Taonga and mahinga kai of the Te Arawa lakes: a review of current knowledge - tuna

NIWA Client Report: HAM2007-022
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Prepared for

Te Arawa Lakes Trust

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1. Tuna in the Te Arawa lakes – past and present

Although, the Te Arawa lakes provided a bountiful supply of fisheries resources, such as kōaro, toitoi, kōura and kākahi, the freshwater eel or tuna were, and remain, very rare. In contrast, tuna were abundant in many other waterways in the rohe, such as, the Kaituna River, where they provided a valuable food source. Soon after the discovery of the lakes, the absence of tuna was promptly recognised, and liberations began. Hatupatu is credited with the first introduction of tuna into Lake Rotorua (Stafford, 1967).

‘He (Hatupatu) sent a party of slaves to catch them (tuna) in the Pukerimu and Oraka Streams on the Tokoroa Plains and bring them back to Rotorua. An old Tohunga living at Ohinemutu told Hatupatu that it would be necessary for him to perform some special rites over the eels before they could be successfully liberated, and to this Hatupatu agreed. Accordingly, the old man produced a quantity of dry fern and set it alight where the shore sloped steeply into the lake. When there was nothing but white ashes the eels were emptied onto them, and they wriggled into the water more or less torched. Several days elapsed, then dead eels were seen floating on the surface of the water. They were quickly collected and eaten by the tohunga. Hatupatu was not too pleased about this and it is said that he promptly dispatched the old man to the land of his fathers’.

Of all the Te Arawa lakes, tuna were, and are, most common in Lake Tarawera. Tuna are still harvested using hīnaki (eel nets), hi-tuna (set lines), and rama tuna (spearing tuna at night using mataura or spears) (pers comm., Ngāti Pikiao and Ngāti Tuhourangi hui, 2006). The fishery is comprised of low numbers of very large eels. The largest recorded in recent times was a 20 kg longfin eel caught in Te Wairoa Bay in 1995 by John Waaka (this eel was weighed and recorded by Eastern Region Fish and Game Council staff at the Te Wairoa fish trap). The eel was aged at approximately 50 years old by Ben Chisnall, NIWA. These large tuna are a highly prized delicacy and are the subject of modern day legend. Many regular lake users have stories regarding large eels, from seeing eels as big as taniwha, to pet dogs disappearing. Others consider these large tuna to be tūpuna (or ancestors) (pers. comm., Peter Paul).

Tuna have also been recorded in the following lakes; Rotorua (Wildlife Service, Te ure or Uenukukopako hapū hui, 2006), Ōkareka (Young, 2002), Rotokākahi (pers. obs., I Kusabs 1994), Rotoiti (Joe Malcolm in Habib, 2001), Rotoehu and Rotomā (hui with Ngati

Pikiao, 2006). The presence of tuna in these lakes is almost certainly due to deliberate or accidental liberations. For example, in the 1980's tuna were common in Lake Rotorua around Hinemoa's Point, following the escape of tuna from cages belonging to two commercial eel fisherman which were situated in the Waingaehe Stream (Wildlife Service, Te ure or Uenukukopako hapū hui, 2006).

2. Distribution

There are currently 18 recognised species of freshwater eels (*Anguilla spp.*) worldwide (Tesch, 2003), distributed in both tropical and temperate zones, with some species overlapping between these two zones (Figure 1):

Temperate zone

- *Anguilla anguilla* – Europe, North Africa, Mediterranean, Iceland.
- *A. rostrata* -– East coast of North, Central and South America, Greenland.
- *A. japonica* – China and Japan.
- *A. australis* [shortfin] – Australia and New Zealand.
- *A. dieffenbachii* [longfin] – New Zealand, Chatham and Auckland Islands.

Tropical zone

- *Anguilla marmorata* – Indian Ocean to Polynesia.
- *A. bicolor* – Indian Ocean to Papua New Guinea.
- *A. celebensis* and *A. borneensis* – Indonesia – South China Sea.
- *A. nebulosa* and *A. mossambica* – Indian Ocean.
- *A. obscura* and *A. megastoma* – New Guinea to Polynesia.
- *A. reinhardtii* [Australian Longfin]– Australia, New Caledonia to North Island of New Zealand.

Three species occur in New Zealand; the endemic longfin (*Anguilla dieffenbachii*); the shortfin[1] (*Anguilla australis*), which also occurs in eastern Australia; and the Australian

[1] The term shortfin applies to four other Indo-Pacific species, all other species are longfin. In New Zealand, the only shortfin is *A. australis*, and longfin refers to *A. dieffenbachii*.

longfin[2] (*A. reinhardtii*), which has recently been confirmed as present in New Zealand, and is also found in Australia and New Caledonia.

The New Zealand longfin (*A. dieffenbachi*) is found throughout New Zealand including the Chatham Islands from the coast to any upstream habitat it can reach. It is the eel typical of rivers and streams. Although it was recorded as present in the Auckland Islands during the 19th century, it has not been found there since (McDowall, 1990a).

