LAKES TIKITAPU & ROTOMAHANA

TE ARAWA LAKES - KŌURA MONITORING PROGRAMME

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Cover photo: Geyser erupting at the steaming cliffs Lake Rotomahana, 25 February 2018.

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EXECUTIVE SUMMARY

Kōura or freshwater crayfish are an abundant macroinvertebrate in many of the Rotorua Te Arawa lakes and are considered a taonga species by Te Arawa iwi. The aim of this study was to provide baseline information on kōura populations in lakes Tikitapu and Rotomahana as part of a regular kōura monitoring programme in twelve Te Arawa lakes in the Bay of Plenty Regional Council (BOPRC) district.

Lakes Tikitapu and Rotomahana were sampled using the tau kōura a traditional Māori method of harvesting kōura in Te Arawa and Taupō lakes. Two tau kōura were located in each lake with each tau kōura composed of 10 whakaweku (bracken fern bundles).

The Lake Tikitapu kōura population was characterised by moderate numbers of small-sized kōura (< 20 mm OCL); the smallest in the nine Te Arawa lakes where kōura have been recorded. Lake Tikitapu ranked fifth in terms of kōura CPUE and eighth in terms of BPUE in the 13 Te Arawa lakes where kōura monitoring has been undertaken. The reason for the small size of kōura is unknown, however, it may be related to the unusual water chemistry in this lake which is low in calcium (< 0.7 mg l^{-1}), silica and all major ions. The calcium content of water is very important both for adequate growth and survival, as kōura are particularly susceptible to cannibalism and predation whilst soft.

No kōura were found in Lake Rotomahana, consistent with previous studies in this lake. The absence of kōura in this lake is most probably due to high geothermal inputs and anoxia in the bottom waters of this lake.

1 INTRODUCTION

The Bay of Plenty Regional Council (BOPRC) is leading the restoration and protection programme for the Rotorua Te Arawa lakes (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 Te Arawa lakes henceforth known as the Te Arawa lakes kōura monitoring programme.

Kōura are the largest bottom living crustacean and an important ecological component of the 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 Te Arawa lakes. Kusabs *et al.* (2015b) found that kōura abundance and distribution in seven 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 Te Arawa lake kōura and used this data to determine fisheries regulations as part of the sustainable management of kōura in 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 method is currently undertaken in three Rotorua Te Arawa lakes –lakes Rotoiti, Rotoehu and Rotorua (Kusabs 2017c; Kusabs 2017b). The purpose of this programme, therefore, is to carry out regular monitoring of kōura populations in the other nine Te Arawa lakes in the BOPRC district i.e., lakes Okaro, Ōkaro, Ōkataina, Rerewhakaaitu, Rotokakahi, Rotomā, Rotomahana, Tarawera and Tikitapu. The lakes are to be monitored on a five-yearly basis, that is, two lakes per year, with lakes not already surveyed having priority i.e., lakes Ōkataina, Rotomahana and Tikitapu. The lakes surveyed in this year's survey (2017 – 2018) were lakes Rotomahana and Tikitapu.

1.1 Aims

The aims of this study are to provide baseline information on kōura populations in the lakes in order to determine long-term population trends. In addition, it is envisaged that information collected on kōura biological traits will be of use to the fisheries manager - Te Arawa Lakes Trust (TALT).

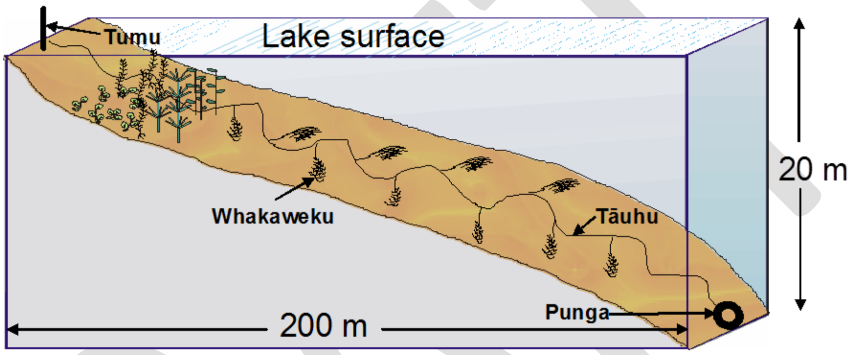

Figure 1 Schematic diagram of a tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

2 STUDY AREA

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

Rotomahana means "warm lake". Prior to the Tarawera eruption, this lake comprised two smaller lakes - Lake Rotomahana (warm) and Lake Makariri (cold). Today, Lake Rotomahana occupies craters formed by steam-blast eruptions which accompanied the Tarawera eruption of 1886 and is the most recently formed larger natural lake in New Zealand. Lake Rotomahana is a medium sized (8.0 km^2), deep (the deepest in the Rotorua district), monomictic lake with an average depth of 60 m and maximum depth of 125 m. Lake Rotomahana is a mesotrophic lake and in 2016 had a Trophic Level Index (TLI) of 4.0 (P. Scholes, BOPRC, pers. comm.).

