New Zealand Journal of Marine and Freshwater Research, 2009, Vol. 43: 713–722

0028–8330/09/4303–0713

Use of a traditional Māori harvesting method, the tau kōura, for monitoring kōura (freshwater crayfish, *Paranephrops planifrons*) in Lake Rotoiti, North Island, New Zealand

IAN A. KUSABS
Te Arawa Lakes Trust
P.O. Box 128
Rotorua, New Zealand
email: ian@kusabs.co.nz

JOHN M. QUINN
National Institute of Water and Atmospheric Research Limited
P.O. Box 11 115
Hamilton, New Zealand

Abstract Sampling of kōura (freshwater crayfish *Paranephrops planifrons*) to assess population abundance and structure in lakes is often difficult or impractical because of the absence of representative methods. The tau kōura is a traditional Māori method used to catch kōura in central North Island lakes by placing whakaweku (bundles of bracken fern *Pteridium esculentum*) on the lake bed that kōura then colonise. It has advantages as a monitoring tool over conventional methods, such as baited traps and dive surveys, as it samples all kōura size classes, can be used in turbid waters and at a wide range of depths, and does not require expensive equipment or specialised expertise (e.g., SCUBA). We demonstrate its use to monitor kōura populations in Lake Rotoiti (mean depth 32 m), North Island, New Zealand. Application of the method allowed differences in population size structure to be distinguished between a shallow and a moderate depth site within Lake Rotoiti and to discern seasonal breeding patterns.

Keywords Te Arawa; Ngati Tūwharetoa; Rotorua lakes; population size structure; abundance; catch-per-unit-effort; sex ratio; egg-bearing

M08031; Online publication date 25 June 2009
Received 26 June 2008; accepted 27 November 2008

INTRODUCTION

Large populations of kōura (freshwater crayfish, *Paranephrops planifrons*) have been reported in several central North Island lakes in New Zealand, e.g., Rotoiti, Rotoma, Okataina, Tarawera, and Taupō (Devcich 1979). Kōura are an important traditional food source for Māori (Hiroa 1921). Furthermore, Māori throughout New Zealand are reasserting the principle of kaitiakitanga—the sustainable protection of resources (Tipa & Teirney 2006). Kaitiakitanga ensures conservation, protection and maintenance of resources through responsible actions, behaviour, conduct, and practices. Therefore it is important for iwi (Māori tribe) and hapū (Māori sub-tribe) organisations to be active participants in the resource consent monitoring process, i.e., kaitiakitanga, in which Māori monitor their own mahinga kai (traditional food resources and places where they are gathered) as part of active participation in the sustainable management of lake ecosystems.

There is considerable anecdotal evidence of declines in lake populations of kōura since European settlement (Hiroa 1921). A number of environmental factors may be responsible for this decline, including introductions of exotic fish which prey upon kōura (McDowall 1987; Barnes & Hicks 2003), exotic plant species which likely hinder movement and accumulate large amounts of organic detritus (I. Kusabs pers. obs.), as well as reduced concentrations of dissolved oxygen in the bottom waters of lakes owing to eutrophication (Vincent et al. 1984; Hamilton et al. 2005). Although these changes have been documented individually, their collective influence may have had a considerable impact on kōura populations.

The ecology of stream-dwelling kōura is relatively well studied in New Zealand (Hopkins 1967a,b; Hicks & McCaughan 1997; Rabeni et al. 1997; Parkyn 2000; Parkyn et al. 2001, 2002a,b), but little is known about kōura populations in New Zealand lakes. The only detailed study of lake-dwelling kōura was carried out by Devcich (1979), who focused on the ecology of kōura in Lake Rotoiti (North Island).

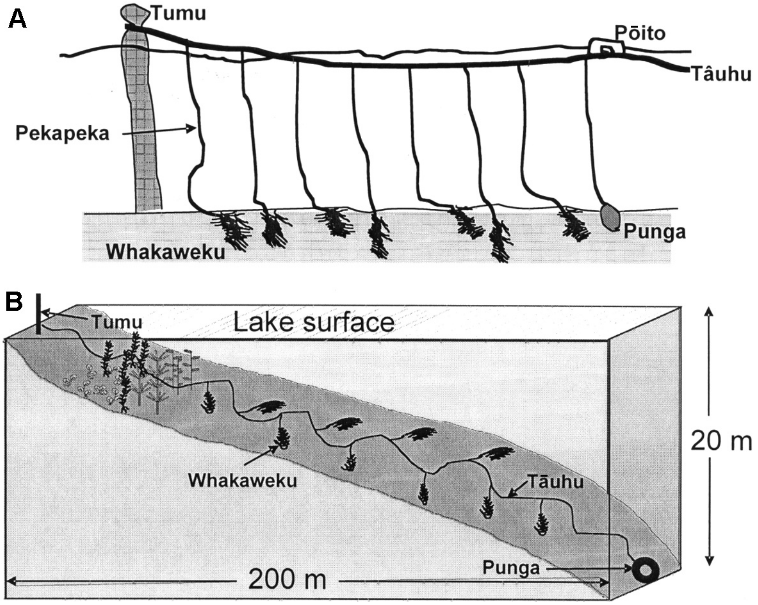


Fig. 1 Diagrams of: **A**, the tau kōura, a traditional Māori method for harvesting kōura (freshwater crayfish *Paranephrops planifrons*) after Hiroa (1921). Pekapeka (drop line), punga (anchor), pōito (float), tāuhu (surface line), tumu (post) whakaweku (fern bundles); **B**, the modern-day tau kōura. The depth and length of tau are indicative and can be varied depending on lake bathymetry.