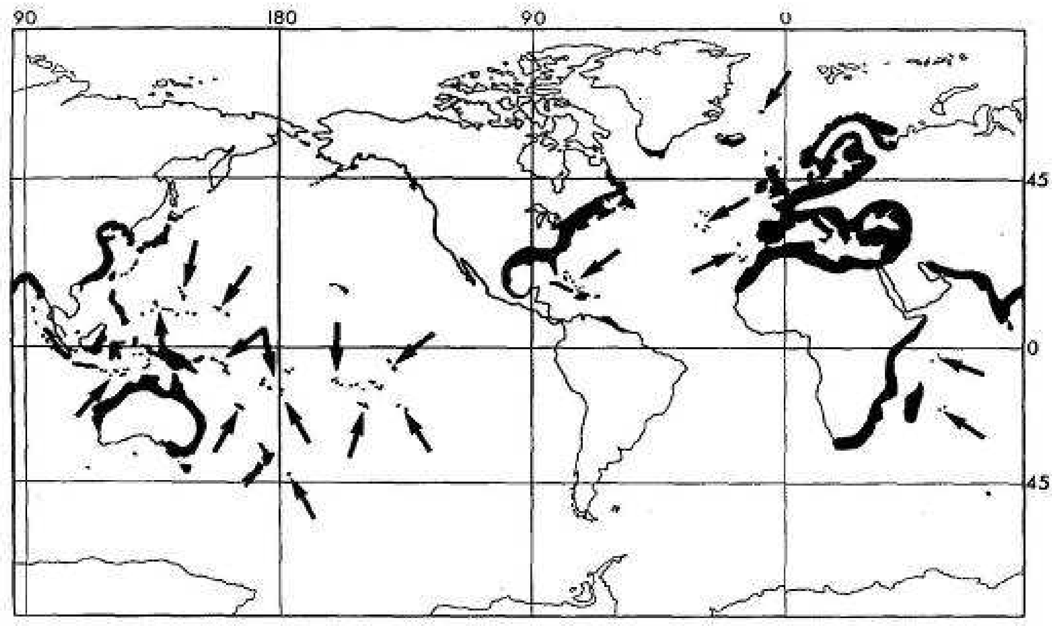

Figure 1: Worldwide distribution (shaded areas) of freshwater eels in tropical and temperate zones. Arrows indicate spawning regions (McDowall, 1990a).

[2] Confirmed in 1997, from 19 eels caught in the Waikato River. The method of arrival in New Zealand is unknown but may be due to changes in oceanic currents that transport the passive larvae from the spawning grounds in the South Pacific. Although this confirmation is recent, anecdotal evidence suggests "reinhardtii" may have been in New Zealand for at least 25 years. (For additional information see http://www.niwascience.co.nz/rc/freshwater/fishatlas/species/australian_longfin_eel).

The shortfin eel (*A. australis*) is more commonly found and is widely distributed in rivers, streams, lakes, swamps and estuaries near the sea and some distance inland. It is usually the most common species where eel populations are very dense, and does not penetrate as far upstream as longfins (McDowall, 1990a).

3. Life cycle

Freshwater eels have a diadromous life cycle, having extended periods of their life cycle in marine, estuarine, and freshwater habitats, and also have a unique larval stage known as a leptocephalus. Breeding occurs in the marine environment, following an extended adult growth stage in freshwater, and a long migration from their freshwater habitat (Figure 2).

During spring, maturing eels undergo a transformation and cease feeding. The head becomes flatter and slender, lips become thinner, the head and back may darken, and the belly lightens to a grey or silver colour. In addition, the pectoral fins and eyes enlarge and become surrounded by a narrow ring. In New Zealand, these sexually maturing adults, often called silver eels or tuna heke, migrate downstream from lakes, streams and rivers in autumn. In some areas migrations can also occur is spring. Migration may be triggered by changes in water temperature, and increases in rainfall and flow (Boubée et al. 2001). Low barometric pressure has also been found to trigger migrations (Boubée and Williams, 2006).

