

The kōura populations in lakes Ōkataina and Rotomā were characterised by high numbers of harvestable sized (>28mm OCL) kōura. Length frequency analyses showed that the kōura populations in both lakes had well-balanced size structures, with kōura ranging in size from 3 to 52 mm OCL in Lake Rotomā and 6 to 45mm in Lake Ōkataina. The collection of small juvenile kōura (< 10mm) at depths >20 m reflects the excellent water quality (oligotrophic) in the two lakes and also the absence of catfish. In contrast, in lakes Rotorua and Rotoiti where catfish are now established, the kōura populations are mostly composed of medium and large sized individuals with few kōura <23mm in Lake Rotorua and <28 mm in Lake Rotoiti (at Te Ākau site).

In Lake Rotomā, kōura abundance and biomass were lower in 2019 compared to the 2009 baseline surveys. Mean CPUE has decreased by 21% from 32.6 to 25.8 kōura whakaweku^{-1} while mean BPUE has declined significantly by 50% from 749 to 448 g kōura whakaweku^{-1}. These decreases can be attributed to reduced catches at the West sampling site. The reason for this is unknown but it is located next to a tau kōura, where kōura are regularly harvested by a local practitioner.

The proportion of kōura in breeding condition was highest in Lake Ōkataina in winter and autumn, which is consistent with most of the Rotorua Te Arawa lakes (Kusabs *et al.* 2015a). Lake Rotomā is similar to lakes Rotorua and Tikitapu where the highest proportion of egg-bearing kōura are present in spring (Kusabs 2018, Kusabs 2019c, Kusabs *et al.* 2015a).

The presence of very small juvenile kōura at water depths greater than 20 m in lakes Rotomā and Ōkataina was a surprising finding of this study. Previously, female kōura were thought to release their juveniles exclusively in the shallow littoral (<10 m water depth) where food resources are more abundant (Devcich 1979). The capture of recently-fledged juvenile kōura at depths >30 m in Lake Rotomā is definitive evidence that kōura do not have to enter the littoral zone to complete their lifecycles.

In Lake Taupō, high numbers of kōura have been reported despite catfish establishment in the 1980's (Kusabs & Taiaroa, 2015). Dedual (2002) used ultrasonic telemetry to investigate the vertical distribution and movement of catfish in Motuoapa Bay, and found that catfish generally swim within the top 10 m of water and occasionally in water as deep as 17 m. Catfish were found to favour the presence of rooted plants, therefore they were mainly concentrated in the littoral zone where weed beds were present (Dedual 2002). Kusabs & Taiaroa (2015) hypothesised that the relatively high abundance of kōura in Lake Taupō was due to minimal habitat overlap between the two species, with catfish present mainly in the littoral zone (<10 m), and kōura at depths >10 m. It is highly likely that female kōura in Lake Taupō also release their juveniles at depths (>~20 m) where catfish are rare.

Furthermore, it is possible that kōura populations in oligotrophic lakes (where the bottom waters remain well oxygenated throughout the year) may be less severely impacted by catfish predation than those in mesotrophic and eutrophic lakes, where hypolimnetic deoxygenation leads to the movement of kōura into the littoral zone where catfish are most abundant. Improving and maintaining water quality to ensure that the bottom waters remain well oxygenated, and kōura can complete their lifecycles at depth, may be the best means of maintaining abundant kōura populations in lakes with (and without) catfish.

Summary and conclusions

Lakes Ōkataina and Rotomā support abundant populations of koura with a mean CPUE of 15.4 kōura whakaweku^{-1} recorded in Lake Ōkataina and 25.8 kōura whakaweku^{-1} in Lake Rotomā.

Lake Rotomā was ranked first in terms of mean CPUE and second in mean BPUE in the 15 Rotorua Te Arawa lakes where kōura monitoring has been undertaken. Whereas, Lake Ōkataina ranked third in both mean CPUE and mean BPUE.

In terms of mean kōura size, Lake Rotomā was ranked fifth (25.6 mm OCL) and Lake Ōkataina sixth (24.2 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded. The size structure of kōura in both lakes was well-balanced with kōura ranging in size from 3 to 52 mm OCL in Lake Rotomā and 6 to 45 mm OCL in Lake Ōkataina. The presence of small juvenile kōura (<10mm) at depths >20 m reflects the excellent water quality (oligotrophic) in the two lakes and that catfish are unlikely to be present.

In Lake Rotomā, kōura abundance and biomass were lower in 2019 compared to the 2009 baseline survey. Mean CPUE has decreased by 21% and mean BPUE by 50%, the majority of this decline has occurred at one sampling site. The reasons for this are unknown but it could be due to customary kōura harvesting near our West site.

The capture of recently fledged juvenile kōura at water depths >30 m in Lake Rotomā is evidence that kōura do not have to enter the littoral zone to complete their lifecycles. This suggests that improving and maintaining water quality to ensure that the bottom waters remain well oxygenated, and kōura can complete their lifecycles at depth, may be the best means of maintaining abundant kōura populations in lakes with (and without) catfish.

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