The lack of quantitative information on kōura abundance and ecology makes it difficult for iwi and government agencies to manage kōura populations in lakes. The main reason for the lack of quantitative information on lake-dwelling kōura is the absence of suitable methods to representatively sample populations; hence the need for a more appropriate sampling method. In this paper we describe an adaptation of a traditional kōura harvesting method for use as a monitoring tool by researchers, iwi and community groups, and demonstrate its application for assessing kōura population size and structure in Lake Rotoiti.

Background to the traditional tau kōura fishing method

Tau kōura was the predominant traditional fishing method for harvesting kōura used by the Te Arawa (a confederation of iwi and hapū based in the Rotorua district) and Ngati Tūwharetoa iwi in the Rotorua (Hiroa 1921; Stafford 1994, 1996) and Taupō lakes (Fletcher 1919), respectively. This method involved the placement of bracken fern (*Pteridium esculentum*) bundles (known as whakaweku) on the lake bed for kōura to take refuge in. To harvest the kōura, the whakaweku were lifted onto a net of woven flax or kōrapa, which prevented the kōura from escaping as they were lifted out of the water and into a waka (canoe). A traditional tau kōura (Fig. 1A), comprised a surface line (tāuhu) attached at one end to a surface-reaching pole (tumu) and a float (pōito) at the other end, held in place by an anchor (punga). From the tāuhu, drop lines (pekapeka) extended to the lake bottom to which whakaweku were attached. A tāuhu held the pekapeka together over distances of up to 180 m along the water surface and was pulled taut by an anchor or punga (Mair 1918). Traditionally, tāuhu comprised roots from a climbing plant (e.g., rata, *Metrosideros florida*). Whakaweku were set at intervals of approximately 10 m and were renewed approximately every 3 years or upon becoming ineffectual owing to decay.

The favoured materials for the tumu were rewarewa (*Knightia excelsa*) and ponga fern (*Cyathea dealbata*) trunks. These had a dual purpose; they were an attachment point for the tau but also a mark of ownership and helped to delineate the boundaries of the various hapū and whānau (extended family groups) (Hiroa 1921). Another variation of the tau kōura was a submerged tau. It was set without tumu or floats, and the tāuhu was allowed to sink to the lake bottom (Hiroa 1921). Submerged tau kōura were less obvious than "surface" tau and were used to avoid korara (kōura thieves) from finding and emptying the tau kōura.

Modern use of tau kōura

Until recently, the tau kōura method was used by relatively few whanau in the Te Arawa rohe (tribal district). Most of these whanau are affiliated

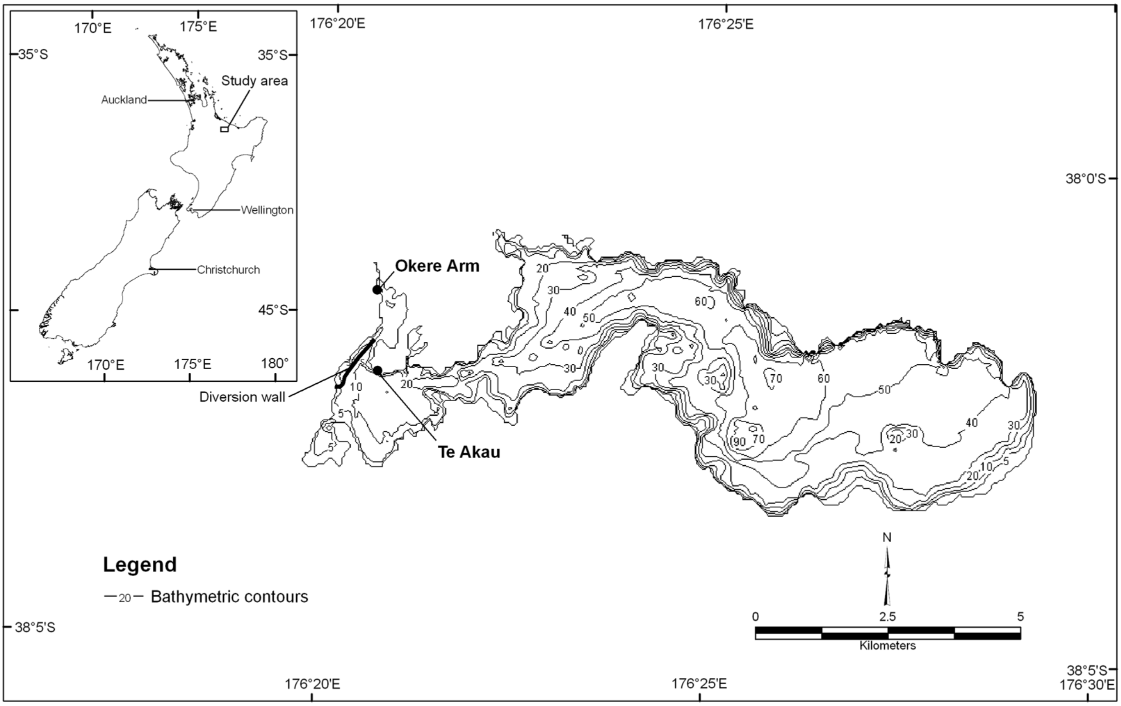


Fig. 2 Lake Rotoiti, New Zealand showing the location of the tau kōura (a traditional Māori method for harvesting kōura, freshwater crayfish *Paranephrops planifrons*) sampling sites.