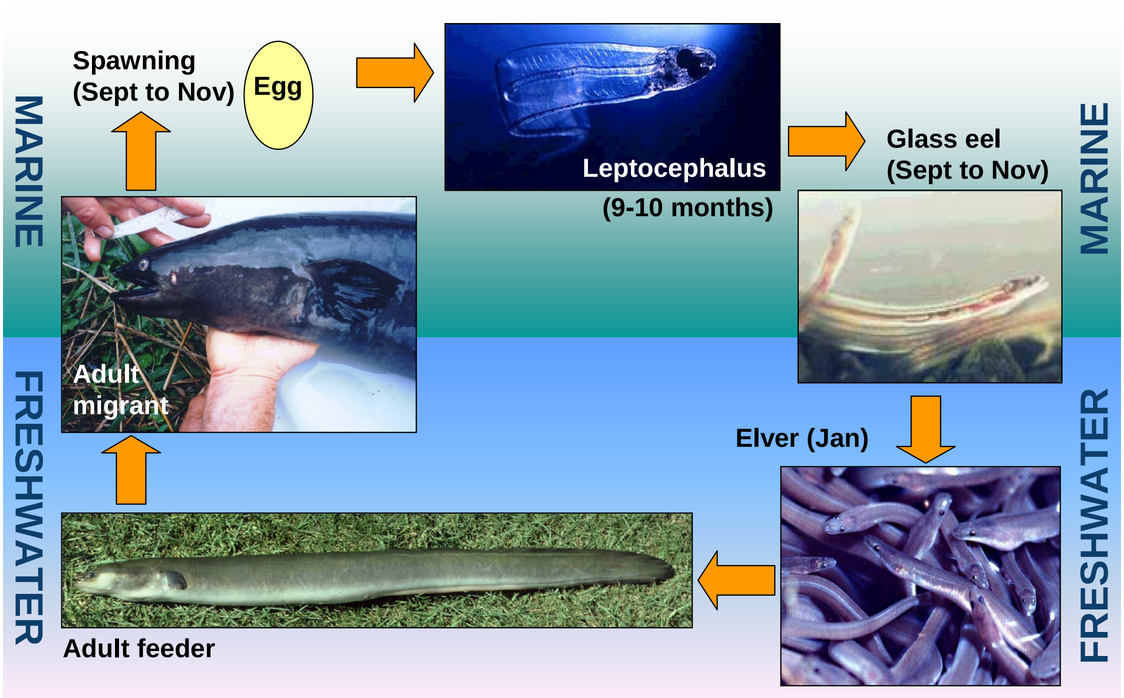

Figure 2: General life cycle of New Zealand freshwater eels, showing the marine (top half of diagram) and freshwater (bottom half of diagram) components.

In the last 50 years many barriers have been constructed across major rivers (e.g., flood control structures, water supply dams, hydro-electric dams), adversely affecting eels by impeding downstream migration of the adults to the sea, and also preventing upstream migration of the young elvers and eels. Hydro-electric turbines as well as flood pumps inflict a heavy toll on migrating adults. Virtually no female non-migratory eels are expected to survive passage through most of New Zealand's hydro-electric power plants (Beentjes et al. 2005). Although regulations were introduced in 1980 requiring the provision for indigenous fish passage at barriers, there is still ongoing debate about application of the regulations to structures that existed before the introduction of the regulations (Boubée and Williams, 2006). Opening of spillways and small diameter bypasses would provide safe downstream passage, as long as entrainment and impingement at the intake screens can be prevented (Watene and Boubée, 2005, Boubée and Williams, 2006).

The age and size of the migrating adults varies depending on the species, sex, and location (Table 1). Shortfins generally migrate at a younger age than longfins, and are smaller than longfins when they migrate. Males are smaller and migrate at an earlier age than females (Table 1). The size difference between males and females is strategically important. Fecundity has been estimated as between 1.5 and 3 million eggs in migrant shortfin females 500-800 mm in length while large migrant longfin females (1400-1600 mm length) may contain over 20 million eggs (Todd, 1981). On the other hand, males do not need to be large to produce a large quantity of sperm, so they grow rapidly to a size that enables them to migrate to the spawning ground (McDowall, 1990a).

Table 1: Age, sex, size and location of mature adult shortfin and longfin eels in New Zealand.

Species	Age y	Size mm	Location	Reference
Males:				
A. diffenbachii	12-35	482-736	Makara Stream	Todd (1980)
(NZ longfin)				
A. australis	6-23	381-598	Makara Stream	Todd (1980)
(Shortfin)	8-22	370-549	L. Onoke	Todd (1980)
	9-24	338-554	L. Ellsmere	Todd (1980)
Females				
A. australis	17.2	1,051	Hopkins R. & Merri R., Australia	De Silva et al. (2002)
(Shortfin)	–	640-1200	Mokau R.	Boubée & Williams (2006)
	10-30	563-933	Makara Stream	Todd (1980)
	12-35	550-1023	L. Onoke	Todd (1980)
	13-35	483-1,024	L. Ellsmere	Todd (1980)
	13	–	L. Aniwhenua	Boubée et al. (2001)
A. diffenbachii	26-60	737-1,560	L. Ellsmere	Todd (1980)
(NZ longfin)		800-1,300	Mokau R.	Boubée & Wlliams (2006)
	25-48	781-1,333	Makara Stream	Todd (1980)
	96	–	L. Rotoiti	Jellyman (1995)

The migration to the spawning grounds probably takes many months. Sexual development in the longfin is considerably more advanced than the shortfin at the beginning of migration, suggesting that the longfin spawning grounds may be much closer than those of the shortfin (McDowall, 1990a). Although the exact location of the spawning grounds for New Zealand species has not yet been determined, evidence obtained by satellite tracking indicates them to be somewhere in the southwest tropical regions of the Pacific Ocean (Jellyman, 2006). Following spawning in spring (i.e., September to November), the adults do not return to New Zealand, but are thought to die at or near the spawning ground.

Navigation to the spawning regions is probably undertaken by a combination of mechanisms. Debate over migration mechanisms for European and North American freshwater eels suggests they may possibly navigate by detecting increases of salinity and possibly temperature towards the spawning areas in the tropical regions (Tesch, 2003). In addition, olfactory orientation towards certain odours and ocean currents may also be a major factor. Tesch (2003) also suggests that a strong directional sense and sensitivity to the Earth's magnetic field are the primary long distance navigation mechanisms that enable the migrating adult to reach the spawning region. Once at the spawning region, other short distance mechanisms, such as emission and detection of pheromones, probably ensure the congregation of spawning populations.

Fertilised eggs develop and hatch rapidly, and the newly hatched larvae then develop through several stages to become the characteristic leptocephalus larvae (Figure 2). These leaf-shaped larvae drift back to New Zealand, using the near-surface currents. These larvae develop through many stages and become the transparent and actively swimming ‘glass eels’ (5.5-7.0 cm) after encountering the continental shelf, between August and December.

