3 Tuna (Freshwater Eels)

Family: Anguilla

Species: *Anguilla australis, Anguilla diffenbachii*

There are currently 18 recognised species/subspecies of freshwater eels worldwide (Tesch 2003), distributed in both tropical (around the equator) and temperate (between the tropics and polar circles) zones, with some species overlapping between these two zones. Recent studies indicate that tropical eels make much shorter migrations (c. 100's km) to spawn in areas near their freshwater habitats when compared to the long distances travelled by temperate (e.g., Aotearoa-NZ) eels (c. 1000's km) (Aoyama 2009).

Māori have an extensive knowledge of tuna. It is not the place of this report to collate and publicise the extensive body of mātauranga Māori that has been actively practised over centuries by whānau, hapū and iwi. While our tuna species are often characterised in terms of biophysical science (family, genus, species), mana whenua have an extensive range of classifications for tuna related, for example, to appearance, colouration, season of the year, size, behaviour, locality, and palatability. According to science, three tuna species occur in Aotearoa-NZ (Figure 4); the longfin (*Anguilla dieffenbachii*), which is only found in Aotearoa-NZ; the shortfin (*A. australis*), which also occurs in eastern Australia and the Pacific; and the Australian speckled longfin[1] (*A. reinhardtii*), which has recently been confirmed as present in Aotearoa-NZ, and is also found in Australia and New Caledonia.

Longfins are distinguished from shortfins by the length of the dorsal (top) fin; when viewed side on, the dorsal fin is longer than the anal (bottom) fin, and extends well forward past the end of the anal fin. In shortfins, the dorsal and anal fin ends are almost the same length (Figure 4). The Aotearoa-NZ longfin is one of the largest eel species in the world (Tesch 2003) and can get to more than 50 kg (Potts 1882, Cairns 1941, Graham 1956). Shortfins do not grow as large as longfins. The Australian speckled longfins look like our longfins but have black blotches all over their body, except for their belly (Figure 4). Although the habitat of the Australian longfin overlaps that of the *A. dieffenbachii*, it is thought that there is little danger that the Australian longfin will edge out *A. dieffenbachii* because researchers believe that each eel species has a single spawning ground. It is thought that the arrival of *A. reinhardtii* in Aotearoa-NZ will continue to be erratic and intermittent, although the confirmed presence of several year classes suggests their migration to Aotearoa-NZ is not an isolated event (Jellyman et al. 1996, McDowall et al. 1998, Chisnall 2000a).

3.1 Life Cycle

To complete their life cycle, tuna must be able to move freely between fresh water and the ocean, spending extended periods in marine, estuarine, and freshwater habitats. The freshwater eel has a larval stage known as leptocephalii, which is only found in the ocean. These transparent leaf-shaped larvae are transported to Aotearoa-NZ using near-surface ocean currents. After encountering the continental shelf the larvae transform into the transparent and actively swimming 'glass eels' which are approximately 55–70 mm. Once glass eels (Figure 6) have entered a catchment, each catchment effectively contains a separate population of eels. Once in freshwater, glass eels develop into darker pigmented juvenile eels known as elvers. After reaching suitable habitat, tuna grow, often for several decades, before maturing and beginning the return trip to their oceanic spawning grounds (Figure 5, Table 2).

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[1] Confirmed in 1997, from 19 eels caught in the Waikato River.

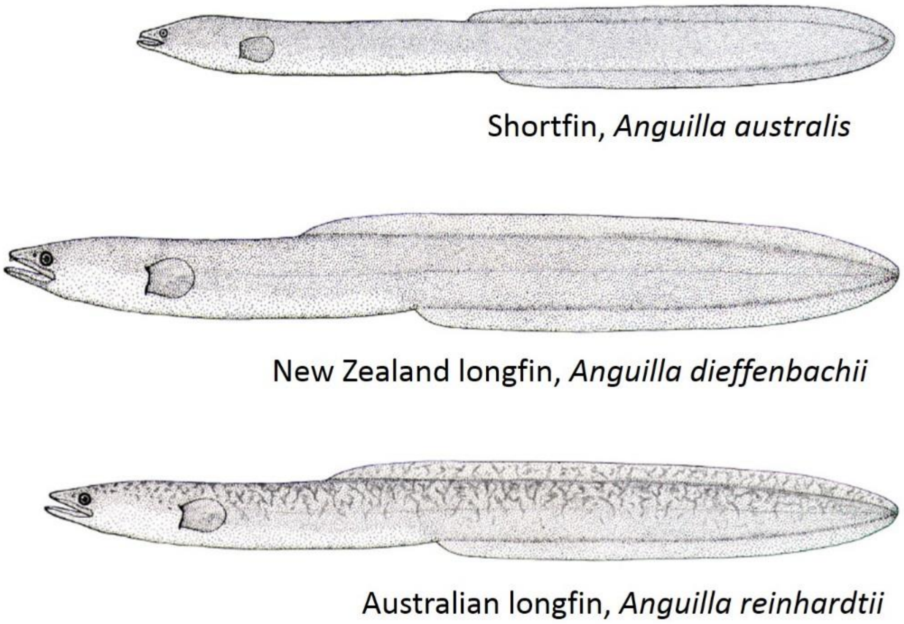

Figure 1: According to science three freshwater eel species occur in Aotearoa-NZ; (top) the shortfin (*A. australis*); (middle) the endemic longfin (*A. dieffenbachii*); and (bottom) the Australian longfin (*A. reinhardtii*) which was confirmed in Aotearoa-NZ in 1997 but is relatively rare. (Diagrams: Bob McDowall).

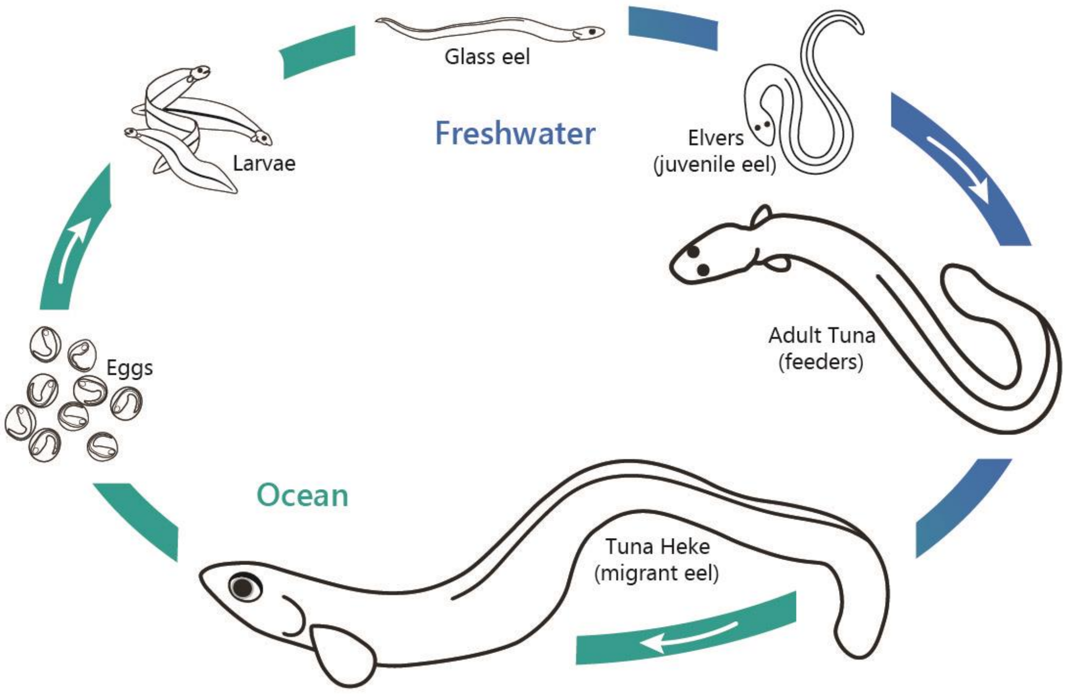

Figure 2: Freshwater eel life-cycle showing the marine (green) and freshwater (blue) life stages. (Source: Aarti Wadhwa).

Table 1: **Key features of each tuna life stage.** (References include: Cairns 1941; 1942, Burnet 1952, Jellyman 1977, Jellyman 1979, Jellyman & Todd 1982, Jellyman & Ryan 1983, Chisnall 1987; 1989, Chisnall & Hayes 1991, Chisnall & Hicks 1993, Chisnall & Kalish 1993, Glova et al. 1998, Jellyman et al. 1999, Chisnall et al. 2002, Jellyman et al. 2002, Jellyman & Tsukamoto 2002, McCleave & Jellyman 2002, Jellyman & Lambert 2003, Tesch 2003, Graynoth & Niven 2004, Graynoth & Taylor 2004, McCleave & Jellyman 2004, Davey & Jellyman 2005, Jellyman & Tsukamoto 2005, August & Hicks 2006, Graynoth et al. 2008a; 2008b, Jellyman & Tsukamoto 2010, Jellyman & Arai 2016).

Life stage	Key features	Key habitats	Agencies with responsibilities
Fertilised egg	• Spawning occurs in spring (September to November). • The exact spawning locations of *A. australis* and *A. diffenbachii* are yet to be determined. Likely to occur somewhere in the southwest tropical regions of the Pacific Ocean, from north-west of Fiji to just west of Vanuatu for *A. australis*. • Fertilised eggs develop and hatch rapidly in the ocean.	• Pacific Ocean – In deep water.	• New Zealand Ministry of Foreign Affairs and Trade (MFAT) (international agreements on ocean governance and fisheries management, e.g., UN Convention on the Law of the Sea). • Environmental Protection Agency (EPA) (e.g., managing environmental effects of restricted activities in NZ's Exclusive Economic Zone and Continental Shelf).
Larvae (leptocephalii)	• Transparent, leaf-shaped. • Spend 9–12 months in the plankton before arriving on the coast of Aotearoa-NZ. • Transported closer to Aotearoa-NZ using near-surface ocean currents.	• Pacific Ocean to Aotearoa-NZ continental shelf. • Planktonic.	• As above.
Glass eel	• Transparent. • Glass eels are the product of a 5,000 km migration by adults, the act of spawning itself, and the uncertainties of a 6-month larval life at sea. • About 50–65 mm in length. • Generally arriving in Aotearoa-NZ waters between August and December. • Numbers of glass eels arriving at river mouths are subject to considerable year-to-year variation. • Entry into fresh water often correlated with lunar phase and spring tides, and occurs mainly at night. • Length and weight declines in both species of glass eels as the season progresses.	• Aotearoa-NZ continental shelf to fresh waters. • Lower reaches of waterways open to the sea. • Small eels seem to favour runs and riffles of waterways where the substrate is coarse and the current is swift.	• MPI (e.g., lower size limit, special permits, exotic pests, biosecurity, fish passage). • Regional councils (e.g., land use change/management as it affects water quality, biosecurity, fish passage, habitat, ecological flows, point source discharges, pollution events, esplanade areas, flood control, gravel extraction, drain clearance). • District councils (e.g., land use zoning, land use change/management, esplanade areas). • DOC (e.g., fish passage, exotic pests, habitat, national parks, conservation estate, scientific reserves, research/collection permits, grazing licences for riparian areas, and marginal strips). • Land Information New Zealand (LINZ) (e.g., administration incl. use of riverbeds, fairway maintenance).
Elver	• Pigmentation covers 100% of the juvenile eel's body. • About 70–150 mm in length. • Migrate upstream during summer (when temperatures reach about 17°C), sometimes over several years. • Use surface tension to surmount damp, vertical surfaces, such as waterfalls.	• Fresh waters. • Elvers of both longfins and shortfins are common in swiftly flowing gravelly rapids and riffles, where they live and feed amongst the gravel. • Small shortfins (<100 mm) prefer water <0.5 m deep.	• MPI (e.g., as above). • Regional councils (e.g., as above). • District councils (e.g., as above). • DOC (e.g., as above). • LINZ (e.g., as above).

Table 2: Continued.

Life stage	Key features	Key habitats	Agencies with responsibilities
Pre-reproductive adults	• Opportunistic feeders and eat a diverse range of food, including stream insects, terrestrial insects, snails, earthworms, kōura, fish, small birds. Size of their prey depends largely on the gape (mouth) size of eels. Large eels are often the top predator in freshwater ecosystems. • Have poor eyesight, are sensitive to strong light, and are active nocturnal foragers. Food and prey are located primarily by odour detection, using a consistent behavioural response to flow, which results in direct upstream movement toward the odour source when in an odour plume. • Flooded river margins are also important feeding grounds for eels, particularly shortfins. • Eel growth rates are highly variable. High growth rates may occur where food is abundant, but can be very poor in highly modified habitats with high recruitment/high densities. • Eels are not born a particular sex, it is determined as they get older by the environment they are living in. The environment and the number of individual eels who share that same environment contributes to determining the sex of an eel, with females tending to be more common at lower eel population densities. This may be due to large female eels being cannibalistic feeders, and this habit may also influence the distribution of eels. Without this ecological relationship, a higher density of smaller eels can induce sexually immature juveniles to become male. This may have implications not only on inter-related species, but also on the number of female eels contributing to the spawning population. • Large eels, particularly longfins, play an important role in determining the population structure of eels, including species composition, sex ratios and size distribution.	• Eels occupy a wide variety of freshwater habitats, including, coastal estuaries, lakes, wetlands, rivers, mountain streams and alpine tarns. • As eels grow larger, many move upstream/further inland, they hide beneath overhanging banks and logs. • Larger eels (>300 mm) of both species are commonly associated with cover, such as macrophyte beds, willow roots, overhanging banks, in-stream debris and shade. • Several studies describe the behaviour of eels as having a “home range”. • Shortfins prefer slower flowing, lowland and coastal waters. • Longfins penetrate further inland and prefer faster flowing water and stony substrates. • As eels increase in size the preference is for deeper water; eels >499 mm generally prefer water almost twice as deep.	• MPI (Quota Management System, upper and lower size limits, number of fishing licenses, catch limits, exotic pests, biosecurity, fish passage, mātaitai reserves, co-management, bylaws). • Iwi/hapū/rūnanga (e.g., customary harvest, mātaitai reserves, co-management, bylaws). • Regional councils (e.g., land use change/management as it affects water quality, biosecurity, fish passage, habitat, ecological flows, point source discharges, pollution events, esplanade areas, flood control, gravel extraction, drain clearance). • District councils (e.g., land use zoning, land use change/management, esplanade areas). • DOC (e.g., fish passage, exotic pests, habitat, national parks, conservation estate, scientific reserves, research/collection permits, grazing licences for riparian areas, and marginal strips). • LINZ (e.g., administration incl. use of riverbeds, fairway maintenance).

