
**Taonga and mahinga kai species of the
Te Arawa lakes: a review of current
knowledge - Koura**



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Prepared for

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1 Kōura in the Te Arawa Lakes – past and present

1.1 Introduction

Kōura are a valued mahinga kai species and considered a delicacy by the Te Arawa iwi. However, in the past, kōura were a much more important fisheries resource, not only were they a staple food item but they were a delicacy that was used for bartering with Māori from outlying districts.

Europeans would take a string of dried kōura and placed it around their necks for snacking while travelling. This was considered an immense delicacy. In Mair's view there was no greater prize in the North Island. Consequently kōura were a very popular article for barter (Mair, 1918).

Although, found in many other freshwater streams and waterways, the Te Arawa and Taupō lakes were considered the most productive kōura fisheries in New Zealand (Mair, 1918; Hiroa, 1921; Best, 1929). An example of this productivity was at the opening of Tamatekapua at Ohinemutu in 1873, where a reputed 500 rohe (a rohe was roughly the equivalent of a modern sack) of dried kōura and inanga were consumed (Hiroa, 1921).

Kōura were cooked in baskets in steam holes, hot springs or ovens in vast numbers (Mair, 1918). They were also preserved. The tails, after being cooked, were threaded on a string of flax-fibre and dried in the sun; and in this condition they would keep for a year (Hiroa, 1921). Kōura were dried and then stored in baskets lined and covered with fern leaves or were preserved and stored on long strings that were then packed in baskets, eight baskets being termed a 'rohe' (again equivalent to a modern sack).

1.2 Kōura varieties

As with other fish species, Māori recognised varieties of kōura. One particular variety was known as 'Ngārara' which was found in Lake Rotomā and had spines on the back. These kōura were released back into the lake and not eaten (Te Tiako, 1918; Stafford, 1996).

1.3 Management

In the past, the kōura fishery was actively managed by a combination of rāhui and ownership rights. Occasional releases of kōura were also made into waterways to boost populations.

Rāhui

Rāhui was used to protect kōura stocks from over fishing. If there was a decline in the kōura population then a rāhui was enacted or a halt to all activity within the hapū boundary (pers comm., Joe Malcolm 2006; also Habib, 2001). Rāhui was sometimes placed on large-scale harvesting methods such as the tau. For example, ruku kōura (or free diving) was the only method permitted to harvest kōura at a fishing ground called Waitakahi in Lake Rotorua (Papakura, 1938; Hemi Tupara 1889 in Habib 2001).

Ownership rights

Kōura fisheries were present in all of the Te Arawa lakes; however, the populations in Lakes Rotorua, Rotoiti and Tarawera (Mair, 1918) were the most prized. Māori Land Court records of the late 19th century clearly delineate, describe and name some 152 individual ancestral fishing grounds within Lake Rotorua, 40 in Rotoiti, 19 in Lake Rotoehu and 11 in Lake Rotomā (Stafford, 1994 & 1996). Although not defined as such, it is probable that kōura were an important component of the harvest at these fishing grounds. Ancestral fishing grounds were also present in the many of the other lakes but were not officially documented (Stafford, 1996). For example, Mair (1918) knew of 700 fishing grounds in Lake Rotorua alone.

In most cases fishing grounds were situated in shallow water (less than 10m in depth) and on rocky substrates (Stafford, 1994 & 1996). Given Lake Rotorua's shallow depth (a mean depth of 11 m and maximum depth of 26 m) it is not surprising that it had the most productive kōura fishery in the Te Arawa lakes. This is supported by Hiroa (1921) who wrote:

‘Lake Rotorua must have teemed with food and what an invaluable asset it must have been to the tribes fortunate to possess it.’

The punishment for fishing someone else's fishing ground was severe and transgressions could result in death (Habib, 2001).

Liberations

Kōura were often transferred between lakes and streams, for example, there is a suggestion in Māori legend that Ihenga secured inanga and kōura from Lake Tiringa near Kawakawa in Northland with the intention of releasing them into Lake Rotorua (Stafford, 1967).

Selective harvesting

In Lake Rotoiti, females carrying eggs or young are returned to the water, this form of selective harvesting has been practiced since the early 20th Century (pers. comm. W. Emery). However, there is no mention of such a practice in the historical literature and it is unclear whether this was common practice in pre-European times.

1.4 Fishing methods

It is probable that kōura were harvested all year, although Hiroa (1921) wrote:

‘The kōura came in October, and lasted from November to March. They ceased to be fat in April.’

A number of methods were, and are still used to capture kōura in the Te Arawa lakes. These are: the tau kōura, the paepae or hao (a dredge net), collecting kōura by hand and rama kōura (lights at night) and hi kōura.

Tau kōura

Tau kōura was the favourite traditional fishing method for harvesting kōura in Te Arawa lakes (Hiroa, 1921). This method involves the placement of bracken fern bundles (known as whakaweku) on the lake bed for kōura to take refuge in and then retrieving the bundles into a canoe to harvest the kōura (see http://www.niwascience.co.nz/maori/research/monitoring_koura/background). The figure below shows a traditional tau kōura, comprising the 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 which drop lines (pekapeka) that reached to the bottom with fern bundles (whakaweku) attached. To harvest the kōura the fern bundles were lifted onto a net of woven flax or kōrapa, which prevented the tau kōura

from escaping as they were lifted out of the water. Tumu were made out of rewarewa and ponga ferns (*Cyathea dealbata*). Not only did they mark the fishing ground but they were also a mark of ownership and helped to delineate the boundaries of the various hapū and whānau (Hiroa, 1921).

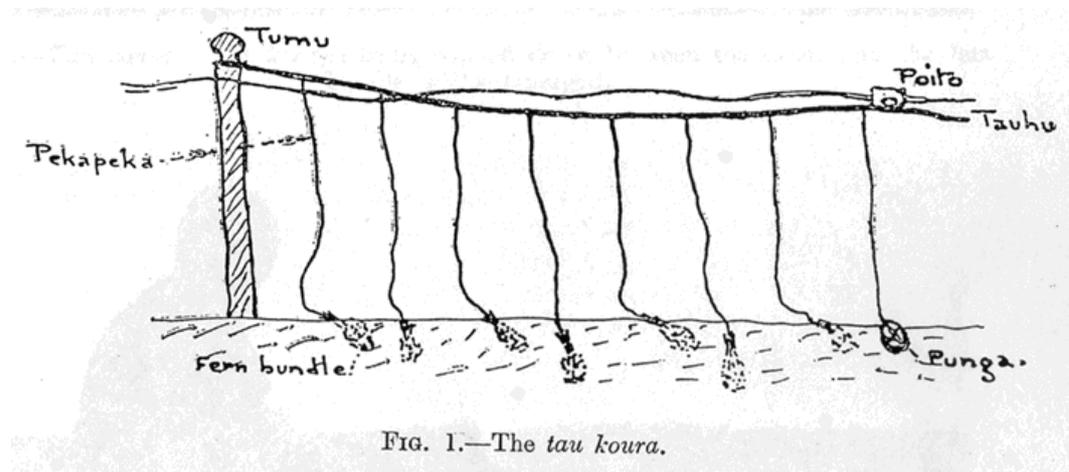


FIG. 1.—The *tau koura*.

