ROTORUA TE ARAWA LAKES KŌURA MONITORING PROGRAMME

LAKE TIKITAPU 2020/2021

REPORT NUMBER 5 PREPARED FOR BAY OF PLENTY REGIONAL COUNCIL

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Rotorua Te Arawa lakes kōura monitoring programme - Lake Tikitapu 2020/21

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Cover image

Setting whakaweku in Lake Tikitapu with Soweeta Fort-D'ath and Niao Leonard, cadets from the Department of Conservations Sentinel A Nuku rangatahi training programme, 14 May 2021. Photo I. Kusabs.

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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 is to regularly monitor kōura populations in the Rotorua Te Arawa Lakes. This report provides an analysis of monitoring data for kōura from Lake Tikitapu and compares it with baseline data collected in 2017/18 and with kōura data recorded from 14 other Rotorua Te Arawa lakes.

The kōura population in Lake Tikitapu was sampled using the tau kōura, a traditional Māori method of harvesting kōura in the Rotorua Te Arawa and Taupō lakes. Two tau kōura were deployed, each composed of 10 whakaweku (bracken fern bundles). Whakaweku were attached to the tau kōura on 14 July 2020 and were retrieved on 16 November 2020, 12 February 2021, 14 May 2021 and 10 September 2021.

Kōura relative abundance in Lake Tikitapu was significantly lower (-69%) in 2020/21 than in 2017/18. An examination of length frequency data shows that small-sized (9 -15 mm OCL) kōura have been most affected. It appears that there was very little juvenile recruitment in 2019, and this looks likely to continue, with no female kōura in breeding condition recorded in 2020/21. There are a number of possible reasons for this including: high prevalence of white tail disease (Fig. i), unusual water chemistry, or the presence of predatory brown bullhead catfish (although no sign of catfish was found in an eDNA survey carried out in May 2021). Further monitoring is required to determine if this trend continues in Lake Tikitapu.

Figure i Kōura (ranging from 15 to 54 mm OCL) collected from Lake Tikitapu on 14 May 2021, infected with *Thelohania contejeani*, which causes white-tail disease. It is fatal and appears to be transmitted by ingestion of spores via cannibalism of dead or dying crayfish.

The highest abundance and biomass of kōura are now found in the three oligotrophic lakes Tarawera, Rotomā and Ōkataina, whereas in 2009 the highest CPUEs and BPUEs were recorded in lakes Rotorua, Rotoiti and Rotomā (Fig ii). The decline in kōura CPUE and BPUE in lakes Rotoiti and Rotorua has coincided with the recent establishment of brown bullhead catfish in these lakes.

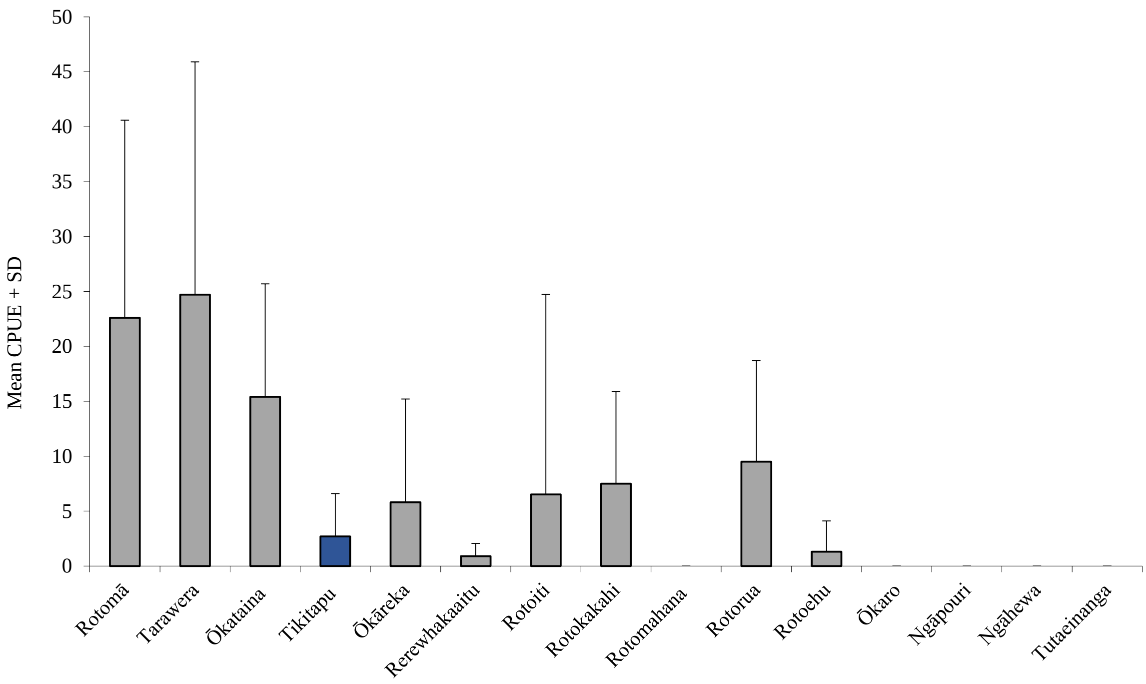

Figure ii Mean catch-per-unit-effort (CPUE; + SD) of kōura collected using the tau kōura method in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing TLI (Trophic Level Index) value. Lake Tikitapu is highlighted in dark blue.