Table 2: Continued.

Life stage	Key features	Key habitats	Agencies with responsibilities
Adult migrant	• Once eels become migrants they stop feeding. • Female eels from the same species grow larger and are older than males at maturity. • Precise trigger that causes eels to develop into migrants is not well known, but high fat content that provides sufficient energy to develop gonads (reproductive organs) and cover the long distance to spawning grounds appears to be essential. • External features change to better cope with oceanic conditions, including: the head becomes flatter and slender, belly lightens to a grey or silver colour, the pectoral fins and eyes enlarge. • Shortfin males tend to migrate in February and March, followed soon after by the shortfin females. Longfin males migrate during April, and longfin females during late April and May. • Shortfins generally migrate at a younger age than longfins, and are smaller than longfins when they migrate. • Males (both species) are smaller and migrate at an earlier age than females. 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. • Larger female eels are much more fecund (contain more eggs) than smaller female eels. • The size difference between males and females is strategically important. Fecundity has been estimated at between 1.5 and 3 million eggs in migrant shortfin females 500–800 mm in length while large migrant longfin females (1,400–1,600 mm length) may contain over 20 million eggs. • Migration to oceanic spawning grounds probably takes many months (not a straight line, they are also diving down between about 200 m and 700 m depth each day). • Spawning grounds located somewhere in the southwest tropical regions of the Pacific Ocean, potentially the South Fiji Basin. • The adults do not return to Aotearoa-NZ and are thought to die at or near the spawning ground.	• Fresh waters to the ocean.	• MPI (e.g., Quota Management System, upper size limits, special permits, exotic pests, biosecurity, co-management, bylaws). • Iwi/hapū/rūnanga (e.g., customary harvest, mātaitai reserves, co-management, bylaws). • Regional councils (e.g., land use change/management as it affects water quality, biosecurity, fish passage, habitat, ecological flows, point source discharges, pollution events, esplanade areas, flood control, gravel extraction, drain clearance). • District councils (e.g., land use zoning, land use change/management, esplanade areas). • DOC (e.g., fish passage, exotic pests, habitat, national parks, conservation estate, scientific reserves, research/collection permits, grazing licences for riparian areas, and marginal strips). • LINZ (e.g., administration incl. use of riverbeds, fairway maintenance). • MFAT (international agreements on ocean governance and fisheries management, e.g., UN Convention on the Law of the Sea). • EPA (e.g., managing environmental effects of restricted activities in NZ's Exclusive Economic Zone and Continental Shelf).

Figure 3: (Left) A glass eel; and (Right) Mixture of glass eels and elvers. The dark pigment spots (called melanophores) appear on the skin as the glass eel continues to grow and change into the next stage of their life cycle when they become completely brown and are known as elvers. (Photos: [Left] NIWA, [Right] Joe Potangaroa).

Each species is assumed to consist of a single genetic stock despite occupying broad geographic ranges. Shortfins from Australia and Aotearoa-NZ show small but significant differences in their form/shape (Jellyman 1987, Watanabe et al. 2006), but whether these small differences are a result of spawning in separate areas is unknown. On the weight of current evidence this seems unlikely, meaning that the species should be recognised and managed as a single trans-Tasman one. In contrast, the Aotearoa-NZ longfin is only found in this country and our offshore islands, meaning there is no reserve stock or "buffer" should numbers on mainland become seriously depleted (Jellyman 2013).

3.2 Distribution

Longfins are found throughout Aotearoa-NZ, including the Chatham Islands, from the coast to any upstream habitat they can reach. Although longfin were recorded as present in the Auckland Islands during the 19th century, they have not been found there since (McDowall 1990). There are a few areas of the country where longfins have been observed very frequently, including Taranaki, between Manukau Heads and Warkworth (North Auckland), West Coast of the South Island and top of the South Island (Figure 7).

Shortfins are less widely distributed across Aotearoa-NZ. Shortfin eels are generally found in lowland rivers, streams, lakes, swamps and estuaries (Figure 7). Shortfin eels are predominantly located close to the ocean in the South Island, but are found further inland in the top-half of the North Island. In particular, shortfins are commonly encountered throughout the Waikato Region through to the south of Auckland. It is usually the most common species where eel populations are very dense, and they generally do not travel as far upstream as longfin (McDowall 1990). *A. australis* is also found in Australia (East Coast), Tasmania, New Caledonia, Lord Howe and Norfolk Islands (McDowall 1990).

Figure 4: **Locations of NZFFD records where: (Left) Longfin eels, and (Right) Shortfin eels, are present (black circles) and absent (grey circles).**

3.3 State and Trends in Abundance

3.3.1 Method Recap

To account for some of the limitations in the NZFFD data, Crow et al. (2016) drew on several statistical approaches to address some of the biases that come with using this dataset. To identify if the 'probability of capture' for a taonga freshwater species through time appears to be increasing (getting better), decreasing (getting worse) or staying the same, Crow et al. (2016) completed simple linear regression[2] calculations (how does X relate to Y?) using two different techniques.

The first technique was the Sen Slope Estimator (SSE), while the second technique was a weighted version of the SSE. The weighted SSE (called WSSE hereafter) assigns a weighting value based on the size of the confidence intervals[3] (CI). In the WSSE, pairs of years that collectively have small CIs are weighted more heavily than pairs of years that collectively have large CIs because we were more confident in these probability of capture values.

Both WSSE and SSE results are presented in this report because, together, they help us understand whether or not we can be confident in the analysis and detect a trend over time (either increasing or decreasing) – or if we cannot detect a trend.

3.3.2 Tuna Results

The SSE slope for **longfin eels** was indeterminate over the 1977–2015 period, while the WSSE slope showed a median (± 95% CI) decreasing trend of 0.09 (± 0.06) %/year (Figure 8). The estimated probability of longfin capture for each year displayed high levels of variance between years. For example, over 2010–2015, values close to both the highest and lowest probability of capture values were observed.

Both SSE and WSSE showed increasing trends for **shortfin eels** over the 1977–2015 period (Figure 8). The SSE results suggested that shortfin probability of capture was increasing at a median (± 95% CI) rate of 0.13 (± 0.02) %/year, while WSSE results suggested that shortfin probability of capture was increasing at a median (± 95% CI) rate of 0.18 (± 0.01) %/year.

In summary, the high levels of variance in the longfin eel data meant that the two trend analyses over the full-time series available (1977–2015) were not in agreement and did not show a strong trend in either direction; while for shortfin eels both methods agree that population trends are increasing (Crow et al. 2016).

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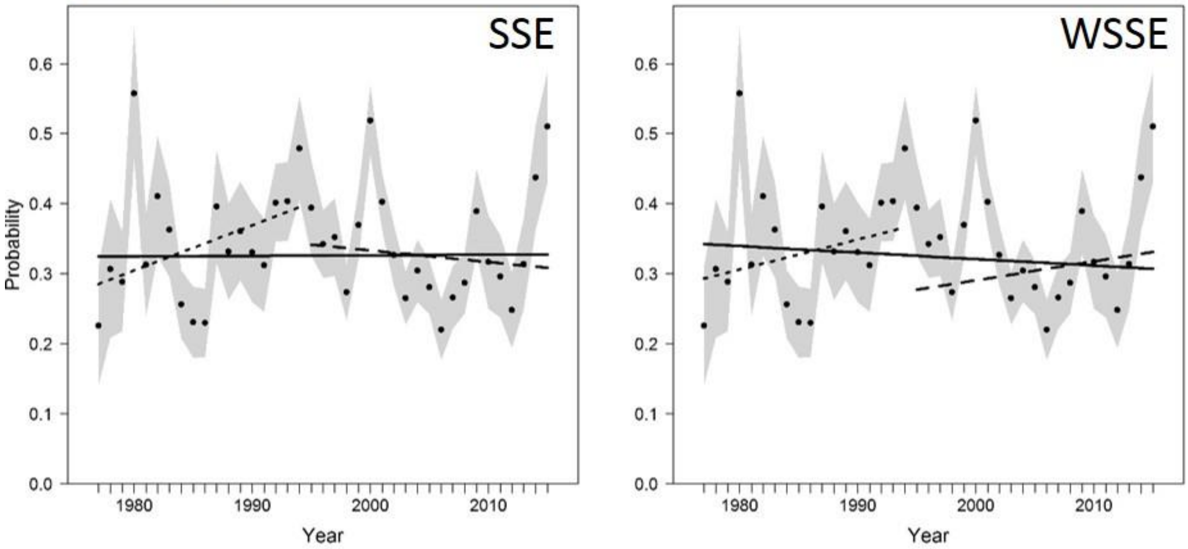
[2] Simple linear regression is a statistical method that allows us to summarise and study relationships between two continuous (quantitative) variables.

[3] A confidence interval is a range of values we are fairly sure our true value lies within.


(A) Longfin

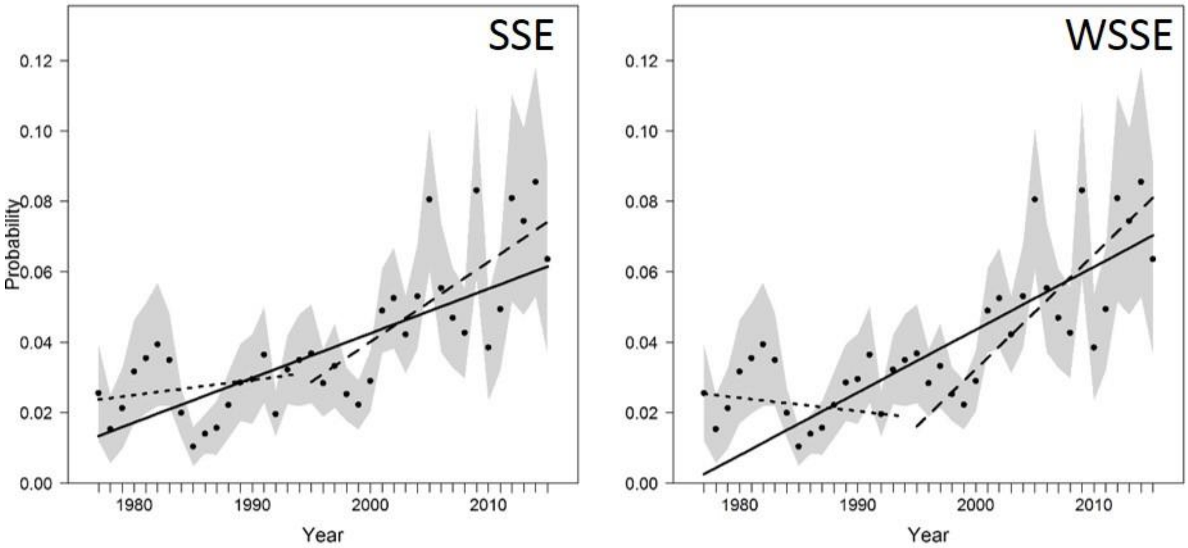

(B) Shortfin

Figure 5: Change in the probability of capture of longfin (A) and shortfin (B) eels associated with year using data from the NZFFD. Plots show 'probability of capture' for each year (black circles) and 95% CI (grey shaded area). SSE (left) and WSSE (right) are shown for 1977–2015 (solid black line), 1977–1994 (dotted black line) and 1995–2015 (dashed black line). (Source: Crow et al. 2016).

3.3.3 Trends in Elver Recruitment

The past few decades have seen a decline in the recruitment of Northern Hemisphere species of freshwater eels. Eels recruit into Aotearoa-NZs rivers as transparent glass eels in their first year of life and spend some time in estuarine reaches before moving upstream. Elvers, the next stage in the life-cycle, are 1–4 years old and move upstream as they grow older. In Aotearoa-NZ, there are indications that the huge elver runs that were both witnessed (e.g., Best 1929) and filmed (Hayward & Hayward 1992) prior to the 1960s are no longer seen. It is not known how present recruitment relates to historical runs, but since 1995 MPI has been monitoring elver recruitment (e.g., Martin & Bowman 2016).

Monitoring elver catches at sites where trap-and-transfer operations (e.g., Figure 9) are undertaken provides an opportunity to track the relative abundance of elvers over time. Provided data are collected in a consistent manner each year, it can be used to determine overall trends in recruitment.

Recruitment is predominantly monitored by trapping elvers at hydroelectric dams and other man-made structures (e.g., weirs). Estimates of the numbers of elvers (by species) arriving at hydroelectric dams on several Aotearoa-NZ rivers are recorded by stakeholders, mostly (but not exclusively) as part of resource (operating) consent conditions. The datasets generated are currently compiled by NIWA under contract to MPI. Every two to three years this data is collated into reports for MPI which are publicly available. Elver trapping data are one of the information sources used by MPI to **monitor trends in eel recruitment** and inform eel management at a national scale.

Figure 6: Elver trap-and-transfer activities. (Left to right) Elver trap at Karāpiro dam; An example of an elver ramp; Estimating the total elver catch using a sub-sample; and Transfer of elvers into transportation tanks for release. (Photos: Mike Martin and Jacques Boubée).

Over the last 25 years, elver data has been recorded from 22 sites in Aotearoa-NZ (Figure 10), but most of these data have inconsistencies due to modifications to the trapping arrangements or time periods where data were not collected (e.g., structures being modified). NIWA developed standard methods for the trapping and transfer of elvers and recording of the catches in the early 1990s (Martin et al. 2007). Elver trapping has occurred consistently in a standardised manner at six main sites, and these form the basis of the elver abundance time series. The time series of data collected from the main sites varies from 5 years (Wairua Falls) to 22 years (Karāprio Dam).

Longfin and shortfin elver recruitment at a site is temporally variable with abundance varying two-fold between some years; overall there has been no consistent trend in recruitment across the main sites (Figure 11 & 12). Matahina Dam and Karāpiro Dam both show similar annual patterns over the 15 years of continuous data collection. Pātea Dam also has high levels of recruitment variability, but the most recent longfin catch index in 2015–16 is more than double that of next highest year in 2007–08. Shortfin recruitment at the Pātea Dam decreased from 2005–2011, but has steadily increased each year after this. In contrast, Piripaua longfin and shortfin catches have remained very stable during the early 2000’s and have increased markedly over the last five years. Data across all sites have been used by Martin and Bowman (2016) to conclude that there has been no decline in recruitment over the last 25 years.

