LAKES TARAWERA AND ŌKĀREKA

ROTORUA TE ARAWA LAKES KŌURA MONITORING PROGRAMME 2020

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Cover image

Kōura collected from Mōura Bay (White Cliffs), Lake Tarawera, on 10 July 2019.

Table of Contents

EXECUTIVE SUMMARY

Kōura are considered a taonga species by Te Arawa iwi and are an important ecological component in lakes where they are present. The purpose of this study was to survey kōura populations in lakes Tarawera and Ōkāreka as part of the Rotorua Te Arawa Lakes kōura monitoring programme. This report provides an analysis of monitoring data for kōura from lakes Tarawera and Ōkāreka and comparisons with baseline data collected in 2009, as well as with kōura data recorded from 13 other Rotorua Te Arawa lakes.

The Tarawera and Ōkāreka 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). Tau kōura surveys had previously been carried out in these lakes in April, July and November 2009 (Kusabs et al. 2015).

In this study, new monitoring sites were established at Te Toitoi Point in Lake Tarawera and at the outlet at Lake Okareka. These sites were selected to provide a more representative geographical spread across the two lakes. Comparisons with the 2009 baseline surveys were, therefore, only carried out at the Te Mōura site in Lake Tarawera and the East site in Lake Okareka.

Lake Tarawera supports an abundant population of koura with a mean CPUE of 24.7 kōura whakaweku^{-1} and a mean BPUE of 631.2 g kōura whakaweku^{-1}. Lake Tarawera is now ranked first in terms of relative abundance and biomass in the 15 Rotorua Te Arawa lakes. Whereas in 2009, Lake Tarawera was ranked sixth in relative abundance and fifth in biomass. There are a number of reasons for this rise in the rankings, these include; (a) higher catches of kōura in spring and summer at Te Mōura site, (b) high catches of kōura at the new Te Toitoi Point site (compared to the low catches recorded in 2009 at Te Wairoa Bay site), and (c) a drastic decline in kōura CPUE and BPUE in lakes Rotoiti and Rotorua due to the establishment of (and increased predation pressure by) brown bullhead catfish.

Lake Ōkāreka supports a low to moderate population of kōura with a mean CPUE of 5.6 kōura whakaweku^{-1} and a mean BPUE of 91.4 g kōura whakaweku^{-1}. Lake Ōkāreka is ranked ninth in terms of relative abundance and sixth in terms of relative biomass in the 15 Rotorua Te Arawa lakes. Kōura abundance and biomass in Lake Okareka (East site) were lower than those recorded in 2009. Mean CPUE decreased by - 41.3% from 4.6 to 2.7 kōura whakaweku^{-1} while mean BPUE decreased by - 49.7% from to 52 g kōura whakaweku-^{1}. The decreases in relative abundance and biomass were due to the low catch recorded in spring (i.e., November 2019), which was most likely due to earlier stratification and deoxygenation of the hypolimnion.

The size structure of kōura in both lakes was well-balanced with kōura ranging in size from from 3 to 47 mm OCL in Lake Tarawera and 6 to 47 mm in Lake Ōkāreka. The balanced size structure, and the fact that kōura sizes have not increased significantly in either of the lakes, suggests that catfish are absent (or present in very low numbers).

Given the size of Lake Tarawera, it is recommended that, in future, five tau kōura monitoring sites are used to representatively sample the kōura population in this large lake i.e., tau kōura sited in the northern, southern, eastern and western areas of the lake and the Wairua Arm.

List of Figures

List of Tables

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 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 lakes and are considered a keystone species acting as predators, shredders, and detritivores (Nyström 2002). They are also an important mahinga kai species for Te Arawa iwi (Hiroa 1921; Stafford 1996, Kusabs et al. 2015a) supporting important customary fisheries in lakes Ōkataina, Rotoiti, Rotomā and Tarawera.

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, Kusabs et al. 2015, Kusabs et al. 2015a) has greatly increased understanding of kōura populations in the Rotorua Te Arawa lakes.

Regular monitoring of kōura is important because it can answer conservation questions such as ‘What are the impacts of invasive fish species on kōura?’, ‘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 3 – 4-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 survey kōura populations in lakes Tarawera and Ōkāreka as part of the Rotorua Te Arawa Lakes kōura monitoring programme.

METHODS

Study area

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

Lake Tarawera, is one of the largest lakes in New Zealand and is of great cultural significance to the tāngata whenua, Tūhourangi and Ngāti Rangitihi (TALT 2019). Lake Tarawera is in the southwest section of the Haroharo Caldera. The lake has a total area of 41 km^2 and a catchment area of 145 km^2. The average depth of the Lake is 50 m and at its deepest point it is 87.5 m (LAWA 2019a). Lake Tarawera is an oligotrophic lake, with the trophic level index (TLI) fluctuating between 2.7 and 2.9 in the last five years (BOPRC, 2020). The target TLI for the lake is 2.6. The catchment is largely covered in indigenous forest and scrub, with about 20 percent pasture cover and 16 percent exotic forest (LAWA 2019a). Lakes Ōkāreka, Ōkataina, Rotokakahi, Rotomahana and Tikitapu all drain into Lake Tarawera either via surface water or groundwater flows. Lake Ōkaro and Lake Rerewhakaaitu drain first to Lake Rotomahana, then to Lake Tarawera. Lake Tarawera is the main source of the Tarawera River, which flows into the Bay of Plenty at Matata.

Lake Ōkāreka is of significant cultural importance to Tūhourangi and Ngāti Tarāwhai (TALT 2019a). Ōkāreka is a medium sized, mesotrophic lake with a 3-year average TLI of 3.3 (BOPRC, 2020). The target TLI for the lake is 3.0. The lake has total area of 3.4 km^2 and a catchment area of 19.6 km^2 (LAWA 2019b). The catchment is approximately half forested (75% native) with the remaining land largely pastoral. The average depth of the lake is 20 m and the deepest point of the lake is 34 m (LAWA 2019b). Lake Ōkāreka drains to Lake Tarawera via Waitangi Springs and an artificial surface channel and pipeline.

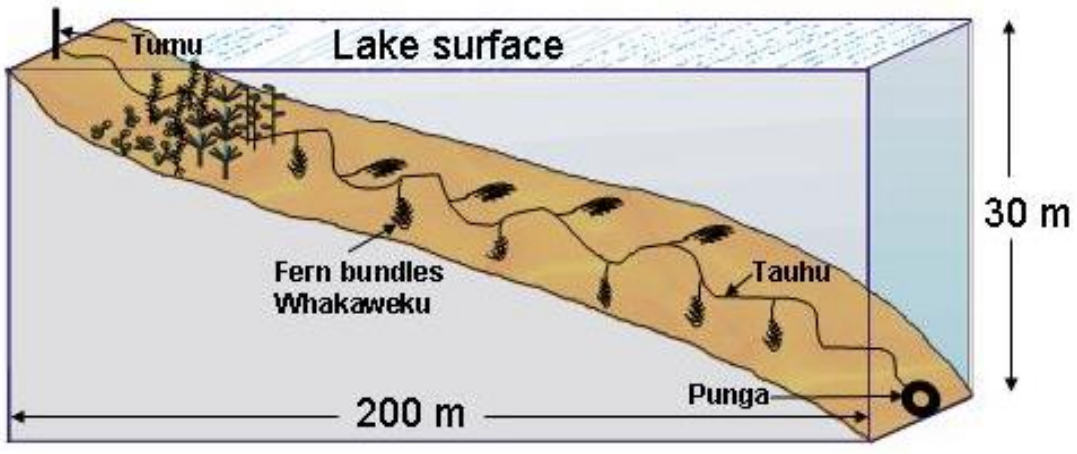

Figure 1 Schematic diagram of the tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