to Ngati Pikiao (a Te Arawa iwi), with fishing carried out in only two lakes, Rotoiti and Rotoma. These practitioners apply the same concepts as the "submerged" tau, but make use of modern materials. The traditional whakaweku are attached by synthetic ropes to a tāuhu of copper wire or synthetic rope which is attached to the shore, typically on a jetty piling, tree or large boulder, and anchored at the lake end by a heavy weight (e.g., a car tyre filled with concrete) (Fig. 1B) (Kusabs et al. 2005a). The korapa is made of shade cloth or plastic mesh with an aluminium or steel frame (Kusabs et al. 2005a). In a preliminary study of kōura sampling methods in the Rotorua lakes, it was found that conventional sampling methods, baited traps, SCUBA and underwater video camera surveys had a number of disadvantages (Kusabs et al. 2005b). Trapping was found to be highly biased towards large individuals and complicated by bait quality influences in relation to time and the level of natural food abundance affects (Devcich 1979). SCUBA and underwater video camera surveys are biased towards large individuals and are greatly dependent on underwater visibility (Devcich 1979; I. Kusabs pers. obs.).

Given the disadvantages of these conventional kōura assessment methods, we hypothesised that the traditional Māori method, the tau kōura, would provide a better monitoring method that would provide information on population size structure, catch-per-unit-effort (CPUE), sex ratios, and egg-bearing, and be suitable for use by fisheries managers and researchers as well as by iwi and community groups.

To test whether the tau kōura can be used to distinguish key population attributes we compared kōura population structure at a shallow lake outlet (Okere Arm) and a moderately deep site (Te Akau) within Lake Rotoiti (Fig. 2). It was hypothesised that the tau set in the deeper waters would capture larger kōura. Moreover, juvenile kōura are released by females in the littoral zone (such as the Okere Arm), where there is more food and warmer temperatures (Devcich 1979), therefore it was expected that this tau would capture more juvenile kōura than that at Te Akau.

MATERIALS AND METHODS

Study site

Lake Rotoiti, North Island, New Zealand, is a deep (126 m maximum depth, average depth 32 m), moderately large (33.9 km^2), eutrophic lake which lies at 278 m a.s.l. on the central volcanic plateau (Gibbs 1992) and is known to have large populations of kōura (Devcich 1979). The lake is monomictic, stratifying for c. 9 months of the year starting in spring and mixing in late autumn. The main inflow (approx. 80%) to the lake is the Ohau Channel which flows out of Lake Rotorua (average discharge of 16 $m^3 s^{-1}$) and into the western basin of Lake Rotoiti (Gibbs 1992). Water leaves Lake Rotoiti by a single outflow, the Kaituna River; the Lake Rotoiti catchment contributes 5 $m^3 s^{-1}$ or about 20% of the total lake discharge to the Kaituna River (Gibbs 1992). Water quality sampling at the Lake Rotoiti outlet at fortnightly or monthly intervals between 1985 and 2003 showed temperature averaged 15.3°C (SD = 4.1), dissolved reactive phosphorus 7 (5) mg m^{-3}, total phosphorus 27 (15) mg m^{-3}, ammonium N 15 (15) mg m^{-3}, nitrate + nitrite N 31 (36) mg m^{-3}, and total nitrogen 332 (106) mg m^{-3} (Environment Bay of Plenty unpubl. data for site BOP110026).

There are three native fish species in Lake Rotoiti, koaro (*Galaxias brevipinnis*), common bully (*Gobiomorphus cotidianus*), and common smelt (*Retropinna retropinna*)). Brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) were introduced into the Lake Rotoiti catchment in 1888 and 1898, respectively (Burstall 1980). The invasion of exotic macrophyte species has resulted in marked changes to the submerged vegetation in Lake Rotoiti with the replacement of native species by dense, mono-specific weedbeds (Coffey & Clayton 1988). *Elodea canadensis* was first to invade the lake, followed by *Lagarosiphon major* in the 1950s, and *Ceratophyllum demersum* in the 1970s, which is now the dominant tall-growing species in Lake Rotoiti (Coffey & Clayton 1988).

Tau kōura construction and use

Tau kōura were set at two locations in Lake Rotoiti: Okere Arm (New Zealand map grid: N 6348162, E 2803800) and Te Akau, off Te Akau Peninsula (N 6346463, E 2803747) (Fig. 2). Each tau kōura comprised a 200 m length of 10 mm diameter polyester rope (the tāuhu), with one end attached to the shoreline (the base of a tree), and the other tied to a weighted concrete tyre. Ten whakaweku each with c. 10 bracken fronds per whakaweku were attached to each tāuhu. The fern fronds were bound together using 300 mm lengths of industrial strength plastic cable ties and attached to the tāuhu using hay baling twine (approx. 2.5 m long) at approximately 3 m intervals (Fig. 1B).