Glass eels migrate into estuaries, and rivers and streams in early spring, and migration is often correlated with lunar phase and spring tides. Olfaction is highly developed in glass eels, and they are able to differentiate and respond to various water odours, characteristic of the preferred habitats (Jellyman et al. 1999). Therefore, glass eels are able to make specific choices about the type of river or stream they migrate to, and there may be different responses to different habitats for shortfin and longfin glass eels (Jellyman et al. 1999; McCleave and Jellyman, 2002).

Current evidence suggests that there has been a worldwide decline in recruitment of glass eels (Dekker, 2002; Jellyman et al. 2002). Factors contributing to this decline are likely to include climatic change, loss of habitat, parasite infestation, pollutants, over fishing, and obstacles to migration (Feunteum, 2002).

Once in freshwater environments, the glass eels develop into darker pigmented juvenile eels, known as elvers (Figure 2). Elvers migrate upstream during summer, sometimes over several years and use surface tension to surmount damp, vertical surfaces, such as waterfalls, but are easily blocked by dry or overhanging structures (Beentjes et al. 2005). They are able to climb up waterfalls as long as there is a damp rocky surface, up to a size of 5 g, above which surface tension is not sufficient to hold them onto the surface.

Migration may be blocked by both natural and anthropogenic barriers (e.g., weirs, hydro dams, and overhanging culverts), where the elvers congregate and may be caught and transferred upstream (Beentjes et al. 1997). In pre-European times, the transfer of elvers above natural barriers was a recognised means of maintaining populations where access was restricted or not possible (e.g., Sherrin, 1886; Best, 1929).

Facilitation of upstream elver passage over hydro dams has been undertaken in New Zealand since at least 1982-1983, when an estimated 20,000 elvers were transferred from the base of Matahina Dam to Lake Aniwhenua and upstream habitats (Beentjes et al. 1997). Since this first operation, trap and transfer of elvers and juvenile eels has become a viable method of enhancing eel populations and increasing productivity above hydro structures (Annala et al. 2003), and currently over four million elvers annually are captured and transferred to upstream locations (Martin et al. 2006). In the Waikato hydro lakes, over sixteen million elvers have been transferred from the base of Karapiro Dam since the beginning of the 1995-1996 migration season, 21 percent of the transferred elvers were longfins. Transfers to Lake Atiamuri (812,000 elvers; 172,000 longfins) and Lake Ohakuri (3,071,000 elvers; 745,000 longfins) have accounted for 5% and 19% of the total transfers respectively since the start of the 1995-1996 season (Martin et al. 2006).

After reaching suitable habitat, the eels grow, often for several decades, before maturing and beginning the return trip to the sea. Growth rates are highly variable due to species, sex, location, water temperature, season, population density, food supply and the types of habitats. Female eels from the same species grow larger and are older than males at maturity. Growth rates may also vary with age. For instance, in a Canterbury stream growth rates were estimated for longfins as 25 mm/yr for a 300 mm long eel, but decreased to 15 mm/yr for a 1000 mm eel (Burnet, 1968). In addition, decreases of length of up to 12% have been noted after the winter (Burnet, 1968), which is consistent with low winter metabolism (Chisnall, 1989). For longfin eels, the maximum size can be approximately 2 m long and 20 kg. Females mature at 20 years to over 40 years, and they grow 15-25 mm/yr. Male longfins mature at much younger ages (12-45 years). Female shortfin eels can grow to approximately 1 m and 3.5 kg, and usually mature at 20 years of age (Burnet, 1968; Chisnall and Hicks, 1993). High growth rate may occur where food is abundant (e.g., 41 mm/y, recorded for eel transplanted into virgin habitats by Beentjes and Jellyman (2003), but can be very poor in highly modified habitats with high recruitment (e.g., Lake Waikare in the Waikato, pers. comm, Mike Holmes eel fisher).

4. General biology

The adult eel is elongated, slender bodied, with no pelvic fins. The caudal and anal fins are united to form a continuous fin along the back around the tail and along the belly. The skin is thick and leathery with an embedded tiny mosaic of scales, which is more noticeable in the shortfin than the longfin. There are several anatomical differences which are used to differentiate between the New Zealand shortfin and longfin, which are summarised in Table 2.

Table 2: Differences between the two species of New Zealand eel (modified from Cairns, 1941).

***A. dieffenbachia* (Longfin eel)**	***A. australis* (Shortfin eel)**
Dorsal fin considerably longer than anal fin	Dorsal fin only slightly longer than anal fin
Vomerine teeth form a narrow band	Vomerine teeth form a compact, club-shaped band
Eye in front of and above the corner of the mouth	Eye directly above the corner of the mouth
Lips thick	Lips thin
Head broad	Head narrow
Olfactory organ large	Olfactory organ small
Mouth opening large, strong jaw	Mouth opening small, small jaw
Tail broad, tail fin well developed	Tail narrow, tail fin poorly developed
Pectoral fins large	Pectoral fins small
Grows to over 180 cm in length and 18 kg in weight	Rarely more than 90 cm long and 1.8 kg in weight
Male silver eels 55 to 65 cm long and 0.9 to 1.1 kg in weight	Male silver eels 35 to 45 cm long and an average weight of 0.25 kg
Scales not very distinct	Scales clearly visible

Eels have poor eyesight, but are sensitive to strong light, and are active nocturnal foragers (McDowall, 1990a). Eels are opportunistic and intermittent feeders mostly in the benthic zone, and prey is located primarily by odour detection, using a consistent behavioural response to flow, which results in direct upstream movement toward the odour source (i.e., rheotaxis) when in an odour plume (Carton and Montgomery, 2003).