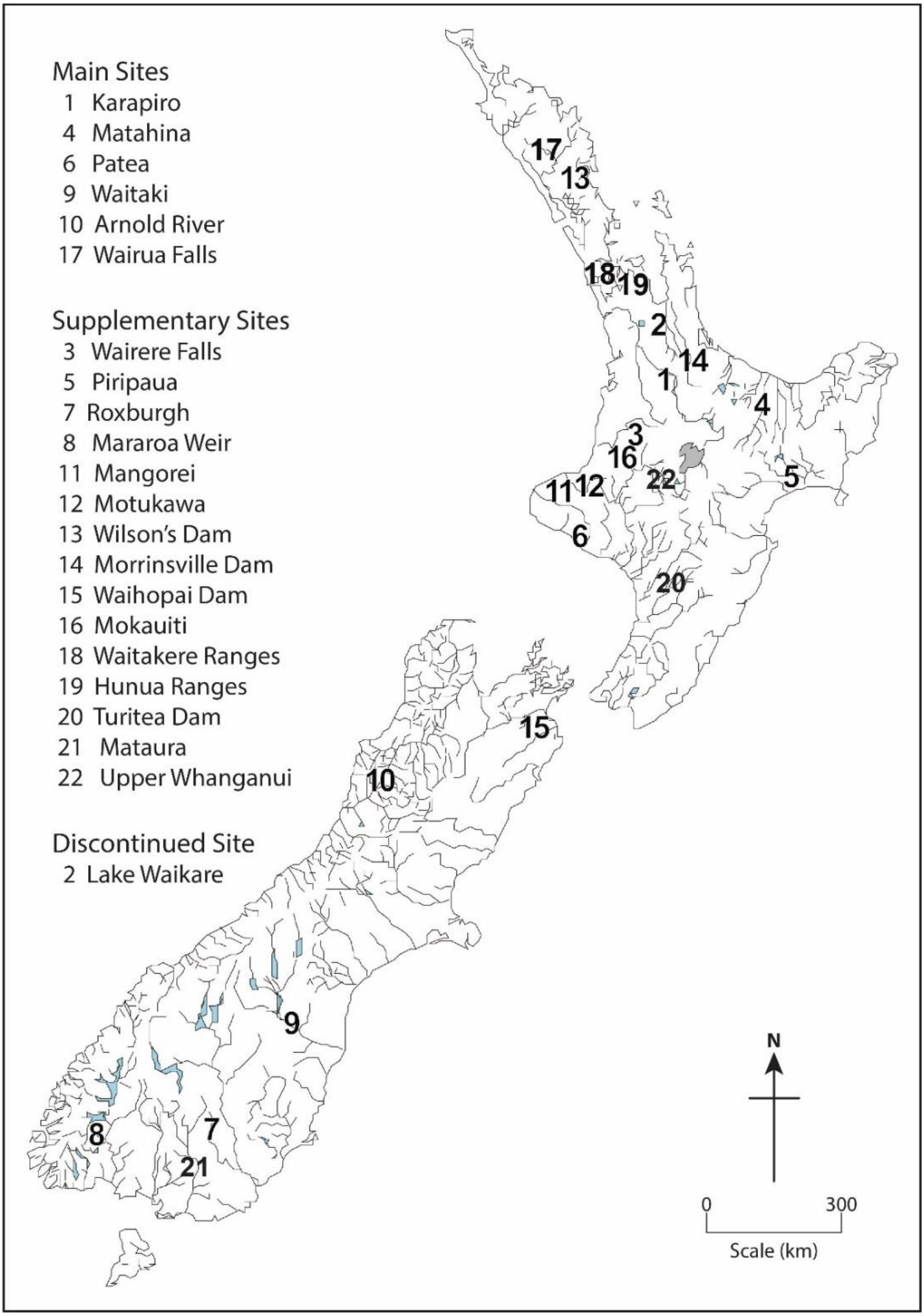


Figure 7: Locations of the 22 sites where elver trapping has occurred in Aotearoa-NZ over the last 25 years. Main sites have elver data collected each year, while supplementary sites have data collected intermittently. (Source: Martin & Bowman 2016).

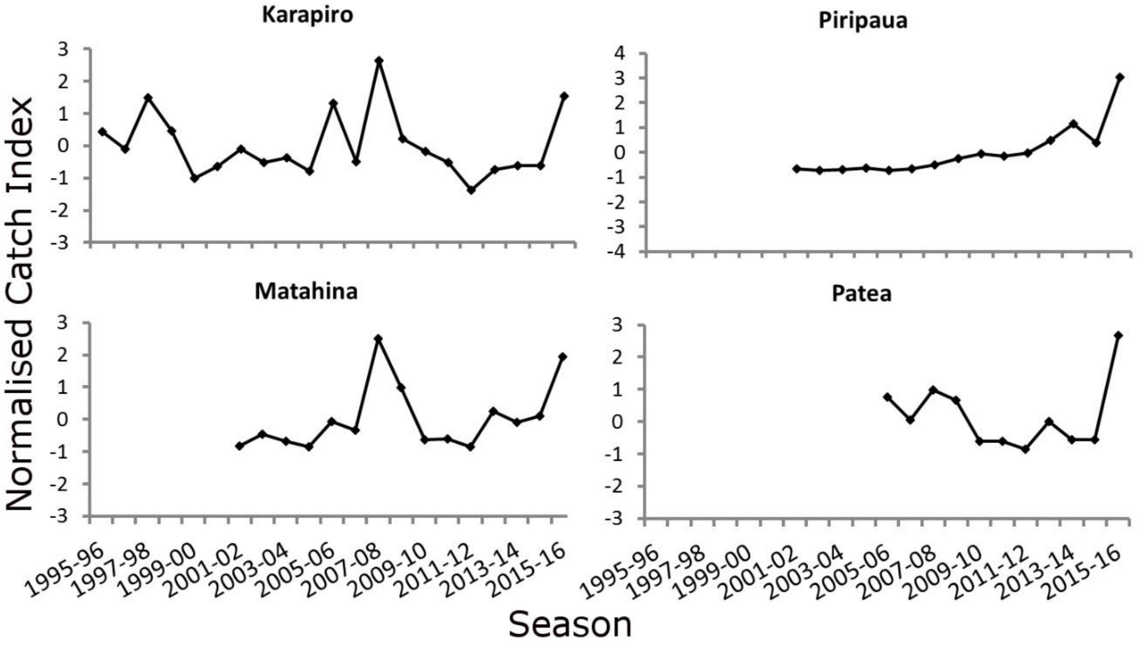


Figure 8: **Index of relative abundance for longfin elver catches from 1995–96 to 2015–16.** (Source: Martin & Bowman 2016). Because of the variability between sites and years, elver catch records were normalised following the method of Durif et al. (2008), and a “normal” catch index was calculated for each species, season, and location (MPI 2017).

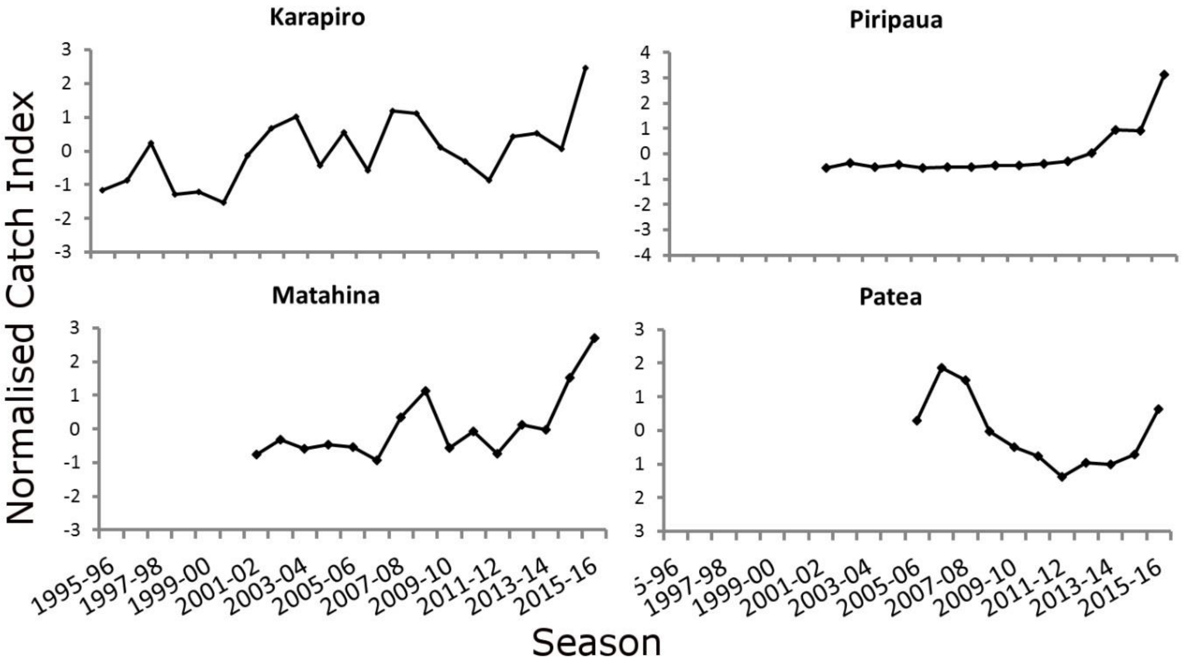


Figure 9: **Index of relative abundance for shortfin elver catches at selected hydro dams from 1995–96 to 2015–16.** (Source: Martin & Bowman 2016). Because of the variability between sites and years, elver catch records were normalised following the method of Durif et al. (2008), and a “normal” catch index was calculated for each species, season, and location (MPI 2017).

3.4 Threat Rankings

The latest New Zealand Threat Classification System assessment classified shortfins as being ‘Not Threatened’, while longfins are classified as ‘At Risk–Declining’ (Goodman et al. 2014). The shortfin classification was based on an increasing population (over what time period they used is unknown), while the longfin classification was based on a declining population of 10–70% in two generations (i.e., 80 years). The Australian longfins were considered to have a secure overseas population and were not assessed. The IUCN threat rankings are yet to be completed for Aotearoa-NZ eels (Table 3).

Table 2: Threat rankings for Aotearoa-NZ tuna species according to the New Zealand Threat Classification System and IUCN. (see Section 2.3 for more information about these assessment methods).

Species	DOC Ranking	IUCN Ranking
Longfin (*A. dieffenbachii*)	At Risk–Declining	Not assessed
Shortfin (*A. australis*)	Not Threatened	Not assessed

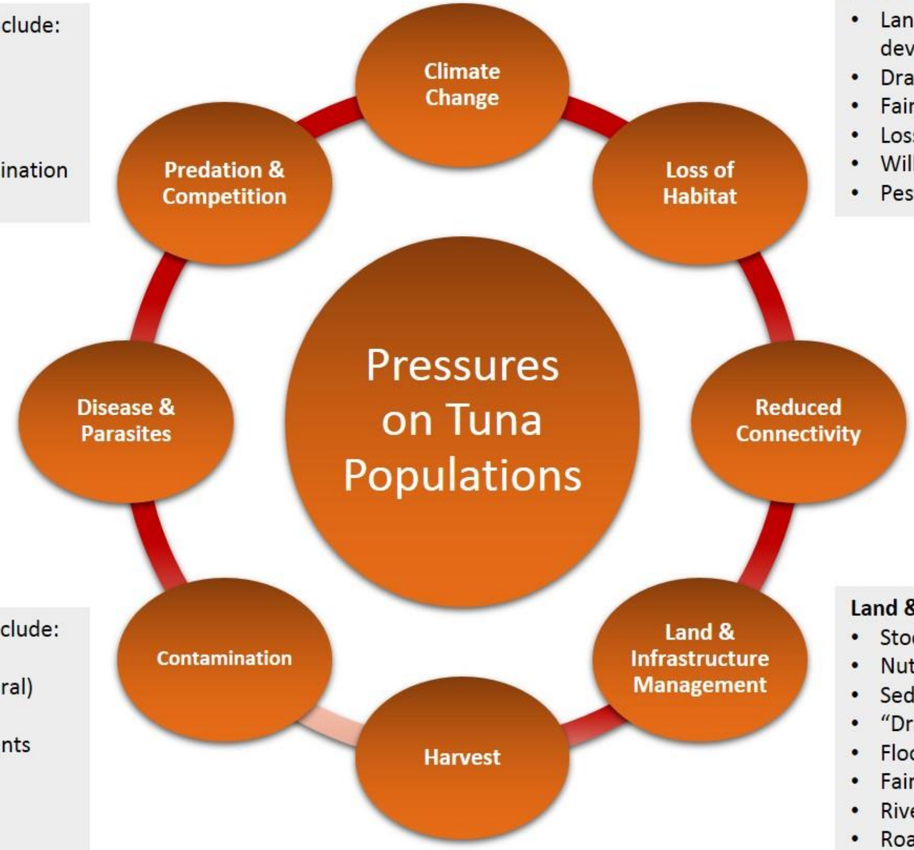
3.5 Pressures on Populations

In Aotearoa-NZ, although longfins are still one of the most common freshwater fish, there are concerns about the scarcity of very large specimens. Multiple factors are likely to be impacting eel populations around the world, including changes in oceanic currents, habitat loss, over-exploitation of adult stocks, mortality and migration delays experienced by upstream and downstream migrants at barriers, parasites and diseases, predation, and pollutants (e.g., Castonguay et al. 1994, Haro et al. 2000, Arai 2014, Jacoby et al. 2015, Belpaire et al. 2016). The potential implications of climate (and climate change), particularly on species with marine life stages, also needs to inform our long-term thinking (e.g., Bonhommeau et al. 2008).

Key pressures on Aotearoa-NZ eel populations include habitat loss, loss of connectivity for migrations between the sea and freshwater habitats, land and infrastructure management and harvest (commercial, recreational and cultural). Other pressures may arise from competition (e.g., with exotic fish species such as catfish and koi carp), predation on the vulnerable juvenile stages in rivers and lakes, toxins, diseases and parasites, and marine factors (e.g., food availability) influencing the survival of larvae, growth and recruitment of glass eels to river mouths (Figure 13) (e.g., Miller & Tsukamoto 2017). The impact of these latter factors is currently unknown.

