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Tini a Tangaroa

An assessment of the eel population structure in the Waikato hydro-reservoirs and their tributaries with respect to elver stocking, up to 2013

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EXECUTIVE SUMMARY

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Pressures on the lower Waikato commercial eel fishery, and hapū/iwi concerns about the decline of customary catches due to lack of passage for recruits over hydro-electric dams led to the implementation in the early 1990s of an elver trap-and-transfer programme from the base of Karāpiro Dam to the chain of hydro-reservoirs upstream. Although the elver trap-and-transfer programme has been well monitored, there is little information on the resulting eel population in the upstream hydro-reservoirs that are now commercially fished. This study was initiated in partnership with hapū/iwi and other stakeholders to assess the status of eel populations in selected hydro-reservoirs, and their associated tributaries, which have cultural and historical significance.

In total, five Karāpiro, seven Arapuni, and eleven Whakamaru tributaries were fished between December 2010 and November 2012 using electric fishing, as well as a variety of fyke nets. Lake Arapuni was also intensively fished with fyke nets in December 2012 and February 2013. Both Lake Ātiamuri and Lake Whakamaru were fished with fyke nets in February 2012. Information obtained included species distribution, catch per unit effort, species composition, size and age structure, as well as growth rates, and these were compared with historical records.

The types of nets and method of deployment varied between locations, to account for differences in depth, flow, and macrophyte cover. Furthermore, it was known that some habitats, notably sections of the hydro-reservoirs, and some stream reaches with woody debris and/or rocky substrate may not only be more productive, but also favour longfin eels. This makes direct comparisons of eel populations between hydro-reservoirs, tributaries, and years problematic. However, records clearly indicate that eel populations had increased markedly in the hydro-reservoirs and most associated tributaries since elver trap-and-transfer operations began. Furthermore, survey results indicate that longfins were far more widely distributed than shortfins in tributaries, but that small shortfins dominated the catches from hydro-reservoirs. Eel growth rates in the hydro-reservoirs surveyed (i.e., Arapuni, Whakamaru, and Ātiamuri) were linear, though variable, and have declined over the last two decades. However, growth rates were still higher than growth rates observed in the lower Waikato River.

Eels have gained access to the tributaries from the hydro-reservoirs, although where natural barriers are present the recruitment has been limited, and there could be value in stocking tributaries directly. In habitats where kōura are harvested for food, it would be best to delay any direct elver transfers until the effect of eel predation on kōura populations had been thoroughly examined.

Mortality of downstream migrant eels passing through the hydro-turbines remains a major concern for hapū/iwi, stakeholders, and the power scheme owners. Maximising eel harvest in both the tributaries and the reservoirs, with the option of transferring large eels to the river below Karāpiro Dam, would minimise the number of migrant eels affected.

The outcomes of this study were presented to the Eel Working Group in Christchurch on 11 October 2012, and in Hamilton on 1 November 2012. The project was undertaken in partnership with Ngāti Koroki Kahukura, Raukawa, the Te Arawa River Iwi Trust, Waikato-Tainui, and the Eel Enhancement Company, with co-funding provided by Mercury Energy (Waikato River Iwi Summer Internship Programme) and the Ministry of Business, Innovation and Employment (Contract No. C01X1002).

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1. INTRODUCTION

The Waikato River catchment has been modified by a series of hydro-electric developments which have restricted freshwater fish passage. There are nine hydro structures between Port Waikato (Te Pūaha of Waikato) and the control gates at the outlet of Lake Taupō (Figure 1). Karāpiro is the first in this series of dams that prevent migratory freshwater fish from accessing upstream areas. Dams are known to restrict the movement of diadromous fish, like the freshwater eel (*Anguilla* spp.), generally resulting in their reduction or loss from above-dam habitats. Further, they create artificial lentic ecosystems that exotic species can successively exploit (Jellyman & Harding 2012).