Feeding activity is seasonal, with reduced feeding usually occurring in winter in New Zealand, which may be due to low water temperatures (<10°C) reducing activity, or an absence of suitable prey (Cairns, 1941; Hopkins, 1970; Ryan, 1984). In addition they exhibit a diel pattern when feeding. Little feeding activity occurs until dark, and continues until daylight, although some exceptions to this pattern have been reported (Ryan, 1984).

The composition of their diet depends much on the habitat they occupy, and the prey available (Table 3). Research on eel feeding habits and diet has been mostly restricted to river habitats. The size of their prey depends largely on the gape (mouth) size of these eels. Large eels (>450 mm) almost exclusively feed on fish and kōura. Important food sources for small (<300 mm) and medium (300-450 mm) sized eels are mayfly and caddisfly larvae, which are large (15-20 mm), have soft bodies, and high protein contents. Smaller eels prefer free-living caddisflies, as only larger eels are able to digest the cased-caddisflies (Cairns, 1941; Sagar and Glova, 1994 & 1998). Large numbers of chironomids have also been reported in the diet of eels (Kangur et al. 1999). Molluscs may also be part of the eel diet, although they have low energy contents when compared with other invertebrates. Examination of the stomach contents of larger eels has revealed that snails are often found with their shells still intact. One species, *Physa*, has a thinner shell than other common snails (e.g., *Potamopyrgus*), and is easier to digest and thus has a higher energy content (McCarter, 1986). In floods, eels may consume large quantities of prey such as earthworms (Chisnall, 1987; Jellyman, 1989). Generally eels feed on whatever prey is the most abundant, which tends to change with location and season (Table 3).

Habitats occupied by eels are variable and dependent on the life-stage or size, substrate, water depth and quality, temperature, water level stability and velocity, and amount of cover. Elvers of both longfins and shortfins are common in the swiftly flowing gravely rapids and riffles, where they live and feed amongst the gravel. As the eels grow larger and move upstream, or further inland, they hide beneath overhanging banks and logs, where they move and feed during most of the year. Larger eels (>300 mm) of both species are commonly associated with cover, such as macrophyte beds, overhanging banks, in-stream debris and shade, but longfins may utilise a greater variety than shortfins (Glova et al. 1998).

Both species have broad habitat differences; shortfins prefer slower flowing, lowland and coastal waters, while longfins penetrate further inland and prefer faster flowing water and stony substrates; but they frequently coexist, in similar size classes (Jellyman et al. 2003, Jellyman and Chisnall, 1999). Small shortfins (<100 mm) have a preference for water < 0.5 m deep, and with increasing size the preference is for deeper water, and for eel over 499 mm they generally preferred water almost twice as deep. Longfins have a similar depth preference to shortfins (Jellyman et al. 2003).

Table 3: Review of eel diet and prey characteristics of freshwater eels (the number of + indicates the suitability of a particular invertebrate group. Groups with the most +s are best suited for that eel size group).

Invertebrate group	Prey size [1]	Energy contents & digestibility [2;3;11]	Prey selection & capture	Suitability of the food items for eel size classes		
				<300 mm	**300-450 mm**	**>450 mm**
Annelida	6-15 mm		+ [2]	+ [4;5]		Mainly fish, kōura, crustacea, mayflies and Molluscs. [4;5;6;7;11;12]
Chironomidae	20 mm (4th stage)	17500-22000 $^{j}/_{g}$ mean dry weight: 0.12 mg	++ [5]	++ [8;9;11]	+ [8;11]	
Coleoptera	5-10 mm		[4]			Above 700 mm shortfins feed almost exclusively on fish and kōura [7;12].
Crustacea	3 mm	14500-17500 $^{j}/_{g}$ mean dry weight 0.03 mg	+[4;7]	+ [5;7;9;10] ++ [7;9;12]	+ [5;7]	
Diptera (soldierflies) and craneflies)	2.5 mm		[4;7]	+ [9] ++ [7]		[11] sets this size at 500 mm
Hemiptera	6 mm					
Mollusca	2.5-8 mm	5500-9800 $^{j}/_{g}$	+ [4;5;7]	+ [5;11;12] - [7;9;10]	+ [5;10] ++ [7;11]	
Odonata	16-27 mm		[4;5;7]			
Trichoptera	4-20 mm		+ [4;5]	+ [5;9;10]	+ [4;5]	
Fish and kōura	>50 mm	20000-22000 $^{j}/_{g}$		+ [12]	++ [11;12]	

References:
[1] Moore (1997); [2] Ryan (1982); [3] McCarter (1986); [4] Burnet (1952); [5] Cairns (1941); [6] Hopkins (1970); [7] Jellyman (1989); [8] Kangur et al. (1999); [9] Sagar & Glova (1994); [10] Sagar & Glova (1998); [11] Ryan (1986); [12] Chisnall (1987).

