Ecology of the New Zealand Lamprey (*Geotria australis*)

A literature review

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Ecology of the New Zealand Lamprey (*Geotria australis*)

A LITERATURE REVIEW

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Executive summary

1. Lampreys along with hagfish are the only living representatives of the most primitive vertebrates, the jawless fishes. New Zealand has one species of lamprey, *Geotria australis* which is also found in Australia and southern South America. They are widely distributed in New Zealand.
2. Adults spend several years at sea feeding parasitically on other fish. They enter freshwater and spend up to 16 months reaching sexual maturity and migrating upstream to small, shady, hard-bottomed streams where they spawn and die. Larvae spend around 4 years as filter feeders in freshwater buried in fine sediments before metamorphosing into miniature adults that then migrate downstream to begin their parasitic life stage in the ocean.
3. Historically lampreys have great value as a food source for Maori. Extensive fisheries existed in the Whanganui and Taranaki regions of the North Island and in the far south of the South Island. Maori developed sophisticated methods for the capture of lamprey.
4. As for other native New Zealand diadromous fish species, lampreys are threatened by habitat loss and in-stream barriers. However, their extreme climbing abilities mean that only larger in-stream structures (e.g. hydro dams) are likely to be a barrier to upstream migration.
5. While we know the general details of the lamprey lifecycle and freshwater habitat, the actual spawning process has never been observed. Additionally, we know virtually nothing of *G. australis* once it enters the ocean.

Introduction

Lampreys give us a glimpse of the form and possibly the lifestyle of some of the early vertebrates. Along with hagfish they are the only living representatives of the most primitive vertebrates, the jawless fishes (Hubbs & Potter, 1971). This has led to significant research into lampreys, especially their biochemical and physiological features (e.g. Collin *et al.* 1999; Sower *et al.* 2000; Trivett *et al.* 2002). Currently, three families, six genera and 41 species of lamprey are recognised (Allen *et al.* 2003). Extant lampreys exhibit an "antitropical" distribution in that they only inhabit temperate waters. All southern hemisphere records come from south of 32°S (Potter *et al.* 1986). Most lamprey species are anadromous, with ocean going adults that feed by sucking the body fluids of other fish. Once they attain a certain size, lamprey travel upstream to spawn in small, shady, hard bottomed freshwater streams. Larvae then live for a time as filter feeders in freshwater before metamorphosing into 'miniature' adults and migrating downstream to the ocean to begin their parasitic adult stage.

In some regions, lamprey are taken commercially as a food species (e.g. France, Finland). In New Zealand they were historically an important food source for Maori and were subject to significant fishing effort in some parts of the country (e.g. Whanganui, Taranaki). Conversely, the unwitting introduction of lamprey to new areas has led to them becoming a pest. In North America, the sea lamprey *Petromyzon marinus* invaded the Great Lakes region in the early 20th century via shipping canals that circumvented natural barriers. Here this species established landlocked populations and have had a major impact on fisheries. This prompted the development of a larvicide and significant and continuing control efforts.

Studies into the ecology of New Zealand's single lamprey species (*Geotria australis*) has tended to occur in fits and starts. During the 1800s, when this species was first described in the scientific literature, the distinct differences in the life stages led to a number of species being incorrectly assigned. The names given to the life stages now, ammocoetes (larvae), macrophthalmia (miniature adults migrating to sea) and velasia (full size adults returning to freshwater) are relics from when each life stage was thought to be a different species. The first significant coverage of the biology and life history of this species is given by Maskell (1929). Between the late 1960s and the 1980s Ian Potter and colleagues studied the life history and ecology of Australian *G. australis* in great detail. The only recent detailed work on New Zealand *G. australis*, which included some radio tagging studies, was done in the 1990s (e.g. Todd & Kelso, 1993; Kelso & Glova, 1993; Jellyman & Glova, 2002). All this work has provided us with a good knowledge of the life history of New Zealand lamprey and the habits of larvae and upstream migrating adults. However, the actual spawning process has never been observed and we know virtually nothing about the habits of ocean going adults. The cryptic nature of the species and lack of information makes it impossible to deduce how common or rare New Zealand lampreys are.

This review seeks to bring together previously published information on the New Zealand lamprey with emphasis on their life history and ecology. Comment is made on the cultural importance, potential conservation issues and current knowledge gaps.