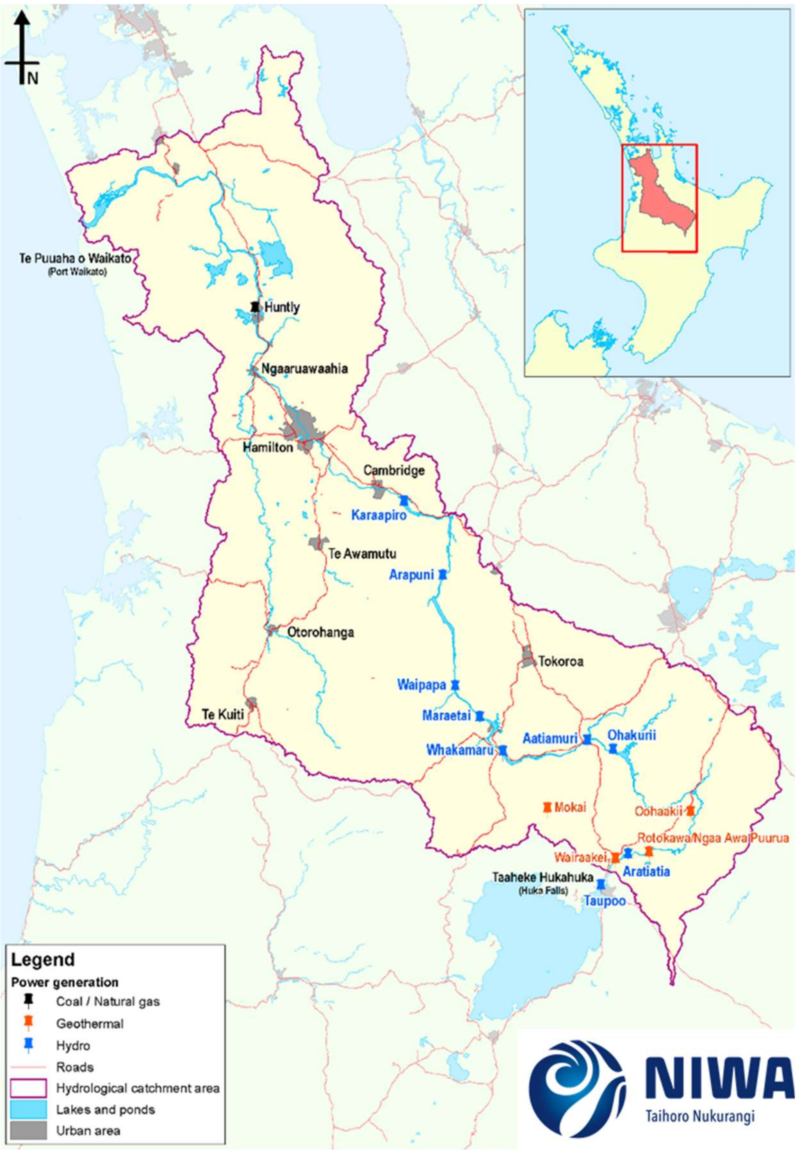

Figure 1: Location of major electricity generation sites within the Waikato River catchment (source: NIWA 2010). Note: this map uses the double vowel convention preferred by Waikato-Tainui.

Historically, freshwater fishes had unimpeded access up the Waikato River as far as the Horahora rapids (Figure 2), but these were submerged after the Karāpiro Dam was commissioned in 1947 and Lake Karāpiro was formed. In its natural state, upstream passage of fishes beyond the Horahora rapids was limited to species with good climbing abilities such as juvenile longfin (*Anguilla dieffenbachii*) and shortfin (*A. australis*) eels. However, further upstream passage for even these species was yet again restricted by a series of rapids and waterfalls (Figure 3), notably those that were submerged after the Arapuni Dam was commissioned in 1929, as well as the Waipāpa Falls which were believed to have been as large as the Huka Falls at the head of Lake Aratiatia. However, it is likely that construction of Arapuni Dam [with its original leaky board spillway] actually eased the upstream passage of eels beyond these rapids and waterfalls (Hobbs 1940, Cairns 1941, McDowall 1991).