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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 in 2016, the BOPRC committed to regular surveying 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 in the lakes and an important ecological component, acting as predators, shredders, and detritivores (Kusabs & Quinn, 2009). They are also an important mahinga kai species for Te Arawa iwi supporting important customary fisheries in lakes Ōkataina, Rotoiti, Rotomā and Tarawera (Hiroa 1921; Stafford 1996, Kusabs *et al*. 2015a).

Until recently, there was a lack of quantitative information on lake 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 (Kusabs *et al*. 2015 & 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, Rotoehu and Rotorua. 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[1].

Objectives

The aim of this study was to survey kōura populations in Lake Tikitapu as part of the Rotorua Te Arawa Lakes kōura monitoring programme.

[1] Note: Lakes Ngāpouri, Tutaeinanga and Ngāhewa are in the Waikato Regional Council district.

METHODS

Study area

Lake Tikitapu is located on the Central North Island of New Zealand within the Taupo Volcanic Zone (Fig. 2). Tikitapu is of significant cultural importance to Ngāti Tumatawera and Ngāti Wahiao / Tūhourangi (Butterworth 2008). Lake Tikitapu is a relatively small (1.5 km^2) but deep (27.5 m) lake in the mid-west of the Rotorua Te Arawa Lakes region at 415 m above sea level (Fig. 2). It was formed approximately 13,500 years ago, and has a 5.7 km^2, 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. It is an attractive and popular lake with oligotrophic-mesotrophic water quality (LAWA 2021a). The target Trophic Level Index (TLI) for Lake Tikitapu is 2.7, whereas TLIs have ranged between 2.6 and 3.0 over the past five years (Scholes & Dare, 2020).

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.

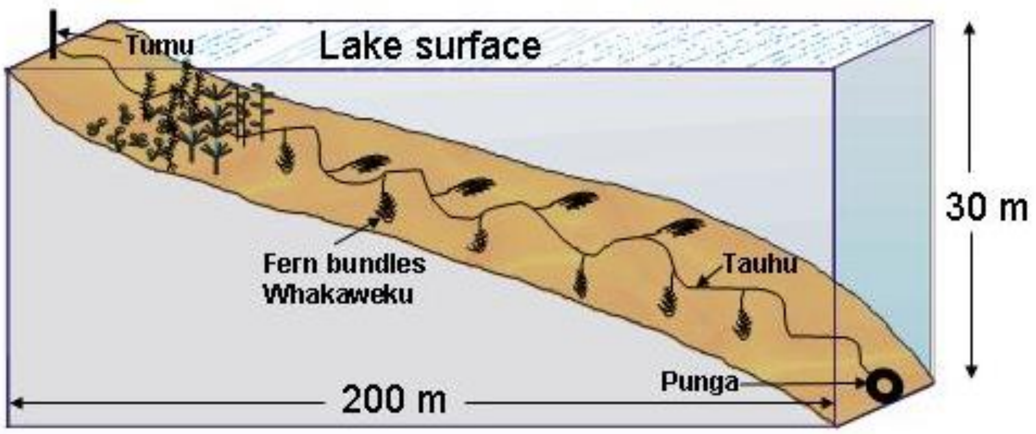

Figure 1 Schematic diagram of the tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

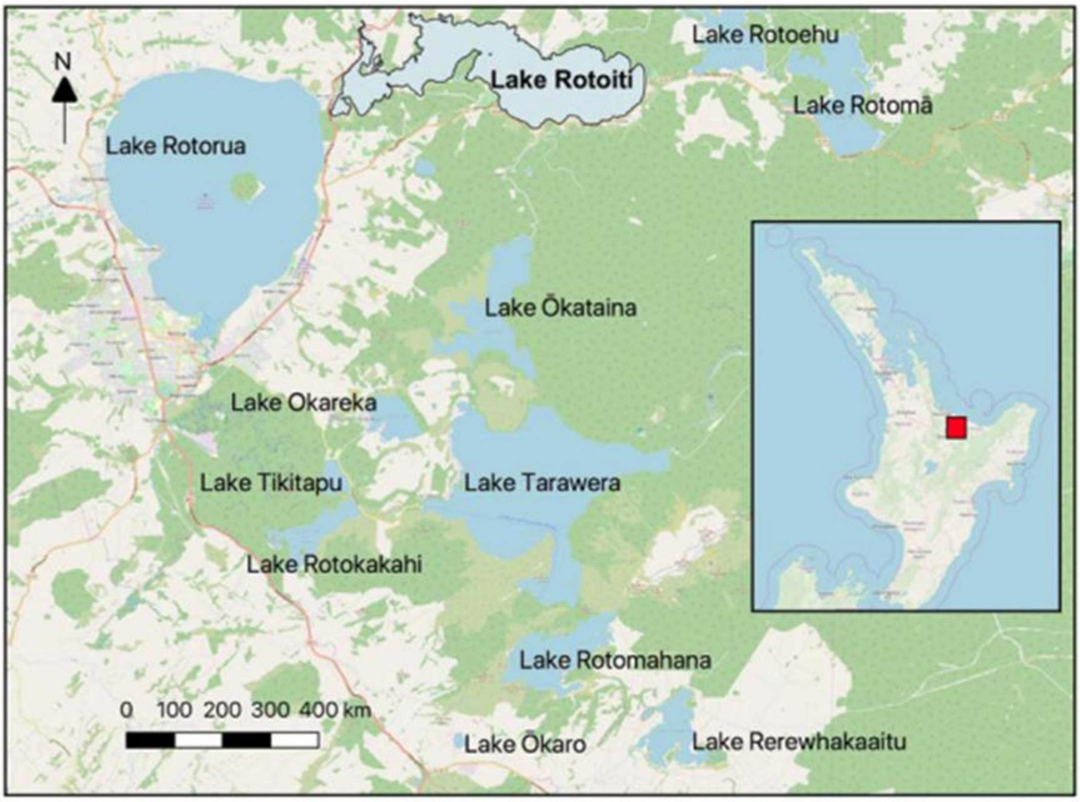

Figure 2 Map of the Rotorua Te Arawa Lakes showing the location of Lake Tikitapu.