The study was conducted from November 2005 to September 2007. A tau was set in the Okere Arm in an area relatively free of large aquatic macrophytes and where water depth varied from approximately 3 to 7 m. A second tau was set in Te Akau at water depths ranging from 7 to 20 m, i.e., outside the depth range of the tall-growing submerged aquatic macrophyte beds. The tau kōura were left for one month and then subsequently sampled every 3 months. Owing to decomposition, whakaweku were replaced on 15 March 2006, 3 January 2007, and 31 May 2007.

Kōura collection and measurement

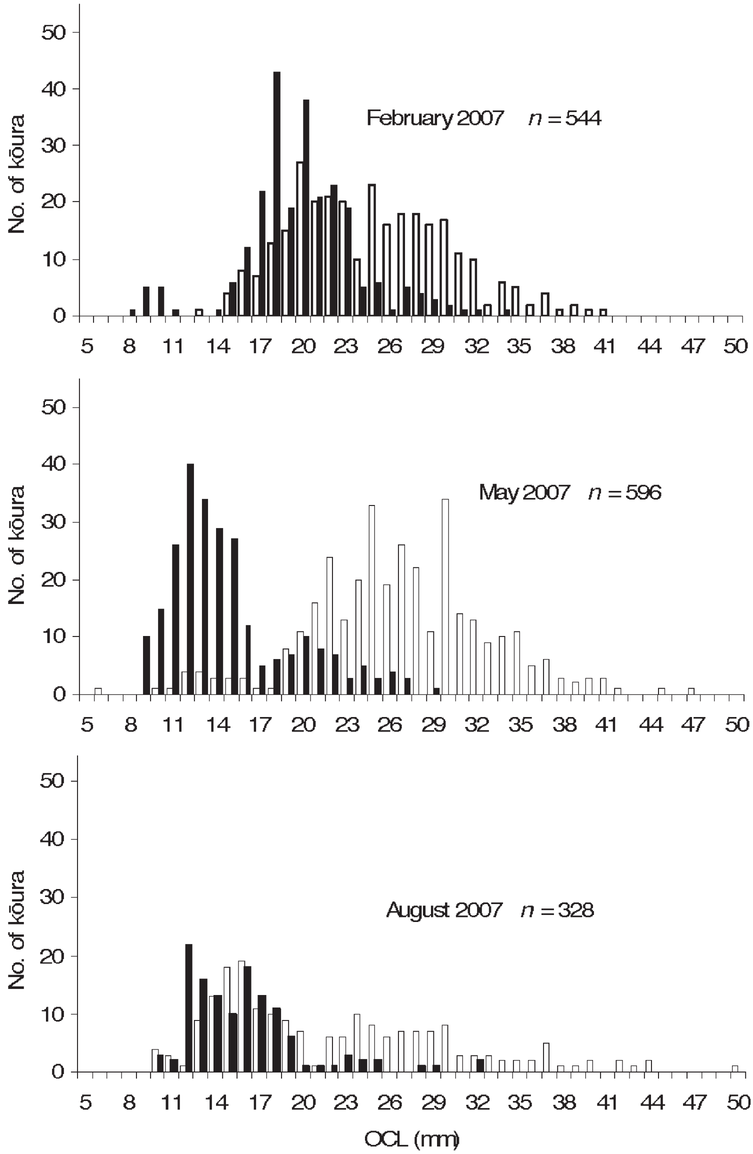
Harvesting was achieved by lifting the shore end of the tau kōura and successively raising each whakaweku while moving along the tāuhu in a boat. A korapa was placed beneath the whakaweku before it was lifted out of the water and shaken to dislodge all kōura from the fern into the korapa, before being returned to the water. All kōura were placed into labelled (2 litre) plastic containers covered by lids to keep kōura shaded and reduce stress before data collection. The analysis consisted of counting all captured kōura and visually estimating biovolume (litres of kōura per whakaweku). In addition, total wet weight of the catch from each tau kōura (i.e., all 10 whakaweku) was recorded using a Salter spring balance accurate to 10 g. Subsamples of the population, typically involving measuring all kōura captured on whakaweku 3, 5 and 7, or at least 100 individuals, were assessed for sex, reproductive state (presence of eggs or young), and shell softness (soft or hard). Orbit carapace length (OCL) of each kōura in the subsamples was measured using vernier callipers accurate to the nearest 1 mm. After processing, all kōura were returned to the water in close proximity to the tau. CPUE was defined as the number of kōura per whakaweku.

The minimum breeding size for kōura was determined from observations of the smallest size at which females were bearing eggs or young. Harvestable size was defined as >30 mm OCL based on recommendations by Te Arawa kaumatua (W. Emery pers. comm.).

Data analysis

Two-way ANOVAs, with post-hoc Scheffé test multiple comparisons, were used to compare the two sites

Fig. 3 Length (orbit carapace length OCL) frequency distributions of kōura (freshwater crayfish *Paranephrops planifrons*) captured from tau kōura (a traditional Māori method for harvesting kōura), at Te Akau Point and Okere Arm, Lake Rotoiti, New Zealand, February, May and August 2007.



and three sampling months for kōura CPUE and for analysing differences in size between the sites, sampling months and site versus sampling month combinations (Zar 1984). All data were $\log_{10}$-transformed before ANOVA to approximate a normal distribution.