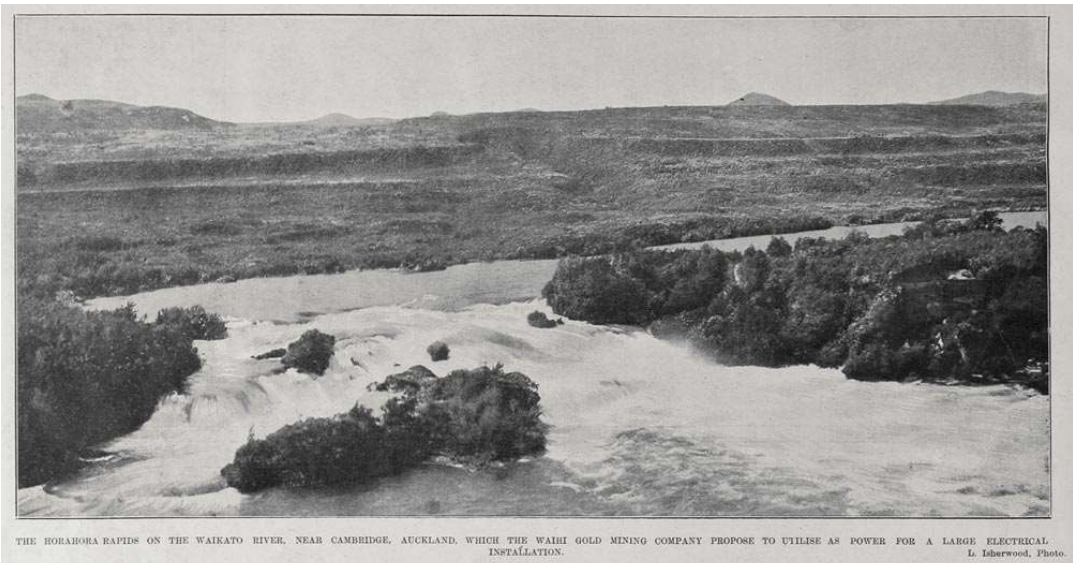

Figure 2: Photograph taken in March 1906 of the Horahora rapids on the Waikato River (held by Sir George Grey Special Collections, Auckland Libraries, AWNS-19060308-2-2). These rapids were submerged when Karāpiro Dam was completed around 1947.

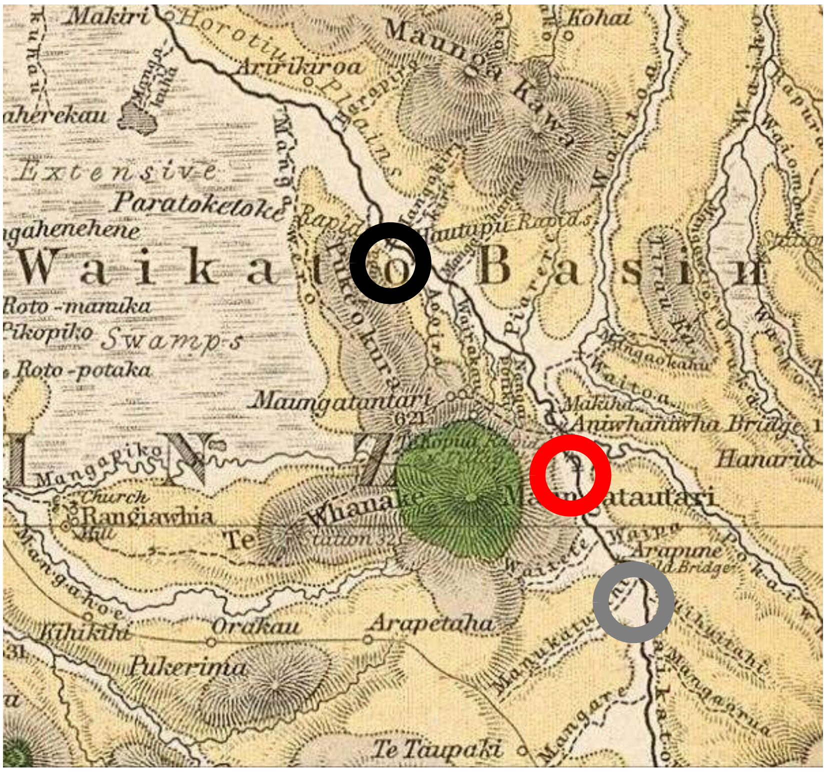

Figure 3: Map of the "Southern Part of the Province of Auckland" produced by Ferdinand von Hochstetter and published in 1867. This close-up of the Waikato River shows the sites where von Hochstetter observed rapids and waterfalls that were submerged by the formation of lakes Karāpiro and Arapuni (source: https://teara.govt.nz/en/zoomify/27081/hochstetters-map). The black circle shows the site of the Karāpiro Dam, the red circle shows the location of the Horahora rapids depicted in Figure 2, and the grey circle shows the location of the Arapuni Dam.

The Karāpiro Dam blocked most elver (juvenile eel) recruitment when it was constructed two decades after the Arapuni Dam. At the request of the Auckland Acclimatisation Society (AAS), an electric barrier was even incorporated into the spillway at the Karāpiro Dam to prevent elvers climbing the spillway (AAS 1947). At the same time, the AAS made strenuous efforts to eradicate eels above Karāpiro Dam (AAS 1948). Despite these efforts, a remnant population of eels (which are long-lived), remained, at least up to Mangakino, well into the 1990s (Bioresearches 1994). Some passage of eels over Karāpiro Dam must have still been possible because a limited commercial fishery existed through the mid-1980s to early 1990s in Karāpiro Reservoir, which could not have been maintained without new recruits. A commercial fishery also existed to a more limited extent in Arapuni Reservoir over the same time frame, but this may have been supplemented by artificial seeding (Chisnall 1993, Bioresearches 1994, Allen 2010).

A fyke netting and electric fishing survey undertaken between November 1992 and April 1993 in the catchments of lakes Karāpiro, Arapuni, and Waipāpa indicated that, although a few eels remained in Karāpiro and Arapuni reservoirs, very few made it up the tributaries that were traditional eel fishing grounds for hapū/iwi (Bioresearches 1994).