Lake Tikitapu is a relatively small (1.4 km^2) but deep (27.5 m) lake in the mid-west of Te Arawa Lakes region at 415 m above sea level (Fig. 2). It was formed approximately 13500 years ago, and has a 430 ha, predominantly forested catchment. The lake has no permanent surface water inflows or outflows; however, water is presumed to enter the lake via groundwater inputs and drain to adjacent Lake Rotokakahi via groundwater (BOPRC 2011). It is an attractive and popular lake with oligotrophic-mesotrophic water quality. The target Trophic Level Index (TLI; Burns 1999) for Lake Tikitapu is 2.7, whereas a TLI of 2.6 was recorded in in 2016 (P. Scholes, BOPRC, pers. comm.).

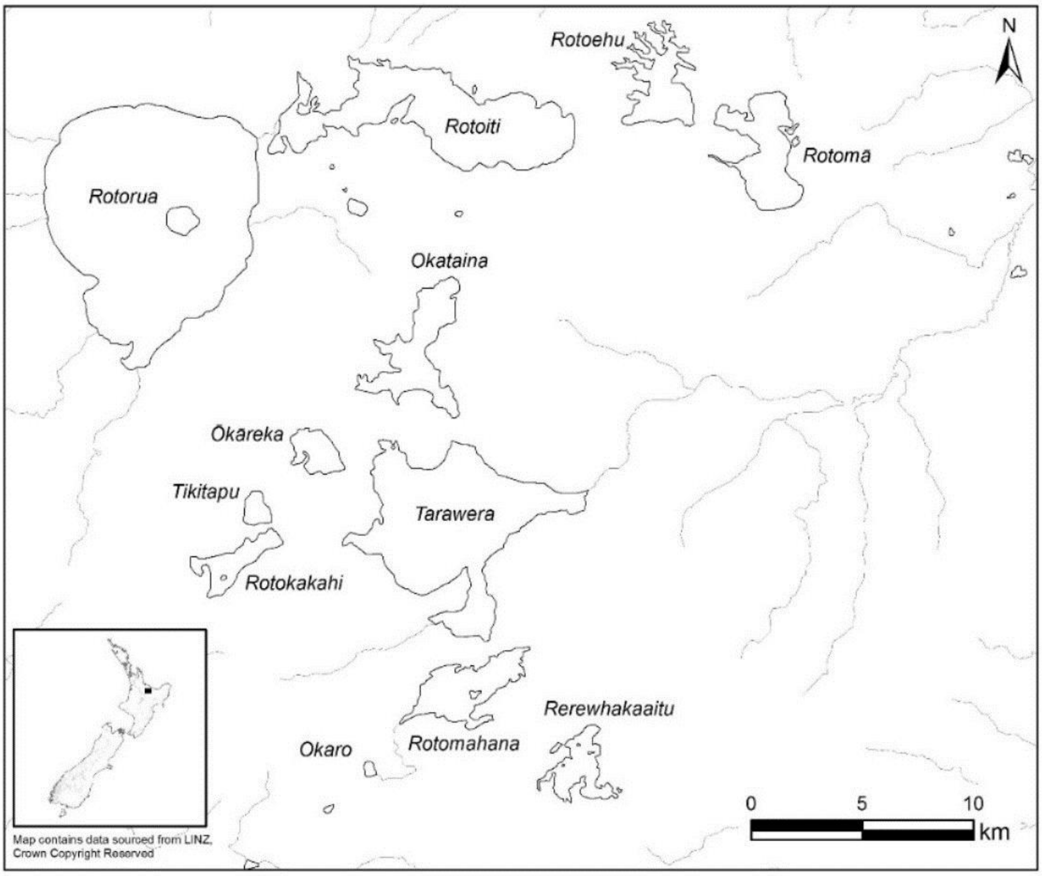

Figure 2 Map of the Rotorua Te Arawa Lakes region showing location of lakes Rotomahana and Tikitapu.

Table 1 Sampling site, grid reference and approximate location of kōura monitoring sites, lakes Rerewhakaaitu and Ōkaro, March 2016 to February 2017.

Lake	Sampling site	Latitude Longitude (Decimal degrees)	Water depth (m)
Tikitapu	Site 1	38 11 54 176 19 30	8 - 23
Tikitapu	Site 2	38 12 01 176 20 13	7 - 22
Rotomahana	Site 1	38 16 19 176 26 45	11 - 30
Rotomahana	Site 2	38 15 32 176 26 09	6 - 28

3 METHODS

3.1 Tau kōura construction and use

Kōura populations in lakes Rotomahana and Tikitapu were sampled using the tau kōura (Fig. 1) a traditional Māori method of harvesting kōura in the Te Arawa and Taupō lakes (Hiroa 1921; Kusabs and Quinn 2009). Two tau kōura were deployed in both lakes Tikitapu and Rotomahana (Table 1 & Fig. 3). 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) (Table 1). In Lake Rotomahana, whakaweku were set in depths ranging from 6 m to 30 m and 7 m to 23 m in Lake Tikitapu (Table 1, Figs. 3 & 4). Tau kōura were deployed in Lake Tikitapu on 9 June 2017 and 27 May 2017 in Lake Rotomahana and left for approximately six weeks to allow kōura to colonise the fern before first retrieval in July. Tau kōura were retrieved on a 3-monthly basis in Lake Tikitapu (Table 3) and Lake Rotomahana (Table 6).