FIGURE 1. AN ADULT NEW ZEALAND LAMPREY.

Photo: Stephen Moore, Taranaki Regional Council

The colouration indicates this individual has recently entered freshwater after spending several years at sea.

Systematics and taxonomy

Lampreys (Petromyzontiformes) along with hagfish (Myxiniformes) are the last surviving representatives of the agnathan or jawless stage of vertebrate evolution (Kardong, 1998). Hagfish and lampreys lack bone or surface scales and this has been taken as evidence of a close affinity between them. However, the lack of bone in lampreys is now thought to be a secondary loss, where-as it may be the primitive condition in hagfish (Kardong, 1998). Despite this, from the description of the fossil lamprey, *Mayomyzon pieckoensis*, the basic morphology of the Petromyzontiformes has apparently changed little in 280 million years (Bardack & Zangerl, 1971).

Early taxonomy of extant lamprey species was erroneous as the morphologically distinct life stages were assumed to be different species and were named as such. Dendy & Olliver (1901) and Maskell (1929) provide good descriptions of this early confusion with the New Zealand lamprey. At present there are three families, six genera and 41 species recognised as extant (Allen *et al*. 2003). Of the families, Petromyzontidae (37 species) occurs only in the Northern Hemisphere, while Mordaciidae (3 species) and Geotriidae (1 species) are exclusive to the Southern Hemisphere. The only lamprey occurring in New Zealand is the single Geotriidae species, *Geotria australis* Gray (see Figure 2 for full classification). It is also found in south-eastern and the western tip of mainland Australia, Tasmania, and south-western South America (Allen *et al*. 2003).

FIGURE 2:. CLASSIFICATION OF THE NEW ZEALAND LAMPREY (NOTE THAT OTHER CLASSIFICATION VARIANTS EXIST)

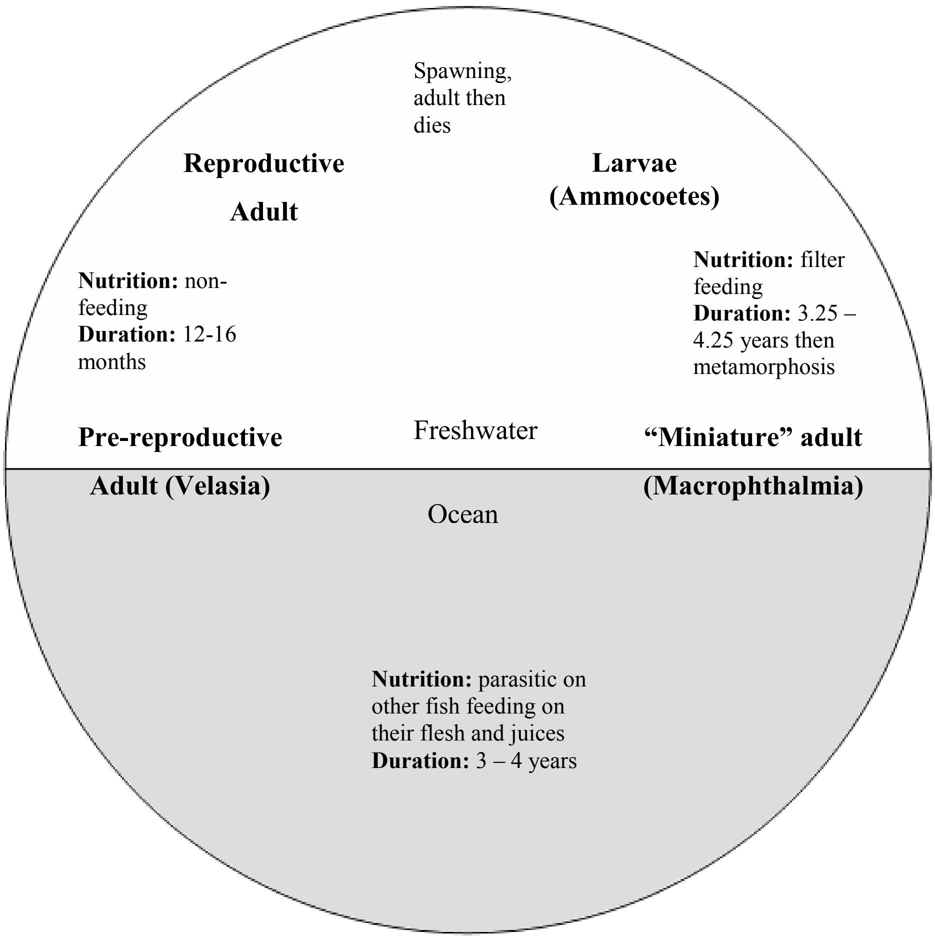
Kingdom:	Animalia
Phylum:	Chordata
Superclass:	Agnatha
Class:	Cephalaspidomorpha
Order:	Petromyzontiformes
Family:	Geotriidae
Genus:	*Geotria*
Species:	*australis*