Gibert Mair (see box below) was given a fishing ground in Lake Rotorua called Te Ruru for his exclusive use until 1875.

The tribe had made a large net for him to which were attached large bundles of fern, every 6 m, for the capture of kōura mainly. It was anchored on fishing grounds about 800 m offshore. He used to send his troops there to fish. It was a very productive fishing place, where he was able to get up to 11 x 4 bushel sacks of kōura at a time. He was also given a tau toitoi near Koutu. Traditional fishing like this was a process followed all over the district for generations, in hundreds of different places.

Many of the fishing grounds were not marked by posts (tumu) but were located by bearings, cross bearings hills or streams on the mainland and so on...

He indicated that practically the whole of the lake was covered by fishing grounds, posts and other marks. Fishing posts were owned by hapū. Tribes had to depend upon fish supplied as it was the main sustenance afforded them. They were concerned about destruction of many of the old posts in recent times meaning that old claims to fishing grounds could no longer be sustained. Some posts were set in 9-10 m of water. They were big posts taken out in big canoes and worked round and round until imbedded in lake bottom. Some had stood in the lake for 100 years. Some posts or tumu were carved, e.g., 'Tuarawera' opposite Te Ngae Bush and 'Korotere', a famous kōkopu ground.

‘Kōura could be taken in deep water by a pahiko or dredge. The net and bundled fern arrangement for catching kōura was set out permanently for about three years of life. Fern bundles were then renewed. Nets lasted a lot longer. Tau were up to 180 m long.’

Some tau were constructed without tumu and floats, and the tāuhu or anchor line allowed them to sink to the lake bottom (Hiroa, 1921). These ‘submerged’ tau were less obvious than ‘surface’ tau and were used to avoid korara (a name given to kōura thieves) from finding and emptying the tau.

Until recently, the tau kōura method was only used by four whānau in the Te Arawa/Ngāti Tūwharetoa rohe. All four whānau belong to te hapū o Ngāti Pikiāo and fished only 2 lakes, these being Rotoiti and Rotomā. These practitioners apply the same concepts as the ‘submerged’ tau, but make use of modern materials. The traditional whakaweku (fern bundles) are attached to synthetic ropes to a tāuhu (bottom line) of synthetic rope or copper wire anchored at both ends to heavy weights (e.g., concrete filled tyres, engine blocks) and the kōrapa is made of plastic mesh with an aluminium or steel frame. There has been considerable interest in recent times in using the tau to harvest and monitor kōura in Te Arawa and Taupō lakes. It appears that the use of tau has declined over the past 50 years following the introduction and rapid growth of exotic macrophytes (which foul the tau line), the convenience of rama kōura (spotlighting at night) and the expense and limited availability of copper wires for use as bottom lines (pers comm., Te Arawa hui, 2006).

The last tau used in Lake Rotorua was in the 1970’s. John Waaka recalled that the Haera family had a tau line off the Waikuta Stream mouth with 50 whakaweku (fern bundles). The fern bundles were set on Labour weekend (i.e., 1 October) and retrieved a month later and again around Christmas. Three sugar bags was a normal catch.

Another variation to the whakaweku is where bunches of fern fronds are sunk to the bottom of the lake; or tau, where bunches of fern are tied to a post (Papakura, 1938; Cowan, 1926).

Dredge net known as paepae or hao or pahiko

The paepae or hao (hao was also the name given to a small, oval scoop net; Papakura, 1938) was a dredge net (approximately 10 feet wide at the base) that was dragged along the lake bottom to catch kōura (Hiroa, 1921). This method is no longer in use in the Te Arawa lakes. Hiroa (1921) describes the paepae as comprising the paepae and

whitiwhiti frame, the uprights (pouwaenga and tangitangi), sinkers (punga) and the main dragrope (pouwaenga). The method of dredging was to attach a rope to a turuturu (a long pole thrust into the lake bed) and then the canoe paddled away. The paepae was then put over the side and the drag rope tied to the stern of the canoe, the canoe was then pulled towards the turuturu dragging the paepae along the lake bottom. The kōura were then emptied into the canoe and the canoe paddled back to the end of the rope to the left or right of the previous drag so as not to drag over the same area twice. Hiroa (1921) reported that “*a couple of drags would secure a sack or two of kōura.*”

Today the paepae or hao is no longer used to harvest kōura. The name *paepae* appears to have been used in Lake Rotorua and *hao* in Lakes Rotoiti (pers. comm. Rewa Hunuhunu, where from), Rotomā (Te Tiako, 1918) and Ngāti Tūwharetoa (Habib, 2001).

Ruku kōura

Ruku kōura or free-diving for kōura was used to capture small quantities of kōura in shallow waters (Papakura, 1938). At times when rāhui were used to protect kōura from over-fishing, this was the only method permitted (Hemi Tupara evidence 1889 in Habib, 2001). This method is still used today to obtain small quantities of kōura (pers comm., W. Emery, Ngāti Pikiao).

Catching kōura by hand

Catching kōura by hand was known as ruku kōura, panao or pahuri. Pahuri involves turning rocks over in shallow water while panao and ruku kōura referred to diving in shallow water (Habib, 2001). Considerable quantities of kōura could be harvested by these means, but only in shallow waters and when water temperatures were warm (Papakura, 1938).

Rama kōura

Rama kōura is the name given to the capture of kōura in the shallow margins of the lakes at night using handheld spotlights and small dip nets. When a kōura is spotted it is scooped up from behind in the net and placed in a floating container such as a bucket. This method is both cheap and convenient and has become more popular with the advent of powerful spotlights and waders. The main season is from November to

the end of February. Prior to the use of battery powered spotlights burning torches (comprised of rubber – pers comm., Peter Paul, Ngāti Whakaue) were used as a light source.