Tau kōura construction and use

The kōura population in Lake Tikitapu was sampled using two tau kōura (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 (Fig. 1). Whakaweku were set in depths ranging from 7 to 27 m in Lake Tikitapu (Table 1; Fig. 3).
Two tau kōura (initially deployed by Kusabs, 2018) were used to sample the kōura population in Lake Tikitapu. These tau kōura were located on the western (A) and southern (B) shorelines of the lake (Fig. 3).

Table 1 Sampling site, grid reference and approximate location of kōura monitoring sites in Lake Tikitapu, depths were recorded on 18 May 2021.

Lake	Sampling site	Latitude Longitude (Degrees, minutes, seconds)	Water depth (m)
Tikitapu	Site A	S 38°11'54" E 176°19'30"	8 - 23
Tikitapu	Site B	S 38°12'01" E 176 20'13"	7 - 22

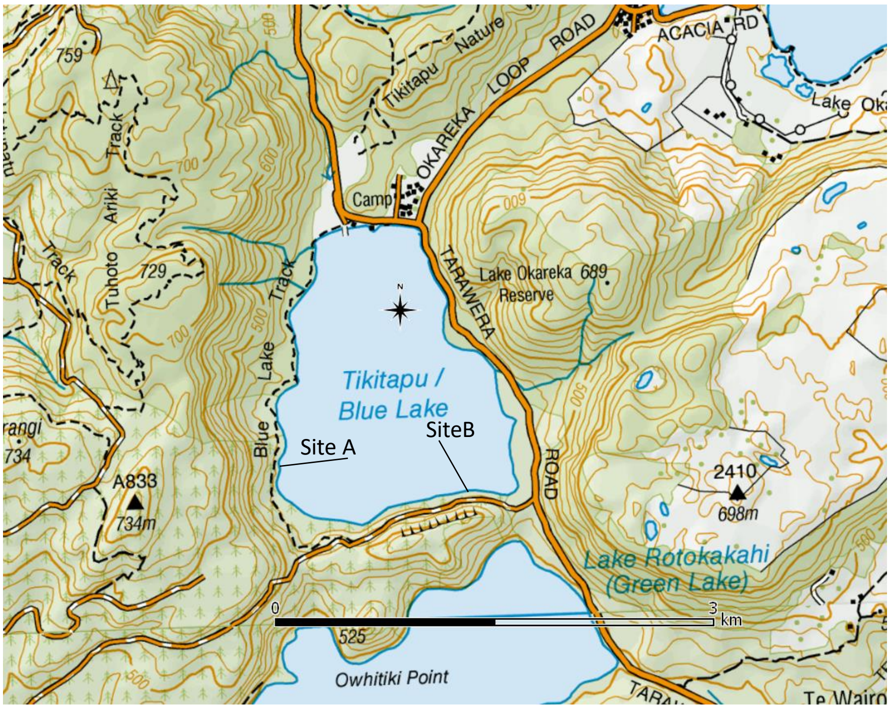

Figure 3 Lake showing the approximate locations and direction of the tau kōura monitoring sites.

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.

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[2] 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.

[2] except those infected with white tail disease, which were destroyed.

Comparison of kōura data with other Rotorua Te Arawa lakes

Kōura data from Lakes Tikitapu was compared with that collected from 14 other Rotorua Te Arawa lakes. The sources of this data are shown in Table 2. In addition, kōura population data recorded in in this study (2020/21) was compared with the baseline survey carried out in 2017/18 (Kusabs 2018).

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

Lake	Month/year sampled	Source
Ngāhewa	December 2016	Kusabs (2017a)
Ngāpouri	December 2016	Kusabs (2017a)
Ōkāreka	November 2019; February, May & August 2020	Kusabs (2020)
Ōkaro	March, June, Nov 2016; February 2017	Kusabs (2017b)
Ōkataina	November 2018; February, May & August 2019	Kusabs (2019d)
Rerewhakaaitu	March, June, Nov 2016; February 2017	Kusabs (2017b)
Rotoehu	November 2020, January 2021	Kusabs (2021a)
Rotoiti	November 2020, January, May & August 2021	Kusabs (2021)
Rotokakahi	May, July & November 2009	Kusabs *et al*. (2015)
Rotomā	October 2018; March, May & August 2019	Kusabs (2019d)
Rotomahana	July 2017, October 2017, January & May 2018	Kusabs (2018)
Rotorua	November 2020, January, May & August 2021	Kusabs (2021b)
Tarawera	November 2019, February, May & August 2020	Kusabs (2020)
Tikitapu	November 2020, February, May & September 2021	This report
	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, and to compare the 2017/18 and 2020/21 surveys in Lake Tikitapu. Data from the two tau kōura sites were combined when comparing the 2020/21 and baseline surveys.

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 and to compare kōura size data with baseline surveys carried out in in Lake Tikitapu in 2017/18.

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.