Ecology

LIFECYCLE

Like many lamprey species, *Geotria australis* are anadromous in that adults must migrate from the ocean to freshwater to reproduce. They have an interesting lifecycle (Fig. 3) with freshwater dwelling, filter feeding larvae that metamorphose into a miniature adult that returns to the ocean. The adult feeds parasitically on other fish until it reaches sufficient size, before migrating up rivers where it spawns before dying.

FIGURE 3. LIFECYCLE OF *GEOTRIA AUSTRALIS*



ADULT HABITAT AND NUTRITION

Very little is known about the distribution of the marine phase where juveniles grow into pre-reproductive adults (Potter *et al.* 1986; McDowell, 1990). Potter *et al.* (1979) concluded that *G. australis* must travel vast distances in large groups based on the presence of adults in the stomachs of albatrosses breeding on South Georgia. It is thought these individuals originated from South American populations, the nearest of which was approximately 1900 km away. Additionally, the feeding ecology of the albatrosses dictated that the lamprey must have been relatively near the waters surface at night during the austral summer. They have also been found attached to marine fish far south into sub-Antarctic waters (Permitin, 1966 cited in McDowell, 1990).

Like most lamprey species, marine phase *G. australis* obtain nutrition by attaching to the body of marine fishes. They use their highly specialised mouth to rasp a hole in the body of the host and then feed off the host's body fluids and tissue (Fig. 4).

FIGURE 4. THE MOUTH OF AN ADULT *G. AUSTRALIS* SPECIALISED FOR THE RASPING OF FLESH.

Photo: Russell Death, Massey University

There is also evidence that lamprey may attach to whales (M. W. Cawthron, pers. comm cited in McDowell, 1990). It is unknown if this activity by adult *G. australis* typically leads to the death of prey animals. However, the North American sea lamprey (*Petromyzon marinus*) caused great mortality in the mackinaw (*Salvelinus namaycush*) populations in the Great Lakes (Smith, 1968), and it is likely the prey of *G. australis* meet a similar fate. It is unknown if *G. australis* has any preferred prey species and if so, how these influence the distribution and movements of marine phase adults.

Also unknown is the length of time spent at sea before returning to freshwater. McDowell (1990) states it is "probably several years", Glova (1995) "several years", and McDowell (2000) suggests three to four years. At the end of the marine phase the pre-reproductive adults are 450-750 mm long (Maskell, 1929; Potter *et al*. 1986; McDowell, 2000) and their body wet-weight consists of ~21% lipids (Bird & Potter, 1983). Newly arrived adults were described by Maskell (1929) as "beautiful and brightly coloured creatures". They have two dorsal longitudinal blue-green or 'electric' blue bands with the sides and ventral surface bearing a silvery sheen.

ADULT UPSTREAM SPAWNING MIGRATION

It is not thought that the adults necessarily re-enter their natal stream via any homing mechanism (Glova, 1995). It has been shown in the North American sea lamprey (*Petromyzon marinus*) that unique bile acids released by larvae may act as a migratory pheromone used by adults to select suitable spawning rivers (Bjerselius *et al*. 2000). The same is quite possible in *G. australis*. Jellyman *et al*. (2002) observed the consistent choice of the same tributary of Southland's Mataura River by migrating lampreys and suggested this may be a response to the odours of conspecifics.