Hi kōura

Another method used to catch small quantities of kōura was line fishing or hi kōura. This method uses a line, hook or bob baited with kākahi, worms or animal liver (Ngāti Pikiao hui, 2006). This fishing method was practised mainly in lake outlets such as Ohau Channel, the Okere Arm, Te Wairoa Stream and the Tarawera Outlet. Hi kōura is still used by children to catch kōura today but is not as common as it was in the 1960's (pers comm., Ngāti Pikiao hui, 2006). River channel works including the straightening, widening and removal of vegetation along the river banks has contributed to a reduction in the abundance of kōura in the Ohau Channel.

2. Overview of scientific information about kōura in the Te Arawa Lakes

The main source of information from scientific studies of kōura in the Te Arawa lakes comes from the work of Alan Devcich who studied populations of kōura in Lake Rotoiti and a number of the other lakes (Devcich, 1974 & 1979). Conventional studies of benthic macroinvertebrates in the lakes generated little information about kōura because the method of sampling benthos (e.g., the Ekman dredge) was generally an ineffective method to determine information about abundance or even presence. For example, bi-monthly surveys from June 1970 to May 1971 in 7 Te Arawa lakes produced only one record of kōura in the Ekman dredge samples and that was in Lake Tikitapu (Forsyth, 1978). Some information about kōura can be gained from the gut content and diet analyses of shags (Dickinson, 1951; Potts, 1977), trout (Cryer, 1991) and from catfish in Lake Taupō (Barnes, 1996).

3 Kōura biology

3.1 Introduction

In New Zealand there are two species of freshwater crayfish or kōura, *Paranephrops planifrons* and *P. zealandicus*. They belong to the family Parastacidae. *P. planifrons* is found in the North Island and in the northwest of the South Island and is separated from *P. zealandicus* by the Southern Alps. The species present in the Central North Island lakes and those administered by Te Arawa in the Rotorua region are *P. planifrons* (Figure 1).

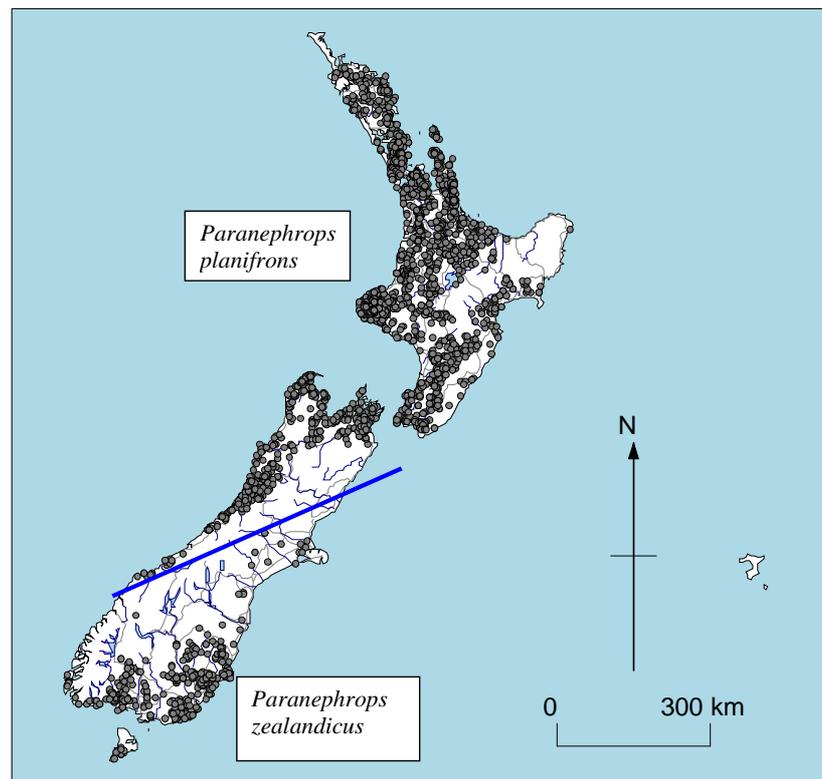


Figure 1: Distribution of kōura in New Zealand (from the New Zealand Freshwater Fish Database 2006). The line roughly indicates the separation between species.

Most of the research on *Paranephrops* sp. has been on stream populations. This review focuses on information about lake populations of kōura, in particular, information specific to the Te Arawa lakes. Biological information about kōura may be augmented from studies of stream populations where there is insufficient knowledge from lake studies.

Table 1: Presence of kōura in Te Arawa lakes.

Lake	Kōura recorded *
Ōkareka	yes
Ōkaro	no
Ōkātina	yes
Rerewhakaaitu	yes
Rotoehu	yes
Rotoiti	yes
Rotokākahi	yes
Rotomā	yes
Rotomāhana	no
Rotorua	yes
Tarawera	yes
Tikitapu	yes
Ngahewa	no
Ngāpouri	no
Tutaeinanga	no

* Source – LakeSPI survey records between 1981 and 2007.

Kōura are often measured (in millimetres (mm)) from behind the eye socket to the back of the carapace and this is called the orbit-carapace length (OCL) and sometimes they are measured from the tip of the rostrum (RCL) (Figure 2).