RESULTS

Lake Tikitapu

Kōura abundance and biomass

Kōura were present in low to moderate numbers in Lake Tikitapu with a total of 213 kōura captured at a mean CPUE of 2.7 ± 3.9 (± 1 SD) kōura whakaweku^{-1} and a mean BPUE of 61.1 g ± 117.8 (±1 SD) kōura whakaweku $^{-1}$. The highest mean CPUE (5.8 kōura whakaweku^{-1}) and mean BPUE (157.6 g kōura whakaweku^{-1}) were both recorded in February at Site A (Table 3). There were no significant differences in kōura mean CPUE (p = .09), and mean BPUE (p = .37) between the two sites in Lake Tikitapu. Mean CPUE was 3.7 ± 4.9 (±1 SD) kōura whakaweku^{-1} at Site A compared to 1.6 ± 2.4 (±SD) kōura whakaweku^{-1} at Site B, while the mean BPUE was 84.8 g ± 140.4 (± 1 SD) kōura whakaweku^{-1} at Site A compared to 37.4 g ± 85.3 (± 1 SD) kōura whakaweku^{-1} at Site B (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 Tikitapu and retrieved from 16 November 2020 to 10 September 2021. n = number of kōura, g = grams, SD = standard deviation.

Date	Mean CPUE (*n* ± 1 SD)		Mean BPUE (g ± 1 SD)	
	A (West)	B (South)	A (West)	B (South)
16 November 2020	4.5 (4.4)	0.6 (0.8)	98.1 (125.3)	2.8 (5.8)
12 February 2021	5.8 (5.6)	2.2 (2.5)	157.6 (196.3)	65.6 (95.8)
14 May 2021	2.9 (6.2)	2.8 (3.5)	64.1 (136.1)	66.0 (130.6)
10 September 2021	1.7 (1.9)	0.8 (1.0)	19.3 (36.0)	15.1 (39.8)
Mean all	3.7 (4.9)	1.6 (2.4)	84.8 (140.4)	37.4 (85.3)

Kōura size

The mean OCL of all kōura collected in Lake Tikitapu was 25.6 ± 11.2 mm (± 1 SD) with individuals ranging from 7 to 56 mm OCL (Table 4). Female kōura were significant larger in size (28.2 ± 11.1 mm ± 1 SD) than male kōura (24.4 ± 10.8 mm ± 1 SD) in Lake Tikitapu (p <.05). There was no significant difference in kōura size between the two sites, with a mean OCL of 25.5 mm ± 11.3 mm (± 1 SD) at Site A compared to 25.8 ± 11.1 mm (± 1 SD) at Site B (p =.78).

Two size classes were identified as cohorts in the kōura samples recorded in May 2021, an age-0+ year class ~12 to 16 mm and an age 1-year class ~16 to 21 mm (Fig. 4). The likelihood of overlap was too high to reliably determine year classes above these ages.

Table 4 Mean OCL (mm ± 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 Tikitapu and retrieved from 16 November 2020 to 10 September 2021. *n* = number of kōura sexed; SD = standard deviation.

Date	Mean OCL (mm ± SD)		OCL Range (mm)		Female to male % (*n*)	
	A (West)	B (South)	A (West)	B (South)	A (West)	B (South)
16 November 2020	23.8 (11.9)	15.8 (6.3)	10 - 54	8 - 27	18.2 (44)	20.0 (5)
12 February 2021	27.4 (11.1)	28.1 (12.1)	12 - 56	13 - 54	41.4 (58)	40.9 (22)
14 May 2021	28.2 (11.6)	26.7 (10.3)	7 - 49	15 - 48	44.4 (18)	57.1 (28)
10 September 2021	20.6 (8.1)	23.6 (11.0)	11 - 47	14 - 48	56.3 (16)	12.5 (8)
Mean/range	25.5 (11.3)	25.8 (11.1)	7 - 56	8 - 54	36.0 (136)	42.9 (63)