RESULTS

A total of 4204 kōura were captured in the Okere Arm tau kōura in the eight surveys from 8 December 2005 to 13 August 2007; 2345 kōura were captured at Te Akau in four surveys between 14 February 2007 and 10 September 2007 (Table 1). The highest catch of kōura (n = 972) at Okere Arm was recorded in September 2006, but the greatest biovolume of 17.4 litres was recorded in February 2007 (Table 1). In comparison, the highest catch of kōura (n = 967) at Te Akau was recorded in February 2007 whereas the largest weight (13.8 kg) and biovolume (44 litres) were recorded in May 2007 (Table 1). Kōura at Te Akau were on average 47% larger (mean OCL, $F_{1413,1}$ = 681, $P < 0.0001$ for ANOVA of 3 months of data when both sites were sampled), and yield (weight of catch) was greater than at Okere Arm. The length–frequency distributions of kōura captured from Okere Arm and Te Akau in February 2007 (Fig. 3) show the differences between the populations at these sites.

The percentage of females in subsamples from Okere Arm and Te Akau ranged from 43.8% to 55.4% and 41.3% to 52.8%, respectively (Table 2). Females with eggs or young were present at Okere Arm in June 2006, September 2006, and August 2007 and at Te Akau in May, August, and September 2007 (Table 2). However, no females with eggs or young were sampled in February at Okere Arm (2007 or 2006) or at Te Akau (2007). Minimum breeding size as determined by females bearing eggs or young was 23 mm OCL. The proportion of breeding size females with eggs was highest at Te Akau in September 2007 (55.6%) but also comprised a high proportion in May and August (Table 2). The proportion of kōura with soft shells was least in February at both sites (0.8 and 0.7%) and was greatest in June 2006 at Okere Arm (14.8%) and May 2007 at Te Akau (6.2%) (Table 2).

The mean CPUE at Okere Arm ranged from 25.5 to 97.2 kōura per whakaweku, whereas the mean CPUE at Te Akau ranged from 26.7 to 96.7 kōura per whakaweku (Fig. 4). There were no obvious trends in mean CPUE over the 2-year sampling period at Okere Arm, whereas there appeared to be a steady decline in the numbers of kōura caught at Te Akau over the four sampling periods (Fig. 4). There was no significant difference in CPUE between the Okere Arm and Te Akau sites for the three sampling months, February, May and August 2007 ($F_{54,1} = 2.6$, $P > 0.05$) when data were available for both sites. However, there

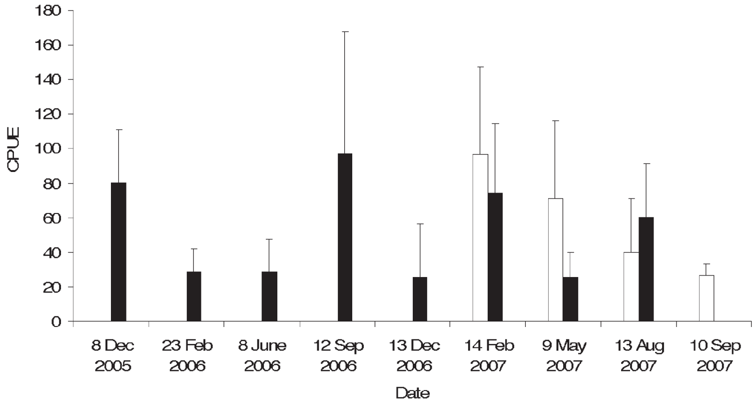
Table 1 Number, biovolume, wet weight and mean (± SD) orbit carapace length (OCL) of kōura (freshwater crayfish *Paranephrops planifrons*) captured in tau kōura (traditional Māori harvesting traps comprising 10 whakaweku or fern bundles) set in Okere Arm between 8 December 2005 and 13 August 2007, and at Te Akau (Lake Rotoiti, New Zealand) between 14 February 2007 and 10 September 2007. (ND, no data collected.)

	No. of kōura		Biovolume (litre)		Wgt. of catch (kg)		Mean OCL (mm ± SD)		OCL range (mm)	
Sampling date	Okere	Te Akau	Okere	Te Akau	Okere	Te Akau	Okere	Te Akau	Okere	Te Akau
8 December 2005	803	ND	14.9	ND	ND	ND	20.5 (5.9)	ND	12–40	ND
23 February 2006	286	ND	5.7	ND	ND	ND	21.6 (4.6)	ND	9–36	ND
8 June 2006	288	ND	7.9	ND	ND	ND	19.2 (6.4)	ND	9–44	ND
12 September 2006	972	ND	12.3	ND	ND	ND	15.0 (3.5)	ND	9–29	ND
13 December 2006	256	ND	9.7	ND	1.0	ND	17.0 (4.0)	ND	11–31	ND
14 February 2007	742	967	17.4	38.5	6.6	12.8	19.8 (4.1)	24.9 (5.5)	8–34	13–41
9 May 2007	255	712	2.7	44.0	1.8	13.8	14.8 (4.3)	26.8 (6.2)	9–29	6–47
13 August 2007	602	399	6.6	16.0	2.0	4.7	15.8 (4.1)	22.2 (8.2)	10–32	10–50
10 September 2007	ND	267	ND	12.7	ND	4.6	ND	22.1 (7.3)	ND	10–38

Table 2 Percentage of females, percentage of breeding size females with eggs or young (defined as >23 mm orbit carapace length) and percentage of kōura (freshwater crayfish *Paranephrops planifrons*) with soft shells, in subsamples taken from tau kōura (traditional Māori harvesting traps comprising 10 whakaweku or fern bundles) set in Okere Arm, 8 December 2005 to 13 August 2007 and at Te Akau (Lake Rotoiti, New Zealand), 14 February 2007 to 10 September 2007. (*n*, number of females with eggs or young; ND, no data collected.)