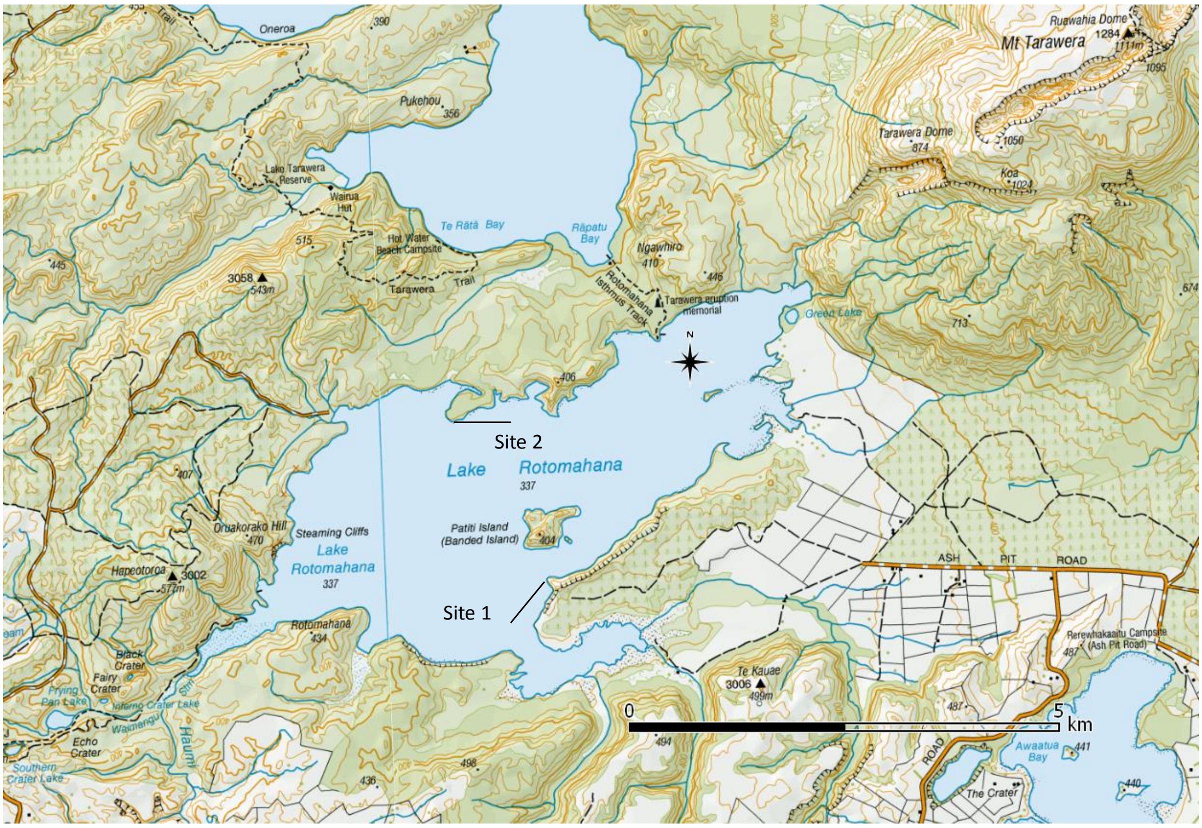

Figure 3 Lake Rotomahana showing approximate location and direction of kōura monitoring sites.

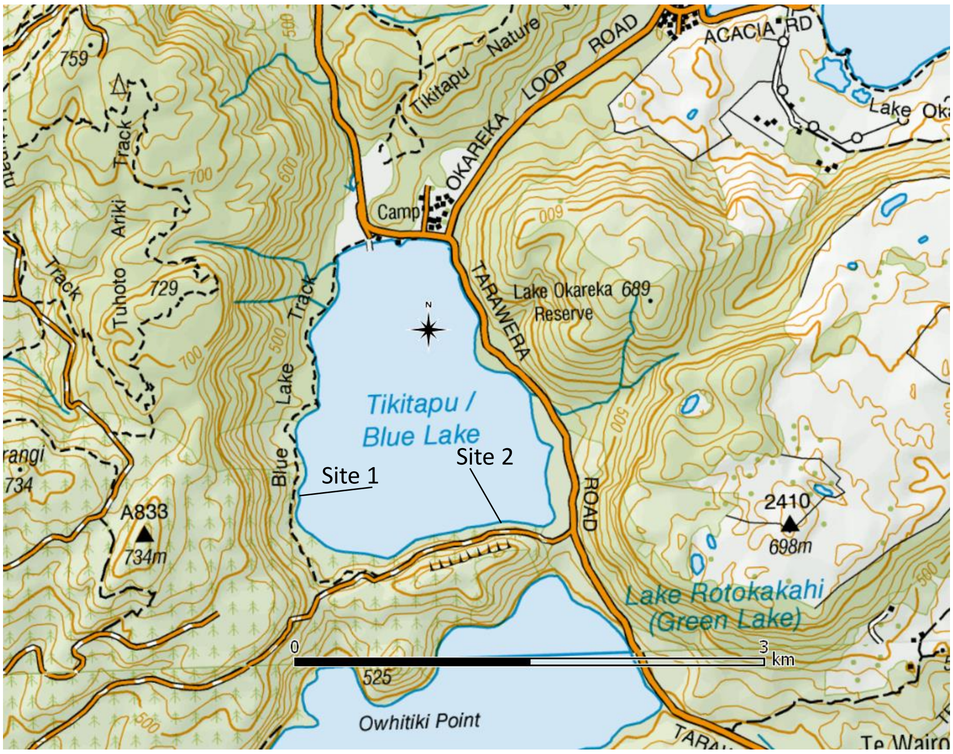

Figure 4 Lake Tikitapu showing approximate location and direction of kōura monitoring sites.