In New Zealand, *G. australis* adults enter rivers during winter and spring (Jellyman & Robertson, 1997), as early as April (Maskell, 1929) and as late as August (Downes, 1918). Maskell (1929) states that "In the South Island they appear to enter the rivers somewhat later" compared to the North Island. In south-western Australia, migration into freshwater begins late June – early July (Potter *et al*. 1986). Upon entering freshwater, adults cease feeding and travel upstream. Upstream movement always occurs at night and is stimulated by increases in stream discharge (Maskell, 1929; Kelso & Glova, 1993) but curtailed by large floods (Jellyman *et al*. 2002). Additionally, Potter *et al*. (1983) states that upstream migratory movements are most intense when the water temperature is between 12 – 14.5 °C, when rain is falling and extensive cloud cover or the dark phase of the moon is present.

When not moving upstream, adults typically hide under boulders and amongst instream debris. In a Banks Peninsula stream, Kelso & Glova (1993), found adults typically to be concealed under boulders (approx. 25 cm diameter) or complexes of smaller boulders. Jellyman *et al*. (2002) found adults were generally associated with bank side debris cover during the day. It is likely that adult lampreys actively seek cover and avoid sunlight under whatever is available in a particular reach as opposed to having some preferred habitat type (Jellyman *et al*. 2002).

The rate of upstream movement is somewhat variable and erratic. Kelso & Glova (1993) found that the daily distance travelled by radio tagged upstream migrating lampreys declined from a high of 88 metres to 0 metres between August and November. In another radio tagging study, Jellyman *et al*. (2002) found that most movement occurred within a few days of release and recorded a maximum daily movement of 12.6 km in the Mataura River, Southland. Jellyman *et al*. (2002) suspected that the consistent extensive movement of lamprey following tagging may have been a result of the tagging process. Whatever the case, the rate of movement of adult lampreys will depend on a number of factors, including the timing of flow increases, new moons, and the availability and distance upstream of appropriate spawning habitat.

Depending on the length of the catchment they enter, adults may travel a considerable distance upstream. For example, in the Whanganui River, Maskell (1929) found ammocoetes 240 km upstream at Taumarunui and stated that they were likely present further upstream in more inaccessible parts of the river. Using their sucking disc mouth they are able to get past seemingly impassable steep, swift and high barriers. They also will leave the water when necessary and travel along the river edge. Adults have been observed using this method to get past a 14 metre high hydro dam on the Arnold River (McDowell, 1990).

Upon arrival in freshwater, adults are pre-reproductive. They have undeveloped gonads. Kelso & Glova (1993) found the gonads to be "far from mature" in adults that had entered freshwater approximately 3 - 4 months earlier. Potter *et al*. (1986) also found in Australian *G.*

australis, that the gonads of adults caught up to 6 months after entering freshwater were immature. Potter raised adults in aquaria under light and temperature conditions paralleling natural conditions and found spawning occurs in October or early November of the year following their entry into the rivers. This implies a period of approximately 16 months from initial adult freshwater entry until spawning (Potter *et al*. 1986). During this period the adults do not feed, instead they use their fat reserves for energy to move upstream and to complete gonad development. Maskell (1929) demonstrated this by keeping an adult caught in Wellington's Makara Stream for at least 17 months "in a tank of fresh water in the laboratory without anything to eat".

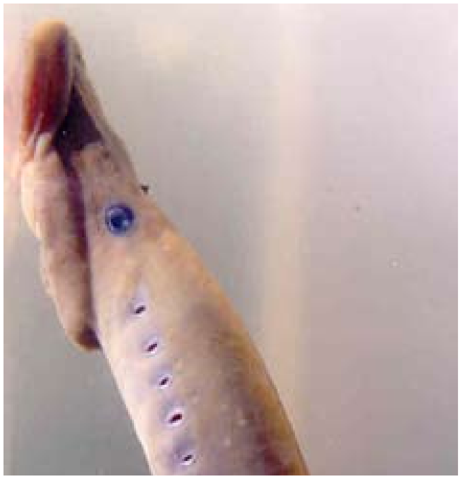
As they spend time in freshwater and become sexually mature, the appearance of adults changes from the "beautiful and brightly coloured creatures" described by Maskell (1929) to a "drab, muddy-brown colour, with bluish halos around the gill slits and eyes" (Glova, 1995) (Fig. 5).

FIGURE 5. AN ADULT NEARING SEXUAL MATURITY. COMPARE THE BROWN COLOURATION WITH THAT OF FIGURE 1.

Photos: Russell Death, Massey University

Additionally, they lose weight and length as they mature (Maskell, 1929; Glova, 1995). The male also develops a gular pouch behind the mouth and a bulbous snout (Glova, 1995) (Fig. 6).