In response to increased pressures on the lower Waikato River commercial eel fishery and hapū/iwi concerns about the decline of customary catches, a series of initiatives were started in 1991–92 that aimed to increase the overall biomass of the eel fishery and improve the availability for all (see Allen 2010 for details). These initiatives included the stocking/enhancement of the Waikato hydro-reservoirs. Once negotiations and permits were issued by the Ministry of Agriculture and Fisheries [now Fisheries New Zealand], 110 kg of elvers were captured from the base of Karāpiro Dam and released into the Karāpiro reservoir in early January 1993. Further consultation led to the amendment of the permit to include transfers to Lake Arapuni in February 1994. The special permit issued in January 1995 included the seven lowermost reservoirs (i.e., excluding Lake Aratiatia), with the first transfer made to Waipāpa and Maraetai in summer 1994–95. The first official transfer to lakes Whakamaru, Ātiamuri, and Ohakurī did not occur until summer 1996–97. The maximum quantity of juvenile eels that could be released at these sites annually were as follows: Lake Karāpiro (no limit), Lake Arapuni (550 kg), Lake Waipāpa (100 kg), Lake Maraetai (250 kg), Lake Whakamaru (450 kg), Lake Ātiamuri (140 kg), and Lake Ohakurī (750 kg). The special permits to transfer elvers into the seven hydro-reservoirs continued in varying forms until summer of 2017–18 when, at the request of Ngāti Tahu-Ngāti Whaoa Runanga Trust, the two uppermost reservoirs were excluded as permitted elver stocking/enhancement sites.

Between 1992–93 and 2011–12, when this study was initiated, it is estimated that around 26 831 000 juvenile eels (approximately 19% longfin) were captured and transferred upstream from Karāpiro Dam (Martin & Bowman 2016). Over the first 20 years of the Karāpiro trap-and-transfer programme, the majority (67%) of juvenile eels were transferred into three hydro-reservoirs: Karāpiro (29%), Arapuni (20%), and Ohakurī (19%) (Figure 4).

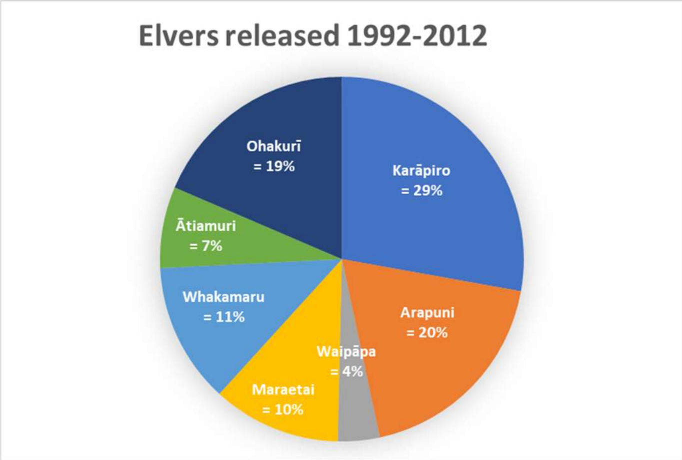

Figure 4: Estimated proportion of juvenile eels transferred into each of the Waikato River hydro-reservoirs between 1992 and 2012. During this period, it is estimated that around 26 831 000 juvenile eels (approximately 19% longfin) were captured and transferred upstream from Karāpiro Dam (source: Martin & Bowman 2016).

Early indications of the effect of juvenile eel stocking were very positive, with an increased abundance of commercial-sized eels and accelerated growth rates observed in the enhanced reservoirs, which are part of Fisheries Management Area SFE 21 (shortfin) and LFE 21 (longfin) (Beentjes et al. 1997, Boubée et al. 2003, Boubée & Jellyman 2009). Accordingly, the commercial eel industry anticipated that the hydro-reservoirs would be important additions to the areas available for commercial fishing; and that this, in turn, could reduce commercial fishing pressure on downstream reaches of the Waikato River. However, despite the implementation of the Karāpiro elver trap-and-transfer programme, the commercial harvest from the enhanced hydro-reservoirs in more recent times is substantially less than members of the commercial eel industry anticipated. Boubée et al. (2003) noted that slower growth rates would be expected if stocking densities exceeded food availability. In addition, power station operators have observed that many of the elvers that are released continue to migrate upstream and accumulate at the base of the next power station, where further mortality occurs through desiccation on the dam face as well as predation by fish, birds, and rodents.