3.2 Kōura collection and measurement

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 (large 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 was then returned to the water. The kōura were then collected and placed into labelled (2 litre) plastic containers covered by lids to keep kōura shaded and calm before analysis.

All kōura were counted and assessed for shell softness (soft or hard) and those kōura >12 mm OCL[1] assessed for sex and reproductive state (presence of eggs or hatchlings). Orbit carapace length (OCL) of each kōura was measured using vernier callipers (± 0.5 mm). A power regression equation previously determined (Hicks and Riordan unpublished data) was used to estimate kōura wet weight (g) from OCL (mm): Wet weight = 0.000648 $OCL^{3.0743}$

Common bullies were counted. After processing, all kōura and common bullies were returned to the water in close proximity to the tau kōura. Catch per unit effort (CPUE) was defined as

[1] The sex of kōura < 12mm OCl could not be assessed in the field due to their small size.

the number of kōura per whakaweku and biomass per unit effort (BPUE) as estimated wet weight (g) of kōura per whakaweku.

3.3 Comparison of kōura data with other Te Arawa lakes

Kōura data from lakes Tikitapu and Rotomahana was compared with that from 12 other Te Arawa lakes. The sources of this data are shown in Table 3.

Table 2 Lake, month/year sampled and source of kōura data for 14 Te Arawa lakes. Lakes are ordered in terms of survey date.

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

3.4 Data analysis

Differences between mean kōura CPUE and BPUE at the two tau kōura in Lake Tikitapu were assessed using the Mann-Whitney test which was performed using R version 3.3.3. 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.

4 RESULTS

4.1 Lake Tikitapu

4.1.1 Kōura abundance and biomass

A total of 696 kōura captured in Lake Tikitapu with a mean CPUE of 8.7 (SD 11.7) kōura whakaweku^{-1} and a mean BPUE of 78.2 (SD 120.5) g kōura whakaweku^{-1} (Table 3). The highest mean CPUE of 22 kōura whakaweku^{-1} was recorded at the Site 1 in October while the highest mean BPUE of 134 g kōura whakaweku^{-1} was also recorded at this site in January (Table 3).

Kōura were significantly ($P < 0.05$) more abundant at the Site 1 than at the Site 2, however, there was no significant difference in kōura biomass ($P > 0.05$). Kōura were significantly ($P < 0.05$) less abundant at Site 1 in May compared to previous surveys due to whakaweku being smothered with native charophytes (Fig. 5).

Table 3 Mean CPUE (*n* ± SD) and biomass (g ± SD) for kōura captured in two tau kōura (each composed of 10 whakaweku) deployed in Lake Tikitapu, July 2017 to May 2018.

Date	Mean CPUE (*n* ± SD)		Mean BPUE (g ±SD)	
	Site 1	Site 2	Site 1	Site 2
11 July 2017	11.8 (9.9)	5.2 (4.4)	58.4 (42.9)	52.0 (55.9)
13 October 2017	22.3 (14.9)	1.6 (1.4)	127.7 (119.7)	40.6 (76.4)
21 January 2018	16.9 (18.2)	3.1 (3.9)	133.7 (159.3)	68.0 (115.1)
18 May 2018	3.1 (4.8)	5.9 (7.4)	45.9 (88.4)	99.5 (212.6)
	13.5 (14.4)	3.9 (4.9)	91.4 (114.0)	65.0 (126.7)

Figure 5 A whakaweku completely smothered with native charophytes at Site 1, Lake Tikitapu, 18 May 2018.

4.1.2 *Kōura size*

The mean OCL of all kōura collected in Lake Tikitapu was 18.6 ± 8.0 mm (± 1 SD) with individuals ranging from 8 to 54 mm OCL (Table 4; Fig. 6). There was no significant difference between the size of male and female kōura ($P > 0.5$). The mean OCL of males was 21.1 ± 8.7 mm (± 1 SD) compared to 20.8 ± 7.4 mm (± 1 SD) for females. Two size classes were identified as cohorts in Lake Tikitapu in the July 2017 sample (Fig. 6). The young-of-the-year (YOY) cohort ranged from 8 to ~18 mm. The age 1-year class was ~18 to 26 mm. Numbers were too low to reliably identify year classes above these ages.