FIGURE 6. THE BULBOUS SNOUT AND GULAR POUCH OF AN ADULT MALE NEARING SEXUAL MATURITY.



SPAWNING

The actual spawning of *G. australis* has not been observed. Jellyman *et al*. (2002) attempted to observe spawning by keeping thirteen adults in tanks for a year and releasing them just before sexual maturation. However, upon release these individuals failed to move significantly and spawning was never observed. Earlier, Glova (1995) attempted captive breeding. In this study, adult lampreys were collected from three waterways and transferred to concrete tanks. They survived in good health for a year but as spawning condition approached they began to show deterioration such as loss of sight, loss of muscle tone and haemorrhaging (Glova, 1995). Most of the captive lampreys matured 14-16 months after capture; however some had not reached spawning condition after 18 months. Although the sexually mature adults were provided with what was deemed suitable substrate and flow conditions for spawning, none occurred and the individuals slowly died.

Since adults ultimately travel into small, cobbled, forested tributaries it would seem these are the locations of spawning. If the spawning of *G. austalis* is similar to Northern Hemisphere lamprey then the adults likely construct a shallow oval depression in gravel using their sucking discs before twinning together for spawning (McDowell, 1990). The eggs are probably sticky and attach to the gravel. The adults may then cover the eggs with gravel but as mentioned this has not been observed. Maskell (1929) apparently searched intensely for evidence of spawning but found none. He did mention some anecdotal second-hand evidence where someone "saw, some years ago, lamprey carrying a stone about the size of a tennis ball..." and additionally describes "An old Maori told me he once saw some lampreys high up the Patea River with a nest of stones..." Whatever the case, adult *G. australis* obviously spawn somewhere in small, forest streams.

After spawning, the adults most likely die as is the case with most other lamprey species (McDowell, 1990). Maskell (1929) gives an account of a farmer in Okato who "now and then finds pouched lampreys floating dead on the surface of streams on his farm". However, some may survive the spawning and return downstream according to Dendy & Olliver (1901) who suggest from Maori statements that some pouched individuals return to the sea. Additionally, Maskell (1929) mentions Maori at the mouth of the Manawapou River reporting the capture of pouched lamprey in their eel nets. Given the morphological changes that lead to sexual maturity (e.g. body shortening, reduction in gut) and the general exhaustion of such a protracted spawning process, individuals that do make it back to sea never return to spawn again (Maskell, 1929).

LARVAL HABITAT AND NUTRITION

The smallest *G. australis* ammocoetes (larvae) captured in New Zealand were 11 mm long (Maskell, 1929). In south-western Australia, Potter & Hilliard (1986) captured 10 mm long individuals in December and identified these as "very small 0+ recruits". They considered their appearance as consistent with the October spawning period they had earlier calculated (Potter *et al*. 1983). Maskell (1929) noted that ammocoetes are typically found in "sandy spots and shallows at the banks of the rivers" where they live buried in the sand at depths of between 3 and 9 cm. Potter *et al*. (1986) investigated the influence of environmental variables on the density of larval *G. australis* in a south-western Australian stream. Ammocoetes preferred shady microhabitats with high chlorophyll *a* and organic matter levels, shallow water depth and medium-sand substrate. Kelso & Todd (1993) in two New Zealand streams concluded that sediment depth and composition were the dominant environmental factors influencing density and distribution of ammocoetes. More recently, Jellyman & Glova (2002) investigated habitat use by ammocoetes in a "large" New Zealand river (Mataura River, Southland). They found high densities of ammocoetes were associated with run habitat, overhead shade and water <0.3 m deep, with velocity <0.05 ms-1 and substrate of <1 mm in size.

Ammocoetes remain buried during daylight but emerge during the night. They have no eyes and possess an oral hood around their mouth which aids in the filtering of algae, micro organisms and detritus from the water column (Maskell, 1929; Potter & Hilliard, 1986). The preference of microhabitats high in chlorophyll *a* noted by Potter *et al*. (1986) is likely related to food supply. The duration of the ammocoete filter feeding life stage has been estimated to be 3.25 to 4.25 years (Potter & Hilliard, 1986; Todd & Kelso, 1993).