One approach that has been proposed to reduce loss of elvers, and perhaps discourage their tendency to migrate upstream towards the next dam, is to make some releases directly into hydro-reservoir tributaries and associated ponds and wetlands. Such areas would provide the flowing water preferred by longfins (Jellyman et al. 2003) and wetlands/ponds preferred by shortfins (McDowall & Taylor 2000), which could lead to improved abundance and sizes of both species. However, upstream of Karāpiro Dam very little is known about the present status of the eel populations.

1.1 Project objectives

In December 2011, the predecessor of Fisheries New Zealand contracted NIWA (project EEL2011-01) to establish the status of eel populations in two Waikato hydro-reservoirs (where elvers have been stocked) and their associated tributaries. The specific objective of the study as defined in the project description was:

- To establish the distribution, population structure and growth rate of eels in tributaries of two of the middle Waikato systems (preferably tributaries of lakes Karāpiro and Whakamaru that have special cultural and traditional significance) and compare findings with records obtained in the hydro reservoirs.

The project was undertaken in partnership with Ngāti Koroki Kahukura, Raukawa, the Te Arawa River Iwi Trust, Waikato-Tainui, and the Eel Enhancement Company (EECo), with co-funding provided by

Mercury Energy (Waikato River Iwi Summer Internship Programme) and the Ministry of Business, Innovation and Employment (MBIE) (Contract No. C01X1002).

1.2 Project limitations

The project's Specific Objectives stated that eel survey efforts should preferably target the tributaries of lakes Karāpiro and Whakamaru and to compare eel distribution, population structure, and growth rates between the tributaries and the hydro-reservoirs. However, there were several sampling and logistical limitations which prevented robust comparisons of eel populations between all tributaries and all the lakes. In particular:

1. The project endeavoured to set fine- and coarse-mesh fyke nets in both the hydro-reservoirs and tributaries of Lake Karāpiro and Whakamaru so that eel populations could be directly compared between tributaries and hydro-reservoirs as per the project objectives. However, most tributaries of Lake Karāpiro and Whakamaru proved too small to set fyke nets effectively. Where a tributary could be fished with fyke nets, invariably the space available to set a net was very restricted. Electric fishing was therefore the only method that could consistently be used to survey the tributaries of Lake Karāpiro and Whakamaru. Unfortunately, electric fishing could not be completed in the lakes because they are too deep, which means the results from electric fishing surveys in tributaries and fyke netting data from the lakes could not be directly compared. Similarly, tributaries of Lake Ātiamuri could not be surveyed using fyke netting methods, which limited comparisons between hydro-reservoirs and tributaries for the Lake Ātiamuri catchment.
2. The eel population in Lake Karāpiro was not surveyed in this project because a comprehensive eel dataset already existed (Matheson et al. 2010), which was reused in this study. These eel surveys were completed as part of monitoring undertaken for an aquatic macrophytes control programme undertaken by Land Information New Zealand (LINZ) between 2007 and 2010 (see Matheson et al. 2010). This existing dataset was therefore re-examined in the context of this project. This was done so that efficiencies could be gained, and survey efforts redirected to parts of the catchment (i.e., Arapuni and Ātiamuri) where fyke netting of the tributaries was more likely to be successful, while also surveying sites with knowledge gaps in the eel populations.
3. Because of the low eel numbers observed in many of the tributaries, the hapū/iwi partners requested that all eels captured in the tributaries be returned live at the place of capture, so no ageing was possible. This meant that age and growth rates could not be compared amongst tributary sites, or between tributaries and the hydro-reservoirs.

Given all of the aforementioned limitations and the limited datasets available, our comparison of the eel population between tributaries and hydro-reservoirs was focused on the Karāpiro catchment only. Characteristics of the eel populations from the other hydro lakes (i.e., excluding Lake Karāpiro) are described in this study (i.e., distribution, population structure, and growth rates), and where possible, these results are compared with historical records.

2. METHODS

2.1 Survey overview

In the Whakamaru hydro-reservoir catchment, eel populations in both the lake and tributaries were surveyed. Eel populations in the tributaries of Lake Karāpiro were surveyed but not the lake itself (see Section 1.2). In the Arapuni hydro-reservoir catchment, both the lake and the tributaries were surveyed, whereas only the lake populations in the Ātiamuri hydro-reservoir catchment were examined.

It was necessary to use a mixture of electric fishing and fyke netting to sample eel populations in the tributaries and lakes of each hydro-reservoir. A summary of habitats sampled and the different fishing methods used is given in Table 1. At present, there is no single survey method that can sample all eel size classes effectively across the range of freshwater habitats they occupy (e.g., lakes, river mainstems, and streams of varying depth, water velocity, and macrophyte cover). Electric fishing is typically more effective in shallow streams, especially where elvers are present, whereas fyke nets are typically more effective for deeper waters with larger eels. In the lakes, different fyke net types and means of deployment were used to account for variability in depth, flow, and substrate (see Section 2.2). Consequently, a direct comparison of the distribution and population structure of eels between tributaries and lakes in the hydro-reservoir catchments by quantifiable means is not possible (see explanation in Section 1.2.)