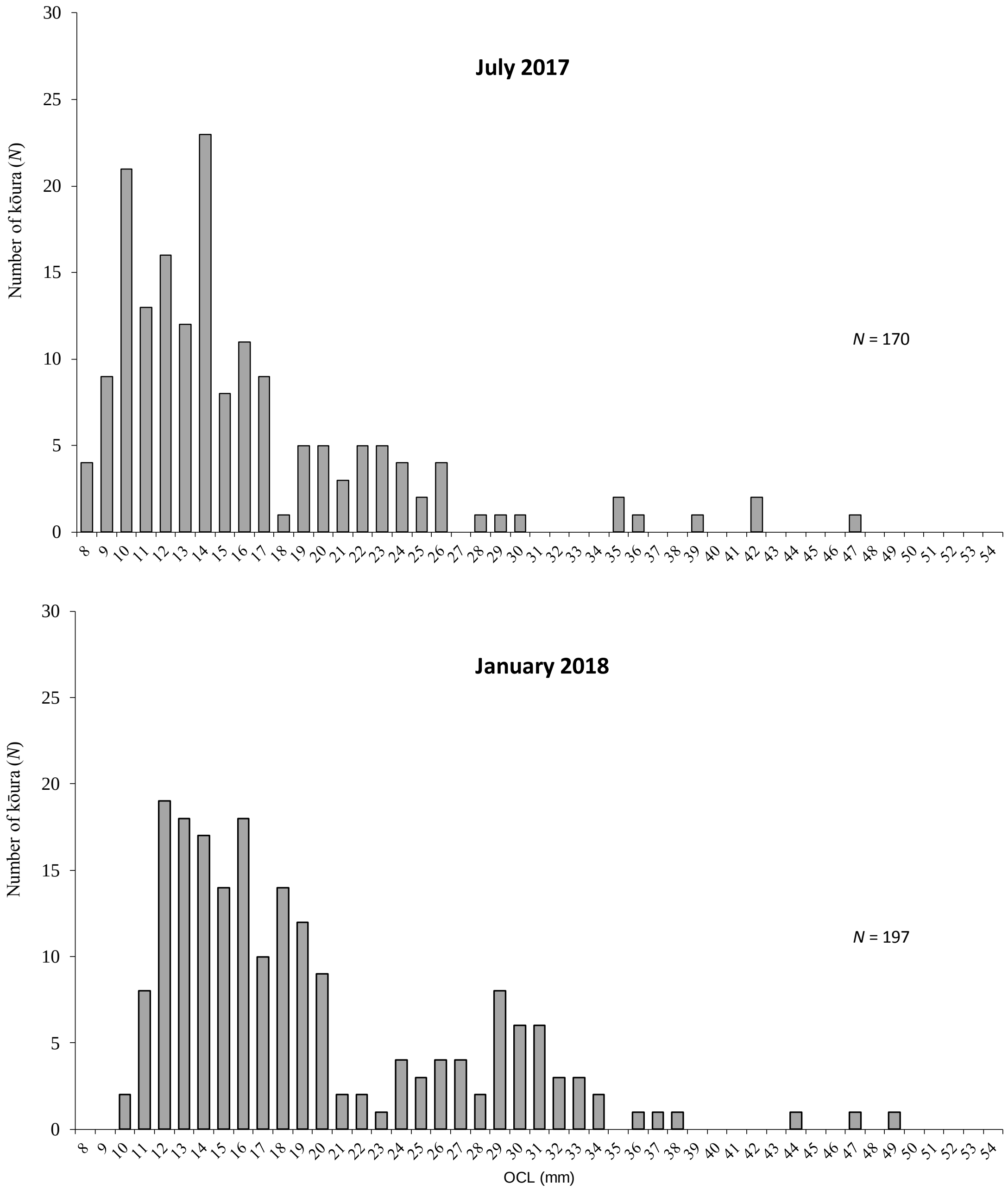

Figure 6 Length frequency distribution of kōura captured on two tau kōura (each composed of 10 whakaweku) deployed in Lake Tikitapu, July 2018 and January 2018.

4.1.3 *Kōura - sex ratio*

The overall ratio of female to male kōura in Lake Tikitapu was about 1:1. The percentage of females caught over the sampling period ranged from 33.3% to 53.1% (Table 4).

Table 4 Mean OCL (*n* ± SD) and range (mm) and percentage of females (*n* = number of kōura sexed) for kōura captured in two tau kōura (each composed of 10 whakaweku) deployed in Lake Tikitapu, 30 March 2016 to 21 February 2017. (*n*) = number of kōura.

Date	Mean OCL (*n* ±SD)		OCL Range (mm)		Female to male % (*n*)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
11 July 2017	16.1 (5.9)	18.8 (8.6)	9 - 37	8 - 48	50.0 (88)	38.3 (47)
13 October 2017	16.7 (6.2)	24.4 (14.0)	11 - 43	12 - 48	51.6 (126)	33.3 (15)
21 January 2018	19.2 (6.4)	26.9 (10.4)	10 - 37	13 - 50	53.0 (132)	42.9 (28)
18 May 2018	21.0 (10.8)	22.7 (10.4)	9 - 49	11 -54	50.0 (26)	53.1 (49)

4.1.4 *Egg-bearing females and moulting kōura*

Egg-bearing kōura were recorded in Lake Tikitapu in October (17%) and January (3.2%) (Table 5). Female kōura bearing hatchlings or eggs ranged in size from 34 to 43 mm OCL. Kōura in soft shells were present on all four sampling occasions (Table 5).

Table 5 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) deployed in Lake Tikitapu, July 2017 to May 2018. (*n*) = number of kōura.

Survey date	Number of kōura sampled	% Breeding size females with eggs	Range breeding size OCL mm	% Soft shells
11 July 2017	170	0	-	3.5
13 October 2017	239	17.0 (4)	34 - 43	4.2 (10)
21 January 2018	197	3.2 (1)	34	3.6 (7)
18 May 2018	90	0	-	2.2 (2)

4.1.5 *Common bullies*

A total of 96 common bullies (*Gobiomorphus cotidianus*) were captured over the sampling period with the highest catches recorded in July (*n* = 31) and October (*n* = 32) with catches dropping off in January and May.