In lakes the distribution of eels may be attributable to several factors such as lake size and depth, the size class of the eels, and the stability of the water level of the lake. In Te Waihora, the preferred depth for eels was 0.6-1.2 m, as the shallow inshore littoral area tended to be unattractive due to the absence of macrophyte cover, and the influence of wave action causing re-suspension of sediment (pers. comm., Don Jellyman, NIWA, 2007) The shallow littoral zone is occasionally subject to de-watering due strong winds that may change the water level by up to 1.1 m. In a more stable lake, such as Lake Waahi in the Waikato region, the shallow littoral zone provides more suitable habitat, and juvenile eels (250-350 mm) tend to be found almost exclusively in this zone. Larger eels (>350 mm) were almost exclusively found offshore (Jellyman and Chisnall, 1999).

5. Distribution in Te Arawa lakes

The Rotorua area lakes originated from volcanic activity, which had a profound influence on the biology of the lakes. Lake Rotorua lies in the Rotorua caldera, formed c. 140,000 ka[3] following the eruption of the Mamaku Ignimbrite. Lake levels have since fluctuated considerably, with the highest estimated level occurring when pyroclastic flows from the Ōkataina eruption (c. 50,000 ka) blocked the northward drainage from Lake Rotorua. The origins of most of the other lakes in the Rotorua area are associated with volcanic activity of the Ōkataina Volcanic centre (Lowe and Green, 1987). The Haroharo Caldera and Tarawera Volcanic Complexes have been built in 11 post-25 ka eruption episodes (Hodgson and Nairn, 2005). Lakes Tarawera, Ōkataina, and parts of Rotoiti and Rotoehu are situated in the Haroharo Caldera and were formed largely by lava damming streams and outlets. Lakes Ōkataina and Tarawera probably attained their present day forms less than 10,000 ka. Other small 'proto' lakes in the Rotorua area would also have been periodically modified by eruptions from the Tarawera and Haroharo volcanoes (Lowe and Green, 1987). For example, the 1886 eruption of Mount Tarawera resulted in a c. 12 metre rise in the level of Lake Tarawera (Figure 3), due to damming of the lake outlet (Tarawera River) by scoria (Lowe and Green, 1987; White et al. 1997). Damming of the lake outlet also occurred following the Kaharoa eruption (AD 1315). Lake Rotomāhana formed after the 1886 Tarawera eruption, and in the associated Waimangu thermal area several small lakes occupy craters produced during and following the 1886 eruption. Lakes Rotokawau, Rotongata and Rotoatua, occupy explosion craters near Lake Rotoiti, and

[3] Geologic ages are reported with the abbreviations ka for thousands of years before present and Ma for millions of years before present

there are numerous small lakes originating from hydrothermal eruptions in the Waiotapu thermal area, three of which contain hot water (Lowe and Green, 1987).

In addition, the geomorphic stability of volcanic areas may be prone to disruption by events not immediately associated with any eruption, but as equally damaging. Following an eruption, and its associated tephra deposition, many years of intense erosion and deposition of unconsolidated tephra may occur. Two dam-break floods have occurred from Lake Tarawera following eruptions and damming of the lake outlet (Figure 3), following the 1315 Kaharoa, and the 1886 Tarawera eruptions (Hodgson and Nairn, 2005; White et al. 1997). Large scale erosion and re-deposition occurred in 1904, when a tephra bank controlling the level of Lake Tarawera collapsed resulting in an abrupt increase in sediment yield, and a decades-long period of intense tributary erosion in the upper catchment of the Tarawera River followed, resulting in damaging stream-bed erosion outside the caldera (Hodgson and Nairn, 2005; White et al. 1997).

Both longfin and shortfin eels have been recorded in the Kaituna and Tarawera rivers and in Lakes Rotorua, Rotoiti and Tarawera, and are known to be present, but not recorded on the New Zealand Freshwater Fish Database (NZFFD), in lakes Ōkareka, Rotokākahi, Rotoehu and Rotomā (Figure 4). The NZFFD has only seven records of eels in the Te Arawa lakes, but show that eels are widely distributed downstream of the lakes (Figure 4)