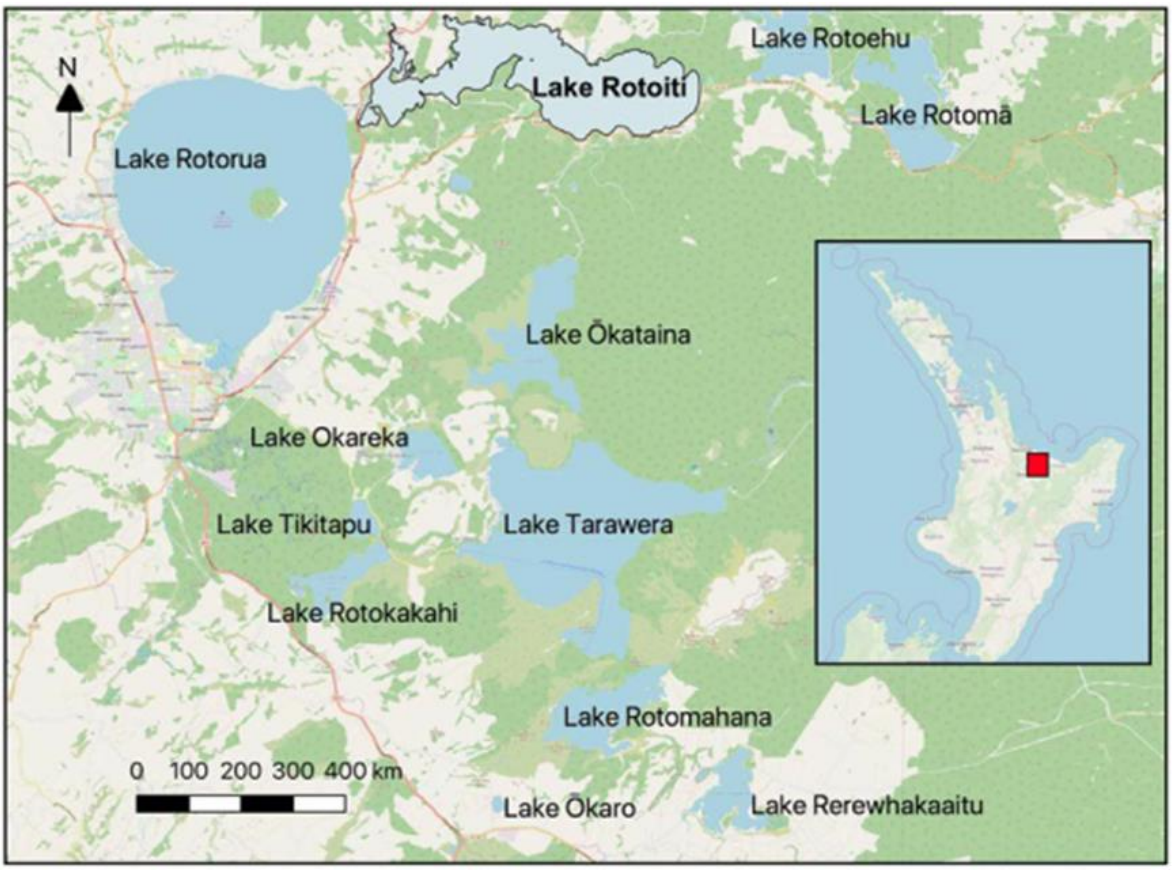

Figure 2 Map of the Rotorua Te Arawa Lakes showing the location of lakes Tarawera and Ōkāreka.

Tau kōura construction and use

The kōura populations in lakes Tarawera and Ōkāreka 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). Whakaweku were set in depths ranging from 7 to 27 m in Lake Tarawera and 7 to 24 m in Lake Ōkāreka (Table 1; Figs. 3 & 4).

Two tau kōura were set in Lake Tarawera, one in Te Mōura Bay (an existing site used by Kusabs et al. 2009) and another at Te Toitoi Point, a new site, which was chosen to sample kōura populations along the extensive northern shoreline of the lake (Figure 4). The tau kōura were deployed in Lake Tarawera on 10 July 2019 and were left for approximately 15 weeks to allow kōura to colonise the fern before first retrieval on 7 November 2019, they were retrieved again on 3 February 2020, 20 May 2020 and 14 August 2020.

Two tau kōura were set in Lake Ōkāreka, one on the eastern shoreline (an existing site used by Kusabs et al. 2009) and another at a new site near the lake outlet (Figure 3). Tau kōura were deployed in Lake Ōkāreka on 10 July 2019 and were left for approximately 13 weeks to allow kōura

to colonise the fern before first retrieval on 8 November 2019, they were retrieved again on 4 February 2020, 20 May 2020 and 14 August 2020. Owing to decomposition of whakaweku, some whakaweku were replaced in both lakes with fresh bracken fern on 22 June 2020.

Table 1 Sampling site, grid reference and approximate location of kōura monitoring sites in lakes Tarawera and Ōkāreka, depths were recorded in Lake Tarawera on 7 November 2019 and in Lake Ōkāreka on 8 November 2019.

Lake	Sampling site	Latitude Longitude (Degrees, minutes, seconds)	Water depth (m)
Tarawera	Te Toitoi Point	S 38°10'10.6" E 176°26'35.5"	7 - 27
Tarawera	Mourā Bay	S 38°13.917' E 176°25'11,6"	13 - 24
Ōkāreka	East (A)	S 38°10'00.5" E 176°22'05.2"	7 - 24
Ōkāreka	Outlet (B)	S 38°10'37.4" E 176°22'32.2"	7 – 22

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.

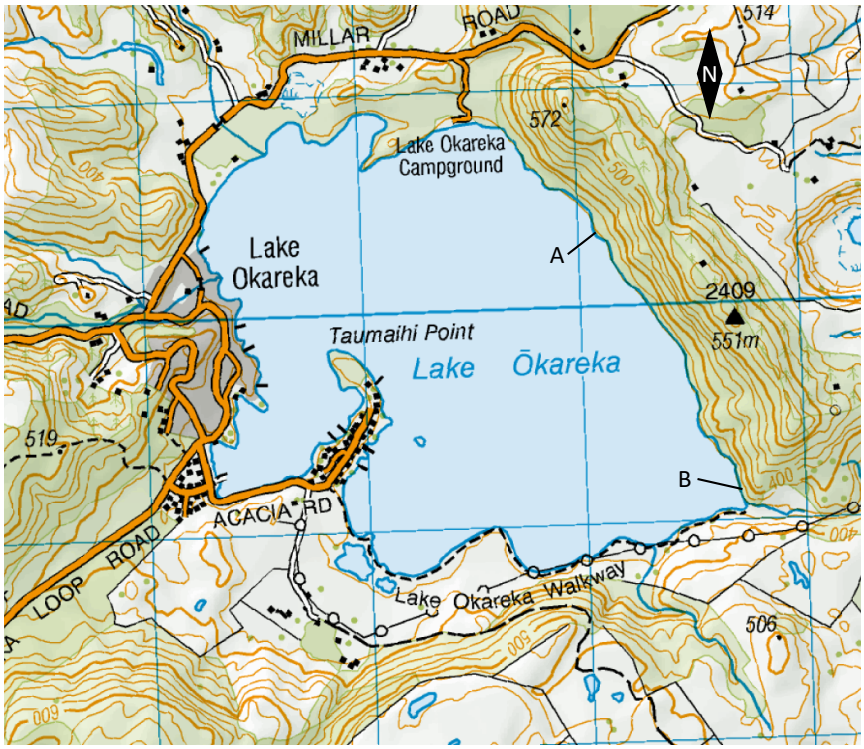

Figure 3 Lake Ōkāreka showing the approximate locations and direction of the East (A) and Outlet (B) tau kōura sampling sites.