Figure 7 Kōura collected from a tau kōura set in Lake Tikitapu, 24 July 2017.

4.2 Lake Rotomahana

No kōura were collected from Rotomahana. Common bullies were moderately abundant and were most numerous in July and October with catches dropping in February and June (Table 6). There was no significant difference in common bully CPUE or size (total length, TL) between the two sampling sites. (*P* > 0.05). Common bully ranged in size from 31 to 87 mm TL (Table 6). No bullies were captured below 21 m water depth in February 2018 when the lake was stratified. Freshwater snails were abundant on all four sampling occasions in Lake Rotomahana (Fig. 8).

Table 6 Mean CPUE (*n* ± SD), mean size (TL; mm ±SD) and range of common bully captured in two tau kōura (each composed of 10 whakaweku) deployed in Lake Rotomahana, July 2017 to June 2018.

Date	Mean CPUE (*n* ± SD)		Mean TL (mm ±SD)		Range TL (mm)	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
24 July 2017	3.3 (4.2)	3.6 (7.1)	55.9 (9.2)	58.9 (6.3)	36 - 87	49 - 77
18 October 2017	4.4 (6.0)	6.5 (10.0)	45.9 (7.5)	53.4 (7.4)	31 - 66	36 - 72
25 February 2018	0.6 (1.0)	0.5 (1.3)	58.3 (4.8)	57.7 (4.7)	52 - 64	50 - 64
2 June 2018	2.5 (6.6)	0.7 (1.7)	60.0 (8.7)	54.7 (5.5)	48 - 81	48 - 62
	2.8 (5.0)	2.9 (6.6)	53.1 (10.2)	53.4 (7.3)	31 - 87	36 - 77

Figure 8 Freshwater snails collected from a tau kōura set in Lake Rotomahana, 12 October 2017.

4.3 Kōura population dynamics in relation to other Te Arawa Lakes

Lake Tikitapu ranked fifth in terms of kōura CPUE and eighth in terms of BPUE in the 13 Te Arawa lakes where kōura monitoring has been undertaken (Fig. 9). Although, CPUE was relatively high, BPUE was lower due to the small size (mean OCL 18.6 mm) of kōura present; the lowest in the nine Te Arawa lakes where kōura have been recorded (Fig. 10).

Kōura CPUE (8.7 kōura whakaweku^{-1}) and BPUE (78.1 g kōura whakaweku^{-1}) were very similar to neighbouring Lake Rotokakahi CPUE (8.3 kōura whakaweku^{-1}) and BPUE (83.2 kōura whakaweku^{-1}) (Fig. 9). Populations in both lakes were dominated by small-sized kōura with a mean OCL of 18.9 mm and 21.8 mm in lakes Tikitapu and Rotokakahi, respectively (Fig. 10).

Lake Rotomahana is one of five Te Arawa lakes (lakes Ōkaro, Ngāhewa, Ngāpouri, Tutaeinanga) where kōura are now absent (Fig. 9).