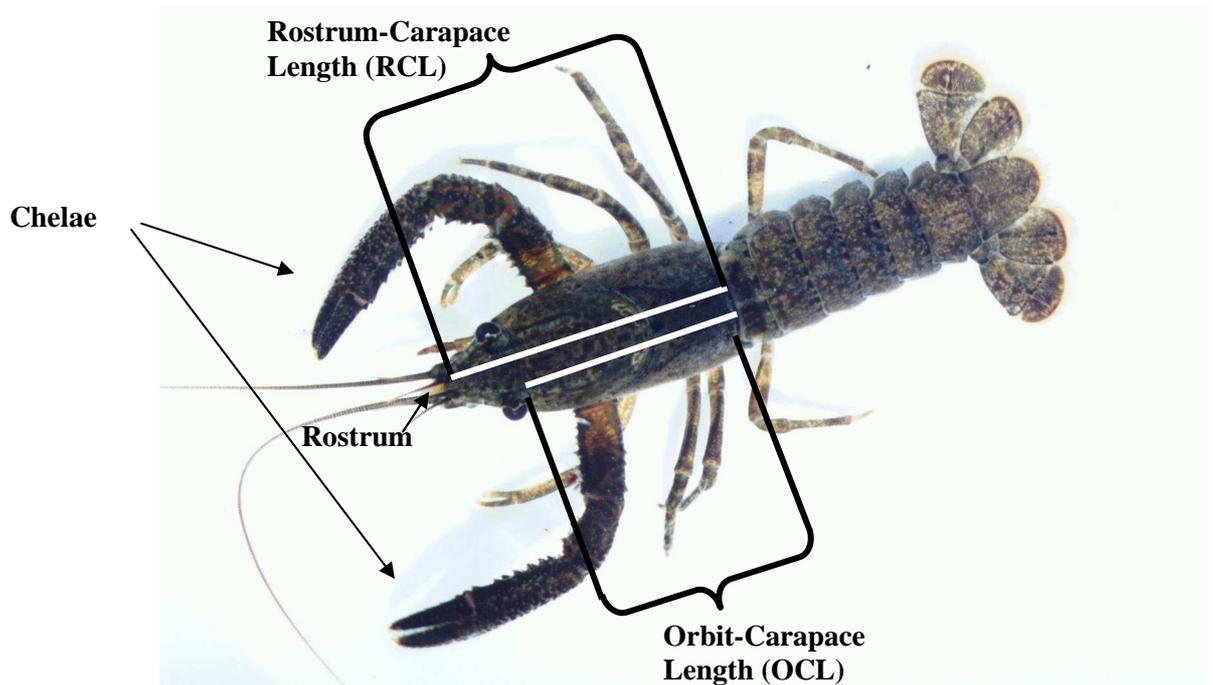


Figure 2: The orbit-carapace length (OCL) is measured from behind the eye to the end of the carapace (above the tail) along the top and centre of the back. The rostrum-carapace length (RCL) is sometimes measured and this is taken from the anterior tip of the carapace to the end of the carapace.

Most measurements of kōura in this report will be OCL (mm) but this can be converted to total body length by the following equation determined for stream *P. planifrons* (Parkyn, unpubl. data):

$$\text{Body length (mm)} = 3.2 \times \text{OCL (mm)} + 1.2.$$

To determine the wet weight of an individual, apply the formula developed for stream *P. planifrons* (Riordan, 2000):

$$\text{Wet weight (g)} = 0.0009(\text{OCL mm})^{2.9584}$$

Therefore, a 30 mm OCL kōura = 21 g, and by rearranging the formula a 50 g kōura = 40 mm OCL.

Males and females can be sexed by examining the underside of the animal (Figure 3).

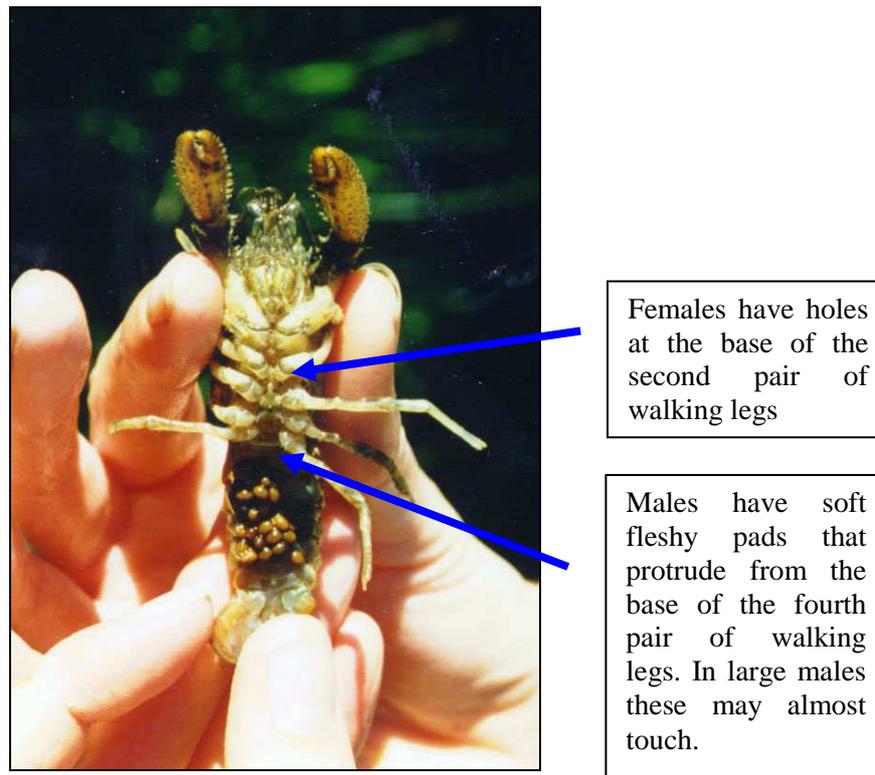


Figure 3: How do you tell males and females apart? This is a young female (small size) carrying eggs that are at an early stage of egg development. The location of where to look for male gonads is also shown.

3.2 Life history in lakes

The only substantial research project undertaken on koura in lakes to date is that by Devcich (1974; 1979). His work focused on Lake Rotoiti and provides considerable insight into characteristics of the breeding population and aspects of growth of this species. The focus of this review is therefore on Lake Rotoiti, but we have drawn on information from other lakes where possible.

Breeding appears to be continuous in Lake Rotoiti, although there may be two separate breeding groups (Figure 4). The least likely time to find females with eggs is February to March (Devcich, 1979). Information from Lake Rotoiti suggests that a main pulse of breeding occurs in late autumn and eggs are carried over winter (i.e., April to July), while a second breeding season may occur in spring/summer where females carry eggs from October to January (Figure 4). For the main breeding season (autumn and winter) eggs develop into juvenile kōura that remain with their mother for about 3 weeks and are released between September and December. The late summer breeders may still be releasing juveniles during April and May. Females release juveniles at depths less than 10 m.

Mating is thought to occur after the females have moulted and males lay a spermatophore between the 3rd and 4th pairs of walking legs on the females. Females pass the eggs through the spermatophore (i.e., external fertilisation) and attach them to their pleopods. The spermatophore slowly dissolves (over 4 weeks) producing a cloud of sperm. The eggs change from khaki green to brown, then deep red during development. From spring and early summer, depending on temperature, the eggs hatch into juveniles that are carried by the mother for up to 3 weeks (although this is variable between individuals) and undergo two moults before they become independent (Hopkins, 1967).

Juveniles that enter the population in spring or early summer are also likely to grow larger in their first year than those that leave the female in late summer as they have the advantage of growth through the summer months. *P. planifrons* is thought to mature in 18 months to 2 years in streams (Jones, 1981a; Parkyn, 2000), depending on temperature, and Devcich (1979) thought that *P. planifrons* probably matured in their third year. *P. zealandicus* females in a stream in eastern Otago were not reproductively active until 6+ years (Whitmore, 1997). Age at maturity seems to depend on growth rate, once kōura are beyond about 20 mm OCL (the smallest female in berry (i.e., having eggs) found by Devcich (1979) was approximately 21 mm OCL when converted from the 31 mm RCL) they are likely to be able to reproduce.