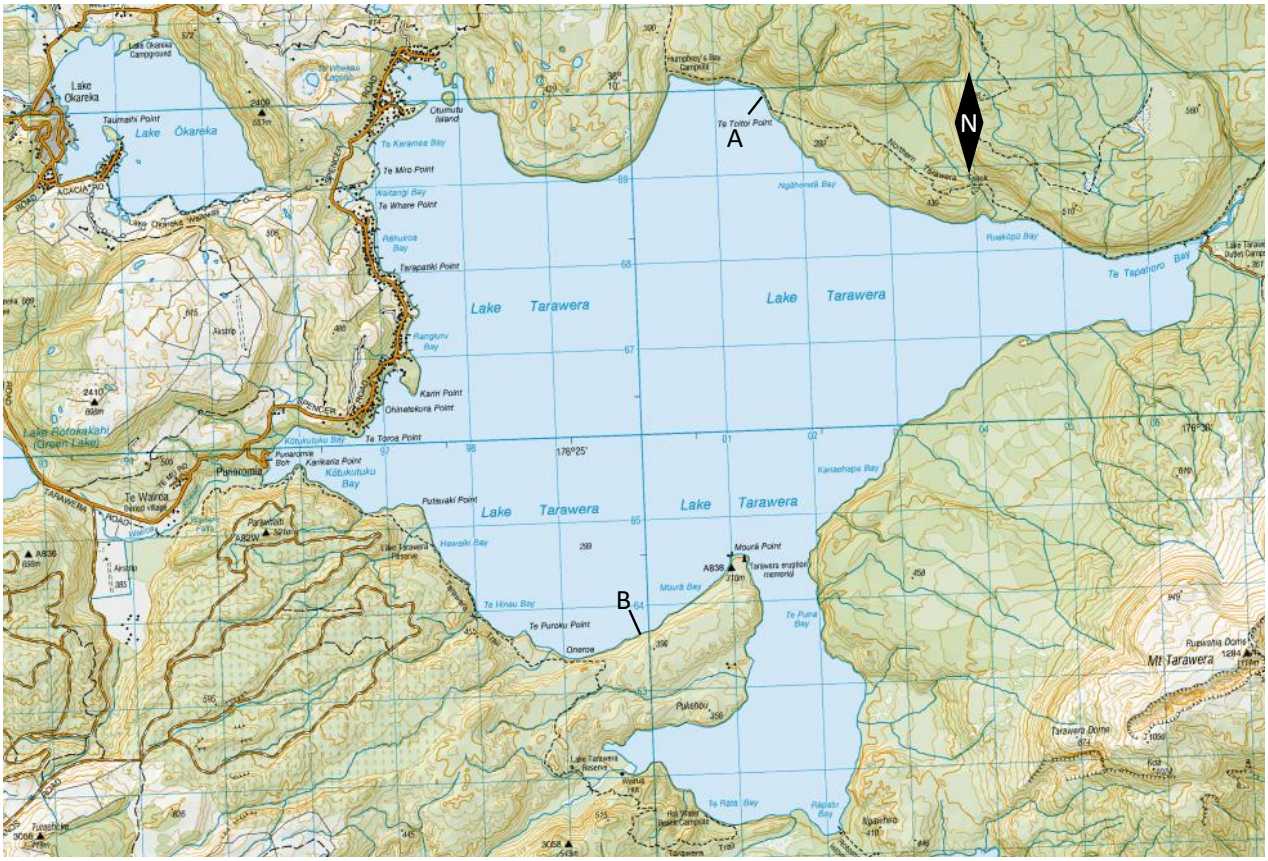

Figure 4 Lake Tarawera showing the approximate locations and direction of the Te Toitoi Point (A) and Te Mōura (B) tau kōura sampling sites.

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 Tarawera and Ōkāreka were compared with that collected from 13 other Rotorua Te Arawa lakes. The sources of this data are shown in Table 2. In addition, kōura population data recorded in this study (November 2019, May 2020 and August 2020) at the East site in Lake Ōkāreka and Te Mōura site in Lake Tarawera, were compared with surveys carried out in 2009 (April, July, November 2009) (Kusabs et al. (2015).

Table 2 Lake, month/year sampled and source of kōura data for 15 Rotorua Te Arawa lakes. Note: Lakes Ngāhewa, Ngāpouri and Tutaeinanga are located in the Waikato Regional Council District.

Lake	Month/year sampled	Source
Ngāhewa	December 2016	Kusabs (2017a)
Ngāpouri	December 2016	Kusabs (2017a)
Ōkāreka	November 2019; February, May and August 2020	Kusabs (2020)
Ōkaro	March, June, Nov 2016; February 2017	Kusabs (2017b)
Ōkataina	November 2018; February, May and August 2019	Kusabs (2019d)
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. (2015)
Rotomā	October 2018; March, May and August 2019	Kusabs (2019d)
Rotomahana	July 2017, October 2017, January 2018, May 2018	Kusabs (2018)
Rotorua	February, May, August, November 2018	Kusabs (2019c)
Tarawera	November 2019, February, May and August 2020	Kusabs (2020)
Tikitapu	July 2017, October 2017, January 2018, May 2018	Kusabs (2018)
Tutaeinanga	December 2016	Kusabs (2017a)

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 sites in each lake. ANOVA was also used to compare differences in kōura abundance and biomass recorded at Te Mōura (Lake Tarawera) and the East site (Lake Ōkāreka) in November 2018, May and August 2019, with baseline surveys carried out in April, July and November 2009[1].

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, if the transformed data was still not normally distributed then the Mann-Whitney U Test was used. 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 Mann-Whitney U Test was also used to determine differences in kōura OCL in the two lakes and to compare kōura size data recorded at Te Mōura (Lake Tarawera) and the East site (Lake Ōkāreka) in November 2018, May and August 2019, with baseline surveys carried out in April, July and November 2009. Data analysis and visualization was performed using Daniel's XL Toolbox add-in for Excel, version 7.3.2 (Kraus, 2014) and R version 4.0.3.

[1] tau kōura located at 'new' sites at Te Toitoi Point (Tarawera) and the Outlet (Okareka) were not used in comparisons with the 2009 baseline surveys.

RESULTS

Lake Tarawera

Kōura abundance and biomass

Kōura were abundant in Lake Tarawera with a total of 1949 kōura captured at a mean CPUE of 24.7 ± 21.2 (± 1 SD) kōura whakaweku^{-1} and a mean BPUE of 631.2 g ± 637.1 (±1 SD) kōura whakaweku $^{-1}$. The highest mean CPUE (62.8 kōura whakaweku^{-1}) and mean BPUE (1823.9 g kōura whakaweku^{-1}) were both recorded in November at Te Toitoi (Table 3). Kōura mean CPUE (p = .005)[2], and mean BPUE (p = .007)[3], were significantly higher at Te Toitoi than at Te Mōura for all sampling occasions except February 2020 (Table 3). Mean CPUE was 31.2 ± 22.8 (±1 SD) kōura whakaweku^{-1} at Te Toitoi compared to 18.0 ± 17.1 (±SD) kōura whakaweku^{-1} at Te Mōura, while the mean BPUE was 811.5 g ± 710.3 (± 1 SD) kōura whakaweku^{-1} at Te Toitoi compared to 446.2 g ± 495.9 (± 1 SD) kōura whakaweku^{-1} at Te Mōura (Table 3).