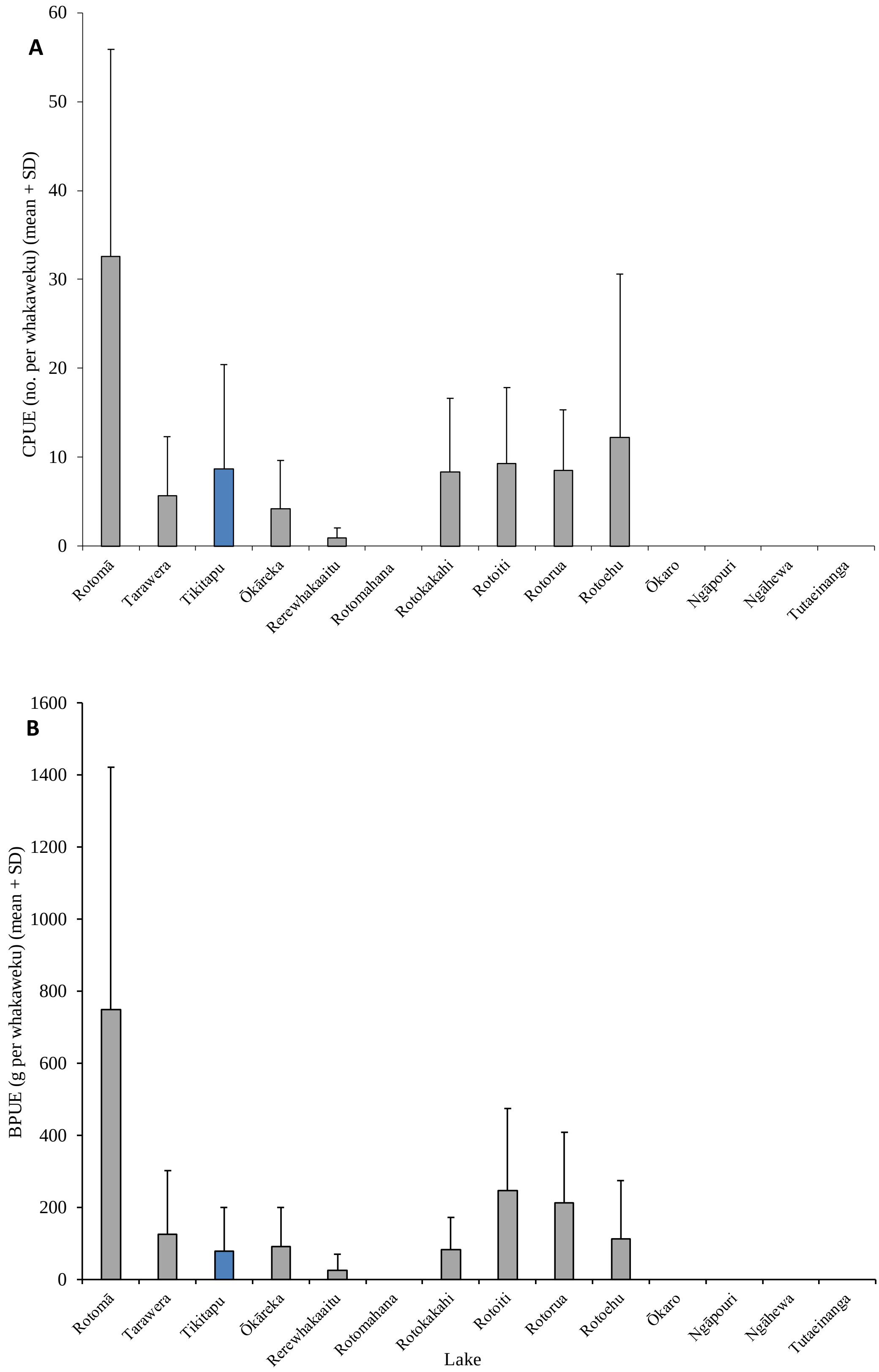

Figure 9 (A) Mean catch-per-unit-effort (CPUE; mm + SD) and (B) mean biomass-per-unit-effort (BPUE; g + SD) of kōura in 14 Te Arawa lakes. Lakes ordered in terms of increasing Chl-a concentration. Lake Tikitapu is highlighted in blue. See section 3.3. for details and source of kōura data.

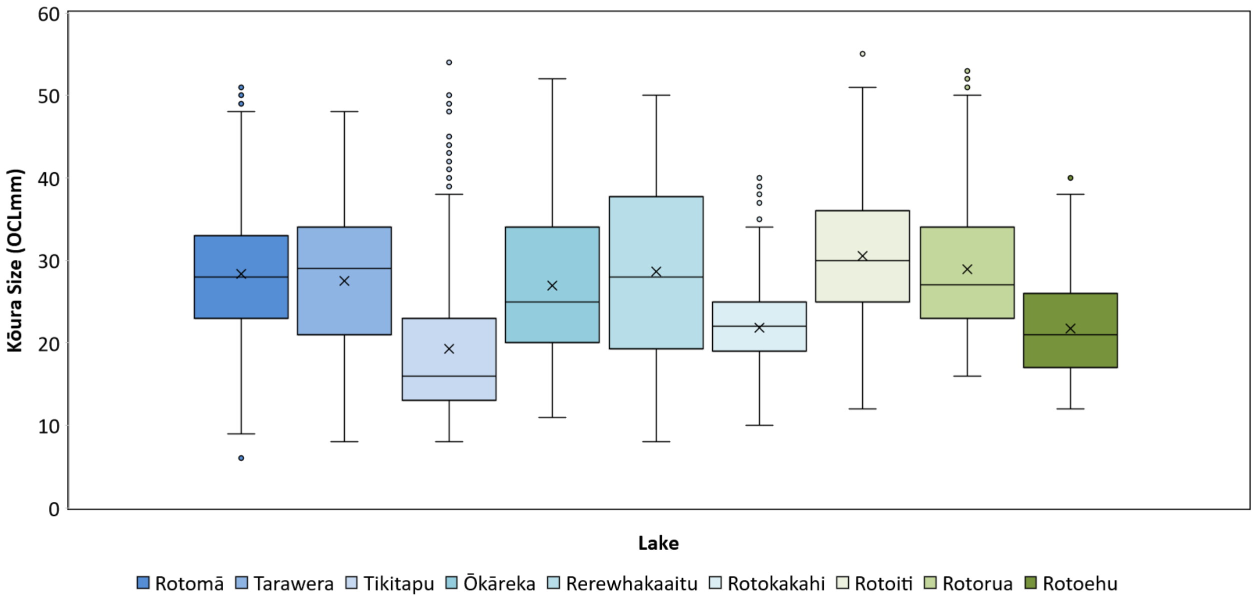

Figure 10: Box-and-whisker plot showing mean (x), median (horizontal line), interquartile range (box), distance from upper and lower quartiles times 1.5 interquartile range (whiskers), outliers (>1.5× upper or lower quartile) for kōura orbit carapace length for kōura collected in nine Te Arawa lakes. Lakes ordered in terms of increasing (approximately) Chl-*a* concentration. See section 3.3. for details and source of kōura data.