3.5.1 Loss of Habitat

Since European settlement there have been many changes in land use in Aotearoa-NZ, with large areas being cleared for human habitation and agriculture. Statistics NZ (2008) categorises three main land uses: production, conservation, and urban development. Over one-third of land is legally protected for conservation purposes, with the remaining majority being used for primary production. Urban and rural residential developments cover a small but growing area. Land-use change varies in scale, with some alterations occurring at the catchment level and others at a much smaller, microhabitat scale. The effect of land-use change on our taonga species are multi-layered affecting the temperature, light, water quality and geomorphology of ecosystems. For example, it is estimated that wetlands that once covered at least 670,000 ha before European settlement have now been reduced to about 100,000 ha (MfE 1997). Within the Waikato catchment alone, the loss of wetlands was estimated to be 84% between 1840 and 1976 (McDowall 1990). Much of this drainage pre-dated the commencement of commercial eel fishing, but nonetheless resulted in a huge loss of tuna habitat.



Predation & Competition - Examples include:
- Shags
- Trout
- Pest fish

- Acclimatisation societies' eel extermination campaigns of the 1930s-1960s

Loss of Habitat - Examples include:
- Land use change (e.g., farming, agriculture, forestry, urban development)
- Drainage of wetlands & swampy areas
- Fairway channel maintenance
- Loss of riparian vegetation
- Willow removal
- Pest plants

Disease & Parasites - Examples include:
- Tape worms
- Nematodes (includes shagworm)
- Protozoa (cysts)

Reduced Connectivity - Examples include:
- Hydroelectric dams
- Culverts, weirs, fords
- Flood control schemes – stopbanks & flood gates
- Water extraction
- River mouth closures
- NB: Turbines & flood pumps also cause direct mortality events

Contamination - Examples include:
- Pesticides
- Geothermal sources (natural)
- Geothermal power
- Point source pollution events
- Stormwater
- Road runoff
- Industry

Land & Infrastructure Management - Examples include:
- Stock in waterways
- Nutrient management
- Sediment management
- "Drain" clearance
- Flood control
- Fairway channel maintenance
- River straightening
- Road infrastructure
- River/stream diversions
- Stormwater management
- Water extraction
- Instream barriers

Harvest includes:
- Commercial
- Customary
- Recreational

Figure 10: Examples of some of the pressures on Aotearoa-NZ tuna populations.

Being a somewhat lowland species, shortfins have been particularly affected by **drainage of wetlands** and channelisation of rivers. Shortfins are also the species that responds most to flooding and feeds extensively in newly inundated areas (Jellyman 1989, Chisnall & Hayes 1991, Chisnall 2000b), and channelization of waterways has reduced such feeding opportunities (Chisnall 1989). The biomass of larger eels is directly related to the amount of suitable cover (Burnet 1952), so the loss of cover by such practices as macrophyte removal and channelisation of waterways, together with siltation, reduces the quality of habitat available to both species. That said, Hicks and McCaughan (1997) found that the conversion of land from forest to pasture resulted in an increase in the abundance of shortfins. It is thought that access to pasture may also provide eels with an additional food source of terrestrial invertebrates (Chisnall 1987, Chisnall & Hicks 1993). Sedimentation may reduce food availability in pasture sites by clogging instream substrates (Hanchet 1990) which is also supported by the work of Jowett and Richardson (1990) who found higher invertebrate biomass was associated with coarse sediments. Sedimentation may also impact juvenile eels who are known to refuge in subterranean substrates (Cairns 1950).

Willows on the margins of streams and rivers are known to provide habitat that is often used by both longfin and shortfin eels. This is important in both an ecological and a commercial sense, as the **removal of riparian willows** from streams and rivers, without replacement with a suitable alternative (e.g., Figure 14) could adversely affect both the amount of habitat available to eels, and the number of large eels available to fishers. Few studies have explicitly examined the importance of willows for fish in our waterways (Glova & Sagar 1994). To date, very few scientific studies on willow-removal effects have been conducted and any documentation/evaluation of rehabilitation projects that include willow removal are equally scarce (Wagenhoff & Young 2013).

Figure 11: Examples of willow removal activities in the Tauweru River catchment. (Photos: Erica Williams). Willows were brought to Aotearoa-NZ in early 1800s from Europe or Asia and widely planted for bank stability. Of the 10+ willow (*Salix*) species/varieties, Crack willow (*S. fragilis*) and Grey willow (*Salix cinerea*) are very invasive and can live for 100 years. It is illegal to propagate or plant crack willow in Aotearoa-NZ (NZ Landcare Trust 2015).

Willow removal will cause short- to medium-term effects that potentially pose risks to taonga species and the ecosystems that support them. Some of the risks are associated with: (1) The removal of willows that have retained large amounts of fine sediment and organic matter; (2) The removal of willows that have modified their environment as ecosystem engineers; (3) The loss of important functions that riparian vegetation fulfils until the native vegetation is re-established, and (4) The removal process itself (Wagenhoff & Young 2013).

A preliminary NIWA scoping study investigating the weights of eels in willowed and non-willowed reaches of three waterways (Jellyman & Glova 1998) found that:

- Longfins more than 220 g were much more abundant in willowed compared to non-willowed reaches.
- Longfins less than 220 g were of roughly similar abundance and density in willowed and non-willowed reaches.
- No shortfins more than 220 g were caught in non-willowed reaches, and only moderate numbers were found in willowed stretches.
- Shortfins caught in the three study streams were predominantly less than 220 g, and these were five times more abundant in the willowed reaches.

The main reason that riparian willows appear to provide habitat for eels is that, being a nocturnal species, eels use willows during the day to avoid light. Eels are generally known as secretive and "cover-loving" and large eels are frequently associated with overhung banks and dense instream cover such as logs and debris. For juveniles, features of the substrate are very important, but larger eels require more complex cover like debris clusters and undercut banks and the availability of such cover will largely determine the density of large eels.

3.5.2 Reduced Connectivity

One of the greatest threats to indigenous fish populations that follow a diadromous life cycle are barriers that prevent or delay migrations between freshwater and marine environments. Connectivity between habitats can be critical to ensuring the long-term success of fish populations (Lake *et al.* 2007, Fullerton *et al.* 2010). Barriers to migration can restrict access to habitats required for foraging and feeding, predator avoidance, shelter, and spawning (Gibson *et al.* 2005). Lack of access to these habitats, particularly for obligate migratory species, can ultimately lead to a reduction in recruitment, population decline, and a loss of biodiversity (e.g., Jellyman & Harding 2012).

In Aotearoa-NZ, **hydroelectric facilities** (e.g., Figure 15) currently produce about 61% of the country’s electricity needs and hydro generation is predicted to continue to be a significant source of energy in the future (Ministry of Economic Development 2003). Anthropogenic barriers and hydroelectric dams in particular are some of the factors thought to have contributed to the decline of eel populations worldwide. Hydroelectric dams impact upon tuna in two ways: (1) By obstructing the upstream migration of glass eels and elvers; and (2) By adversely affecting the safe passage of mature eels downstream.

Minimum flows released from dams are now routinely set as part of resource consents to ensure that habitat for resident fish populations are maintained below the dam, as well as providing passage for migratory fish. However, to ensure that upstream migrating fish can pass over the dam and utilise habitat upstream, the installation of passage facilities may be required. Passage facilities should aim to permit passage for all upstream migrating fish that occur within a catchment, except for those considered to be pest fishes (e.g., DOC 2010) and those situations in which a conservation case can be made for not permitting access. Passage for those upstream migrating fish who have historically been recorded in a catchment and who could reasonably be expected to require passage should also be catered for. A variety of upstream passage facilities have been installed in Aotearoa-NZ, including: (1) Substrate ramp passes (also known as fish ladders); (2) ‘Nature-like’ fish ways; (3) Fish lifts and locks; and (4) Engineered fish passes. The choice of facility installed depends upon the fish species requiring passage and characteristics of the barrier, such as head height, available space and economic resources (Paterson 2010a).

Figure 12: **The Waitaki Dam.** (Photo: Shannan Crow). The Waitaki Hydroelectric Power Scheme consists of eight power stations from Lake Tekapō to Lake Waitaki. Mahinga kai is a value that lies at the heart of Ngāi Tahu culture and identity. More than 30 different species were once gathered across 160 sites in the Waitaki catchment, about 70% of which once sustained tuna. As the most commonly gathered food source, tuna remain a taonga that whānau want to see restored across the catchment. Eighty-one percent of the catchment is now located above the lower-most Waitaki dam, and without fish passage throughout the catchment, is essentially lost as habitat to support tuna populations and mahinga kai values (Tipa & Associates 2015).

In general, small eels are very good climbers and can use surface tension to climb damp walls of **culverts, weirs and fords** as long as the surface is moist and there is a continuous climbing surface (i.e., with no breaks or overhang). Most problems occur when eels encounter barriers that have been designed and/or installed incorrectly; resulting in very strong water flows through the structure and scouring out the stream at the downstream end creating an overhanging perch that the eels cannot climb. In many catchments, smaller-scale obstructions, such as weirs and culverts, are the most common artificial barriers and thus may have a greater influence on taonga species population dynamics. For example, of the estimated 3.6 culverts per 100 hectares in the Waikato Region, 36% or 1.3 out of 100 hectares were a barrier to all fish at all flows (i.e., to tuna, as well as other species). As the catchment area for the lower Waikato River below Karāpiro (excluding the major lakes) is approximately 6,500 km^2, approximately 8,500 culverts could be limiting elver recruitment. Some of these culverts will be more serious barriers than others because they restrict access to larger amounts and/or quality of habitat upstream and/or are not passable at all flows (Watene-Rawiri et al. in press).

Mortality at Hydroelectric Dams and Flood Pumps

Given that factors out in the ocean that may adversely affect eel reproduction and migration are beyond our control, options to support the long-term sustainability of our tuna populations should be focused around maximising the number of eels, particularly large longfin females, that can safely reach the sea. By far one of the most serious issues for taonga species resource managers to address in the immediate future is the significant loss of pre-migrant and migrant eels as they pass through and are killed by turbines at flood control schemes and hydroelectric dams throughout Aotearoa-NZ.

Once eels reach sexual maturity they begin their downstream migration. Where barriers such as **hydroelectric dams** are present, passage can be at best interrupted or blocked, but in most cases passage results in serious injury or death (Figures 16 & 17). Since longfins are the species that penetrate farthest inland, the installation of hydroelectric dams has impacted this species the most by compromising their upstream access.

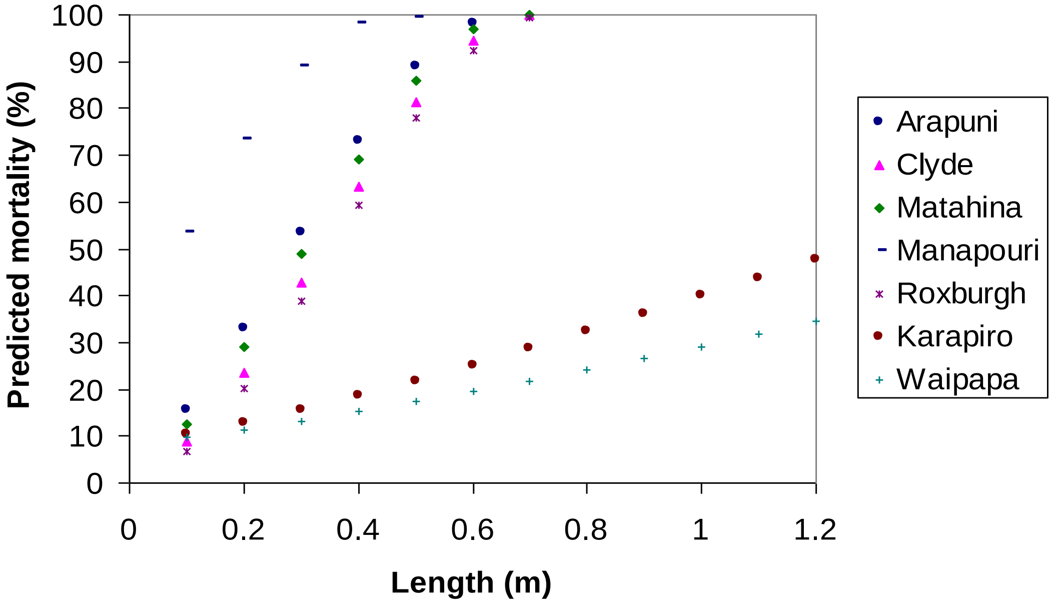


Figure 13: Estimated mortality of migrating eels of varying lengths, for different hydroelectric stations in Aotearoa-NZ. The lower mortalities of Karāpiro and Waipapa are due to different turbine types compared to other stations. (Source: Jellyman 2013). While there have been no specific studies of turbine mortality in Aotearoa-NZ, generic relationships can be used to estimate the probability of death, considering variables such as the size of the eel, speed of rotation, head of water, and type of turbine. Large female longfin eels are at very high risk in such situations (Mitchell & Boubée 1992, Larinier & Travade 2002).

Figure 14: Tuna death row – Some examples of the dead eels that result from hydroelectric operations in Aotearoa-NZ. (Photos: Ben Chisnall, Mike Holmes, Jacques Boubée).

Information on the timing of downstream migrating adults has been successfully used to reduce mortality for a variety of fish species at dams and other passage barriers (Benstead et al. 1999, Achord et al. 2007). In cases where downstream migration can be predicted, implementing mitigation activities such as targeted netting (Boubée et al. 2001), spillway opening (Watene et al. 2003, Watene & Boubée 2005), or bypass opening (Boubée & Williams 2006) has resulted in reduced injury and mortality rates. However, predicting migration is difficult, especially in rivers whose flow patterns are regulated by storage and generation schedules (Haro et al. 2003).

When downstream migrant eels are confronted with a dam, studies (e.g., Durif et al. 2003, Watene et al. 2003) have shown that they spend time searching along the headrace, presumably for an unobstructed pathway downstream. Some eels that are unable to find a pathway have been shown to return upstream, often to the location where they were residing previously (Watene et al. 2003). Many migrants impinge on screens or enter station intakes, and are killed during passage through the turbines (see Figure 17).

At present, none of the hydroelectric dams in Aotearoa-NZ has been specifically equipped to protect the downstream migration of sexually mature eels. However, some retrofitting and mitigation activities have been implemented in the last ten years to protect and/or safely pass migrants (e.g., Wairere Falls Power Station, Boubée & Williams 2006). Ceasing generation completely during major downstream migration events, whilst also providing permanent bypass facilities and protective measures at intakes is the ultimate way of providing safe downstream passage for tuna. Some of the options available to operators to facilitate the safe downstream passage of eels at hydroelectric dams include: (1) Ceasing generation and actively spilling during migration events; (2) Installation of fish friendlier turbines; (3) Installation of physical and behavioural deterrents; (4) Installation of bypasses (e.g., Wairere Falls/King Country Energy); and (5) Trapping large eels above hydro stations and transferring them to locations downstream that are safe from harvest and have open access to the sea (e.g., Manapōuri and upper Waitaki/Meridian Energy) (Paterson 2010b).