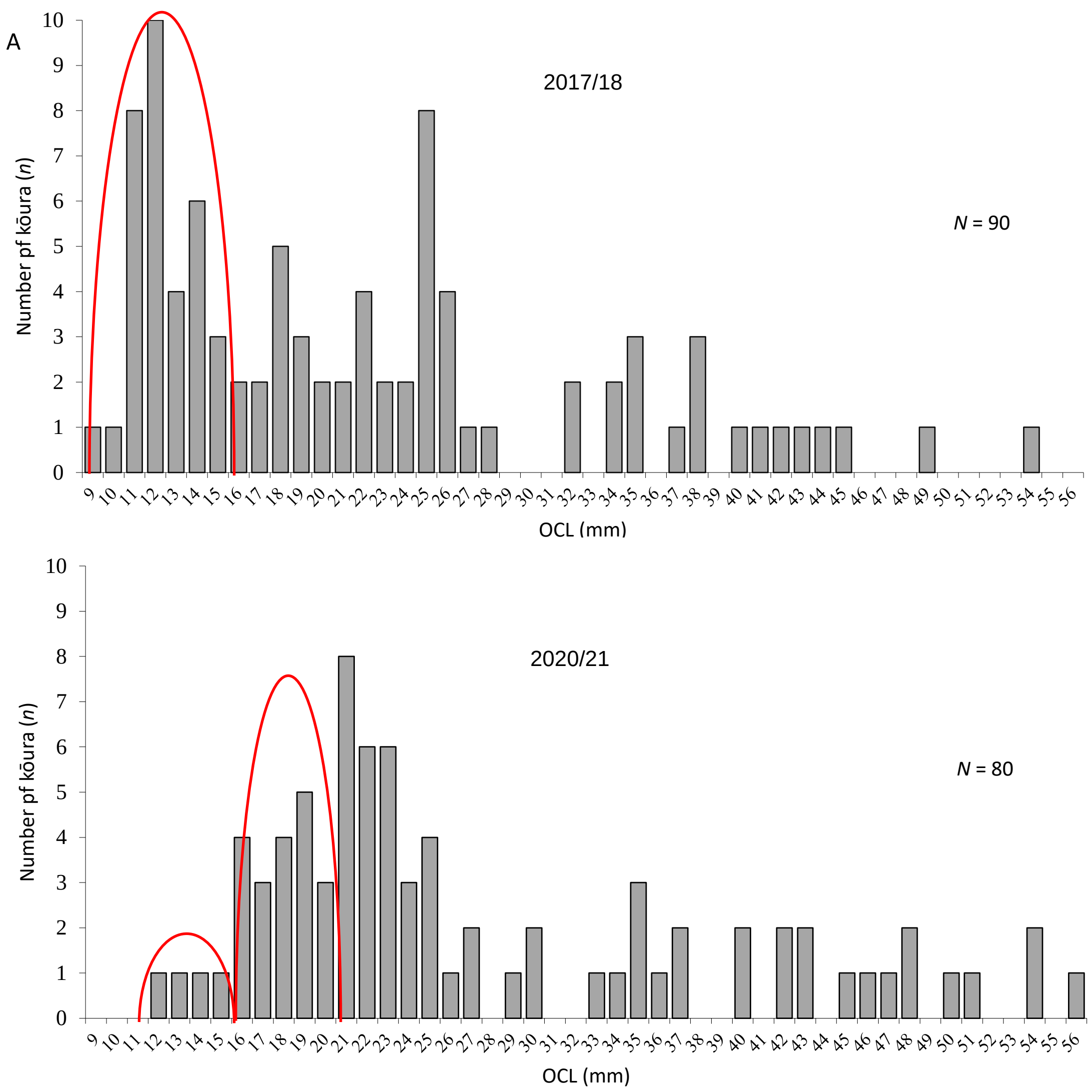

Figure 4 Length frequency distribution of kōura captured on two tau kōura, each composed of 10 whakaweku, set in Lake Tikitapu, sample collected 14 May 2021 (lower) and 18 May 2018 (upper). OCL = orbit carapace length. The age 1-year class is outlined in red. OCL = orbit carapace length.

Percentage females, breeding kōura and soft shells

The overall ratio of female to male kōura in Lake Tikitapu was 38.2%, with the percentage of females caught over the sampling period ranging from 12.5 to 57.1% (Table 4). No egg-bearing kōura were recorded in Lake Tikitapu in the four surveys (Table 5). Kōura in soft shells were present on all four sampling occasions, with the highest percentage (32.5%) recorded in February 2021 (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 Tikitapu and retrieved from 16 November 2020 to 10 September 2021. (*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*)
16 November 2020	51	0.0 (0)	-	0.0 (0)
12 February 2021	80	0.0 (0)	-	32.5 (26)
14 May 2021	47	0.0 (0)	-	25.5 (12)
10 September 2021	25	0.0 (0)	-	16.0 (4)

White tail disease

A total of 28 (13.1%) kōura collected from Lake Tikitapu in 2020/21 were infected with the microsporidian parasite *Thelohania contejeani*, which causes white-tail disease in decapods (Table 6). Infected kōura were recorded on all four sampling occasions with the highest number recorded in February (*n* = 13) (Table 6). Infected kōura ranged in size from 14 to 54 mm OCL. Female kōura comprised 46.4% of all infected kōura despite only comprising 38.2% of the total population (Table 6). Female kōura were therefore disproportionately affected with 17.1% of all female kōura infected with whitetail disease.

Table 6 Number of kōura sampled, mean percentage and range of breeding size females with eggs or young (defined as >21 mm) in samples collected from two tau kōura, each composed of 10 whakaweku, set at two sites in Lake Tikitapu and retrieved from 16 November 2020 to 10 September 2021.

Survey date	Number of kōura sampled	% White tail infection	% Female (*n*)	Size range OCL (mm)
16 November 2020	51	20.0 (10)	30.0 (3)	14 - 48
12 February 2021	80	16.3 (13)	46.2 (6)	15 - 54
14 May 2021	47	8.5 (4)	75.0 (3)	17 - 42
10 September 2021	25	4.0 (1)	100.0 (1)	23

Common bullies and other invertebrates

A total of 325 common bullies (*Gobiomorphus cotidianus*) were captured in Lake Tikitapu over the sampling period with the highest catch recorded in May 2021 (n = 225) and the lowest in November 2020 (n = 22). Large numbers of chironomids (bloodworms or midges) were collected in depths ranging from 17 to 20 m in May 2021, when the lake was stratified, resulting in deoxygenation of the hypolimnion (Fig. 5). Chironomids are indicative of low oxygen concentrations in sediment. This is the first occasion that such large numbers have been collected in 15 years of tau kōura monitoring in the Rotorua Te Arawa and Taupō lakes (I Kusabs, pers obs.).

Figure 5 Chironomid larva retrieved from a whakaweku set at a depth of 18 m in Lake Tikitapu on 14 May 2021.

Comparison with 2017/18 survey

Kōura abundance and biomass

Kōura abundance in Lake Tikitapu was significantly lower in 2020/21 than in 2017/18 (p <.001) (Table 7)[3]. Overall Mean CPUE decreased by -69% from 8.7 kōura whakaweku^{-1} (2017/18) to 2.7 kōura whakaweku^{-1} (2020/21). While overall mean BPUE decreased by -21.9% from 78.2 g kōura whakaweku^{-1} (2017/18) to 61.1 g kōura whakaweku^{-1} (2020/21), although this was not significant (p >.05) (Table 7). Mean CPUE and mean BPUE were higher in winter 2017 than in 2021, while mean CPUE was significantly higher in spring 2017 compared with spring 2020 (p <.001) (Table 7).