Table 1: Summary of the hydro-reservoirs and survey methods used to examine eel populations in this study.

Hydro-reservoir	Fyke netting in lake	Electric fishing of tributaries	Fyke netting of tributaries
Karāpiro	x	✓	✓
Arapuni	✓	✓	✓
Whakamaru	✓	✓	x
Ātiamuri	✓	x	x

2.2 Survey areas and techniques

Electric fishing of tributaries

Electric fishing surveys of Karāpiro, Arapuni, and Whakamaru hydro-reservoir tributaries were conducted over three time periods between December 2011 and November 2012.

- Five Karāpiro tributaries were surveyed between 21 December 2011 and 8 February 2012. These were: Mangakara (1 reach), Huihuitaha (5 reaches), Raparahi (a tributary of the Waipā 3 reaches), Waipā (2 reaches), and an unnamed tributary near Arapuni township (1 reach).
- Seven Arapuni tributaries were surveyed between 17 and 20 January 2012. These were: Makomako (1 reach), Mangare (4 reaches), Mangawhio (3 reaches), Ngautaramoa (3 reaches), Te Rimu (1 reach), Tumai (1 reach), and unnamed tributary A1 (1 reach).
- Eleven Whakamaru tributaries were surveyed between 26 and 30 November 2012. These were: Mangatutu (1 reach), Maraemanuka (2 reaches), Mokautere (2 reaches), Okama (3 reaches), Ongarahu (1 reach), Opareiti (3 reaches), Potungutungu (2 reaches), Te Rakau (1 reach), Waiharuru (1 reach), Waipāpa (4 reaches), and unnamed tributary W1 (1 reach).

At each tributary, electric fishing was conducted in between one and five reaches depending on access and availability of suitable habitat. A Kainga EFM300 battery powered backpack electric fishing machine (EFM) fitted with a single pole-mounted anode was used to fish 15- to 60-m long reaches of accessible stream during daylight hours (machine set on 200 to 300 volts, pulse rate 60 pps and pulse width 2 ms). Details of the surveyed tributaries and fishing effort are given in Appendices 1 and 2.

Beginning at the downstream end of each reach, a small, roughly 4-m long section was electric-fished into a one-metre-wide hand-held stop net. A dip net was also used to quickly remove any fish attracted to the anode. This process was then repeated across the entire width of the stream before progressing upstream. All available habitats within each reach were fished without bias, including shallow margins that may have appeared to be devoid of fish. A combination of single- and multiple-pass fishing was used, depending on the catches obtained, with passes repeated until all fish present were considered to have been removed. Where eels appeared to be absent or present in very low densities, some spot fishing outside the reach was also used to target typical eel habitats (e.g., undercut banks and logjams) to confirm this. All of the catch was placed into a bucket filled with water from the stream before being identified, measured, and generally returned unharmed to the stream.

Fyke netting of tributaries and hydro-reservoirs

A combination of fine (4-mm mesh) and coarse (12-mm mesh) fyke nets with 600-mm drop, D opening, double funnelled and 5-m single leaders were used to sample eel populations in the tributaries and hydro-reservoirs (Table 2). Net types and setting arrangements used were as follows:

- CO = Single-cod commercial eel coarse-mesh fyke with an escapement tube;
- DCO = Double-cods commercial eel coarse-mesh fyke nets set leader to leader (in a linear arrangement), also with an escapement tube;
- DC = Double-cods coarse-mesh fyke nets set leader to leader;
- DF = Double-cods fine-mesh fyke nets set leader to leader;
- SC = Single-cod coarse-mesh fyke nets; and
- SF = Single-cod fine-mesh fyke nets.

The double-cods nets (DCO, DC, and DF) were all set in the deeper water of the hydro-reservoirs but were treated as one set (one of the nets always captured more fish than the other). Coarse-mesh nets (DC) were set where high flows were encountered. Single-cod nets tended to be used along the shoreline and in tributaries, but always so they remained submerged, notably in the reservoirs during lake drawdown. Each net was tagged with a clip-on numbered label that was transferred to the holding bag when the nets were emptied. All nets were baited with rudd or pierced cat food sachets and left to fish overnight.