Connectivity within many Aotearoa-NZ catchments has been substantially altered by **stop banks, floodgates** and **pumping stations.** In the lower Waikato alone it is estimated that about half of the 32,000 hectares of floodplain has been protected by stop banks, which in turn has markedly reduced natural floodplain habitat. Each station generally has a gravity flap/floodgate (Figure 18) which is designed to prevent flows from the main river channel entering the pockets during elevated river levels. During floods, much of the land behind stop banks is actively pumped (in some cases the upstream land is below the receiving water so the pumps are operated more often). At pumping stations the downstream migration of large adult migrant eels is impeded in two ways: (1) Eel mortality through entrainment in scheme pumps; and (2) Impediments to migrant movement into the main river channel during periods of oxygen depletion in the pocket areas following significant storm events (where the river has spilled into the pockets).

Eel mortality events have been observed by both fishermen and tangata whenua during flood events, for example in the Hikurangi Repo (Wairua River catchment), where Chetham and Shortland (2009) describe the rivers downstream of the pumps "*churning with white mutilated bodies of eels*"… and "*estimated that each pump kills 100 of kilograms, if not tonnes of eel over a 24 hour period"* (Alan Gardiner, pers. comm. in Chetham & Shortland 2009). There is also evidence of chopped mature eels downstream of the pump stations (Figure 18). Whangārei District Council are undertaking investigations on eel movements through the Mountain Pump Station in the Hikurangi Swamp Scheme (Twose 2016).

Figure 15: Examples from the Hikurangi Swamp Scheme. (A) A pump station inlet; (B) Flood gates on a pump station outlet; and (C) Some of the tuna killed by one of the Hikurangi pump stations during a flood event in March 2017. (Photos: Jacques Boubée, Alan Halliday). For more information about this particular tuna mortality event, see https://www.maoritelevision.com/news/regional/whangarei-water-turbines-kill-eel-numbers.

In the Waikato, apart from one Archimedes screw pump which only operates at very high flows, the remaining 65 flood pump stations installed do not allow the safe downstream passage of adult tuna (Watene-Rawiri et al. in press). Replacing or modifying flood pumps to make them tuna friendly would allow the safe escape of adult spawners, for example, from an estimated 600 km of waterways in the lower Waikato (i.e., 6% of the total length of waterways downstream of Karāpiro Dam). We understand that the Waikato Regional Council are currently doing some research into the use of passive integrated transponder tags and acoustic hydrophones to document eel movement and mortality through non-gravity fed axial pumping stations in the lower Waikato River catchment. An update on this work will be presented at the forthcoming New Zealand Freshwater Sciences Society Conference to be held University of Waikato in November 2017.

To remedy the adverse effect of flood pumps on downstream migrating tuna it will be necessary to install a safe downstream passage route and fine screens (20 mm spacing or less) to prevent the tuna from entering each pump. In the future behavioural barriers (e.g., light, electricity) could be considered if shown to be effective. The screens need to have enough surface area so the through-screen water velocities remain below 0.5 m/s and do not cause the tuna to impinge on the screens. Screens may require automated screen cleaners to ensure their efficiency. At tide and flood gates, safe downstream passage routes can be provided by either: (1) One or more flap gates that provide a safe route once the downstream water level recedes (note that a mechanism to keep this flap gate open at low flows is essential and when the gate is closed it must not delay the migration); (2) One or more tuna-friendly pumps such as a Ventura pump or an Archimedes Screw pump; or (3) Catch/trap and transfer of adult migrants (Watene-Rawiri et al. in press).

3.5.3 Land and Infrastructure Management

Much of the low-lying land in Aotearoa-NZ requires drainage to be used for pastoral purposes. Beentjes et al. (2005) collated information on the extent of **drain cleaning practices** (e.g., Figure 19) throughout Aotearoa-NZ; the total estimated length of waterways cleaned in Aotearoa-NZ each year is about 15,500 km, most of which (66%) are drains, followed by stock water races and natural waterways (12 %) (Beentjes et al. 2005). However, in unrated catchments, landowners can carry out their own drain clearance activities (within the region's respective rules), so the length of cleared waterways could be much larger than this.

Beentjes et al. (2005) state that three councils carry out nearly half the total length of waterways cleaned in Aotearoa-NZ: Waikato Regional Council (22%), Selwyn District Council (16%), and Environment Southland (11%). The frequency with which waterways are cleaned is highly variable, ranging from several times per year to once every 10 years, or as required, and most common methods used are herbicide spray and mechanical excavation (Beentjes et al. 2005).

Figure 16: Drain clearance activities in the Hikurangi Repo. (Photo: Whangārei District Council).

There are few published studies in Aotearoa-NZ that have attempted to quantify or document the effects of mechanical or chemical drain cleaning on mortality of tuna (e.g., Allibone & Dare 2015) and the results are inconclusive. Anecdotal evidence indicates that eels are frequently scooped out of drains by mechanical excavators and that some operators dump them on the bank side where they die if they are unable to return to the watercourse. Complaints from the public about destructive and poorly monitored land management practises are turning up in the media more frequently (e.g., [4], [5], [6]). Drain Maintenance Technical Guidance (Greer et al. 2015) has been produced by DOC for RMA and concession applications and provides the following recommendations for conditions and mitigation activities of relevance to longfin tuna:

- During weed cutting and mechanical excavation operations the consent holder shall ensure any stranded fish, kōura and kākahi are returned to the waterway. All fauna shall be released upstream of the affected section of waterway, or, where this is impractical (e.g., appropriate upstream release sites cannot be easily accessed), in a downstream section of the waterway that is below the mixing zone and does not have elevated levels of suspended sediment—to avoid exposing fauna to sediment-induced anoxia (lack of oxygen) when returned to the water.
- If a species listed as threatened under the New Zealand Threat Classification System is recovered during excavation or weed cutting in a waterway that is not previously known to contain that species, works in the area the fish was discovered shall cease immediately.

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[4] Sediment cleaning under review (http://www.stuff.co.nz/marlborough-express/news/5594063/Sediment-cleaning-under-review);

[5] Council apologises after dozens of dead eels found in protected pond (https://www.tvnz.co.nz/one-news/new-zealand/council-apologises-after-dozens-of-dead-eels-found-in-protected-pond-6245239); and

[6] The destruction of the river erosion control programme (http://wairarapareviews.kiwi.nz/environmental/river-erosion-programme/).

- If Threatened or At Risk (i.e., longfin tuna, lamprey, īnanga, shortjaw kōkopu, giant kōkopu, and kōaro) fish are known to be present in the waterway, or the waterway is known or expected to contain a large fish population, a person shall be present at all times to return any stranded fish to the waterway.

3.5.4 Contamination and Safe to Eat

While fish are an important part of a balanced and healthy diet, nearly all fish species contain traces of metals like mercury and other contaminants (that occur both naturally and because of human activities) that may build up over time and pose a risk to human consumers. Many toxic contaminants are stored in the lipids (or fats) of biota and can biomagnify up through the food chain, increasing the risk to humans of consuming long-lived, higher predatory animals, such as tuna. Generally, bioaccumulative contaminants of most concern include organochlorine pesticides (especially DDTs and dieldrin), polychlorinated biphenyls (PCBs) and dioxins (particularly near timber treatment plants), pentachlorophenol, and selected heavy metals such as mercury, arsenic, cadmium, and lead.

A range of chemical contaminants enter our waterways, including direct inputs from industrial and municipal wastewater discharges, and indirectly via diffuse source inputs and natural background inputs of geothermal contaminants. Geothermally-derived arsenic (As) and mercury (Hg) naturally enter catchments like Taupō-nui-a-Tia, Waikato River, Te Arawa Lakes, Kaituna River, and Waiaruhe River. For example, a major point source of geothermally-derived contaminants enters the upper Waikato catchment from the Wairakei Geothermal Power Station, and much of these contaminants are thought to accumulate in the sediments of Lake Ohakurī. There are several other locations down river including Mangakino, Hamilton and Waikare where small natural geothermal sources may still be producing naturally-derived metal contaminants (NIWA 2010).

Mercury is of concern because of its ability to biomagnify through the food chain. Surveys of trout from the Waikato River in the 1990’s found that Hg levels exceeded health regulations in only 11 of the 285 fish sampled; however, comparison with accepted daily intake values indicated that some sites "could conceivably pose some threat to human health". Eels live considerably longer than trout (30–50+ years versus five years), so could potentially accumulate more Hg than trout and be of greater risk to high consumers. In addition to metal contaminants, it is known that quantities of DDT and other pesticides were historically used throughout Aotearoa-NZ to control grass-grub on pasture and lice in cattle. At this stage, it is not clear if these residues are potential sources of concern and if so which catchments are most affected. To date “contaminants in kai” risk assessment studies, which also considers the actual consumption rates of whānau, have been completed with the Te Arawa Lakes Trust, Te Rūnanga of Arowhenua and the Te Waihora Management Board (e.g., Stewart et al. 2011, Phillips et al. 2014, Stewart et al. 2014).

3.5.5 Disease and Parasites

All fish carry pathogens and parasites usually at some cost to the fish. Fish can be exposed to various pathogens and/or parasites depending on the habitat they are living in or at different stages of their life cycle (i.e., fish are exposed to different parasites depending on their diet which may change as they get bigger). In Aotearoa-NZ there has been little transfer of new organisms, brought into the country by introduced species, into native fishes (Boustead 1982, Duignan et al. 2003).

Across all our indigenous fish fauna a total of 65 different species of parasites have been reported, six of which are introduced (Hine et al. 2000). To date 36 different parasite species have been reported in Aotearoa-NZ shortfin and longfin eel populations (e.g., Hewitt & Hine 1972, Hine 1978, Hine et al. 2000, Duignan et al. 2003). Over the last 30 years infectious diseases have not been observed to have caused a significant morbidity or mortality event in our indigenous fish populations (Duignan et al. 2003). However, to the best of our knowledge, there is no regular surveillance programmes monitoring the incidence of pathogen/parasite prevalence in our freshwater taonga species populations; the last survey occurred around 2003 (Duignan et al. 2003). The presence/absence of visible parasites could be monitored by communities using the parasite infestation index outlined in Richardson (1998), where each individual eel examined receives a parasite infestation ranking: 0 = No parasites present externally or internally; 1 = One or two parasites present; 2 = Numerous parasites present; 3 = Heavy parasite infestation. Some examples of a few of the parasites observed in tuna from Tai Tokerau, Waikato and Murihiku waterways are shown in Appendix C.

3.5.6 Predation and Competition

Longfin eels are the largest and longest-lived fish in our fresh waters, and where they are present, and large enough, they are the top predator. Tuna are opportunistic feeders, usually eating anything they can find. What they eat depends on their size (and the size of their mouth), the habitat occupied, and the prey available. Tuna are usually more active at night and rest during the day. Feeding slows down during cold temperatures (less than 10°C). Small eels eat a range of invertebrates, including small insect larvae, worms, snails, midges, shrimp, molluscs and crustaceans, although small eels themselves are predated upon by larger eels and birds (e.g., shags, herons). As their mouths get bigger, tuna eat larger animals such as kōura, fish, small birds, mice and rats (e.g., Jellyman 1996, Sagar & Glova 1998).

As previously mentioned, flooded river margins are important feeding grounds for eels. During a flood, eels will move out of the main river channel to the margins where they will feed on organisms not usually found in the water, like earthworms, spiders and beetles (Chisnall 1987; 2000b).

Introduced fish such as trout, perch, gambusia, rudd, catfish, koi carp, and tench continue to spread within Aotearoa-NZ. These pest species can impact eel populations through competition for food resources, degrading habitat and reducing biodiversity (Rowe 2004).

3.5.7 Acclimatisation Societies

As a result of European settlement, acclimatisation societies were set up to facilitate, implement and maintain a host of plant and animal introductions into Aotearoa-NZ waterways, including salmon and trout, for the benefit of recreational fishers. McDowall (2011) contends that even if Māori were consulted at the time (they generally weren't), no one could have predicted the way acclimatisation societies and trout populations proliferated and impacted Aotearoa-NZ's indigenous fisheries; thus, impacting whānau who relied on taonga freshwater fish species for food and made living long distances inland possible for many.

Eels were promoted by these societies as the enemy of trout. For example, in 1933, a acclimatisation society ranger advised *"Where infestation is bad it is possible to wade up a stream beheading the eels in one's stride."* In 1943, the Wellington Acclimatisation Society printed on their fishing licenses that *"Every angler should make war on eels."* (Parliamentary Commissioner for the Environment 2013, and references therein). Acclimatisation societies, with the support of government agencies, declared tuna to be 'public vermin', launching massive extermination campaigns in some regions from the 1930s to 1950s. For example, in South Canterbury, the Acclimatisation Society reported the death of 4,270 eels in 1934 using eel baskets that had been distributed to farmers. During the 1960's, although the intensive eel destruction campaigns had finished, many regions still had a bounty on eels, to encourage people to kill them (Jellyman 2013). Research was carried out on the effect of eels on a trout population which showed that the presence of eels, especially longfins, was useful in stopping trout from becoming over-populated and having fisheries stocked with numerous small, stunted trout rather than fewer large trout of angling size (Burnet 1968), so eels actually helped to maintain a higher value trout fishery. This knowledge effectively stopped the bounty system on eels (Jellyman 2013).

Extermination campaigns killed hundreds of thousands of eels, which were heaped on riverbanks to die, or were buried. Because eels are relatively long-lived and only spawn once in their lifetimes, the impacts of these acclimatisation societies misguided and hugely destructive campaigns are still being felt today.

3.5.8 Harvest

Commercial

The commercial eel fishery in Aotearoa-NZ began in earnest in the late 1960s and expanded rapidly until the early 1970s, peaking at slightly over 2,000 t in 1972 (Figure 20). Jellyman (2013) describes the development of the commercial eel fishery in three phases: (1) An exploitation phase (1965–1980); (2) A consolidation phase (1980–2000); and (3) A rationalization phase (2000 to 2012).