Table 7 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 Lake Tikitapu in 2017/18 and 2020/21. 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
	2017/18	2020/21		2017/18	2020/21	
Summer	9.9 (14.7)	4.0 (4.6)	p = .10	100.8 (139.4)	111.6 (157.6)	p = .82
Autumn	4.5 (6.2)	2.9 (4.9)	p = .36	77.7 (160.8)	65.1 (129.8)	p = .88
Winter	8.5 (8.2)	1.3 (1.6)	p < .001	55.2 (48.6)	17.2 (37.0)	p < .01
Spring	12.0 (14.8)	2.6 (3.7)	p < .001	84.1 (107.5)	50.4 (99.2)	p = .34
All	8.7 (3.9)	2.7 (3.9)	p < .001	78.2 (120.5)	61.1 (117.8)	p = .36

Kōura size

Kōura mean size was significantly higher in 2020/21 (25.6 mm OCL) than in 2017/18 (18.6 mm OCL) (p <.05; Table 8). Further, mean kōura OCL size was significantly higher in 2020/21 for all four seasons (Table 8). There was, however, little difference in the size range of kōura recorded in 2020/21 (7 to 56 mm OCl) compared to 2017/18 (8 to 54 mm OCL) (Table 8, Fig. 4).

Table 8 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 Tikitapu 2017/18 and 2020/21. SD = standard deviation. Significant differences are highlighted in red.

Season	Mean OCL (mm ± SD)		Significance	OCL Range (mm)	
	2017/18	2020/21		2017/18	2020/21
Spring	17.2 (7.2)	22.8 (11.6)	p < .001	11 - 48	8 - 54
Summer	20.3 (7.6)	27.6 (11.3)	p < .001	10 - 50	12 - 56
Autumn	22.1 (10.5)	27.3 (10.8)	p < .001	9 - 54	7 - 49
Winter	16.9 (7.0)	21.6 (9.0)	p < .001	8 - 48	11 - 48
All	18.6 (8.0)	25.6 (11.2)	p < .001	8 - 54	7 - 56

[3] Data for both tau kōura sites was combines for the comparisons.

Percentage females, breeding kōura and soft shells

Female kōura comprised 38% of kōura sampled in 2020/21, far less than the 49.5% recorded in 2017/18 (Table 9). In addition, no female kōura bearing eggs were collected in 2020/21, whereas five were recorded in 2017/18 (Table 9). In contrast, the percentage of kōura in soft shell was far higher in 2020/21 (20.7%) than in 2017/18 (3.6%).

Table 9 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 two tau kōura, each composed of 10 whakaweku, deployed in Lake Tikitapu in 2017/18 and 2020/21. (N) = number of females. (*n*) = number of egg-bearing kōura. (*N*) = number of kōura with soft shells.

Survey date	% Female (N)		% Breeding size females with eggs (*n*)		Range breeding size OCL (mm)		% Soft shells (*N*)	
	2017/18	2020/21	2017/18	2020/21	2017/18	2020/21	2017/18	2020/21
Spring	49.6 (70)	18.3 (9)	17.0 (4)	0.0	34 - 43	–	4.2 (10)	0.0
Summer	51.3 (82)	41.3 (33)	3.2 (1)	0.0	34	–	3.6 (7)	32.5 (26)
Autumn	52.0 (39)	52.2 (24)	0.0	0.0	–	–	2.2 (2)	25.5 (12)
Winter	45.9 (62)	41.7 (10)	0.0	0.0	–	–	3.5 (6)	16.0 (4)

Common bullies and invertebrates

Common bullies were more numerous (*n* = 325) in Lake Tikitapu in the 2020/21 survey than in 2017/18 (*n* = 96), an increase of 239%. Chironomids were also far more numerous in 2021 than in 2017/18, when none were recorded.

Kōura health

13.1% (n = 28) of all kōura sampled in Lake Tikitapu in 2020/21 were infected with whitetail disease (Fig. 6). No infected kōura were recorded in 2017/18 despite a far higher sample size (*n* = 696) than 2017/18 (*n* = 213). *Thelohania* is the most commonly encountered disease in freshwater crayfish in New Zealand (Fig. 6). The reason for the high incidence of white tail disease in kōura surveyed in 2020/21 is unknown.

Figure 6 Kōura collected from Lake Tikitapu on 14 May 2021 infected with *Thelohania contejeani*, which causes white-tail disease. Kōura range from 15 to 54 mm OCL.

Kōura population dynamics in relation to other Rotorua Te Arawa Lakes

Kōura abundance and biomass

Lake Tikitapu is ranked eighth in terms of mean CPUE (2.7 kōura whakaweku^{-1}) and mean BPUE (61.1 g kōura whakaweku^{-1}) (Figs. 8A & 8B). The highest abundance and biomass of kōura are now found in the three oligotrophic lakes Tarawera, Rotomā and Ōkataina, whereas in 2009 the highest CPUEs and BPUEs were recorded in lakes Rotorua, Rotoiti and Rotomā. The decline in kōura CPUE and BPUE in lakes Rotoiti and Rotorua has coincided with the recent establishment of brown bullhead catfish in these lakes (*Ameiurus nebulosus*) (Kusabs *et al*. 2019c).