Table 3 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 Tarawera and retrieved from November 2019 to August 2020. n = number of kōura, g = grams, SD = standard deviation.

Date	Mean CPUE (n ± 1 SD)		Mean BPUE (g ± 1 SD)	
	Te Toitoi	Te Mōura	Te Toitoi	Te Mōura
7 November 2019	62.8 (18.3)	35.3 (14.4)	1823.9 (632.0)	1046.3 (506.8)
3 February 2020	26.2 (10.5)	24.4 (16.4)	448.8 (204.2)	472.7 (349.4)
20 May 2020	18.8 (15.0)	4.1 (4.4)	479.5 (376.7)	106.0 (122.6)
16 August 2020	17.0 (7.6)	7.0 (5.8)	493.8 (289.3)	128.0 (123.6)
Mean	31.2 (22.8)	18.0 (17.1)	811.5 (710.3)	446.2 (495.9)

Kōura size

The mean OCL of all kōura collected in Lake Tarawera was 29.1 ± 8.3 mm (± 1 SD) with individuals ranging from 3 to 47 mm OCL (Table 4). There was no significant difference (p =.39) in the size of male and female kōura in Lake Tarawera. However, kōura were significantly larger at Te Toitoi (p =.04), with a mean size of 29.4 mm ± 8.6 mm (± 1 SD) compared to 28.5 ± 7.7 mm (± 1 SD) for Te Mōura kōura.

Only the age 1-year class (~13 to 24 mm) was apparent in the kōura data recorded in February 2020 (Fig. 5). The likelihood of overlap was too high to reliably determine year classes above these ages.

[2] ANOVA
[3] Mann-Whitney U Test

Table 4 Mean OCL (*n* ± SD), OCL range (mm) and percentage of females of kōura captured in two tau kōura (each composed of 10 whakaweku) set at two sites in Lake Tarawera and retrieved from November 2019 to August 2020. *n* = number of kōura sexed; SD = standard deviation.

Date	Mean OCL (mm ±SD)		OCL Range (mm)		Female to male % (*n*)	
	Te Toitoi	Te Mōura	Te Toitoi	Te Mōura	Te Toitoi	Te Mōura
7 November 2019	30.5 (9.3)	30.7 (8.5)	10 - 47	12 - 44	58.3 (211)	68.1 (116)
3 February 2020	24.7 (8.3)	26.8 (7.0)	13 - 46	3 - 40	55.6 (124)	50.8 (120)
20 May 2020	30.4 (6.6)	30.1 (6.2)	14 - 44	19 - 45	50.8 (179)	46.3 (41)
16 August 2020	30.5 (8.6)	26.4 (7.0)	10 - 44	14 - 40	42.9 (159)	50.8 (63)
Mean	29.4 (8.6)	28.5 (7.7)	10 - 47	3 - 45	52.8 (673)	56.1 (340)

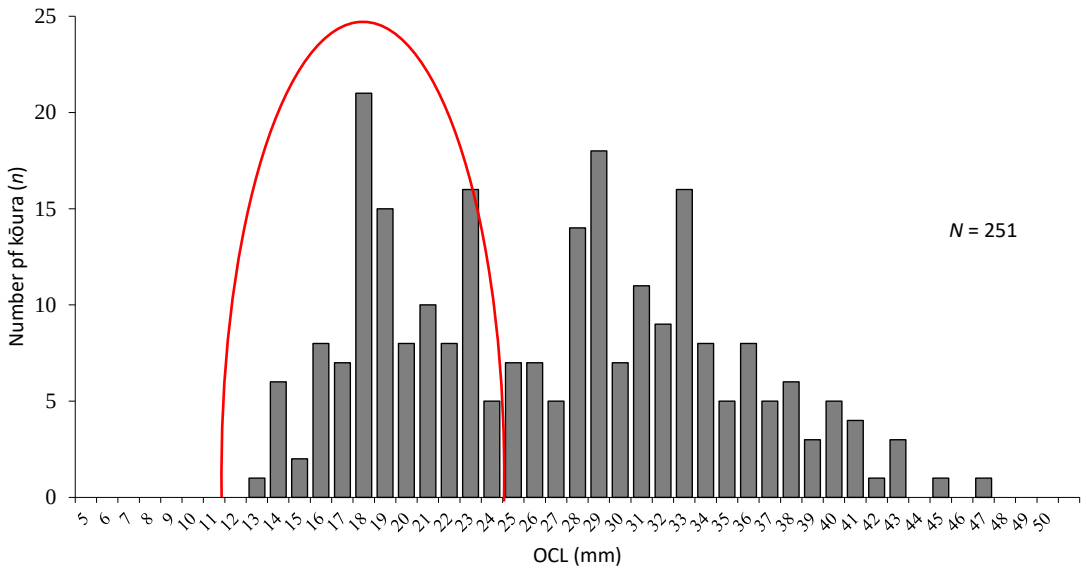

Figure 5 Length frequency distribution of kōura captured on two tau kōura (each composed of 10 whakaweku) set in Lake Tarawera, sample collected 3 February 2020. OCL = orbit carapace length. The age 1-year class is outlined in red. OCL = orbit carapace length.

Percentage females, breeding kōura and soft shells

The overall ratio of female to male kōura in Lake Tarawera was ~54%, with the percentage of females caught over the sampling period ranging from 42.9 to 68.1% (Table 4). Egg-bearing kōura were recorded in Lake Tarawera in November, May and August but none were collected in February (Table 5). Female kōura bearing hatchlings or eggs ranged in size from 26 to 47 mm OCL. Females with spermatophores were only recorded in May, suggesting that breeding occurs mainly in late autumn with eggs carried over winter and juveniles released in spring and early summer. Kōura in soft shells were present on all four sampling occasions, with the highest percentage recorded in May (11%) (Table 5).

Table 5 Number of kōura sampled, mean percentage and range 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 Tarawera and retrieved from November 2019 to August 2020. (*n*) = number of egg-bearing kōura. (*N*) = number of kōura with soft shells.

Survey date	Number of kōura sampled	% Breeding size females with eggs (*n*)	Range breeding size OCL mm	% Soft shells (*N*)
7 November 2019	358	74.5 (140)	27 - 47	2.0 (7)
3 February 2020	250	0.0	-	3.2 (8)
20 May 2020	220	24.6 (30)	29 - 43	11.3 (25)
16 August 2020	233	45.6 (41)	26 - 44	9.4 (22)

Common bullies

A total of 111 common bullies (*Gobiomorphus cotidianus*) were captured over the sampling period with the highest catch recorded in November (*n* = 40) with the lowest catch in February (*n* = 22).

Lake Ōkāreka

Kōura abundance and biomass

Kōura were common in Lake Ōkāreka with a total of 446 kōura captured at a mean CPUE of 5.6 ± 9.4 (± 1 SD) kōura whakaweku^{-1} and a mean BPUE of 91.4 g ±141.1 (± 1 SD) koura whakaweku^{-1}. The highest mean CPUE (17.0 kōura whakaweku^{-1}) and highest mean BPUE (239.5 g kōura whakaweku^{-1}) were both recorded in February at the Outlet site (Table 6). The Mann-Whitney U test showed that mean kōura CPUE (p = .01), and mean BPUE (p = .02), were significantly higher at the Outlet site than at the East Site.