Breeding in *Paranephrops* spp. appears to be every second year for individual females, as not all females of a reproducing size captured in winter are in berry.

The number of eggs is dependent on the size of the female; smaller and younger kōura will have fewer eggs than larger and older females. Hopkins (1967a) found about 20-30 eggs on 17 mm carapace length females of *P. planifrons*, and up to 150 eggs on 30 mm carapace length females. Large size classes (i.e., old kōura) (may be up to 7 years) still contribute to the breeding population, as Devcich (1979) found a gravid female measuring 70.9 mm RCL.

Compared to the number of juveniles that enter the population, few kōura survive beyond their first year. The largest kōura commonly found in stream populations of *P. planifrons* (about 35 mm OCL) are believed to be between 4 and 5 years old, whereas the largest in lake populations (56.7-64.4 mm RCL) may be between 11 and 16 years old. Larger individuals are rare but can also be found; one female in Lake Rotoiti was estimated to be 20 years old (Devcich, 1979). Lake populations of the same species generally grow larger (probably because they live longer), and may have a more continuous growing season with even temperatures in a lake environment generally

above 10°C that is thought to be limiting to growth. *P. zealandicus* achieve much greater sizes than *P. planifrons* and the largest (85 mm carapace length) found by Whitmore (1997) was estimated to be 29 years old.

Females in Lake Rotoiti seem to move up into the shallows around the time that they release their young to the water (Devcich, 1979). Similar results were found in Lake Taupō in 2006, in a study capturing kōura at 20 m, 15 m and 10 m depth, where more females with young were found in the shallower depths during spring about the time when juvenile release would occur (Parkyn et al. 2006). The shallow littoral zone is likely to more abundant food sources for juvenile kōura.

3.3 Habitat

Kōura are strongly influenced by light levels. Devcich (1979) reported that *P. planifrons* in Lake Rotoiti assembled into high-density bands that migrate up and down the lake with respect to daily light levels. Most kōura retreat to the darker depths during the day and some may burrow into mud or find other cover items. In Lake Rotoiti, suitable shelters occurred mainly above 20 m depth and included rocky areas, piles of allochthonous debris, empty kākahi shells, cans and bottles. The size of shelters chosen was generally directly related to kōura size and usually one kōura in each shelter. In soft sediments they may also excavate small fan shaped depressions 6-15 cm in diameter and less than 8 cm deep (Devcich, 1979). These depressions were most common in lakes Rotoiti, Rotomā, Ōkātina, and Taupō and occurred between 12-30 m depth. At night they travel upwards to feed in the shallow water zone. An important shelter is also provided by the sediment vegetation interface at the bottom depth boundary of submerged plant growth, with both native vegetation and invasive weed beds serving this function. Kōura often forage onto bare mud flats beyond this boundary and quickly retreat when disturbed.

In streams, kōura seek cover during the day. Natural habitat for kōura in native forest streams consists largely of cover such as fallen logs, undercut banks, tree roots, leaf litter, etc. (Parkyn and Collier 2004; Jowett et al. in prep.). Kōura are well camouflaged amongst dead tree fern fronds. Tree fern roots that project into the water provide excellent dense cover for juvenile kōura.

Kōura prefer shade, and in land-based aquaculture facilities, deaths from stress and cannibalism increase when kōura are subject to clear water and bright sunlight (Jones, 1981a).

The high density band of kōura that forms during the day in Lake Rotoiti above the 30 m contour could be a response to the most energetically efficient place to stop where light levels are dark enough to afford protection from shags. However, it could also be influenced by lake oxygen levels as one effect of greater area of bottom deoxygenation could be to push the high density band into increasingly shallow water and into the diving range of shags. In this case, lake oxygen content would be a control mechanism of population size.

3.4 Growth

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). Kōura also consume their moulted skin once their mouthparts have hardened, presumably to gain extra calcium. 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.

Growth can be influenced by a number of factors including diet (see below) and temperature. Jones (1981b) followed the growth of *P. planifrons* in heated (ranged between 18-21°C) and unheated (ranged between 10-21°C) aquaria for two years. He found that in unheated aquaria they grew to 20 mm OCL after 12-18 months but this was increased to 35 mm OCL in 18 months in the heated aquaria. *P. zealandicus* grew to 20 mm OCL after only 9-10 months in the unheated aquaria which was much faster than that of wild populations near Dunedin in cooler temperatures. Survival was very low for both species. Jones (1981a) suggests an optimum temperature of 19°C above which the kōura become stressed. *P. planifrons* can survive at temperatures up to 35°C for a short time (Devcich, 1979) but large *P. zealandicus* may die at temperatures above 21°C (Diver, 1998).

Moulting is thought to cease if water temperatures fall below about 10°C, so no growth occurs during the winter months for the southern species *P. zealandicus*. Growth occurs all year round for populations of *P. planifrons* in the Waikato region,

however growth is slowed from June to September, particularly in cooler native forest streams (Parkyn et al. 2002).

3.5 Diet

Musgrove (1988a & b) studied *P. zealandicus* diet in Lake Georgina in the South Island and concluded that *P. zealandicus* was unable to degrade cellulose with indigenous enzymes and suggested that most of the limited cellulitic activity was generated from microbial sources. He suggests that New Zealand freshwater crayfish may have a diet that is composed of more animal tissue than plant matter, as the enzyme repertoire produced by kōura was better suited for digesting protein.

It is thought that microbial biofilms may have an important role in the digestion and diet of kōura, but the nature of this role is yet to be discovered (Riordan, 2000).

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). The most common method of feeding observed in aquaria is where the first two pairs of walking legs probe the substrate for food, picking up pieces with the small “pincers” on the end of each leg.

Juvenile kōura probably require more protein than adult kōura to sustain their high rate of growth. In many kōura species, including *P. zealandicus*, the juveniles consume more invertebrates and the adults more plant material. However, it has been shown for *P. planifrons* that where abundant invertebrate food is available the adults will consume as much invertebrate food as juveniles (Parkyn et al. 2001). Juvenile kōura (*P. planifrons*) were not able to survive on detritus alone in laboratory experiments, whereas adults could exist for some time in aquaria fed on decaying leaves (pers. obs., S. Parkyn).