Single-cod fyke nets were the only net type used in the tributaries where the water depth was more than 600 mm. In the Karāpiro catchment, five tributaries were sampled using fyke nets, but in the Arapuni catchment only one tributary was large enough for fyke nets to be deployed (Table 2). The fyke nets were all set with the cod end upstream. Fine-mesh fykes were preferred because they can catch a wider range of fish species and sizes, but they could only be set where water velocities were low enough so as not to displace the net. Consequently, coarse-mesh fykes were also set where needed.

Table 2: Summary of single-cod fyke net types and numbers used to survey eel populations in the tributaries of Karāpiro and Arapuni hydro-reservoirs. Refer to text for description of net type codes.

Hydro-reservoir	Tributary	No. & type of net	Date sampled
Karāpiro	Waipā	2 x coarse-mesh (SC)	17 November 2011
	Mangakara Site 1	3 x coarse-mesh (SC) 2 x fine-mesh (SF)	21 December 2011
	Mangakara Site 2	3 x coarse-mesh (SC) 2 x fine-mesh (SF)	22 December 2011
	Waitete	2 x coarse-mesh (SC) 1 x fine-mesh (SF)	22 December 2011
	Huihuitaha (upper)	7 x fine-mesh (SF)	26 January 2012
	Huihuitaha (lower)	7 x fine-mesh (SF)	27 January 2012
	Rapahi (trib. of Waipā)	7 x fine-mesh (SF)	1 February 2012
Arapuni	Mangare	3 x coarse-mesh (SC) 1 x fine-mesh (SF)	22 December 2011

A combination of commercial fine- and coarse-mesh fyke nets were used in the three hydro-reservoirs that were surveyed during the study (Table 3). The locations of the fyke nets set in each hydro-reservoir are shown in Figures 5–8.

Table 3: Summary of fyke-net types, numbers, and survey methods used to examine eel populations in three hydro-reservoirs. Refer to text for description of net type codes.

Hydro-reservoir	No. & type of net	Date sampled	No. of overnight sets	Total no. of nets
Arapuni	8 x CO, 5 x DCO, 37 x DC, 13 x DF, 15 x SC, 33 x SF	10–20 December 2012	8	111
Arapuni	8 x DCO, 8 x DC, 32 x SC, 27 x SF,	3–7 February 2013	4	75
Ātiamuri	6 x CO, 5 x DC, 2 x DF, 1 x SC, 1 x SF	22–23 February 2012	1	15
Whakamaru	15 x CO, 14 x DC, 4 x DF, 10 x SF	19–22 February 2012	3	43

Figure 5: Location of the fyke nets set in Lake Arapuni, 10–20 December 2012. (Map Source: Google Earth)

Figure 6: Location of the fyke nets set in Lake Arapuni, 3–7 February 2013. The middle section of the lake was not fished on this occasion because of high public use of this reach and the associated risk of nets being disturbed and/or causing safety issues. (Map Source: Google Earth)

Figure 7: Location of the fyke nets set in Lake Ātiamuri, 22–23 February 2012. (Map Source: Google Earth)