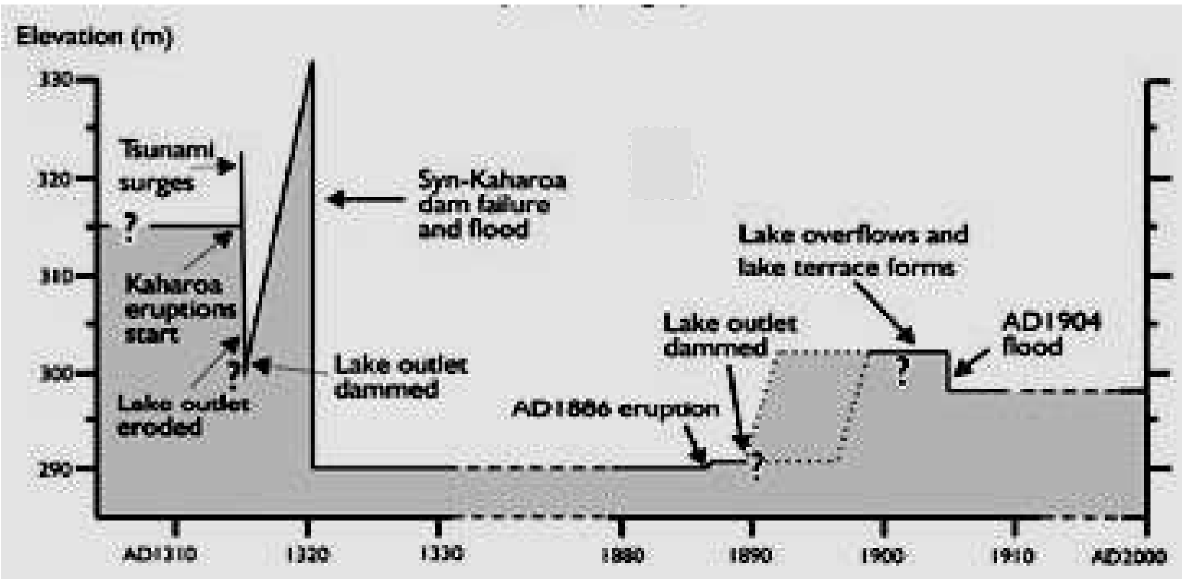

Figure 3: Lake Tarawera historical water levels (from Hodgson and Nairn, 2005).

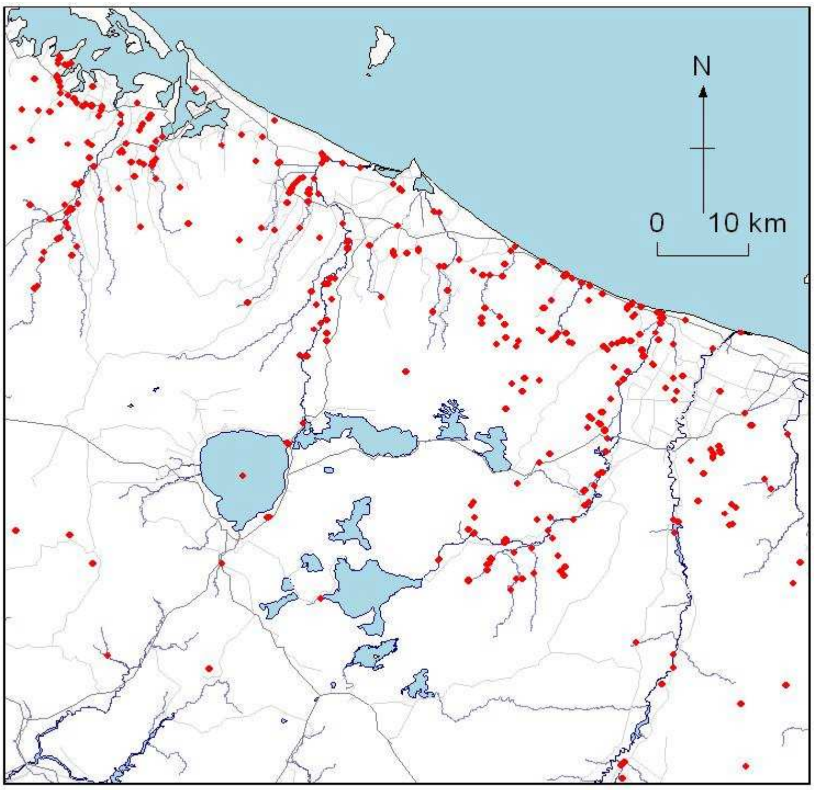

Figure 4: Distribution of freshwater eels in the Te Arawa lakes and central Bay of Plenty (red dots indicate recorded captures – New Zealand Freshwater Fish Database).

Natural barriers (e.g., waterfalls and rapids) are known to limit the upstream passage of eels in many New Zealand waterways. These barriers are the primary reason why eels are very rare in the Te Arawa lakes (Figure 5). On the Waikato River there were major waterfalls at Horahora and further upstream still at Huka Falls. There were also rapids at various locations, notably at Aratiatia. Many of these barriers were submerged by the construction of hydro dams, but the dams themselves now present insurmountable barriers not only for upstream migrants but also for silver eels. On the Kaituna River there are rapids downstream of Lake Rotoiti and few eels reach Okere Falls. Tarawera Falls, which was formed after the last eruption of Mt Tarawera in 1886, are most likely the reason why eels are now rare in the lake.