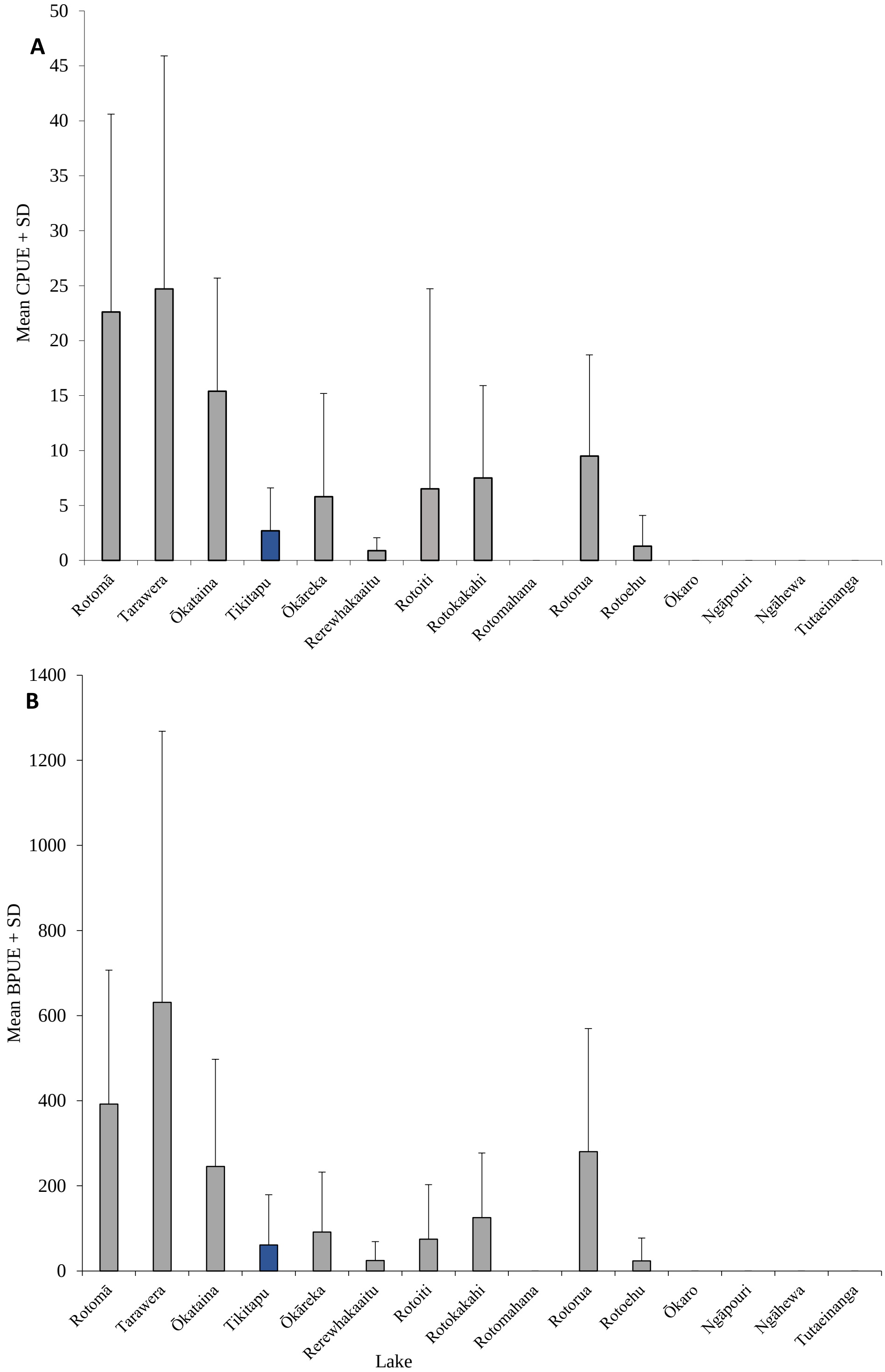

Figure 7 (A) Mean catch-per-unit-effort (CPUE; + SD) and (B) mean biomass-per-unit-effort (BPUE; g+ SD) of kōura collected using the tau kōura method in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing TLI (Trophic Level Index) value. Lake Tikitapu is highlighted in dark blue. Refer Table 2 for details and source of kōura data.

Kōura size

In terms of mean kōura size, Lake Tikitapu was ranked eight (25.6 mm OCL) in the 10 Rotorua Te Arawa lakes where kōura have been recorded (Fig. 9). Lake Tarawera has the largest sized kōura with a mean size of 29.1 mm OCL, which was recorded in 2019/20.