METAMORPHOSIS

Once ammocoetes reach between 80 - 100 mm in length they undergo a seven stage metamorphosis into the adult form (Potter & Hilliard, 1986). During this process, which takes several months, *G. australis* maintains length but loses weight (Potter *et al*. 1986). During metamorphosis lamprey become able to cope with the physiological challenge of moving from a freshwater to a saline environment (McDowell, 1990). Their colouration changes from the dull grey-brown of the larvae to brilliant silver and blue, eyes develop, the fins become larger, the oral hood thickens and teeth develop producing the sucking disc of the adult (McDowell, 1990) (Fig. 7).

Kelso & Todd (1993) found evidence of instream size segregation with metamorphosing larvae typically found in downstream reaches were substrate was coarser and flows higher. It would appear that ammocoetes tend to move downstream as they grow. It is unclear whether this is an active movement, but it is likely this is at least partially the result of passive displacement during high flow events.

FIGURE 7. MACROPHTHALMIA (MINIATURE ADULT READY TO MIGRATE TO OCEAN) CAPTURED VIA ELECTROFISHING IN A WELLINGTON STREAM.

Photo: Mike Joy, Massey University

Metamorphosis begins around January with the macrophthalmia (miniature adults) migrating downstream to the sea in July and August (Potter *et al*. 1986; Empson & Meredith, 1987). This downstream movement occurs at night and during increased river flows (Potter *et al*. 1980). Empson and Meredith (1987) noted that downstream migrating individuals were mainly captured in the mid-river near the surface in the Waikato River where the greatest water velocities are found. They interpreted this as the macrophthalmia minimising energy expenditure while moving downstream. As before mentioned, once they reach the sea, little is known of their distribution or habits except that they feed parasitically on other fish and may travel very far from their land of origin.

Distribution in New Zealand

Geotria australis are widely distributed throughout New Zealand (Fig. 8). They are also present on the Chatham Islands (Todd & Kelso, 1993) and Stewart Island (McDowell, 1990). However, this distribution is unlikely to be a true representation given the difficulty of detecting the presence of ammocoetes and limitations of the New Zealand Freshwater Fish Database (NZFFD). The slow flowing, fine sediment microhabitats that ammocoetes congregate in are often passed over by those performing electro fishing surveys as operators concentrate on features such as undercut banks and instream debris where other fish are found and on zones where the flow is sufficient to make capturing stunned fish easier. Even though all life stages of lamprey are active at night, they could easily be misidentified as eels during spot lighting surveys unless the operator is very familiar with lamprey form.

FIGURE 8. THE DISTRIBUTION OF *GEOTRIA AUSTRALIS* IN NEW ZEALAND. THE RED CIRCLES INDICATE NEW ZEALAND FRESHWATER FISH DATABASE SITES WHERE LAMPREYS HAVE BEEN CAPTURED (AS OF FEBRUARY 2008).

40

N

45

0 200 km

Therefore, it is likely that they are present at a number of other NZFFD sites but simply have not been recorded. Additionally, given their apparent preference to spawn in small forested streams, it is likely that many areas where ammocoetes are present are fairly inaccessible, especially to those electro fishing operators who prefer to not walk too far from a road. McDowell (1990) sums up the situation well in stating that "... in general ammocoetes are not often encountered. Adult lampreys are even less frequently reported. I have seen only half a dozen in more than 20 years in and out of New Zealand's rivers and stream and it is my experience that few New Zealanders know them or anything about them." It is probable that lampreys are present in all New Zealand river catchments excepting those that lack appropriate spawning and ammocoetes habitat.

Cultural significance

The vast majority of New Zealanders have little, if any knowledge of New Zealand's freshwater fish fauna let alone of a species such as *G. australis* that is rarely seen even by aquatic ecologists and when observed, looks much like an eel. Thus, for most people lamprey are of no significance. In some parts of Europe (e.g. France, Finland, Latvia) lampreys are caught for food (Todd, 1992). Apparently the small Latvian population established in New Zealand after WW2 caught small numbers of lamprey for personal consumption (Todd, 1992).