Table 6 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 Ōkāreka and retrieved from November 2019 to August 2020. SD = standard deviation.

Date	Mean CPUE (*n* ± SD)		Mean BPUE (g ±SD)	
	East	Outlet	East	Outlet
8 November 2019	0.7 (1.3)	4.1 (2.8)	22.2 (40.6)	72.7 (52.6)
4 February 2020	7.2 (12.8)	17.0 (19.1)	115.1 (174.6)	239.5 (275.4)
20 May 2020	3.3 (5.2)	4.6 (3.5)	69.5 (107.6)	99.2 (114.2)
14 August 2020	4.1 (2.6)	3.6 (2.5)	64.7 (57.6)	48.1 (43.5)
Mean	3.8 (1.1)	7.3 (1.7)	67.9 (109.4)	114.9 (165.0)

Kōura size

The mean OCL of all kōura collected in Lake Ōkāreka was 25.0 ± 7.2 mm (± 1 SD) with individuals ranging from 6 to 47 mm OCL (Table 7; Fig. 6). There was no significant difference (p =.65) in the size of male and female kōura with a mean size of 25.5 mm ± 7.3 mm (± 1 SD) for females, compared to 24.9 ± 6.7 mm (± 1 SD) for males. Further, there was no significant difference (p =.32), in kōura mean size between the two sites with a mean size of 25.5 mm ± 7.5 mm (± 1 SD) for East Site koura compared to 24.7± 7.0 mm (± 1 SD) for Outlet kōura.

Two size classes were identified as cohorts in the kōura samples recorded in February 2020, a young-of-the-year (YOY) cohort (6 mm OCL), and the age 1-year class ~13 to 25 mm (Fig. 6). The likelihood of overlap was too high to reliably determine year classes above these ages.

Table 7 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 Ōkāreka and retrieved from November 2019 to August 2020. *n* = number of kōura sexed; SD = standard deviation.

Date	Mean OCL (mm ±SD)		OCL Range (mm)		Female to male % (*n*)	
	East	Outlet	East	Outlet	East	Outlet
8 November 2019	32.6 (6.0)	25.5 (7.9)	23 - 41	8 - 40	14.3 (7)	47.5 (40)
4 February 2020	24.9 (6.7)	24.1 (6.4)	15 - 45	6 - 40	38.9 (72)	54.5 (165)
20 May 2020	26.6 (8.5)	26.8 (8.7)	15 - 47	12 - 47	51.5 (33)	37.8 (45)
14 August 2020	24.5 (7.7)	23.8 (5.9)	10 - 40	15 - 40	32.5 (40)	33.3 (36)
Mean	25.5 (7.5)	24.7 (7.0)	10 - 47	6 - 47	38.9 (152)	48.3 (286)

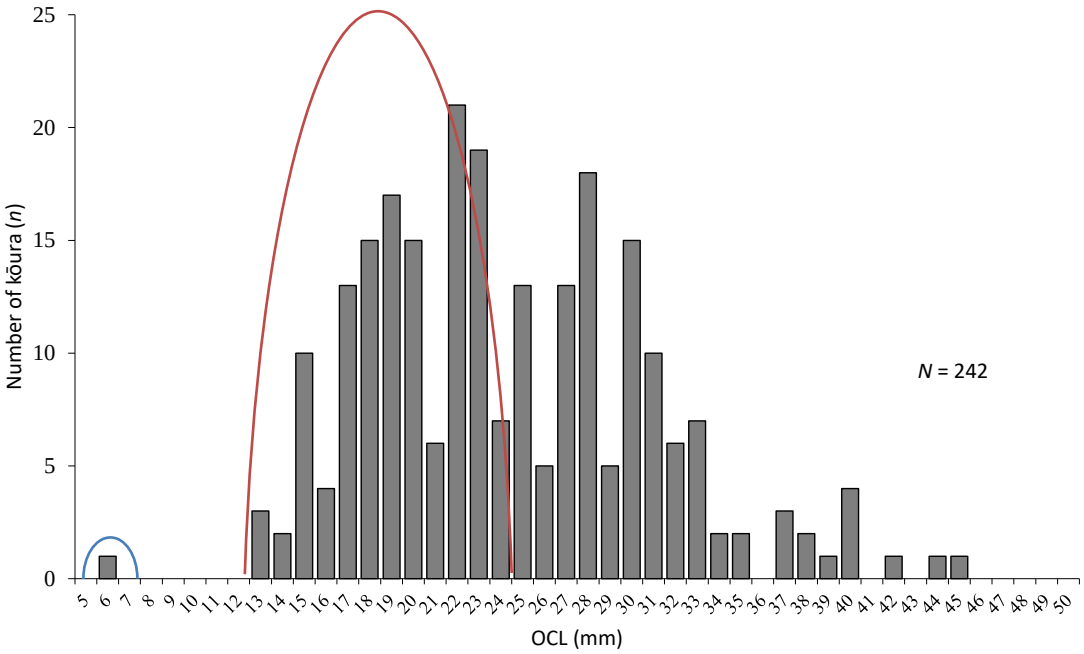

Figure 6 Length frequency distribution of kōura captured on two tau kōura (each composed of 10 whakaweku) deployed in Lake Ōkāreka, samples collected 4 February 2020. The young-of-the-year (YOY) cohort is outlined in blue and the age 1-year class is outlined in red. OCL = orbit carapace length.

Percentage females, breeding kōura and soft shells

Female kōura comprised 45% of the samples collected over the four sampling months (Table 7). Egg-bearing kōura were present in Lake Ōkāreka in May (25%) and August (20%) but not in November and February (Table 8). Female kōura bearing eggs, hatchlings, or spermatophores ranged in size from 28 to 44 mm OCL. Females with spermatophores were only recorded in May. Kōura in soft shells were present on all four sampling occasions with the highest numbers recorded in August (18%) (Table 8).

Table 8 Number of kōura sampled, mean percentage and range 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 Ōkāreka and retrieved from November 2019 to August 2020. (*n*) = number of egg-bearing kōura. (*N*) = number of kōura with soft shells.

Survey date	Number of kōura sampled	% Breeding size females with eggs (*n*)	Range breeding size OCL mm	% Soft shells (*N*)
8 November 2019	48	0.0	-	10.4 (5)
4 February 2020	242	0.0	-	11.2 (27)
20 May 2020	79	25.0 (8)	28 - 44	8.9 (7)
14 August 2020	77	20.0 (3)	28 - 34	18.2 (14)

Common bullies and koaro

A total of 446 common bullies were captured over the sampling period with the highest catches recorded in November (*n* = 266) and February (*n* = 119) with a decline in catches in May (*n* = 43) and August (*n* = 18). In addition, one koaro (92 mm in length) was captured at a depth of 19 m at the East site in May 2020 (Fig. 7).

Figure 7 Koaro captured on a whakaweku set at 19 m in Lake Ōkāreka, 22 May 2020.

Comparison with 2009 baseline surveys

Kōura abundance and biomass

Lake Tarawera

Kōura abundance and biomass at Te Mōura site was higher in 2019/20 than in 2009, although not significantly (p = .10) (Table 9). Overall Mean CPUE increased by 76% from 7.7 kōura whakaweku^{-1} (2009) to 17.1 kōura whakaweku^{-1} (2019/20), while overall mean BPUE increased by 87% from 172 g kōura whakaweku^{-1} (2009) to 437 g kōura whakaweku-^{1} (2019) (Table 9). Mean CPUE and mean BPUE were significantly higher in spring 2019 than in spring 2009, however, mean BPUE was significantly higher in winter 2009 compared with winter 2020 (Table 9).