Kōura in lakes concentrate their feeding in the littoral zone where there is the most food (both animal and detrital) and have probably evolved their diel movement to darker depths during the day and attraction to dark shelters in a response to shag predation. Juveniles are released in the littoral zone as well, probably to enhance growth in this area where there is more food and warmer temperatures.

The energy content of kōura stomachs in Lake Rotoiti was not statistically different across depths of 1 m, 10 m, 20 m, 30 m, and 50 m (averages ranged from 3759-4286 cal g⁻¹ dry weight). However, the calorific value of sediments was only high in the littoral zone (i.e., >3400 cal g⁻¹ dry weight at less than 6 m) and dropped to less than 800 cal g⁻¹ dry weight at the other depths (Devcich, 1979). Therefore, kōura are maintaining a high calorific diet even at depths when they are not thought to migrate up to the littoral zone.

The food sources of kōura in lakes is not well understood and could be investigated using stable isotope techniques. It would be interesting to see what deeper populations of kōura, which do not feed in the littoral zone, are consuming. McBride (2005) addressed this to some extent, although only examining limited lower food groups.

3.6 Predators and cannibalism

Eels, perch, catfish, and trout are major aquatic predators of kōura when present in the same streams or lakes. Of these species, only trout are common in the Te Arawa lakes. Terrestrial predators include kingfishers, shags, scaup, kiwi, rats and stoats. Shags are thought to be the only endemic predator of consequence in the Te Arawa lakes.

Cannibalism is most likely to occur when kōura are sick or soft during moulting. This can be a significant problem in high density situations, such as aquaculture where there may be inadequate cover habitat. Juvenile kōura may be consumed whole and alive by larger kōura. The chelae are important to kōura for defence, when one is lost resources will be diverted away from overall growth, to regenerate the lost limb. Kōura use their chelae to aggressively posture towards predators, and also for fighting amongst themselves where a kōura will attempt to grasp the cheliped of an opponent.

Birds

Three species in decreasing order of abundance in the Te Arawa district are the: little shag (*Phalacrocorax melanoleucos* = *P. brevirostris*), little black shag (*P. sulcirostris*), and large black shag (*P. carbo*). Early work on the diet of shags in the Te Arawa lakes showed that kōura are taken in large quantities, particularly in Lake Rotorua and Lake Rotoiti (Dickinson, 1951). The gut contents of large black shags from Lake Taupō and little pied shags (= little shag) from Lake Taupō, Rotorua, and Rotoiti were examined in Dickinson (1951). The composition of kōura in the diets of shags from Lakes Taupō, Rotorua and Rotoiti are summarised in Table 2. Care must

be taken with these results as they are based on a small number of samples that were taken on only one occasion (July 1949). For every shag stomach containing bullies there were more than two containing kōura. It appears that it is not usual for shags to engage in mixed feeding, i.e., they feed entirely on kōura for a period or on bullies.

Table 2: Kōura in stomach contents of shags in July 1949 (Dickinson, 1951).

Lake	Species	Common name	Kōura present in / total no. stomachs	Average no. per stomach	Size range (presumably total length (mm))
Taupō	<i>P. carbo</i>	Little black shag	7/29	1.4	75-105
Taupō	<i>P. brevirostris</i>	Little shag	7/27	?	?
Rotorua	<i>P. brevirostris</i>		26/31	6	30-100
Rotoiti	<i>P. brevirostris</i>		3/3	4.3	45-80

It appears that there is little difference between the predation of kōura by the two shag species when compared in Lake Taupō. The importance of kōura in the diet of shags seems to be greater in the two Te Arawa lakes than in Taupō. The size range of kōura found approximately equates to 10–35 mm OCL. Even earlier records from between 1929 and 1936 in Lake Taupō for *P. brevirostris*, found that 6 out of 40 birds had kōura in their stomachs (Falla and Stokell, 1945).

Potts (1977) examined the stomach contents of little black shags and little shags monthly from 1970-1972 in Lake Rotorua and Lake Rotoehu. The diets of the shags differed between the two lakes probably in relation to the availability of the fish species (for example, there were high numbers of goldfish in diet from Lake Rotoehu, while smelt and bullies were more important in Lake Rotorua). Analysis of the fish/kōura intake ratios of little shags and little black shags collected from the same lakes in the same months indicated that little shags took significantly higher proportions of kōura than little black shags.

The predatory effects of scaup (*Aythya novaeseelandiae*) are unknown, but this species is an efficient diving bird that is present in the area and they have been seen diving at dusk in water up to 10 m depth in Lake Rotoiti.

Fish

Dietary analysis of rainbow trout in central North Island lakes (Smith, 1959; Rowe, 1984; Cryer, 1991) shows that although smelt are the main food source for all trout, especially juvenile trout, adult trout (>350 mm) also feed on common bullies and

kōura. Only large (>350 mm) rainbow trout consumed kōura in a study of 749 trout stomachs in Lake Taupō and these had a low proportion (0.5%) of kōura in their stomachs (Cryer, 1991). In Lake Rotoma, less than 10% of 2+ trout (310-470 mm) fed on kōura, but this increased to over 20% for 3+ (470-570 mm) trout (Rowe, 1984). Trout fed more on kōura and bullies during the warmer months because shallow waters were too hot for trout, and benthic feeding predominated at this time.

Large trout are distributed mainly around the bottom of the littoral zone in summer, in waters >10 m deep. Trout in clear water lakes feed more on smelt in surface waters than on benthic species (i.e., common bullies and kōura), but this trend was reversed in small, turbid lakes. Growth rates of trout are highest in the large, clear water lakes where smelt feeding predominates and lowest in the small, turbid lakes where benthic feeding occurs.

Brown trout in lakes are more piscivorous than rainbow trout (Graynoth et al. 1986; Rowe et al. 2003) and in Australia, Faragher (1983) found that brown trout ate far more kōura than rainbow trout. However, Cryer (1991) found that brown trout in Taupō had negligible amounts of kōura in their diet compared with rainbow trout, although this may have been a factor of low sample sizes. In the South Island, research on brown trout predation has focused more on streams and rivers. Olsson (2003) reported the presence of trout was the main factor affecting abundance of kōura (i.e., 0.84 kōura/m² without trout, 0.10 kōura/m² with trout) and failed to find any small kōura (i.e., 7-20 mm) in streams supporting brown trout. Shave et al. (1994) found *P. zealandicus* could detect eels more easily than trout (using chemical cues), and hence were better able to avoid predation from eels compared to trout (using chela displays and swimming response). Whitmore et al. (2000) and Usio and Townsend (2000) found a negative effect of trout on stream populations of *P. zealandicus*. In the Te Arawa lakes, brown trout are only found in Lake Rotorua and in small numbers in Lake Rotoiti.