G. australis was (and still is in some localities) considered a great delicacy by Maori (Downes, 1918). Lamprey are known to Maori by a variety of names including pipiharau, piharau, pihapiharau, korokoro, kanakana and nganangana (Best, 1986). It seems piharau was a common North Island name and kanakana a common South Island name (Best, 1986; Jellyman, 1997). Lampreys are taken during the adult upstream phase (velasia), not too long after they have entered freshwater as their quality as a food deteriorates as their gonads develop. Maori take advantage of behaviour and natural barriers to capture lamprey. Best (1986) in his classic work, "Fishing Methods and Devices of the Maori" gives great detail on perhaps the most elaborate method of capture, the lamprey-weir or utu piharau. These weirs were commonly used on the Whanganui River and consisted of large wooden barriers built on the shore with gaps spaced along them. When the river was in flood the lamprey would swim up the edges of the river and then reach the barrier. They would seek out the gaps through which water was flowing at great velocity. The flow would then wash them into nets (hinaki piharau) just downstream of the flow.

Another method (termed whakarau), apparently which had fallen into disuse at the time of Downes' (1918) description involved the construction of a large thick mat of bracken and flax which was then laid down in a natural or artificial backwater. Presumably adults would hide and congregate among this mat whilst waiting for the right time to move upstream (i.e. night, high flows). Two people would then go out and roll up the mat and any lamprey in it towards the shore. Apparently the bracken and flax mat was superseded by the use of sheep skin (Downes, 1918).

The method that requires the least construction is the use of natural barriers. Lamprey are easily collected as they climb the vertical faces of waterfalls. For example, at the Mataura Falls in Southland, strong poles would be inserted in holes beside the falls for collectors to support themselves on as they leant out to collect lamprey (Todd, 1992). Additionally, resting lamprey could often be found in certain holes and crevices in many rivers and easily collected during the day. These sites were highly prized and I expect protected, with the location handed down from generation to generation (Todd, 1992).

Once captured, lamprey are apparently difficult to preserve. According to Downes (1918), it cannot be dried or smoked, although he also states that "Other natives say that the pirahau can be preserved by drying, but the method is somewhat different to that employed by eels, as they are partly sun-dried and then finished by a slow fire." As they do not feed in freshwater, lamprey were easily kept alive in holding baskets (korotete) for months (Downes, 1918).

The location of all historical Maori lamprey fisheries is unlikely to ever be known. However, clearly rivers in Taranaki and Whanganui were North Island hotspots with significant fishing effort. The same can be said for the Mataura, Waikawa and Pomahaka rivers in the South Island (Todd, 1992).

Conservation

Lampreys are widely distributed throughout New Zealand (Fig. 8) and gaps in their distribution (e.g. much of the North Island's east coast) are more likely to do with lack of fishing effort than a real absence. Given the general difficulty in locating lamprey, any accurate estimate of their abundance is impossible. There is historical evidence that lamprey ascend rivers in great numbers. For example, Maskell (1929) recalls one correspondent regarding the Mataura River "Fifteen years ago I saw them in millions!". Phillips & Hodgkinson (1922, cited in McDowell 1990) recorded Maori capturing several tons migrating up a river near New Plymouth in June 1921 and Downes (1918) in reference to the Waitara River, "for a single night's netting during a fresh in June, three sacks were filled – probably between two and three thousand." Some authors note a perceived decline in lamprey. Best (1986) describes that lamprey "were formerly numerous each season in the rivers of Canterbury, but our informant has not seen any there for many years. A few have been seen of late years in the Mangaone Creek at Te Horo, and in the "sixties" we used to see a few in the Kenepuru Stream at Porirua." It is unknown if the abundance has actually changed over the years of European settlement (McDowell, 1990) and Todd & Kelso (1993) concluded that there is insufficient evidence to determine any change in historically abundant adult spawning migrations.

Nowadays, large accumulations of adults are occasionally found where their upstream migration is blocked by obstructions (e.g. dams and waterfalls). Additionally, large numbers of ammocoetes may be found if one looks in the right habitat. This led Todd (1992) to conclude that lampreys are not rare and may be abundant in some areas. It should be noted that Todd (1992) is a report produced for Electricorp Production who at the time controlled many of New Zealand's hydro dams and thus could be considered by some to be potentially biased.