Table 9 Season, year, mean catch per unit effort (CPUE) and mean biomass per unit effort (BPUE) and significance (ANOVA) of kōura collected from one tau kōura each composed of 10 whakaweku, retrieved from Te Mōura Bay, Lake Tarawera in 2009 and 2019/20. n = number of kōura; g = grams; SD = standard deviation. Significant differences are highlighted in red.

Season	Mean CPUE (n ± SD)		Significance	Mean BPUE (g ± SD)		Significance
	2009	2019/20		2009	2019/20	
Autumn	2.9 (3.1)	4.1 (4.4)	p = .49	53.9 (65.5)	106.0 (122.6)	p = .25
Winter	14.4 (10.5)	7.0 (5.8)	p = .08	352.5 (271.5)	128.0 (123.6)	p = .04
Spring	5.8 (4.4)	35.3 (14.4)	p < .001	107.9 (74.5)	1046.3 (506.8)	p < .001
All	7.7 (8.2)	15.8 (17.1)	p = .10	171.5 (208.3)	437.1 (542.4)	p = .19

Kōura size

Kōura ranged in size from 12 to 45 mm OCl in 2019/20 compared to 12 to 48 mm OCL in 2009. Kōura size did not differ significantly (p < .27) between 2019 and 2009, with a mean size of 29.4 mm recorded in 2019 compared to 28.5 mm in 2009 (Table 10). However, there were some seasonal differences with kōura significantly larger in winter 2009 and spring 2019 (p < .001) (Table 10).

Table 10 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). SD = standard deviation. Significant differences are highlighted in red.

Season	Mean OCL (mm ± SD)		Significance	OCL Range (mm)	
	2009	2019/20		2009	2019/20
Autumn	27.1 (7.2)	30.1 (6.2)	p = .16	12 - 42	19 -45
Winter	30.0 (7.4)	26.4 (7.0)	p < .001	12 - 42	14 - 40
Spring	25.6 (9.4)	30.7 (8.5)	p < .001	13 - 48	12 - 44
All	28.5 (8.1)	29.4 (7.9)	p < .27	12 - 48	12 - 45

Percentage females, breeding kōura and soft shells

There was little difference in the percentage of female kōura, size range of breeding size females or the percentage of soft shells in samples collected from Te Mōura Bay in 2009 and 2019/20 (Table 11). However, there was a difference in the peak egg-bearing time of female kōura from winter 2009 (75.4%) to spring 2019 (81.7%) (Table 11).

Table 11 Mean percentage of females, mean percentage and range 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 a tau kōura (composed of 10 whakaweku) deployed at Te Mōura Bay, Lake Tarawera in 2009 and 2019/20. (*n*) = number of egg-bearing kōura. (*N*) = number of kōura with soft shells.

Survey date	% Female		% Breeding size females with eggs (*n*)		Range breeding size OCL (mm)		% Soft shells (*N*)	
	2009	2019/20	2009	2019/20	2009	2019/20	2009	2019/20
Spring	51.7 (15)	68.1 (79)	25.0 (3)	81.7 (58)	31-33	-	10.3 (3)	3.1 (4)
Autumn	43.1 (25)	46.3 (19)	52.9 (9)	36.8 (7)	21-36	29-43	6.9 (4)	9.8 (4)
Winter	54.2 (78)	50.8 (32)	75.4 (49)	50.0 (13)	25-40	28-40	3.5 (5)	11.1 (7)

Lake Ōkāreka

Kōura abundance and biomass was lower at the East site in 2019/20 than in 2009 (Table 12). Overall Mean CPUE has decreased by 41.3% from 4.6 kōura whakaweku^{-1} (2009) to 2.7 kōura whakaweku^{-1} (2019/20) (Table 12). While, overall mean BPUE has decreased significantly (p = .03) by 49.7% from 103.6 g kōura whakaweku^{-1} (2009) to 52.1 g kōura whakaweku-^{1} (2019/20) (Table 12). Mean CPUE and mean BPUE were significantly lower in spring 2019 than in spring 2009 (Table 12). An examination of the spring 2019 kōura catch data showed that no kōura were collected below the 20 m water depth, an indication of low dissolved oxygen concentrations in the hypolimnion. In comparison, kōura were present to a water depth of 22 m in November 2009.

Table 12 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 Ōkāreka in 2009 and 2019/20. N = number of kōura; SD = standard deviation; g = grams.

Season	Mean CPUE (n ± SD)		Significance	Mean BPUE (g ± SD)		Significance
	2009	2019/20		2009	2019/20	
Autumn	6.6 (9.6)	3.3 (5.2)	p = .35	107.9 (140.2)	69.5 (107.6)	p =.50
Winter	5.0 (3.4)	4.1 (2.6)	p = .52	119.9 (86.4)	64.7 (57.6)	p = .11
Spring	2.2 (1.5)	0.7 (1.3)	p = .03	82.9 (75.5)	22.2 (40.6)	p = .04
All	4.6 (6.0)	2.7 (3.6)	p = .14	103.6 (102.2)	52.1 (74.9)	p = .03

Kōura size

Kōura ranged in size from 10 to 47 mm OCl in 2019/20 compared to 11 to 52 mm OCL in 2009. Kōura size did not differ significantly between 2019/20 and 2009, with a mean size of 26.0 mm recorded in 2019/20 compared to 28.2 mm in 2009 (Table 13). There were no significant seasonal differences in kōura OCL between 2009 and 2019/20 (Table 13).

Table 13 Season, year, orbit carapace length (OCL) mean & range, and significance (Mann- Whitney) of kōura collected from a tau kōura each composed of 10 whakaweku, retrieved from the East Site in Lake Ōkāreka in 2009 (May, July, November 2009) and 2019/20 (November 2019, May 2020 and August 2020). SD = standard deviation.

Season	Mean OCL (mm ± SD)		Significance	OCL Range (mm)	
	2009	2019/20		2009	2019/20
Autumn	26.1 (6.2)	26.6 (8.5)	p = .99	18 - 45	15 -47
Winter	28.5 (9.4)	24.5 (7.7)	p = .07	11 - 50	10 - 40
Spring	34.3 (9.2)	32.6 (6.0)	p = .72	19 - 52	23 - 41
All	28.2 (8.4)	26.0 (8.1)	p = .12	11 - 52	10 - 47

Percentage females, breeding kōura and soft shells

There was little difference in the percentage of female kōura, egg-bearing kōura or soft shelled kōura in samples collected from the East Site in Lake Okareka in 2009 and 2019/20 (Table 14). No egg-bearing kōura were recorded in spring 2009 or 2019, although this may be due to low sample sizes (Table 14).

Table 14 Mean percentage of females, mean percentage and range 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 a tau kōura (composed of 10 whakaweku) deployed at the East site, Lake Ōkāreka in 2009 (May, July, November 2009) and 2019/20 (November 2019, May 2020 and August 2020). (*n*) = number of egg-bearing kōura. (*N*) = number of kōura with soft shells.