Devcich (1979) considers that the predatory pressure of trout on kōura may be insignificant, particularly as unprotected kōura at ecdysis (moulting) had been found at depths where the only predator would have been trout.

At present catfish are not known to be found in the Te Arawa lakes, but gut content analysis of catfish in Lake Taupō (Barnes, 1996) showed that catfish (particularly those >150 mm long) eat kōura, and the frequency of this occurring increases with catfish size. Kōura were found in the stomachs of catfish in weedy habitats (37% of catfish sampled) and in rocky habitats (80% of catfish sampled). This may suggest that

kōura are using weed habitats too, and that catfish could be more effective at sampling when compared to scientific methods. Koura have been observed climbing over and within charophyte meadows, but may be limited in their occupation of denser weedy habitats as a consequence of unsuitable sediment type and lowered dissolved oxygen levels (J. Clayton, pers. comm., May 2007).

3.7 Diseases

The fungus disease *Aphanomyces* (crayfish plague) decimated populations of crayfish in Europe in the late 1800's, but fortunately has not been recorded in New Zealand. The only disease that seriously affects kōura is "white tail disease" caused by a microsporidian parasite (*Thelohania contejeani*) that turns the tail flesh pearl white and leads to death (Jones, 1980). A number of kōura infected with the parasite have been found in populations of *P. zealandicus* near Dunedin (Hollows, 1998) but it does not appear to occur significantly in populations of *P. planifrons* and there has been no mention of the disease in the Te Arawa lakes. The disease is spread by cannibalism of the flesh of dead, infected kōura.

Commensal flatworms (*Temnocephala novae-zealandiae*) are commonly found living on kōura, but they are harmless and spend their whole life cycle being transported around by kōura (Chapman and Lewis, 1976).

4 Physico-chemical factors influencing distribution and abundance

The major factors affecting the distribution and abundance of koura in the Te Arawa lakes are temperature, dissolved oxygen levels in the lake bottom and calcium availability (which in turn is influenced by pH). In addition, as an important kai species, accumulation of naturally occurring contaminants such as mercury is an additional consideration.

4.1 Temperature

P. planifrons is tolerant of high temperatures and can survive up to 35°C (Devcich, 1979) at least for a short time, but consistently high temperatures are thought to have contributed to the failure of Devcich's kōura farming venture (ponds cool very little overnight during summer) (Devcich, pers comm.). The optimum temperature for growth may be a mean daily temperature of 19°C (Jones, 1981a). Simons (1985) derived mean critical temperature maxima of 31.9°C when kōura acclimatised to 20°C

and 28.8 °C (when acclimatised to 12°C). Based on these data and consideration of lake maximum temperatures (Livingston et al. 1986) it appears unlikely that temperature will be a limiting factor in the Te Arawa lakes. There may be some gender differences in temperature selection, with females selecting warmer temperatures (at least during night time), which may explain the presence of more females in shallow waters in summer, compared to males (Devcich, 1979).

4.2 Bottom Dissolved Oxygen (DO) levels

In Lake Taupō there is always sufficient dissolved oxygen in the bottom waters, even in summer when the lake is thermally stratified. This is not so in smaller lakes of the North Island's Central Volcanic Plateau, such as Lakes Rotongaio and Ōkaro, where there are no benthic animals in the deeper water in summer (Forsyth, 1983).

Surveys of dissolved oxygen in 1970-1972 at seven of the Te Arawa lakes were undertaken at the time of benthic invertebrate surveys (Forsyth, 1978). The waters of Lakes Tikitapu, Ōkareka, Rotokākahi, Ngāpouri, and Ōkaro became stratified between the October and November and became mixed between May and June. Lake Rotomā stratified in November-December and Ōkātina in October-November; both were mixed in July-August. Lakes Rotomā and Ōkātina never deoxygenated, their sediments were always brown. Deoxygenation became successively more pronounced and of longer duration through the series Tikitapu, Ōkareka, Rotokākahi, Ngāpouri, Ōkaro. Kōura were always present in the deepest parts of Tikitapu, but oxygen depletion excluded kōura from the deepest parts of Ōkareka by May and from those of Rotokākahi, Ngāpouri, and Ōkaro much earlier in November-December. The distribution of worms and chironomids (90% of aquatic fauna) was influenced mainly by the degree of oxygen depletion in the hypolimnion. *P. antipodarum* (snail), and mussels (kākahi and *Pisidium* sp), moved into shallower water in response to lowering levels of dissolved oxygen.

Landman et al. (2005) calculated LC₅₀s (the concentration at which 50% of the test organisms die) for various species; kōura recorded a DO LC₅₀ of 0.77 mg/l (duration 48 hours at 17°C). Devcich (1979) found strong correlations between presence of kōura and DO at both 30 m and 50 m. Although kōura were present at DO >1.6 g m⁻³ there was an appreciable decline in kōura numbers when DO fell below 5 g m⁻³. Kōura were absent below 1.2 g m⁻³. Slight gender differences were observed, with critical tolerances of 1.1 g m⁻³ for males and 1.3 g m⁻³ for females, but this is not likely to be a biologically significant difference. Landman et al. (2005) also found that kōura were

distributed throughout lake in winter, whereas in summer and autumn 62% of lake bottom was unavailable or uninhabitable due to deoxygenation. Kōura may enter oxygen depleted waters when foraging at night.

4.3 Calcium and pH

In comparison to the great majority of Astacoidea (a family of northern hemisphere crayfish), *P. planifrons* and *P. zealandicus* are physiologically tolerant to acidic conditions in their surrounding environment (Ball, 1987) (Table 2). Further, experiments at pH 4 caused no mortality in *P. planifrons* after 7 days, compared with overseas experiments using *Astacus pallipes* where mortality was observed after 3 days of exposure (Ball, 1987). In *P. planifrons* and *P. zealandicus*, exposure to pH 4 reduced haemolymph pH by an extremely small amount of 0.05 (–0.1 pH units in both species). Long term exposure (i.e., 7 days) caused least disturbance to the ionic and acid-base physiology of *P. planifrons* and was closely correlated to the environment where the kōura were collected.

pH may also influence other physiological properties. Short term exposure, where pH 7 was decreased to pH 4, inhibited sodium (Na^+) uptake. Uptake of sodium is required in order to maintain a balance between internal and external salt levels and is associated with excretory activity. The greatest reduction in sodium uptake (55%) was observed in *P. zealandicus* collected from the least acidic habitat (pH 6.6-8.5) and lowest inhibition was in *P. planifrons* (20%) from most acidic habitat (pH 3.8-4.0). *P. planifrons* had a greater rate of sodium uptake than *P. zealandicus* (data not shown), which was attributed to their ability to adapt to the lower environmental Na^+ concentrations in the stream from which they were collected (Table 3). Kōura were acclimated in the laboratory (under the same conditions) for at least a month prior to experiments, therefore these results may suggest some genetic adaptation. Parastacids in general may be more tolerant of acidic conditions (e.g., *Parastacoides tasmanicus* survives at pH 2.75) compared to other families of freshwater crayfish (Newcomb, 1975).