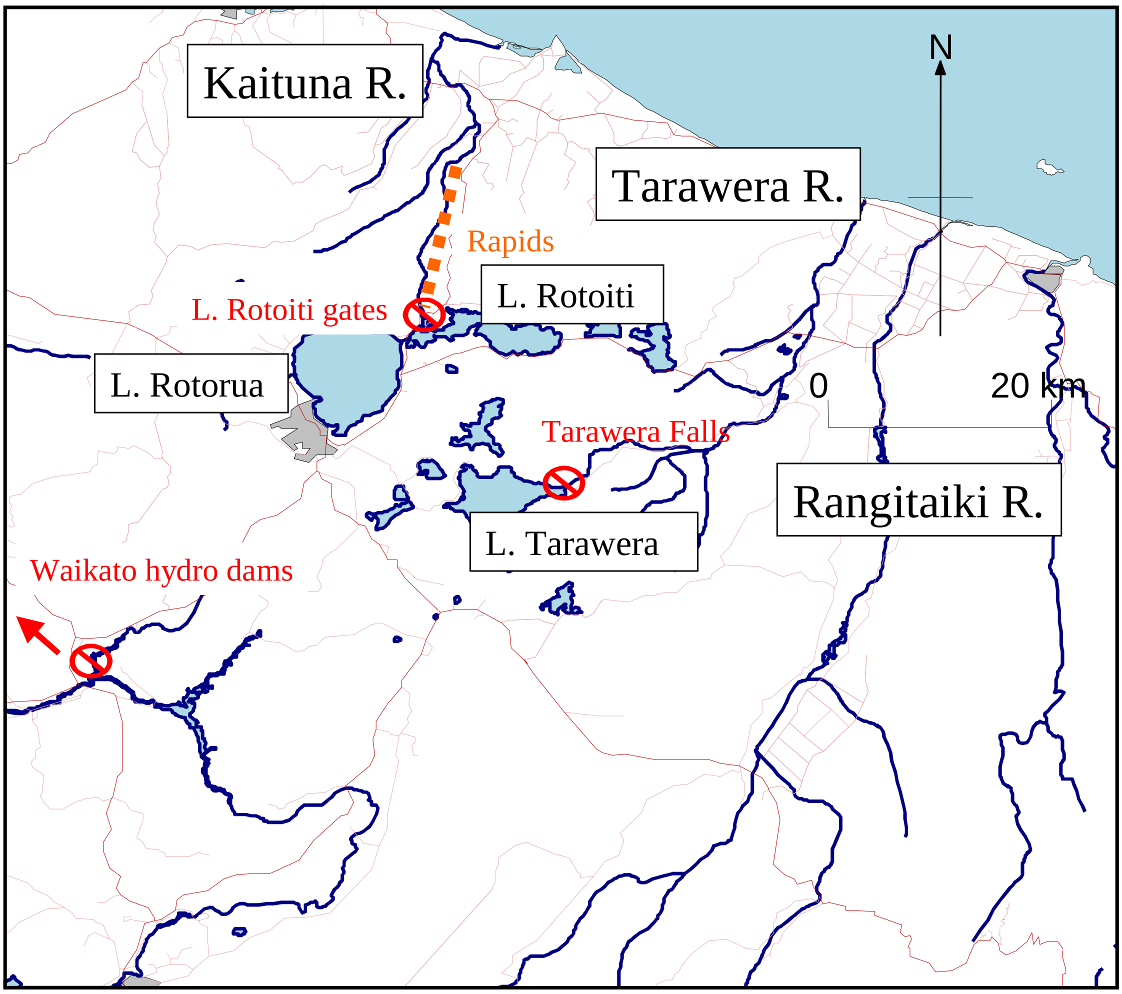

Figure 5: Eel migration barriers (⃠) on the Kaituna and Tarawera rivers.

6. Restoration potential

In summary, although many of the Te Arawa lakes could support eels, few are able to reach the lake because of natural barriers. The small numbers now present in the lakes are almost entirely from accidental or deliberate liberations. Such releases are occurring in the Waikato River with close to two million caught below the Karapiro Dam annually and released to the upstream hydro-lake reservoirs (Martin et al. 2006). Similar releases could, in theory, be made in one or more of the Te Arawa lakes, but sourcing sufficient elvers for stocking could prove difficult. Lakes Ngāpouri and Tutaeinanga are tributaries of the Waikato River. These lakes may be most suitable for stocking. Also farm impoundments that are in the Waikato River catchment but still within the Te Arawa rohe may also be potentially suitable. Provision for downstream passage of mature silver eels, the effects of eels on existing biota, and the risk of introducing new diseases and/or foreign organisms (including pest fish) should also be carefully considered before any artificial eel seeding program is implemented.

Compounds such as persistent pesticides from historical agricultural practices (e.g., organochlorines, pentachlorophenol) and heavy metals from geothermal activity (e.g., mercury) are major aquatic contaminant sources in New Zealand (Hickey, 1995). Mercury, and metalloids such as arsenic, have been reported in high levels in some of the Te Arawa lakes (Vincent and Forsyth, 1987). Eels are long-lived top predators, and therefore they can potentially accumulate high concentrations of these environmentally persistent contaminants, even in moderately contaminated water bodies (Fabris and Theodoropoulos, 1999). Mercury levels in freshwater fish and eels have been found to be of concern in other areas in New Zealand that receive geothermal inputs (Chisnall and Rowe, 1997; Mills, 1995). Residues of DDT compounds have been detected in eels in Australia (Vincent and Forsyth, 1987), and given the agricultural nature of some of the Te Arawa lakes area, a similar pattern would be likely here. The use of the Te Arawa lakes as an ongoing recreational, customary or commercial eel fishery would require careful consideration of the health risks associated with consumption of contaminated eels before proceeding, although such caution should be applied to any of the Waikato hydro lakes.

7. Critical knowledge gaps

Although many of the Te Arawa lakes could support eels, few are able to reach the lake because of natural barriers and thus numbers are low, mostly reflecting deliberate stocking. Unless Te Arawa decide upon an active strategy for stocking tuna in their lakes, there is little need to undertake further research on this species at this stage.

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