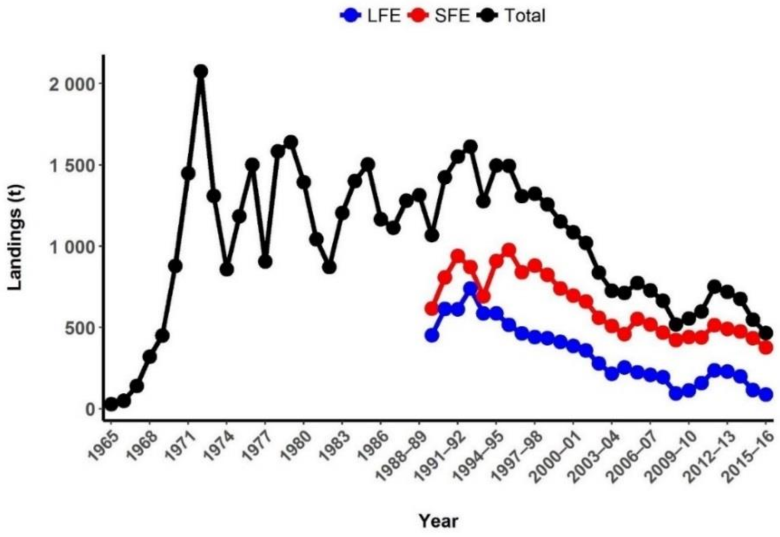

Figure 17: Total eel landings from 1965 to 2015–16, as well as separate shortfin and longfin landings from 1989–90 to 2014–15. Prior to 1988-89, the data points represent estimates for the period prior to the introduction of Eel Catch Landing Return forms, and were generated by pro-rating the unidentified eel catch by the longfin to shortfin ratio (see MPI 2017 for more information). (Source: MPI 2017).

The exploitation phase was characterised by rapid expansion of the industry, a proliferation of processing factories, and generally large export volumes of a relatively low-value product. There were few management constraints. In the early 1990s, 23 processing factories operated (Jellyman 1993), and there was no limit on catches or the number of commercial fishing licences issued. An initial minimum size of 150 g introduced in 1981 was increased to 220 g in 1992, in an endeavour to improve marketability and yield-per-recruit (Jellyman 2013).

During the consolidation phase, there were some concerns about localised overexploitation and MPI implemented two constraints to reduce the pressure on eel stocks: (1) The exclusion of part-time commercial fishers from the industry (in 1982); and (2) A moratorium on the issuing of new licences in 1988. Associated with the licence freeze was a voluntary agreement by the eel industry not to increase fishing effort beyond that of the late 1980's. To assist with this, a legal loophole that enabled multiple fishers to operate from a single fishing permit was closed in 1997. Towards the end of this phase, fishery managers encouraged cooperative management planning by industry and Māori (Te Waka a Maui me ona Toka Mahi Tuna 1996), which resulted in a series of regional management plans for the South Island (e.g., Arai Te Uru, South Canterbury/Waitaki, Te Tau Ihu Mahi Tuna) (see Figure 24). These plans formed the information base for the entry of eels into the Quota Management System (QMS) (Jellyman 2013). However, the committees that were formed to develop these plans also considered a much broader range of impacts on local eel fisheries, and made several recommendations (e.g., existing or potential barriers provide structures which will permit the passage of large eels) that have not yet been realised (Jellyman 2013). Like marine species, Māori received 20% of the commercial quota, and in recognition of the historical importance of eels to them, catch allocations were also made for customary purposes (another 20% of the Total Allowable Catch [TAC]). Iwi control or hold approx. 50% of North Island eel quota[7].

In response to growing concerns about the long-term sustainability of harvest levels, especially of longfins, in the rationalisation phase MPI have taken actions to reduce catches, including changes in the minimum size, an increase in reserve areas, removal of part-time fishers, a moratorium of fishing licences, and reductions in Total Allowable Commercial Catches (TACC's). The fyke nets used by fishermen are highly efficient, and research has indicated that baited nets can consistently remove more than half the longfins (in experimental reaches c. 200–300 m) within a single night's fishing (Jellyman & Graynoth 2005). Also, being ecologically dominant, large longfins are more vulnerable to capture than smaller longfins. Several reviews and research programmes have highlighted the vulnerability of longfins, and the need to implement more conservative management practices to avoid substantial reductions in this fishery (Chisnall & Hicks 1993, Jellyman et al. 2000, Hoyle & Jellyman 2002, McCleave & Jellyman 2004, Jellyman 2009). A 4 kg upper size limit, in place in the South Island commercial fishery since November 1995, was extended in March 2007 to include the North Island. Although this provides protection for large longfins, modelling has indicated that the probability of capture before this size is attained is very high (Hoyle & Jellyman 2002). However, given that only a third of the longfin habitat is fished, this regulation ensures eels growing up in unfished stretches and tributaries are not exploited when they enter the mainstem.

In recognition that eel stocks in some regions are showing signs of depletion, commercial eel fishers have sometimes voluntarily forgone opportunities to catch their annual entitlements to assist stocks to rebuild (Jellyman 2013). A voluntary logbook programme in the South Island has shown that large numbers of longfins more than 4 kg are caught and released by commercial fishers.

A recent study suggests that roughly one-third of the available longfin habitat is currently commercially fished (Beentjes et al. 2016) (Figure 21). Approximately 40% of the longfin eel habitat was estimated to be impacted by both hydroelectric dams and commercial fishing. Beentjes et al. (2016) recently interviewed 53 commercial eel fishers who indicated that their effort had declined in the last 5 to 10 years. This is due to a range of factors including denied access to fishing grounds; an ageing demographic, with fishers retiring or not prepared to fish marginal or difficult to access areas; a decline in the marketability and price of longfin eels compared to shortfin; and requirement to return large eels (over 4 kg). In recent times, there has been a marked reduction in the number of eel processing sites and the remaining sites are: (1) Mossburn Enterprises[8] (Invercargill), New Zealand Eel Processing Company Limited (NZ Eel) (Te Kauwhata), and (3) Levin Eel Trading Ltd[9] (Levin).

Despite the exploitation, there is little evidence that shortfins are declining nationally (Beentjes & Bull 2002, Jellyman 2009). As shortfin males seldom exceed the minimum commercial size of 220 g, the commercial shortfin fishery is effectively for females only (except for the fishery for male silver eels in Te Waihora, where the size restriction is relaxed) (Jellyman 2013).

Recreational

In 1994 a daily bag limit of six eels was introduced throughout the country for recreational fishers. The recreational allowance applies to all individuals who are undertaking recreational fishing, with customary allowances only relating to fishing for customary purposes. Whilst a variety of fishing methods may be employed, including rod and line, only one fyke net per person is permitted. Net

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[7] https://www.eelenhancement.co.nz/

[8] http://www.waituna.co.nz/

[9] http://www.levineel.co.nz/

mesh size is regulated for recreational fishing, with fyke nets and hīnaki having a minimum mesh size of 12 mm. MPI produced a brochure in November 2008 for recreational fishers which recommends that shortfin eels greater than 60 cm in length and longfins greater than 75 cm in length are returned to the water unharmed if they are not being taken for food. Whilst a maximum size does not yet apply to the recreational sector, it has been raised by MPI as a possibility. There is currently no quantitative information available on the extent of recreational tuna harvest.

Customary

Both migrating eels and feeder (non-migrant) eels are captured in the customary fishery. A wide range of fishing methods have historically been employed to catch tuna, with methods varying by area, season and habitat. Examples of customary methods include hīnaki (eel pots), pā tuna (eel weirs), toi (bobbing without hooks), takahi tuna (trampling then catching with hands), rama tuna (using torch light), patu tuna (eel striking), matarau (spearing) and koumu (eel trenches) (Best 1929, Statistics New Zealand 2005). Whilst these methods and variations of these methods may still be used in the present day, much customary fishing now uses modern equipment such as fyke nets. The extent of customary harvest is currently unknown. In a review of eel usage in the King Country (using a postal questionnaire), Maniapoto (1998) noted that capture and usage of tuna for customary purposes could be considerable and estimated that the 45 marae in the rohe could need between 136–164 tonnes per annum. When reviewing the fisheries of Te Waihora, Jellyman and Smith (2008) noted that data supplied by Ngāi Tahu gave a customary harvest of tuna of up to five tonnes per year from this lake. While there are no records of total customary harvest of eels from throughout Aotearoa-NZ, Jellyman (2013) suggests that it could be considerably less than the quantities allowed for within the QMS.

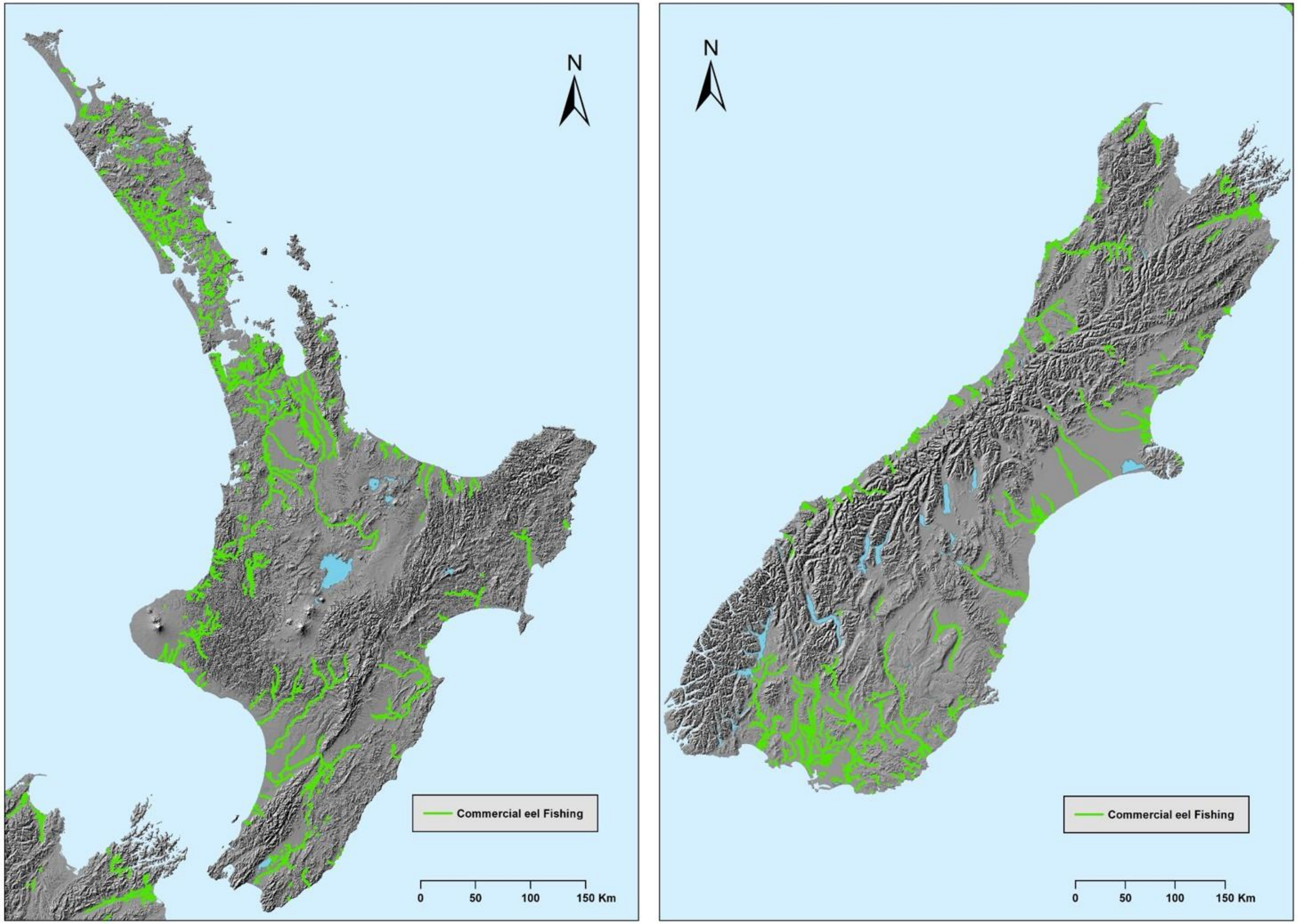

Figure 18: (Left) North Island, and (Right) South Island commercial fishing locations from the period of 2009–2014. Green areas show where commercial fishing occurred at least once. Please note that this analysis excluded lakes (Source: Beentjes et al. 2016).

3.6 Management

Because of their extensive migrations and relatively long life, tuna are a challenging fishery to manage and restore, notably because the relative importance and interaction between habitat, recruitment and fishing pressure have not been quantified. Furthermore, as there is no control on the life stages of tuna while at sea, the management and restoration of the tuna fishery has to rely on activities that enhance the population while in fresh water. In the freshwater domain, the roles and responsibilities for the sustainable management of tuna populations and their associated habitats are spread across a wide range of agencies (including iwi, DOC, MPI, and regional councils, see Table 2).

3.6.1 Ministry for Primary Industries

Commercial fisheries are managed under the QMS where individual transferrable quota for fish stocks is owned by private interests. The quantity of fish that can be taken by commercial fishers in one fishing year is the TACC. On behalf of the Crown, MPI promotes policies and regulations to manage the commercial eel industry in a sustainable manner. MPI is responsible for administering the Fisheries Act 1996 and the QMS, monitoring fishing activity and enforcing fishing rules.

Three main tuna harvest control measures are used by MPI to support the management of the Aotearoa-NZ tuna fishery. The first is that there are upper and lower harvest size limits (e.g., it is currently illegal to harvest an eel less than 220 g without a special permit from MPI). This management measure has been in place for a number of years and essentially prevents the harvest and export of juvenile eels (notably glass eels and elvers) for aquaculture purposes, while large female tuna are also protected from harvest. The second is that tuna harvest is controlled by the QMS which is adjustable across quota/fisheries management areas (Figure 22) as the need arises. The third is the establishment of reserve areas that are free from commercial harvest, although DOC has the discretion to grant fishing concessions in reserve areas under their control. A key component to ensuring the sustainability of eels is to maintain spawner escapement; as a sustainability measure, the Mōhaka, Mōtu and much of the Whanganui River catchments were closed to commercial fishing in early 2005 to aid spawning escapement (MPI 2017).