Table 3: Chemical constituents of lake and stream habitats where kōura were collected in the South Island (SI) of New Zealand (Ball, 1987).

Kōura species	Location	Na ⁺ mM/l	Ca ²⁺ mM/l	Cl ⁻ mM/l	pH
<i>P. zealandicus</i>	Lake Georgina, SI	0.193	0.021	0.048	6.6-8.5
<i>P. planifrons</i>	Stream, West Coast, SI	0.109-0.159	0.015-0.043		5.8- 6.5
<i>P. planifrons</i>	Stream, West Coast, SI	0.044-0.068	0.011-0.017	0.033-0.132	3.8-4.0

Some protection from the effects of pH can be afforded by dissolving the carapace, which results in the production of bicarbonate (HCO₃⁻). Bicarbonate buffers against the toxic effects of low pH (acidosis). Neither *P. planifrons* nor *P. zealandicus* appeared to have dissolved carapace, as there was no corresponding increase in haemolymph Ca²⁺ (as would be expected when carapace is dissolved) (Table 4). Acid intolerant species do use their carapace to gain HCO₃⁻ but acid tolerant species do not. The physiological process associated with acid tolerance are unclear.

Table 4: Major ions measured in haemolymph of kōura (mM/l).

Species	Na ⁺ mM/l	Ca ²⁺ mM/l	Cl ⁻ mM/l	Osmotic pressure
<i>P. planifrons</i> ¹	226	-	226	480
<i>P. planifrons</i> ²	253	9.7	241	483

¹ Wong and Freeman, 1976a; ² Ball, 1987.

The importance of calcium regulation at low pH becomes critical during moulting (90% lost before and during, high uptake rate in 10 days after moult). Moulting was not studied by Ball (1987), but fully grown *P. planifrons* with hardened carapaces were found at very low pH, suggesting that they have evolved methods to take up environmental Ca²⁺. Acidification can inhibit calcium uptake, delaying carapace hardening after moult. Therefore the presence of higher calcium in water decreases the effects of acid toxicity. The effects during moult have not been studied in *Paranephrops*.

4.4 Mercury bioaccumulation

A study of mercury (Hg) bioaccumulation in trout and trout prey (Kim and Burgraaf, 1999) indicated that kōura can accumulate high levels of methyl Hg concentrations (higher than smelt and bullies). The greatest bioaccumulation occurred at lower trophic levels, between zooplankton and water. It was thought that kōura and bullies

could bioaccumulate more methyl Hg due to their proximity to sediments. Some crayfish species “bulldoze” or sieve sediments through their mouths to collect invertebrates, if kōura do this then perhaps their capacity for contamination is greater. Kōura may also feed on zooplankton, particularly juveniles, if these are present in bottom waters, which was a factor not considered by Kim and Burgraaf (1999). This may be expected to reduce their mercury accumulation compared to sole reliance on benthic food sources.

5 Critical knowledge gaps

Most of the research on koura has been on stream populations (e.g., Whitmore, 1997; Parkyn, 2000; Parkyn et al. 2002; 2004). The only substantial research project undertaken on koura in lakes to date is that by Devcich (1974; 1979). His work focused on Lake Rotoiti and provides considerable insight into characteristics of the breeding population and aspects of growth of this species. The conceptual and predictive models we have developed have enabled us to identify important biotic and abiotic parameters influencing koura populations. However, there are gaps in our knowledge of some key determining variables, including density measures across lakes. A PhD study currently underway at the University of Waikato (Ian Kusabs “An Ecological Study of Koura in Te Arawa Lakes”) will go some way to addressing this deficiency in our knowledge. Ian’s project focuses on the use of a traditional harvesting method (tau koura) as a monitoring and research tool. In a preliminary study of lake koura sampling methods, Kusabs et al. (2004) reported that this method had significant advantages over standard ‘western’ methods such as baited cage traps, scuba counts and underwater video surveys. Moreover, this study showed that the tau koura method captures large samples of koura, with all size classes represented, and enables a wide range of habitats and depths to be sampled. As part of his project he will be obtaining basic population information (e.g., densities, gender ratios, breeding cycles) on koura from Rotorua lakes representing a range of trophic status. In addition, we are focusing our koura research in the programme on a more rapid assessment method of determining abundance, which will complement Ian’s research.

Knowledge on the availability and suitability of habitat for koura is probably one of the key information gaps in the Te Arawa lakes. The aeral extent and type of habitat will influence probability of predation, as refuges are important in shallow environments.

The interaction between koura and macrophyte beds is another poorly investigated area. Macrophyte beds are a significant and growing component of Te Arawa lake

ecology and may act as a barrier to migration and a refuge against predators. In addition, they alter sediment characteristics and potentially affect food availability. All of these characteristics are dependent on the type and extent of macrophytes. There is no empirical data available on which to draw conclusions regarding their possible effects on koura in the Te Arawa lakes.

The influence of trophic status on koura numbers needs to be examined and will again be addressed to some extent by Ian's PhD thesis. An interesting area to investigate would be the point at which eutrophication turns from being a beneficial to koura (provision of higher quantities of food) to causing decline in koura numbers.

We know nothing of the impact that blue-green algae has on koura. Freshwater crayfish are known to accumulate microcystin in the hepatopancreas (Liras et al. 1998). The impact of the accumulated toxins on the koura themselves has not been investigated in New Zealand, but overseas research suggests freshwater crayfish are generally tolerant. However, the accumulated toxins may represent a risk to consumers.

Any potential effects of an increase in human harvesting (through increased use of the tau koura) needs to be monitored if this method is to be promoted. In particular, we need to increase our understanding of breeding, recruitment and survivorship in different types of lakes in order to be able to predict the effects of harvesting.

The relative importance of water quality vs habitat quality vs predation effects on determining koura abundance needs to be quantified.

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