5 DISCUSSION

5.1 Lake Tikitapu

The Lake Tikitapu kōura population was characterised by moderate numbers of small-sized kōura; the smallest mean size recorded in the nine Te Arawa lakes where kōura have been surveyed. Length frequency analysis showed that the population was dominated by kōura < 20 mm OCL. The reason for this is unknown, however, it may be related to the unusual water chemistry in this lake. Lake Tikitapu is exceptionally low in calcium (0.7 mg l^{-1}; Forsyth, 1978) and also low in silica and all major ions (McColl, 1972). This is thought to inhibit plant and algal growths and may also explain the absence of kākahi (freshwater mussels; *Echyridella menziesii*), and the low abundance of snails and planktonic diatoms.

To be able to grow, kōura, like all other invertebrates, must moult their exoskeleton. At the onset of moulting their carapace becomes soft, as the calcium is resorbed and the outer "skin" is shed. A new carapace has formed underneath but may take several days to harden using both the calcium that has been stored in two white round lumps (gastroliths) on the stomach wall, and calcium from the surrounding water. Only 10% of the calcium required for hardening the exoskeleton comes from the gastroliths and the rest must be absorbed from the water (Lowery, 1988). The calcium content of water is very important both for adequate growth and survival, as kōura are particularly susceptible to cannibalism and predation whilst soft. Mortality can also be high due to the physiological stress of moulting. Moulting is thought to cease if water temperatures fall below about 10°C, so no, or little, growth may occur in Lake Tikitapu during the winter months. Although kōura do eat a variety of foods, in natural populations it has been found that animal protein contributes most to growth, and that aquatic snails, chironomids and mayflies are the most important invertebrate food sources (Parkyn et al. 2001). Juvenile kōura probably require more protein than adult kōura to sustain their high rate of growth. In many kōura species, including *P. zealandicus* (Southern kōura), the juveniles consume more invertebrates and the adults more plant material. Further research is required to determine the reasons for the small mean size of kōura in Lake Tikitapu.

Egg-bearing kōura were recorded in Lake Tikitapu in October and January but not in July. In most of Te Arawa lakes the peak egg bearing time is winter (Kusabs *et al.* 2015a). Lake Tikitapu is similar to lakes Rotomā and Rotorua where the highest proportion of egg-bearing kōura were present in Spring (Kusabs *et al.* 2015a).

Kōura abundance was significantly different at the two sampling sites in Lake Tikitapu. This intra-lake variation is not uncommon and was probably due to differences in benthic substrates, with kōura abundance increasing with increasing sediment size (Kusabs *et al.* 2015b). There was a significant reduction in kōura abundance at Site 1 in May 2018 due to the smothering of the whakaweku with native charophytes. This not only restricted kōura access to the whakaweku but can also leading to the rapid decay of the fern itself. In addition, aquatic plant proliferation, and accumulation of decaying organic matter, can markedly degrade the habitat quality of the surrounding lake bed resulting in a reduction in kōura abundance (Kusabs *et al.* 2013).

5.2 Lake Rotomahana

No kōura were collected in Lake Rotomahana; consistent with previous studies in this lake. This is most probably due to the high geothermal input to this lake, which results in the bottom waters warming to a greater extent than other Te Arawa lakes. The presence of iron floc on the whakaweku in February indicates that the bottom waters for at least part of the year (Fig. 11). Iron oxide hydroxide, $Fe(OH)_3$, is a form of iron that exits as an insoluble brown floc which settles to the sediment layer. Iron hydroxide can alter food quality, food availability, habitat structure and can attach to vital parts of animals, resulting in stress and tissue damage in benthic feeding macro-invertebrates and fish (Vuori 1995; Gerhardt &Westermann, 1995; Linton *et al.* 2007). Svobodová *et al.* (2012) reported a negative correlation between the presence of crayfish (*Austropotamobius torrentium* and *Astacus astacus*) and Fe and Al concentrations in water. Further, Svobodová *et al.* (2017) attributed the mass die-off of crayfish (*A. torrentium* and *A. astacus*) in the Kalabava Stream, Czech

Republic, to extremely high concentrations of Al and Fe in the gills which resulted in hypoxia and osmoregulatory stress.

Figure 11 Iron floc on kōrapa (landing net) following retrieval of the tau kōura, Lake Rotomahana, 25 February 2018.

6 Summary and conclusions

The Lake Tikitapu kōura population was characterised by moderate numbers of small-sized kōura (< 20 mm OCL); the smallest in the nine Te Arawa lakes where kōura have been recorded. Lake Tikitapu ranked fifth in terms of kōura CPUE and eighth in terms of BPUE in the 13 Te Arawa lakes where kōura monitoring has been undertaken. The reason for the small size of kōura is unknown, however, it may be related to the unusual water chemistry in this lake which is low in calcium (< 0.7 mg l^{-1}), silica and all major ions. The calcium content of water is very important both for adequate growth and survival, as kōura are particularly susceptible to cannibalism and predation whilst soft.

No kōura were found in Lake Rotomahana, consistent with previous studies in this lake. The absence of kōura in this lake is most probably due to high geothermal inputs, which result in the bottom waters warming to a greater extent than other Te Arawa lakes. Iron floc precipitates were found on whakaweku in February 2018, which indicates that the bottom waters are anoxic for at least part of the year. Iron hydroxide precipitates, can decrease growth of food plants and when ingested can attach to gill and gut membranes, disturbing kōura metabolism and mobility, thereby restricting foraging behaviour. Moreover, extremely high Fe levels can result in hypoxia, osmoregulatory stress and death of kōura.

7 ACKNOWLEDGEMENTS

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