	No. of kōura sexed		% of females in sample		% of breeding size females with eggs (*n*)		% of kōura with soft shells	
Sampling date	Okere	Te Akau	Okere	Te Akau	Okere	Te Akau	Okere	Te Akau
8 December 2005	74	ND	44.6	ND	0 (0)	ND	ND	ND
23 February 2006	139	ND	54.7	ND	0 (0)	ND	ND	ND
8 June 2006	121	ND	50.4	ND	33.0 (7)	ND	14.8	ND
12 September 2006	322	ND	43.8	ND	50.0 (8)	ND	7.8	ND
13 December 2006	256	ND	54.7	ND	0 (0)	ND	3.5	ND
14 February 2007	233	299	55.4	52.8	0 (0)	0	0.8	0.7
9 May 2007	240	341	51.6	45.7	0 (0)	36.8 (45)	1.6	6.2
13 August 2007	123	200	50.4	44.0	100.0 (2)	54.3 (19)	2.3	3.5
10 September 2007	ND	75	ND	41.3	ND	55.6 (5)	ND	1.3

Fig. 4 Mean catch-per–unit-effort (CPUE ± SD; $n = 10$, mean number of kōura captured per whakaweku/fern bundle), of kōura (freshwater crayfish *Paranephrops planifrons*) captured in Okere Arm (closed bars) and Te Akau (open bars) tau kōura (a traditional Māori method for harvesting kōura), Lake Rotoiti, New Zealand for all sampling occasions, December 2005 to September 2007.



were significant differences between sampling months ($F_{54, 2} = 6.6$, $P < 0.01$), with CPUE in February greater than in May and August (Scheffé, $P < 0.03$), and for sites × sampling months ($F_{54, 2} = 7.3$, $P < 0.01$), notably with higher CPUE at Te Akau in May 2007 (Scheffé, $P < 0.004$), but no significant differences in February or August 2007 (Scheffé, $P > 0.05$).

DISCUSSION

The tau kōura captured large numbers (mean CPUE from 25.5 to 96.7 per whakaweku) and a wide size range (6 to 50 mm OCL) of kōura in both shallow (<7 m depth) and moderately deep water (7–17 m depth) in Lake Rotoiti. This method also distinguished differences in size structure and biovolume yield between sites and provided information on sex ratios, egg-bearing, and moulting.

The use of any trapping tool makes assumptions that the CPUE is indicative of population density and that the catch composition (sex ratios, egg-bearing females, size distribution, and moulting kōura) is representative of the population (Rabeni et al. 1997). Given the limits of alternative census methods (trapping devices, diving and underwater video surveys), it is difficult to verify that population information from the tau kōura method is representative. One of the main advantages of the tau kōura method over conventional trapping and dive surveys was that it captured large numbers of small kōura (OCL 6–18 mm), thus enabling information to be gathered on recruitment and juvenile abundance. In comparison, the smallest kōura captured by Devcich (1979) using conventional baited crayfish traps in Lake Rotoiti was 18 mm OCL. Moreover, small kōura (<18 mm OCL) are almost impossible to observe when SCUBA diving or using underwater video camera at locations such as the Okere Arm site where underwater visibility is often poor owing to algae blooms and suspended sediment (I. Kusabs pers. obs.). Tau kōura were colonised by male and female crayfish of all size classes and we contend that it provides more representative data on population structure than alternative methods.

A main limitation of the tau kōura method is that it cannot be effectively deployed in high-growing aquatic macrophyte beds, or areas of large boulder or large wood substrate, because the whakaweku become entangled and difficult to retrieve (I. Kusabs pers. obs.). However, dense aquatic macrophyte beds are also a common limitation with conventional baited traps and SCUBA/underwater video camera surveys (Kusabs et al. 2005b). In addition, whakaweku continually decay and must be replaced on a regular basis. In this study, in eutrophic Lake Rotoiti, whakaweku were replaced on a 6-monthly basis; although in a preliminary study in oligotrophic Lake Tarawera, whakaweku lasted for up to 2 years (I. Kusabs pers. obs.). This difference in bracken fern decay rate is attributable to the higher nutrient concentrations in Lake Rotoiti (e.g., 3-fold higher total phosphorus concentration, Environment Bay of Plenty unpubl. data), which are known to increase leaf litter decay in fresh waters (Robinson & Gessner 2000; Royer & Minshall 2001; Gulis & Suberkropp 2003). The development of long-lasting artificial whakaweku would overcome this problem, but would increase the cost of tau materials and may not meet approval by traditional practitioners.

As hypothesised, kōura were significantly larger at Te Akau (moderate depth) than at Okere (shallow depth), where the size range was similar to that of stream populations (Parkyn et al. 2002b). The greater proportion of juveniles at Okere Arm was consistent with the findings of Devcich (1979) that juvenile kōura are released by females into the productive littoral zone in Lake Rotoiti where there is more food and warmer temperatures, whereas adult kōura assemble into high-density bands above the 30 m depth contour during the day. This aggregation of kōura is a response to light levels and, during periods of stratification (i.e., spring to autumn), to deoxygenation of the hypolimnion (Devcich 1979). The declining water quality in Lake Rotoiti in recent years (Hamilton et al. 2005) may have resulted in an exacerbation of this "habitat squeeze" (i.e., hypolimnetic deoxygenation forcing all kōura to move into the oxygenated epilimnetic waters, resulting in effective loss of habitat area).