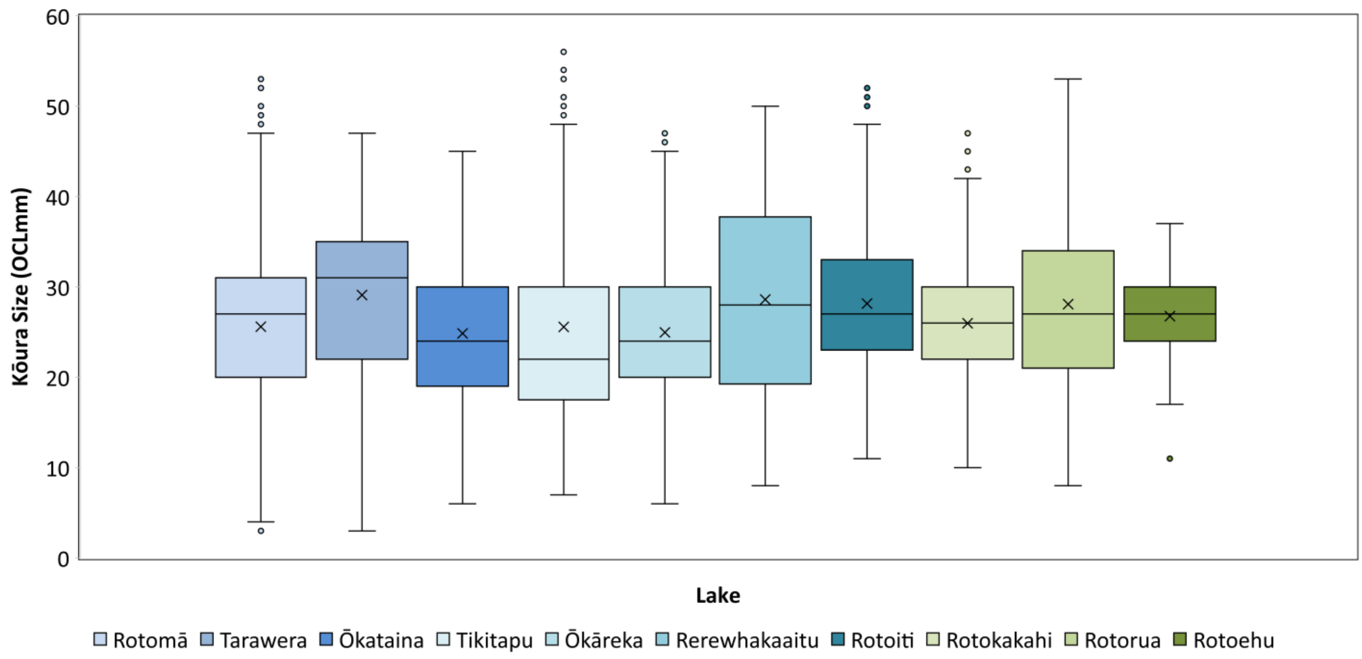

Figure 8 Box-and-whisker plot showing mean (x), median (horizontal line), interquartile range (box), distance from upper and lower quartiles times 1.5 interquartile range (whiskers), outliers (>1.5× upper or lower quartile) for kōura orbit carapace length for kōura collected in 15 Rotorua Te Arawa lakes. Lakes ordered in terms of increasing TLI (Trophic Level Index) value. Refer Table 2 for details and source of kōura data.

DISCUSSION

Lake Tikitapu

Kōura relative abundance in Lake Tikitapu was significantly lower (-69%) in 2020/21 than in 2017/18, with the highest declines occurring in spring and winter. In contrast, relative biomass decreased by only -21.9%. An examination of length frequency data shows that small sized (9 - 15 mm OCL) kōura, which comprised the greatest proportion of the kōura population in 2017/18, have been most affected. It appears that there was very little juvenile recruitment in 2019, and this looks likely to continue with no female kōura in breeding condition recorded in 2020/21.

There are a number of possible reasons for the poor juvenile kōura recruitment since 2018/19, these include; (a) the high prevalence of white tail disease (b) unusual water chemistry, and (c) establishment of catfish – well-known predators of kōura (Barnes and Hicks, 2003).

White tail disease affected 13.1% (*n* = 28) of all kōura sampled from Lake Tikitapu in 2020/21. No infected kōura were recorded in 2017/18 despite a far higher sample size (*n* = 696) than in 2017/18 (*n* = 213). The microsporidian parasite *Thelohania contejeani*, causes "white tail disease" and has been implicated in mass mortalities in populations of the endangered European crayfish *Austropotamobius pallipes* (Imhoff et al, 2020). White tail disease is the most commonly encountered disease in freshwater crayfish in New Zealand. In the later stages of infection, it is easily detected as the underside of the tail turns porcelain white. It is fatal and appears to be transmitted by ingestion of spores via cannibalism of dead or dying crayfish. In natural populations, the disease infects between one and 11% of the population (Hollows, 2016). It has also been reported in most of the Rotorua Te Arawa Lakes, as well as in lakes Taupo and Rotoaira, but only occasionally (<0.01%) (I. Kusabs, unpubl. data).

Lake Tikitapu has unusual water chemistry with very low concentrations of calcium (< 0.7 mg l^{-1}), silica and all major ions. To be able to grow, kōura, must moult their exoskeleton. The calcium content of water is important for adequate growth and survival, as kōura are particularly susceptible to cannibalism and predation whilst soft (Lowery, 1988). Mortality can also be high due to the physiological stress of moulting. It is possible that kōura may be more vulnerable to parasitism when they are moulting and this may be the reason for the high incidence of whitetail disease in Lake Tikitapu.

Similar declines in kōura abundance (and increases in mean koura size) have been reported in lakes Rotoiti and Rotorua, which have been attributed to the establishment of predatory brown bullhead catfish (Kusabs 2021). However, an environmental DNA survey conducted in May 2021 detected no evidence of catfish presence in Lake Tikitapu (pers. comm. W. Anaru, TALT). Further monitoring is required to determine if this trend continues in Lake Tikitapu.

Summary and conclusions

Kōura relative abundance in Lake Tikitapu was significantly lower (-69%) in 2020/21 than in 2017/18. An examination of length frequency data shows that small sized (9 -15 mm OCL) kōura, which have been most affected. It appears that there was very little juvenile recruitment in 2019, and this looks likely to continue with no female kōura in breeding condition recorded in 2020/21. There are a number of possible reasons for this but it may be due to the high prevalence of white tail disease.

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