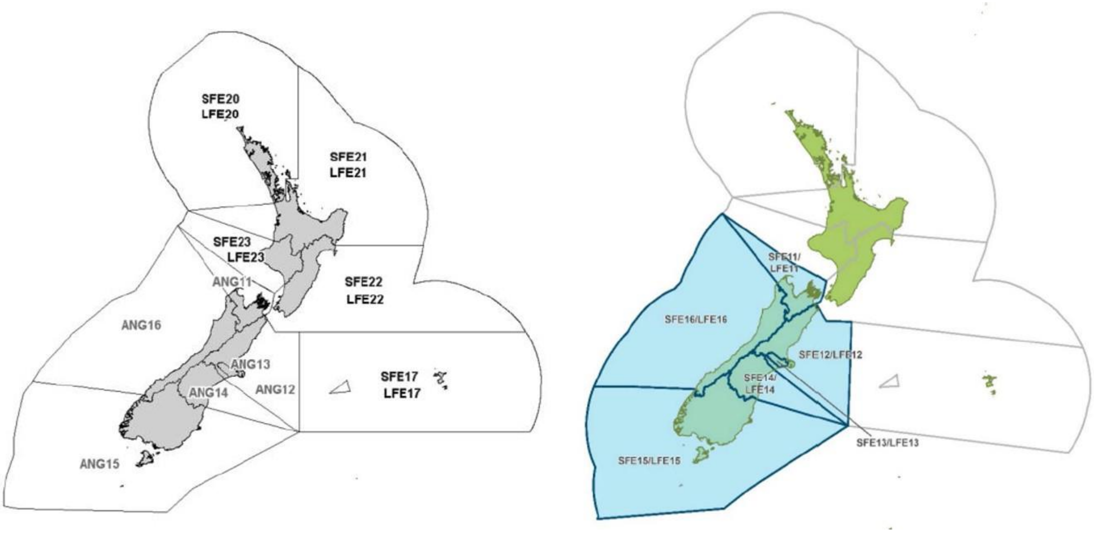

Figure 19: (Left) Current quota management areas for shortfin eel (SFE), longfin eel (LFE) and both species combined (ANG); and (Right) Proposed quota management areas for the South Island eel fishery (SFE11–16 and LFE11–16). (Source: MPI 2016; 2017).

Conventional fisheries assessment techniques (like those used for marine fisheries) are inappropriate for freshwater eel stocks because of their biology and stock structure, and consequently there are no formal stock assessment methods for freshwater eels in Aotearoa-NZ (Dunn et al. 2009). MPI currently relies on: (1) Elver recruitment at selected hydroelectric dams; (2) Commercial catch-per-unit-effort (CPUE) indices by species and Eel Statistical Area (ESA) (Figure 23); and (3) The proportion of longfin habitat impacted by commercial fishing and hydroelectric dams, to undertake cautioned assessments of longfin and shortfin stock status.

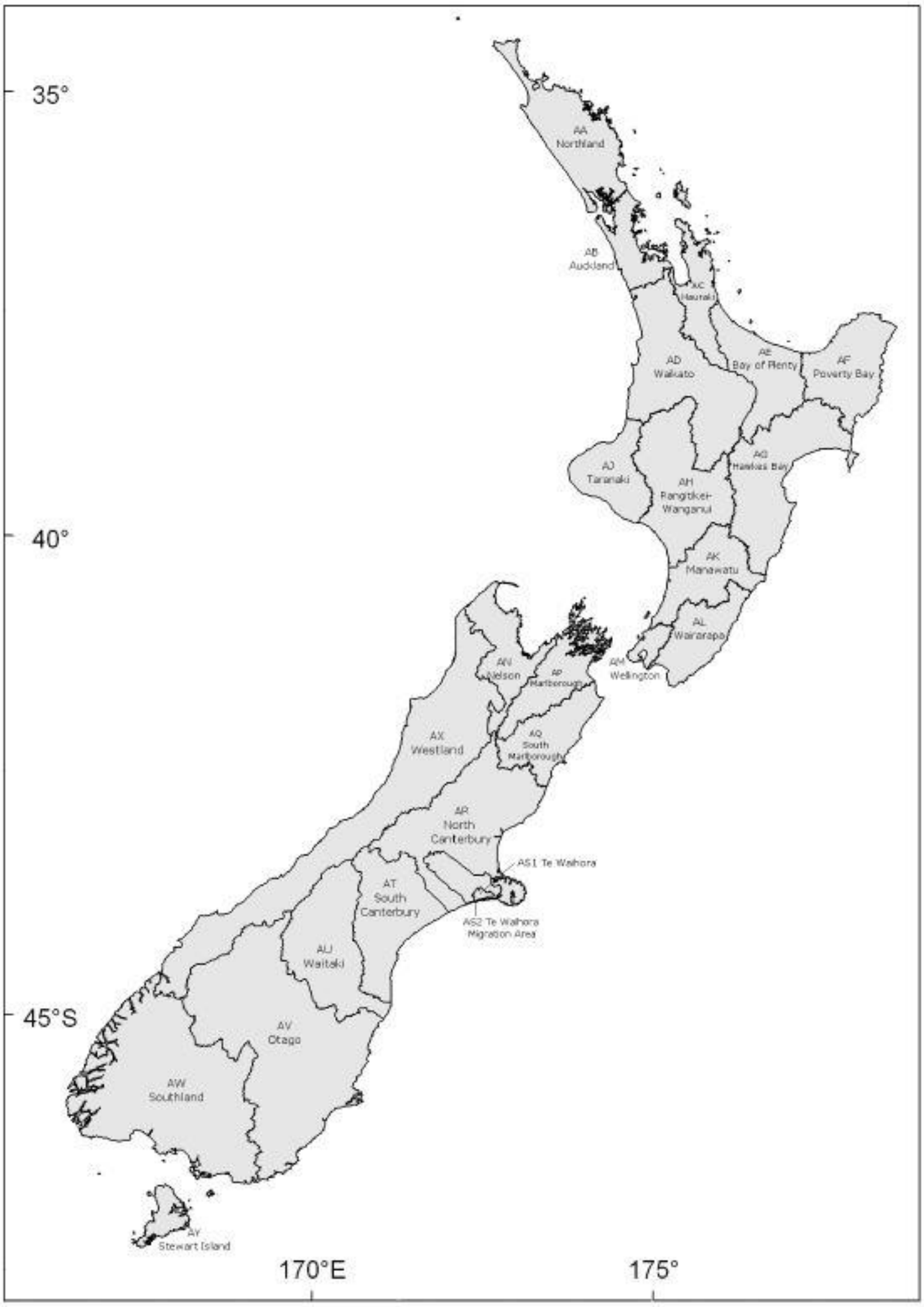

Figure 20: Eel Statistical Areas (ESAs) used for reporting catch from the commercial freshwater eel fishery and analysing trends. (Source: Beentjes et al. 2016).

MPI's current research on recruitment is aimed at establishing a time series of relative abundance of elvers at key locations in Aotearoa-NZ where the upstream passage is restricted by hydroelectric dams (e.g., Martin & Bowman 2016) (see Section 3.3). MPI also uses standardised catch-per-unit-effort (CPUE) analyses for commercial eel fisheries to inform fisheries management decision-making (e.g., Beentjes & Dunn 2015). MPI funds research into each of these areas on a regular basis, the results of which are reviewed by the Eel Working Group before publishing. For example, in August 2017, MPI received tenders to: (1) Standardise CPUE of elvers caught by electric-fishing in the Waikato region (EEL2017-02); and (2) Develop modelling approaches and data requirements for a GIS-based assessment of longfin eels (EEL2017-01).

The South Island eel fishery was introduced into the QMS on 1 October 2000 with shortfin and longfin species combined into six fish stocks (codes ANG11 to ANG16, Figure 22). The Chatham Island fishery was introduced into the QMS on 1 October 2003 with two fish stocks (shortfins and longfins separated into SFE17 and LFE17, respectively, Figure 22). The North Island eel fishery was introduced into the QMS on 1 October 2004 with eight fish stocks (four longfin stocks LFE20–23 and four shortfin stocks SFE20–23, Figure 22). A review considering the separation of South Island longfin and shortfin stocks to support improved management of each species has recently been completed, resulting in an overall reduction in the total 2016–17 TACC across both species (Clements & Associates 2016, MPI 2016) (Tables 4–6).

Table 3: TACCs (t) and reported landings (t) of shortfin eel (SFE) for 2015–16 and TACCs set for 2016–17. (Source: Clement & Associates Limited 2016).

Fish stock	2015–16 Actual TACC	2015–16 Reported landings	2016–17 TACC
SFE11	–	–	19
SFE12	–	–	20
SFE13	–	–	134
SFE14	–	–	10
SFE15	–	–	29
SFE16	–	–	30
SFE17	10	0	10
SFE20	86	51	86
SFE21	134	119	134
SFE22	94	49	94
SFE23	23	10	23
Total	347	230	580

Unlike virtually all other commercial fisheries in Aotearoa-NZ, there is no fine scale reporting of eel catch using latitude and longitude coordinates and the finest spatial resolution of reporting is by Eel Statistical Areas (ESA) on the Eel Catch Effort Return which has been in use since 2001–02 (Beentjes et al. 2016). Eel Statistical Areas are broadly catchment based, but include multiple major river systems (Figure 23). The latest analysis of trends in commercial eel CPUE indices for all ESAs from 1990–91 to 2014–15 are provided in Appendix D (MPI 2017, Beentjes & McKenzie in prep).

In 2013, the **Parliamentary Commissioner for the Environment** (PCE) undertook a review of the longfin eel fishery (PCE 2013) in response to increasing public concern about the sustainability of the longfin eel fishery and the potential risk of extinction. An independent panel of three international experts was assembled to review the scientific information used to guide the management of Aotearoa-NZ's eel fisheries, particularly longfin eels (Haro et al. 2015). The panel considered each of the sources of information and analyses currently used for monitoring trends and assessing tuna stock status, noting the limitations of each and, in most cases, making recommendations for improvement. They also suggested possible supplementary information that could be collected to further strengthen current monitoring. The panel recommended a comprehensive assessment that integrates conventional fisheries information with non-fisheries information, such as the impact of habitat degradation, pollution and other non-fisheries causes of mortality (e.g., hydroelectric dams).

Table 4: TACCs (t) and reported landings (t) of longfin eel (LFE) for 2015–16 and TACCs set for 2016–17. (Source: Clement & Associates Limited 2016).

Fish stock	2015–16 Actual TACC	2015–16 Reported landings	2016–17 TACC
LFE11	–	–	1
LFE12	–	–	1
LFE13	–	–	1
LFE14	–	–	1
LFE15	–	–	52
LFE16	–	–	25
LFE17	1	0	1
LFE20	19	6	19
LFE21	32	9	32
LFE22	21	4	21
LFE23	9	1	9
Total	82	21	163

Table 5: TACCs (t) and reported landings (t) of South Island eels (ANG) for 2015–16. (Source: Clement & Associates Limited 2016). See Tables 4 and 5 for a breakdown of the 2016–17 TACCs for South Island eels.

Fish stock	2015–16 Actual TACC	2015–16 Reported landings	2016–17 TACC
ANG11	40	2	–
ANG12	43	0	–
ANG13	122	109	–
ANG14	35	5	–
ANG15	118	64	–
ANG16	63	20	–
Total	420	201	0

3.6.2 Māori

Tangata whenua in the North and Chatham Islands may customarily fish under Regulation 27A, Fisheries (Amateur Fishing) Regulations 1986 in areas that are not yet covered by the Fisheries (Kaimoana Customary Fishing) Regulations 1998. Regulation 27A limits customary fishing activities to the taking of aquatic life for customary hui and tangi only, under authorisation of a Māori committee, marae committee, a Rūnanga, or Māori Trust Board. Regulation 27A does not adequately provide for the management of customary food gathering as required to by sections

10(b) and (c) of the Treaty of Waitangi (Fisheries Claims) Settlement Act 1992 because they were an interim mechanism to allow for some aspects of customary non-commercial fishing rights until regulations consistent with Section 10 of the Settlement Act are made and in use by tangata whenua.

Consequently, in late 2008 the Fisheries (Kaimoana Customary Fishing) Regulations 1998 were amended to extend their coverage to include aquatic life (that are subject to the Fisheries Act 1996) in fresh water for the North and Chatham Islands, and permits tangata tiaki/kaitiaki to be appointed to manage all non-commercial customary fishing. The Ngāi Tahu Claims Settlement Act 1998 promulgated the development of the Fisheries (South Island Customary Fishing) Regulations 1999. These regulations encompass fisheries resources in freshwater and marine environments (that are subject to the Fisheries Act 1996). The nine South Island iwi accepted that freshwater fisheries were included in the Settlement Act 1992, and are identified as tangata whenua under the Fisheries (South Island Customary Fishing) Regulations. Under these regulations, tangata tiaki manage all non-commercial customary fishing resources and can apply for mātaitai reserves. Tangata whenua with appointed tangata kaitiaki under the customary fishing regulations can apply for the establishment of freshwater mātaitai reserves (e.g., reaches of the Okarito Lagoon, Lake Wairewa, Temuka/Opihi River, Waihao River, Mataura River, Waikawa/Tumu Toka[10], also see Section 11.1.1) to manage all non-commercial fishing within the reserve by recommending by-laws.

In both the North and South Islands, there are areas in which commercial fishing is prohibited in recognition of the special value of these areas for customary non-commercial purposes. In the South Island, Lake Waiwera and its tributaries have been set aside exclusively for Ngāi Tahu. Other areas, such as the lower Pelorus River, Taumutu (Te Waihora), Wainono Lagoon and its catchment, the Waihao catchment, the Rangitata Lagoon and the Ahuriri Arm of Lake Benmore, have been set aside as non-commercial areas. In the North Island, commercial fishing is prohibited from Lake Ōmāpere, Lake Horowhenua, the Taharoa lakes, Whakakī Lagoon, Lake Poukawa, Arahura River, lakes Kohangapiripiri and Kohangaterā and associated catchments (Jellyman & Sykes 2009, MFish 2009, McDowall 2011). In addition, as a sustainability measure, the Mōhaka, Mōtu and parts of the Whanganui River catchments have been closed to commercial fishing to aid spawning escapement (MFish 2009). Some iwi groups have also placed a moratorium on the harvest of longfin eels as they are concerned about declining stocks (e.g., Te Tai Hauāuru Forum, Kawe 2014).