Breeding appeared to be continuous in Lake Rotoiti, although the least likely time to find females with eggs was in February. Parkyn et al. (2002b) found that kōura carried eggs in winter and juveniles were released between September and December in pasture streams and between December and March in cooler, native forest, streams. Hopkins (1967) found that incubation of eggs and juveniles in the Mangatarere River in the Wairarapa district (North Island) takes place between April and December. In the South Island, Whitmore & Huryn (1999) found that another species of freshwater crayfish, *P. zealandicus*, bred in December and January, with eggs hatching the following December and juveniles released by April. The percentage of "breeding" size females with eggs in the current study was highest in September and August at Te Akau and Okere Arm, respectively. This information is particularly valuable to fisheries managers as it can be used to set sustainable fishing regulations, for example, kōura harvesting may be restricted from May to September when female kōura are more likely to be bearing eggs or young. Overall, females with eggs comprised a markedly higher proportion of the catch in the Te Akau tau than in Okere Arm, reflecting the markedly greater number of breeding-sized kōura than at Okere Arm. It is probable that the shallow waters of the Okere Arm provide relatively little habitat compared with the deeper waters of Te Akau where large numbers of breeding-sized kōura are known to assemble into high density bands during the day (Devcich 1979).

The tau kōura method is particularly suited for use by iwi (who have exclusive rights to harvest kōura in the Rotorua and Taupō lakes), as it is inexpensive and does not require specialist expertise and safety requirements associated with SCUBA diving. We hope that the tau kōura method will assist iwi to develop the information base on kōura populations needed for sustainable management of kōura populations in their lakes.

Tau deployment designs will vary with study objectives and lake characteristics such as the depth at which the thermocline develops and the oxygen levels in the hypolimnion. However, as a practical approach for general assessment of lake kōura population abundance, size structure, sex ratio, and time of egg-bearing, we recommend deploying the tau line from the lake edge to 200 m from the edge or 30 m depth (which ever is reached first) with at least 10 whakaweku at equally-spaced intervals along the tau and sampling at monthly to quarterly intervals. Details on duration of deployment before sampling are still being developed, but we recommend allowing at least 1 month for colonisation after deployment before the first sampling. A single tau, deployed as described above, should be adequate to monitor long-term (decadal) trends in kōura populations in a lake. Consideration should be given to deploying multiple tau kōura to include significant variations in lake bathymetry that are likely to influence kōura populations. Furthermore, for between-lake comparisons that focus on water quality influences, we recommend deploying tau kōura in areas of similar lake bathymetry and lake bed substrate in all lakes.

CONCLUSION

We contend that the tau kōura is a suitable tool for monitoring kōura by fisheries managers, researchers, iwi and community groups, as it is inexpensive, captures kōura of all sizes, can be used in a range of habitat types and depths, and appears to have fewer biases than the more conventional kōura/crayfish capture methods, such as baited traps. Studies are underway using the method to evaluate the effects on kōura CPUE and population structure of nutrient enrichment, kōura colonisation rates of whakaweku, lake bed substrate types and aquatic macrophytes. We hope that the development of this method will enable resurgence of research and monitoring on lake kōura populations that have been under-studied in New Zealand despite the ecological and cultural significance of kōura.

ACKNOWLEDGMENTS

Special thanks to Willie Emery (Ngati Pikiao kaumatua) who assisted with the monitoring and deployment of the tau kōura and who also was instrumental in obtaining the necessary approvals from the Ngati Pikiao. Thanks to David Hamilton (PhD supervisor for the primary author at the University of Waikato) for extensive editing of the manuscript and Chris Hickey, Steph Parkyn and Charlotte Severne from NIWA for their contributions on the use of tau kōura for monitoring and research purposes. This work was funded by NIWA through the New Zealand Foundation for Research, Science and Technology programme on Restoration of Aquatic Ecosystems (COIX0305) and by Environment Bay of Plenty. We are grateful to the Te Arawa Lakes Trust (Roku Mihinui and Hera Smith), Ngati Pikiao kaumatua and kuia, Te Runanga ō Ngati Pikiao and the Ngati Pikiao Resource Committee for their approval, advice and support of the project. Julie Balance from Baldwins Intellectual Property is thanked for pro bono advice on intellectual property matters relating to the tau kōura method.

REFERENCES

Barnes GE, Hicks BJ 2003. Brown bullhead catfish (*Ameiurus nebulosus*) in Lake Taupo. In: Munro R ed. Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001, Hamilton. New Zealand Department of Conservation. Pp. 27–35.

Burstall PJ 1980. The introduction of freshwater fish into the Rotorua Lakes. In: Stafford D, Steele R, Boyd J ed. Rotorua 1880–1980. Rotorua and District Historical Society. Pp. 115–121.

Coffey BT, Clayton JS 1988. Changes in the submerged macrophyte vegetation of Lake Rotoiti, central North Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 22: 215–223.