Although their sucker mouth gives *G. australis* the capability to move upstream of seemingly impassable barriers, the installation of hydro dams on many major rivers has probably affected their abundance. Jellyman & Robertson (1997) describe large numbers of migrating adults attempting to get above the Roxburgh Dam on the Clutha River and remark "Unfortunately, unless the lampreys can be caught and transported above the dam, there is little likelihood of their successfully negotiating such an obstacle." It is likely that other large dams effectively prevent lampreys from accessing large parts of their former range upstream. Furthermore, if adults manage to get past such dams and successfully spawn, then the macrophthalmia face the difficulty of negotiating power generation turbines on their return migration to sea. It should also be noted that negotiating large obstacles may increase the risk of predation by birds and affect the fitness of individuals. Because of their superb climbing ability, the myriad of smaller instream structures such as small dams, weirs and culverts are unlikely to be a major problem for the migration of lamprey as they may be for other migratory fish species. For example, McDowell

(1990) reports the successful negotiation by upstream migrating adults of the 14 m high dam on the Arnold River.

Given the probable location of spawning (small, cobbled, bush clad streams), it is hard to imagine that the conversion of most of New Zealand's lowland forest to farmland has not had a profound effect on the distribution and abundance of lamprey as it has on other species (McDowell, 1990). Adults must surely now have to travel further upstream in many parts of the country to find suitable spawning grounds. Additionally, the overall area of suitable spawning habitat has decreased. To ensure the maintenance of lamprey populations, we must ensure both the preservation of spawning and ammocoetes habitat and the free passage between such habitat and the ocean.

Another potential threat to lamprey is the fact that since the development of commercial fishing in New Zealand waters, there are less potential prey fish in the sea. The effect of this on adult survival, growth and fecundity is unlikely to ever be known.

Knowledge gaps

1. The general abundance of lamprey and how this may vary from year to year is unknown.
2. The actual distribution of lamprey in New Zealand is not fully known.
3. Lamprey spawning habitat and behaviour is undocumented.
4. The extent of existing Maori fisheries and whether catches have changed over time.
5. All aspects of the ocean going stage of the lamprey lifecycle, e.g. where, how far, how long, what prey species?

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Appendix

SOURCES OF INFORMATION ON THE ECOLOGY OF NEW ZEALAND LAMPREY

Journal papers

AUTHOR	GENERAL TOPIC	LIFE STAGE COVERED
Downes T.W. (1918)	Maori fishery	Velasia stage adults
Empson P.W. & Meredith A.S. (1987)	Miniature adult migration	Macrophthalmia stage adults
Glova G.J. (1995)	Adult migration	Velasia stage adults
Jellyman D.J. & Robertson M. (1997)	Adult migration	Velasia stage adults
Jellyman D.J. & Glova G.J. (2002)	Larval habitat use	Ammocoetes
Jellyman D.J., Glova G.J. & Sykes J.R.E (2002)	Adult migration	Velasia stage adults
Kelso J.R.M. & Glova G.J. (1993)	Adult migration	Velasia stage adults
Kelso J.R.M. & Todd P.R. (1993)	Larval habitat use	Ammocoetes
Maskell (1929)	Biology and life history	All
Potter I.C., Prince P.A. & Croxall J.P. (1979)	Ocean going adults	Marine phase adults
Potter I.C., Hilliard R.W., Bird D.J. & Macey D.J. (1983)	Adult migration	Velasia stage adults
Potter I.C. & Hilliard R.W (1986)	Larval life history	Ammocoetes
Potter I.C., Hilliard R.W., Bradley J.S. & McKay R.J. (1986)	Larval habitat use	Ammocoetes
Todd P.R. & Kelso J.R.M. (1993)	Larval life history and distribution	Ammocoetes

Book, book chapters and reports

AUTHOR	GENERAL TOPIC	LIFE STAGE COVERED
Best E. (1986) (reprint of 1929 original)	Maori fishing techniques	Velasia stage adults
McDowall R.M. (1990)	General biology	All
McDowall R.M. (2000)	Field identification	All
Potter I.C., Hilliard R.W & Neira F.J. (1986)	General biology (Australian *G. australis*)	All
Todd (1992)	Status report	All

Websites readily accessible to the general public that contain general information on *Geotria australis* (all accessed 3/3/08)

http://www.teara.govt.nz/TheBush/FishFrogsAndReptiles/FreshwaterFish/6/en

http://www.doc.govt.nz/templates/page.aspx?id=33211

http://en.wikipedia.org/wiki/Pouched_lamprey

http://www.fishbase.org/Summary/SpeciesSummary.php?id=6947

http://www.niwa.co.nz/rc/freshwater/fishatlas/species/lamprey

New Zealand Government