Fisheries in the **lower Waikato River catchment** (from Te Pūaha to Karāpiro Dam) are co-managed by Waikato-Tainui and the Crown, under the Waikato-Tainui (Waikato River) Fisheries Regulations 2011[11]. This co-management approach is one of the strategies put in place to achieve the overarching purpose of Waikato-Tainui Raupatu Claims Settlement Act 2010[12] - "*to restore and protect the health and wellbeing of the Waikato River for future generations*". Waikato-Tainui Fisheries Bylaws have recently increased the minimum harvest size to 300 g for shortfins and 400 g for longfins. In addition, lower and upper size limits, seasonal fishing bans on major migration pathways, and protection of all female migrant longfins have been put in place by Waikato-Tainui and the Crown through the Waikato-Tainui Fisheries Bylaws[13].

Prior to the entry of tuna into the QMS, regional eel management committees across the South Island prepared Eel Management Plans[14] (Figure 24). Some of these plans were recognised and accorded the status of Iwi Management Plans (IMPs). As mentioned in Section 3.5.8, each plan

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[10] Source: http://www.nabis.govt.nz/Map.aspx (Mataitai Reserve Boundary Layer)

[11] http://www.legislation.govt.nz/regulation/public/2011/0294/latest/DLM3930995.html.

[12] http://www.legislation.govt.nz/act/public/2010/0024/latest/DLM1630002.html

[13] http://www.fish.govt.nz/en-nz/Maori/Waikato-Tainui+Fisheries+Area+Bylaws.htm

[14] There is one plan for the South Island, plus plans for Te Tau Ihu, North Canterbury, Te Waihora, South Canterbury-Waitaki, Arai Te Uru, Te Tai Poutini and Murihiku.

represents a valuable resource because it lists issues associated with their respective catchments, including identifying where passage is impeded. These plans were updated in 2006–2008.

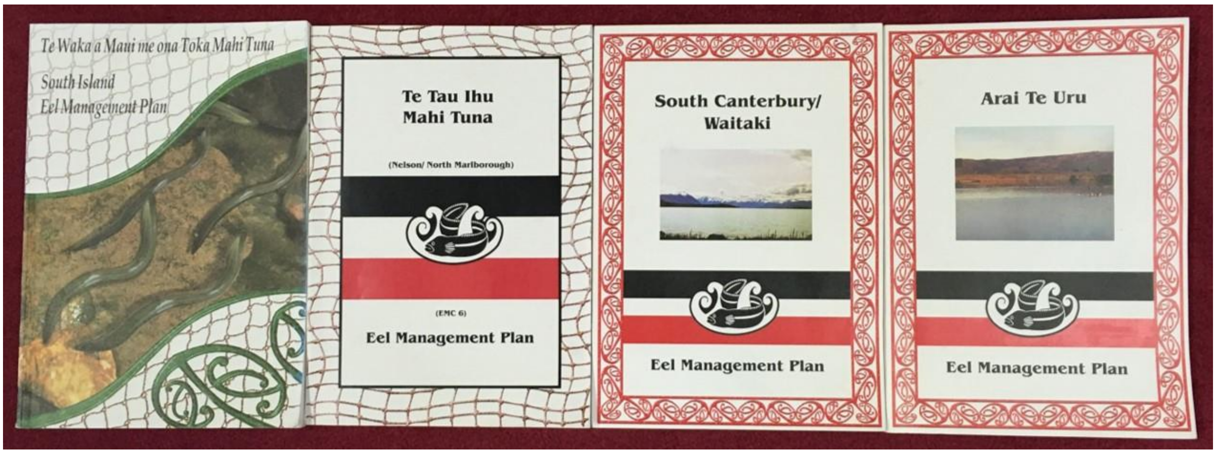

Figure 21: **Example of some of the South Island Eel Management Plans prepared by regional eel management committees in the late 1990s, prior to the introduction of tuna into the QMS.**

3.6.3 Department of Conservation

Longfin eels are listed as one of the 150 priority threatened species listed in DOC's draft **Threatened Species Strategy** (see Section 11.2). DOC has responsibilities under the Conservation Act 1987 to protect indigenous freshwater fish and freshwater habitats and recreational freshwater fisheries. This allows for the management of native fish directly, and for advocacy on behalf of fish and their habitats. DOC also administers the Freshwater Fisheries Regulations 1983, which include provisions for fish passage and control of noxious fish and has the responsibility to ensure that activities (like commercial fishing) carried out in protected areas it manages (e.g., Reserves and Conservation Areas) are consistent with the purposes for which those areas are held. Regulation 42 of the Freshwater Fisheries Regulations 1983 prevents fish passage from being impeded by an instream structure unless written approval for the structure is given by the Director General of DOC. Regulation 43 requires those seeking to construct dams to seek approval or dispensation from the Regulations by notifying the Director General, who may require that a fish pass is also constructed.

Fonterra is a partner with DOC in the Living Water[15] partnership which is focusing on the restoration of five catchments (Kaipara Harbour: Hikurangi Catchment; Firth of Thames/Tīkapa Moana: Pūkorokoro/Miranda Catchment; Waikato Peat Lakes: Areare, Ruatuna, Rotomānuka; Te Waihora/Lake Ellesmere: Ararira/LII Catchment; and Awarua-Waituna: Waituna Catchment). DOC has also set an ambitious 10-year stretch goal of restoring 50 freshwater ecosystems, mountains to the sea[16]. However, it is difficult to source documentation to confirm which catchments DOC are focusing on, and where there will be components of interest to Te Wai Māori and iwi/hapū around the country.

3.6.4 Regional and District Councils

Councils operate under numerous pieces of legislation that give them responsibilities for freshwater taonga species management (and their associated ecosystems, including the marine environment), including Local Government Act 2002, Biosecurity Act 1993, Soil Conservation and Rivers Control Act 1941 (and several special statutes), Reserves Act 1977, etc. Regional Councils are also responsible for

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[15] https://www.livingwater.net.nz/

[16] http://www.doc.govt.nz/about-us/our-role/corporate-publications/statement-of-intent-archive/statement-of-intent-2015-2019/statement-of-intent-20152019-full-content/

many local statutes such as those that govern drainage and flood control, e.g., Taieri River Improvement Act 1920.

Under the Resource Management Act 1991 (RMA), there is also a general requirement for consent authorities to ensure that Aotearoa-NZs resources are managed in a sustainable manner and this broad definition includes ensuring fish passage. As such, two pieces of legislation are available to ensure fish passage throughout Aotearoa-NZ, but enforcement of the legislation has generally been weak and there are many structures currently in existence which affect fish passage in Aotearoa-NZ. Te Wai Māori recently commissioned a report that outlines the names of consent holders for a several hydroelectric dams across the country, the current conditions of consent as they relate to fish passage, and when the resource consent is up for renewal (LMK Consulting Ltd 2014). One difficulty, however, is the number of barriers that are created by the erection of structures that are classed as a permitted activity because they may only be 1–3 metres in height. Although seen as being small in scale they can impede passage and add to the cumulative loss of access to habitats within a catchment.

3.7 Aquaculture

Since 2004, much of the North Island eel quota has been purchased by Māori-owned companies (e.g., Moana New Zealand, formerly Aotearoa Fisheries), making Māori the largest North Island eel quota owners. The commercial wild-eel fishery supplies both a domestic and export market and has an estimated export value of $6.1 M (MPI 2009). In Belgium, Germany, Hong Kong, Italy, Republic of Korea, Netherlands, Taiwan, USA and the UK there is demand for our eels, which are provided in various forms, including frozen, smoked and live. In Japan, freshwater eels are considered a delicacy and importing eels has become increasingly important considering declines in Japan's domestic eel catch (Statistics NZ 2005, Shiraishi & Crook 2015, Okamoto 2016). However, due to size and quality issues, our wild-caught eels do not consistently have access to premium value Asian markets.

On a global scale, the market demand for eels as a foodstuff is high and declines in northern hemisphere wild-eel production have meant that aquaculture is now the primary source of eels for human consumption. Internationally, eel farming is responsible for over 90% of all *Anguilla* production worldwide, and is based on on-growing wild-caught glass eels (Shiraishi & Crook 2015). Recently there has been a large global increase in the price and harvest of glass eels for aquaculture (FAO 2014). Glass eel shortfalls for large Asian eel producers has renewed interest in farming other Anguillid species and aquaculture is now being supplied by glass eels harvested from new or previously lesser-exploited *Anguilla* populations from around the world (Crook & Nakamura 2013).

Internationally, at present, all eel aquaculture relies on the collection of disease and parasite-free glass eels from the wild. Eel aquaculture has been linked to the decline of Northern Hemisphere eel stocks; however, it should be noted that these countries harvest eels across <u>all</u> stages of their unique life cycle (including glass eels, adults and migrants). Glass-eel harvests have been implicated in the decline of wild eel stocks and setting sustainable limits for exploiting new populations requires assessment of the impacts pre-exploitation. However, in countries such as Indonesia, trade in tropical glass eel species has started with little or no scientific or management assessments pre-exploitation (Arai 2014, Nijman 2015).

In Aotearoa-NZ, several organisations sought to participate in land-based eel aquaculture during the 1970–1980s, but they were not commercially successful (Beckett 1975, Jellyman & Coates 1976, Sorrenson 1981). While previous ventures/research has demonstrated the feasibility of eel on-growing, one of the most significant bottlenecks to the development of an industry is the difficulty in obtaining an adequate supply of glass eels for on-growing. Currently, it is illegal to possess eels less than 220 g, except under special permit, and commercial access to shortfin glass eels will require changes in fisheries regulations and the support and approval of Māori, fisheries managers, communities and other stakeholders (Quigley & Baines 2014).

There are iwi, hapū and Māori organisations who are seeking to participate in eel aquaculture at various scales and for different purposes (including restoration e.g.,[17]) ranging from small ventures to large commercial-scale ventures for supplying international markets. The opportunity to develop a tuna aquaculture industry has been a priority for some parties for some time (e.g., Te Puni Kōkiri 2009), and is specifically mentioned in 2015–2016 regional growth study reports for Te Tai Tokerau (MPI 2015a), Bay of Plenty (MPI 2015b), Manawatū-Whanganui (Horizons Regional Council 2016) and the Manawatū-Whanganui Māori Economic Development Strategy (Māori Economic Strategy Group 2016). Some groups have instigated research into the potential sustainability of shortfin glass eel harvest – as the datasets required to responsibly inform this discussion will need to be developed over multiple years (e.g., Williams et al. 2016). To the best of our knowledge, except for an on-going initiative funded by DOC in the Ashley catchment, there are no medium to long-term glass eel monitoring programmes being undertaken in Aotearoa-NZ.

Recognising that the aspirations of some hapū and iwi organisations are not always solely economically driven, the prospect of a potentially secure supply and ready access to farmed tuna attracts them to investigate their options in regards to small/local scale on-growing for customary benefit (e.g., marae-based on-growing for consumption and restoration, e.g., Muaupoko[18]). At the other end of the scale, some iwi are opposed to glass eel-based aquaculture, e.g., the Fisheries Accord between the Minister of Fisheries, the Chief Executive of the Ministry of Fisheries and Waikato-Tainui signed on 20 October 2008[19] stipulates at 5.1 (b) *that the parties agree to establish mechanisms to provide for Waikato-Tainui to protect elvers and glass eels within the Waikato River from exploitation*. The Waikato-Tainui Environmental Plan[20] re-enforces these protective measures for glass eels.

Glass-eel harvest potentially has implications for the sustainability of shortfin eel stocks. In this country, very little research has been done to investigate the effects of glass-eel removal and alternate commercial eel harvest scenarios (e.g., reducing the commercial catch of adult eels) (Jameson undated, Te Wai Māori 2006). It is thought that large scale glass-eel harvesting is likely to reduce elver densities. However, this *may* have little impact on adult eel stocks and the numbers of migrants escaping to sea to breed. The PCE illustrates this concept by explaining "if the numbers of elvers going up a river is reduced, the remaining elvers may have a better chance of finding food and surviving" (PCE 2013). For example, juvenile eels in three small coastal streams experienced high mortality rates at lengths of 300–400 mm. This may be a natural population bottleneck caused by competition with larger eels either for food or for instream cover as they move from being elvers occupying river substrates to live with larger adult eels in other instream habitats (Graynoth et al. 2008a).

Early research conducted by NIWA included the development of techniques for pond-based fattening of large eels (Chisnall & Martin 2002). In the research project, Rapid Commercialisation of New Aquaculture Species (C01X0301), NIWA developed techniques to transport glass eels, and on-grow shortfin eels in a brackish water environment to market size in less than one year (e.g., Kearney et al. 2004, Watene 2004, Kearney et al. 2008, Hirt-Chabbert 2011, Kearney et al. 2011).

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[18] http://www2.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11724285 and http://www2.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11809727 and http://www2.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11905252 and http://www2.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11737502

[19] http://www.fish.govt.nz/NR/rdonlyres/EF84647D-571D-4926-8690-13A913DD1B64/0/WaikatoTainuiFisheriesAccordfinal20Oct2008.pdf

[20] http://www.wrrt.co.nz/wp-content/uploads/EBook_FINAL_EP_Plan_sp.pdf

While there are still some challenges to address in the optimisation of on-growing of glass eels, this component of the potential commercialisation model is the relatively easy part. The most significant research questions to overcome are in relation to social/cultural license to operate, glass eel recruitment (i.e., security of supply), adaptive eel fisheries management options (i.e., sustainability) and the development of economic models that consider both economic viability and environmental sustainability to advise regulation change and alternate fisheries management approaches. Graynoth (2008a) and Graynoth et al. (2015) recommend that fisheries managers, iwi/Māori and stakeholders come together to prepare a list of issues and questions to help researchers design and develop fit-for-purpose glass eel harvesting/fisheries assessment models. In particular, modellers need information on the potential future of adult eel commercial fishing, proposed glass-eel harvesting strategies, and stock enhancement programmes (Graynoth et al. 2015).

An alternate approach to the production of eels for human consumption is the hatchery production of glass eels for on-growing (i.e., artificially breeding and growing eels in the laboratory). Although this has been pursued for some time, to the best of our knowledge international researchers have found it difficult and this approach remains in the development stage in Japan (e.g., Tanaka et al. 2001) and Taiwan. The captive breeding of shortfin eels is also being attempted in Aotearoa-NZ at the Mahurangi Technical Institute[21]. Based on the information available to date it is unlikely that artificial production of glass eel on a commercial scale will be achieved in the short to medium term.

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[21] http://mti.net.nz/research-a-consultancy-at-mti-mahurangi-technical-institute-of-warkworth/research-projects-at-mti-mahurangi-technical-institute-of-warkworth