Devcich AA 1979. An ecological study of *Paranephrops planifrons* (White) (Decapoda: Parastacidae) in Lake Rotoiti, North Island, New Zealand. Unpublished PhD thesis, University of Waikato, Hamilton, New Zealand. 247 p.

Fletcher JH 1919. The edible fish, &c., of Taupo-nui-a-Tia. Transactions of the New Zealand Institute 51: 259–264.

Gibbs MM 1992. Influence of hypolimnetic stirring and underflow on the limnology of Lake Rotoiti. New Zealand Journal of Marine and Freshwater Research 26: 453–463.

Gulis V, Suberkropp K 2003. Effect of inorganic nutrients on relative contributions of fungi and bacteria to carbon flow from submerged decomposing leaf litter. Microbial Ecology 45(1): 11–19.

Hamilton D, McBride C, Uraoka T 2005. Lake Rotoiti fieldwork and modelling to support considerations of Ohau Channel diversion from Lake Rotoiti. Report to Environment Bay of Plenty. Centre of Biodiversity and Ecology Research, University of Waikato, Hamilton, New Zealand. 109 p.

Hicks BJ, McCaughan HMC 1997. Land use, associated eel production, and abundance of fish and crayfish in streams in Waikato, New Zealand. New Zealand Journal of Marine and Freshwater Research 31: 635–650.

Hiroa TR 1921. Māori food supplies of Lake Rotorua, with methods of obtaining them, and usages and customs appertaining thereto. Transactions of the New Zealand Institute 26: 429–451.

Hopkins CL 1967a. Breeding in the freshwater crayfish *Paranephrops planifrons* White. New Zealand Journal of Marine and Freshwater Research 1: 51–58.

Hopkins CL 1967b. Growth rate in a population of the freshwater crayfish *Paranephrops planifrons* White. New Zealand Journal of Marine and Freshwater Research 1: 464–474.

Kusabs I, Emery W, Parkyn S, Hickey C, Quinn J 2005a. Tau kōura sample collection and processing protocol. http://www.niwa.cri.nz/maori/research/freshwater/monitoring_koura/protocol [accessed 10 October 2008].

Kusabs I, Emery W, Parkyn S, Hickey C, Quinn J 2005b. Traditional method a winner for monitoring lake kōura populations. http://www.niwa.cri.nz/maori/research/freshwater/monitoring_koura [accessed 10 October 2008].

Mair G 1918. Fishing places in Rotorua and other observations on traditional fishing. In: Habib G ed. Commercial freshwater fishing rights of Te Arawa. Unpublished report prepared for the Volcanic Interior Plateau project directorate and Te Arawa Maori Trust Board, September 2001. Te Arawa Trust, Rotorua. Pp. 110–111.

McDowall RM 1987. Impacts of exotic fishes on the native fauna. In: Viner AB ed. Inland waters of New Zealand. Department of Science and Industrial Research Bulletin 241. Pp. 333–347.

Parkyn SM 2000. Effects of native forest and pastoral land use on the population dynamics and trophic role of the New Zealand freshwater crayfish *Paranephrops planifrons* (*Parastacidae*). Unpublished PhD thesis, University of Waikato, Hamilton, New Zealand.

Parkyn SM, Collier KJ, Hicks BJ 2001. New Zealand stream crayfish: functional omnivores but trophic predators? Freshwater Biology 46: 641–652.

Parkyn SM, Collier KJ 2002a. Differentiating the effects of diet and temperature on juvenile crayfish (*Paranephrops planifrons*) growth: leaf detritus versus invertebrate food sources at two diurnally varying temperatures. Freshwater Crayfish 13: 371–382.

Parkyn SM, Collier KJ, Hicks BJ 2002b. Growth and population dynamics of crayfish (*Paranephrops planifrons*) in streams within native forest and pastoral land uses. New Zealand Journal of Marine and Freshwater Research 36: 847–861.

Rabeni CF, Collier KJ, Parkyn SM, Hicks BJ 1997. Evaluating methods of sampling stream crayfish. New Zealand Journal of Marine and Freshwater Research 31: 693–700.

Robinson CT, Gessner MO 2000. Nutrient addition accelerates leaf breakdown in an alpine springbrook. Oecologia 122(2): 258–263.

Royer TV, Minshall GW 2001. Effects of nutrient enrichment and leaf quality on the breakdown of leaves in a hardwater stream. Freshwater Biology 46(5): 603–610.

Stafford DM 1994. Landmarks of Te Arawa. Vol. 1: Rotorua. Auckland, Reed Books. 197 p.

Stafford DM 1996. Landmarks of Te Arawa. Vol. 2: Rotoiti, Rotoehu and Rotoma. Auckland, Reed Books. 213 p.

Tipa G, Teirney L 2006. Using the cultural health index: how to assess the health of streams and waterways. Ministry for the Environment, Wellington, New Zealand. 54 p.

Vincent WF, Gibbs MM, Dryden SJ 1984. Accelerated eutrophication in a New Zealand lake: Lake Rotoiti, central North Island. New Zealand Journal of Marine and Freshwater Research 18: 431–440.

Whitmore N, Huryn AD 1999. Life history and production of *Planifrons zealandicus* in a forest stream, with comments about the sustainable harvest of a freshwater crayfish. Freshwater Biology 42: 467–478.

Zar JH 1984. Biostatistical analysis. 2nd ed. Englewood Cliffs, New Jersey, Prentice Hall. 718 p.