Survey date	% Female		% Breeding size females with eggs (*n*)		Range breeding size OCL mm		% Soft shells (*N*)	
	2009	2019/20	2009	2019/20	2009	2020	2009	2019/20
Spring	22.7 (5)	14.3 (1)	0	0	-	-	13.6 (3)	0
Autumn	48.5 (32)	51.5 (17)	8.0 (2)	20.0 (3)	31	28-40	6.1 (4)	3.0 (1)
Winter	40.0 (20)	32.5 (13)	33.3 (6)	25.0 (2)	21-47	33-34	8.0 (4)	17.1 (7)

Kōura population dynamics in relation to other Rotorua Te Arawa Lakes

Kōura abundance and biomass

Lake Tarawera is ranked first in terms of mean CPUE (24.7 kōura whakaweku^{-1}) and mean BPUE (631.2 g kōura whakaweku^{-1}) in the 15 Rotorua Te Arawa lakes (Figs. 8A & 8B). Whereas, Lake Ōkāreka was ranked ninth in mean CPUE (5.6 kōura whakaweku^{-1}) and sixth in terms of mean BPUE (91.4 g kōura whakaweku^{-1}) (Figs. 8A & 8B).

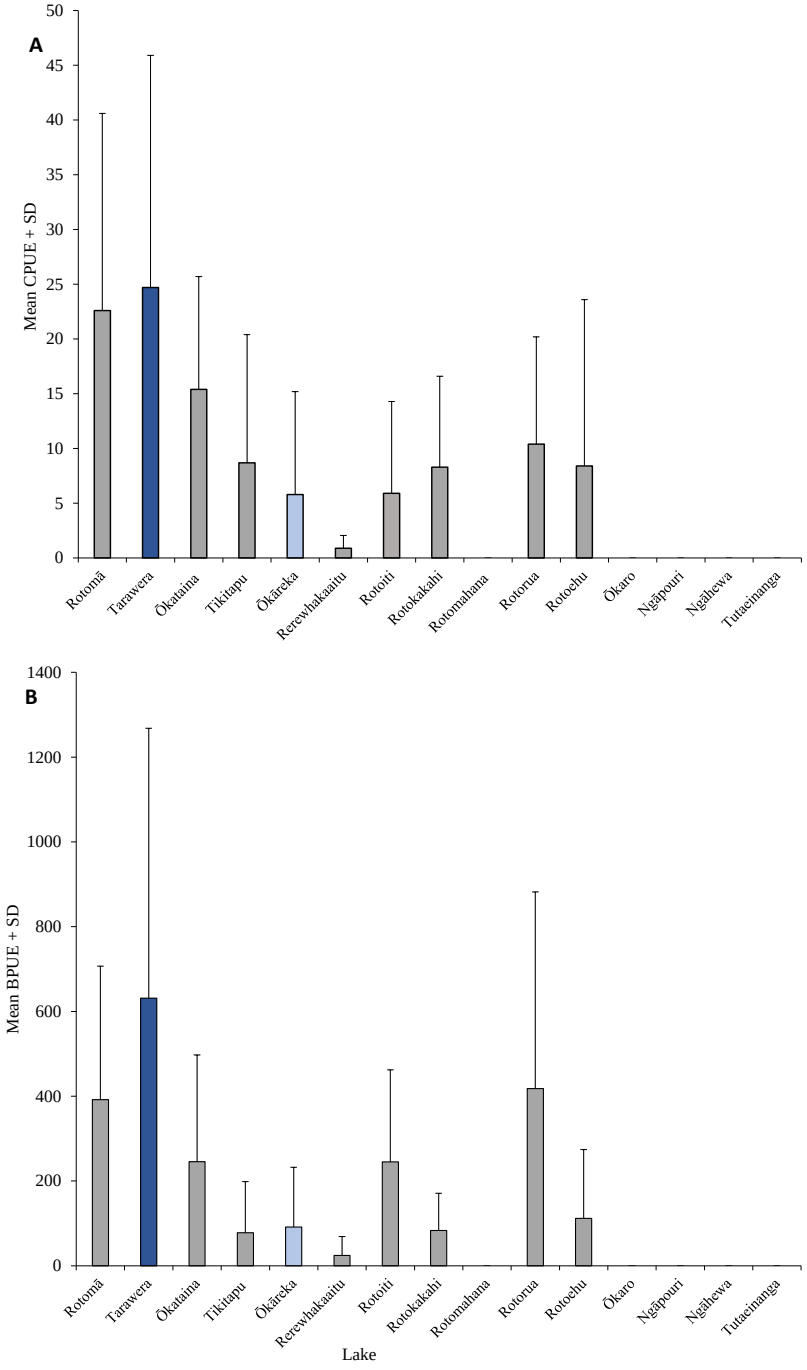

Figure 8 (A) Mean catch-per-unit-effort (CPUE; + SD) and (B) mean biomass-per-unit-effort (BPUE; g+ SD) of kōura collected using the tau kōura method in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing TLI (Trophic Level Index) value. Lake Tarawera is highlighted in dark blue and Lake Ōkāreka in light blue. Refer Table 2 for details and source of kōura data.

Kōura size

In terms of mean kōura size, Lake Tarawera was ranked second (29.1 mm OCL) and Lake Ōkāreka sixth (25.0 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded (Fig. 9). Lake Rotorua now has the largest sized kōura, with mean size increasing by 44.1% from 20.4 mm OCL in 2009 to 29.4 mm OCL in 2018/19. Length frequency analysis of Lake Rotorua kōura samples show that this increase is mainly due to the reduction in small-sized kōura <24 mm OCL, with little difference in kōura size classes >25 mm OCL (Kusabs et al 2019c). The reduction in small-sized kōura has been attributed to increased predation by brown bullhead catfish (*Ameiurus nebulosus*) (Kusabs et al 2019c).

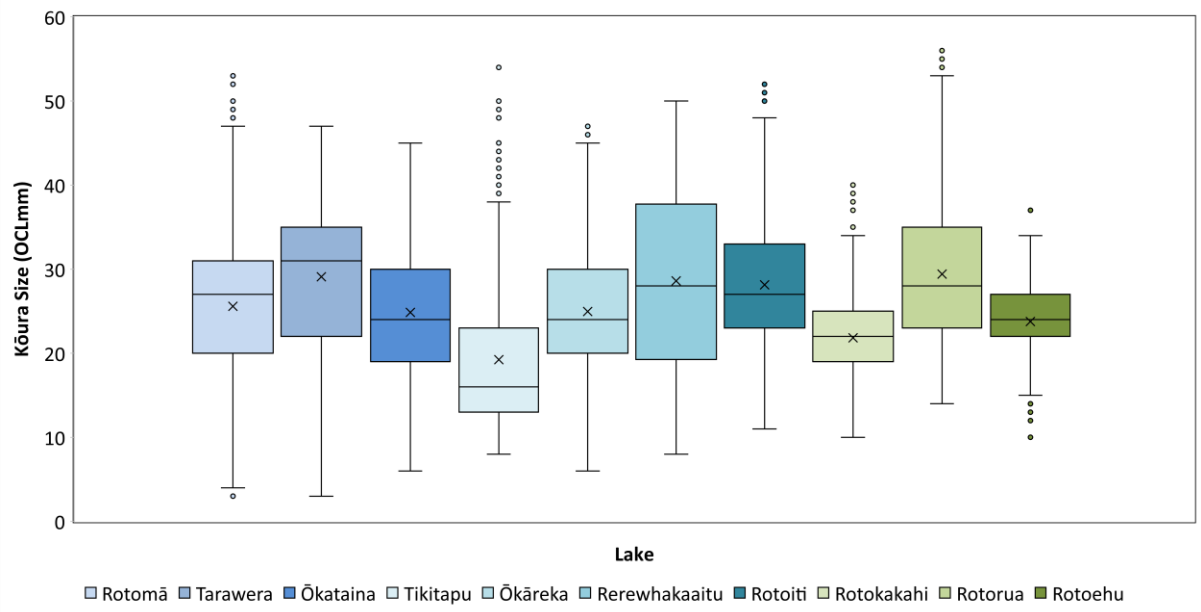

Figure 9 Box-and-whisker plot showing mean (x), median (horizontal line), interquartile range (box), distance from upper and lower quartiles times 1.5 interquartile range (whiskers), outliers (>1.5× upper or lower quartile) for kōura orbit carapace length for kōura collected in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing TLI (Trophic Level Index) value. Refer Table 2 for details and source of kōura data.

DISCUSSION

Lakes Tarawera and Ōkāreka

The kōura population in Lake Tarawera was characterised by high numbers of large-sized kōura, while the Lake Ōkāreka kōura population was composed of moderate numbers of medium-sized 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 47 mm OCL in Lake Tarawera and 6 to 47 mm in Lake Ōkāreka. The balanced size structure, and the fact that kōura mean sizes have not increased significantly in either of the lakes, suggests that brown bullhead catfish are absent (or present in very low numbers). In contrast, in lakes Rotorua and Rotoiti where catfish are now well-established, the kōura populations are now mostly composed of medium and large-sized individuals, with few kōura < 23 mm.

In this study, new monitoring sites were established at Te Toitoi Point in Lake Tarawera and at the outlet at Lake Okareka. These sites were chosen to obtain a more representative geographical spread across the two lakes. Lake Tarawera, in particular, is a large lake (41 km^2) with a wide variety of lakebed substrates, the establishment of a tau kōura monitoring site at Te Toitoi Point meant that the extensive northern shoreline was sampled, while, the kōura population along the southern shoreline could continue to be sampled at the existing Te Mōura site (Figure 4). This, however, meant that comparisons with the 2009 baseline surveys were only carried out at the Te Mōura site in Lake Tarawera and the East site in Lake Okareka. Given, the large size of Lake Tarawera, at least five tau kōura would be needed to representatively sample the kōura population i.e., tau kōura located in the northern, southern, eastern and western areas of the lake and the Wairua Arm.

Lake Tarawera

Kōura relative abundance and biomass were significantly higher at Te Toitoi Point than at Te Mōura Bay. The mean CPUE of 63 kōura whakaweku^{-1} and mean BPUE of 1824 g kōura whakaweku^{-1} recorded at Te Toitoi Point in spring (November 2019) were amongst the highest recorded in tau kōura surveys in the Rotorua Te Arawa Lakes since surveys began in 2005.

In Lake Tarawera (Te Mōura site), kōura abundance and biomass were higher in 2019/20 compared to the 2009 baseline surveys. Mean CPUE increased by 76% from 7.7 to 17.1 kōura whakaweku^{-1}, while mean BPUE has increased by 87% from 171.5 to 437.1 g kōura whakaweku^{-1}. The increase in relative abundance and biomass were attributable to the high catch of kōura in spring (i.e., November 2019), while catches in autumn and winter were similar to those recorded in 2009. Moreover, there appears to have been a shift in peak egg-bearing time of female kōura in Lake Tarawera from winter (75.4%) in 2009, to spring (81.7%) in 2019/20. The reasons for this are

unknown, although, the proportion of kōura in breeding condition is also highest in spring and winter in lakes Rerewhakaaitu, Rotomā, Rotorua and Tikitapu (Kusabs 2019, Kusabs 2019c, Kusabs et al. 2015a).

Lake Tarawera is now ranked first in terms of relative abundance and biomass in the 15 Rotorua Te Arawa lakes where kōura monitoring has been undertaken. Whereas in 2009, Lake Tarawera was ranked sixth in terms of mean CPUE and fifth in terms of biomass. There are a number of reasons for this rise in the rankings, these include; (a) the high catches of kōura recorded in spring and summer at Te Mōura (b) high catches of kōura at the new site at Te Toitoi Point (compared to the low catches recorded in 2009 at the previous tau kōura monitoring site in Te Wairoa Bay), and (c) a drastic decline in kōura CPUE and BPUE in lakes Rotoiti and Rotorua due to the establishment of catfish – well-known predators of kōura (Barnes and Hicks, 2003).

Lake Ōkāreka

Lake Okareka continues to support a moderate population of medium-sized kōura with a mean CPUE of 5.6 kōura whakaweku^{-1} and a mean BPUE of 91.4 g recorded in 2019/20. Lake Ōkāreka was ranked ninth in mean CPUE (5.6 kōura whakaweku^{-1}) and sixth in terms of mean BPUE (91.4 g kōura whakaweku^{-1}). Kōura relative abundance and biomass were significantly higher at the Outlet Site than at the East site.

Kōura abundance and biomass in Lake Okareka (East site) were lower than those recorded in 2009. Mean CPUE has decreased by 41.3% from 4.6 to 2.7 kōura whakaweku^{-1}, while mean BPUE has decreased by 49.7% from 103.6 to 52.1 g kōura whakaweku-^{1}. The decrease in relative abundance and biomass were due to the low catch in spring (i.e., November 2019), while catches in autumn and winter were similar to those recorded in 2009. The low kōura catch in spring is most likely due to earlier lake stratification and deoxygenation of the hypolimnion. In 2019/20, the proportion of kōura in breeding condition was highest in Lake Ōkāreka in autumn and winter, consistent with that recorded in 2009 (Kusabs 2015).

Summary and conclusions

Lake Tarawera supports an abundant population of koura with a mean CPUE of 24.7 kōura whakaweku^{-1} and a mean BPUE of 631.2 g kōura whakaweku^{-1}. Lake Tarawera is now ranked first in terms of relative abundance and biomass in the 15 Rotorua Te Arawa lakes where kōura monitoring has been undertaken. In comparison, Lake Tarawera was ranked sixth in terms of mean CPUE and fifth in terms of biomass in 2009. The reasons for this rise include; (a) higher catches of kōura in spring and summer at Te Mōura (b) high catches of kōura at the new site at Te Toitoi Point (compared to the low catches recorded in 2009 in Te Wairoa Bay), and (c) a drastic decline in kōura CPUE and BPUE in lakes Rotoiti and Rotorua due to the establishment of catfish.

Lake Ōkāreka was ranked ninth in mean CPUE (5.6 kōura whakaweku^{-1}) and sixth in terms of mean BPUE (91.4 g kōura whakaweku^{-1}). Kōura abundance and biomass in Lake Okareka (East site) were lower than those recorded in 2009 with a decrease in mean CPUE of –41.3% and mean BPUE by – 49.7%. These decreases were mainly due to low catches in spring, which may have resulted from early stratification and deoxygenation of the hypolimnion in 2019.

The size structure of kōura in both lakes was well-balanced with kōura ranging in size from from 3 to 47 mm OCL in Lake Tarawera and 6 to 47 mm in Lake Ōkāreka. The balanced size structure, and the fact that kōura sizes have not increased significantly in either of the lakes, suggests that brown bullhead catfish are absent (or present in very low numbers). In terms of mean kōura size, Lake Tarawera was ranked second (29.1 mm OCL) and Lake Ōkāreka sixth (25.0 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded.

Given, the large size of Lake Tarawera, it is recommended that three additional tau kōura sites (a total of 5 sites) be included in future monitoring to representatively sample the kōura population in this lake.

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