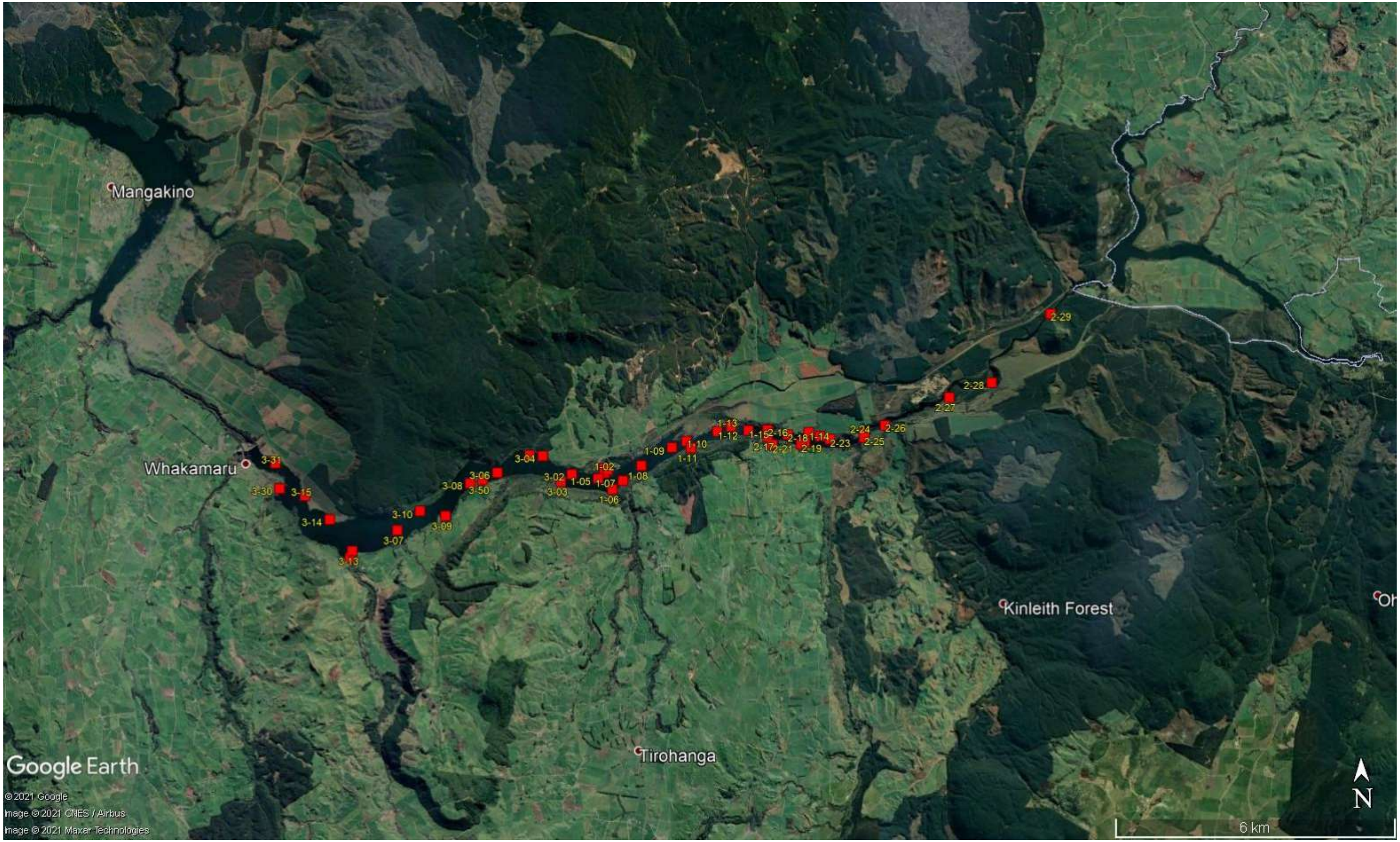

Figure 8: Location of the fyke nets set in Lake Whakamaru, 19–22 February 2012. (Map Source: Google Earth)

2.3 Data collection

Catches from individual reaches and fyke nets were processed separately. All the fish caught were anaesthetised using a fish anaesthetic approved for use in foods (AQUIS®) and identified by species. All eels were measured (to the nearest 1 mm) and most weighed (to the nearest 5 g). Following processing, the eels were revived in fresh water and returned to the waterway, except for 133 longfins and 203 shortfins from the hydro-reservoirs that were euthanised with an overdose of anaesthetic so their otoliths could be removed for ageing to determine growth rates.

Eel age was determined by counting the number of annual hyaline rings of the otolith across the largest axis, ignoring the first ring (freshwater check) that surrounds the core which represents the marine larval growth stage. Otoliths were prepared using the crack and burn method described by Hu & Todd (1981) and revised by Jellyman et al. (2007). Essentially, this method involves breaking the otolith in half with a scalpel blade. The otolith halves are then burnt by placing them on a scalpel blade over a Bunsen flame until they turn brown. Following burning, the otoliths are embedded in clear silastic 732 RTV with the broken edge pressed against a glass slide. Mounted otoliths are viewed using a compound microscope, and the annual rings counted. Ages were independently determined by two readers and then compared for agreement in age estimates. Where differences between readers occurred, the otolith was re-examined, discussed, and an agreed age was assigned.

The habitat characteristics of each electric-fished reach were recorded according to standard procedures used in the New Zealand Freshwater Fish Database (NZFFD). Stream width and water depth measurements were taken in mid-stream at the top and bottom of the reach. Single spot measurements of conductivity and water temperature were taken at most sites with a hand-held YSI water monitoring meter.

Lake Karāpiro eel survey (LINZ dataset)

Lake Karāpiro itself was not surveyed in this study. Instead, the datasets generated by the aquatic macrophytes control programme undertaken by Land Information New Zealand (LINZ, see Matheson et al. 2010) were used. Between 2007 and 2010 four zones in Lake Karāpiro were netted using three single-cod coarse-mesh and three fine-mesh fyke nets set overnight, both before and after weed spraying events. The four zones were: Lower control, Lower treatment, Upper control, and Upper treatment (e.g., Figure 9). The dates fished were as follows:

- 2007a: 9 May for pre-spraying and 27 June for post-spraying.
- 2007b: 29 August for pre-spraying and 25 October for post-spraying.
- 2008: May for pre-spraying and 13 June for post-spraying.
- 2009: 5 May for pre-spraying and 30 June for post-spraying.
- 2010: 7 April for pre-spraying and 27 May for post-spraying.

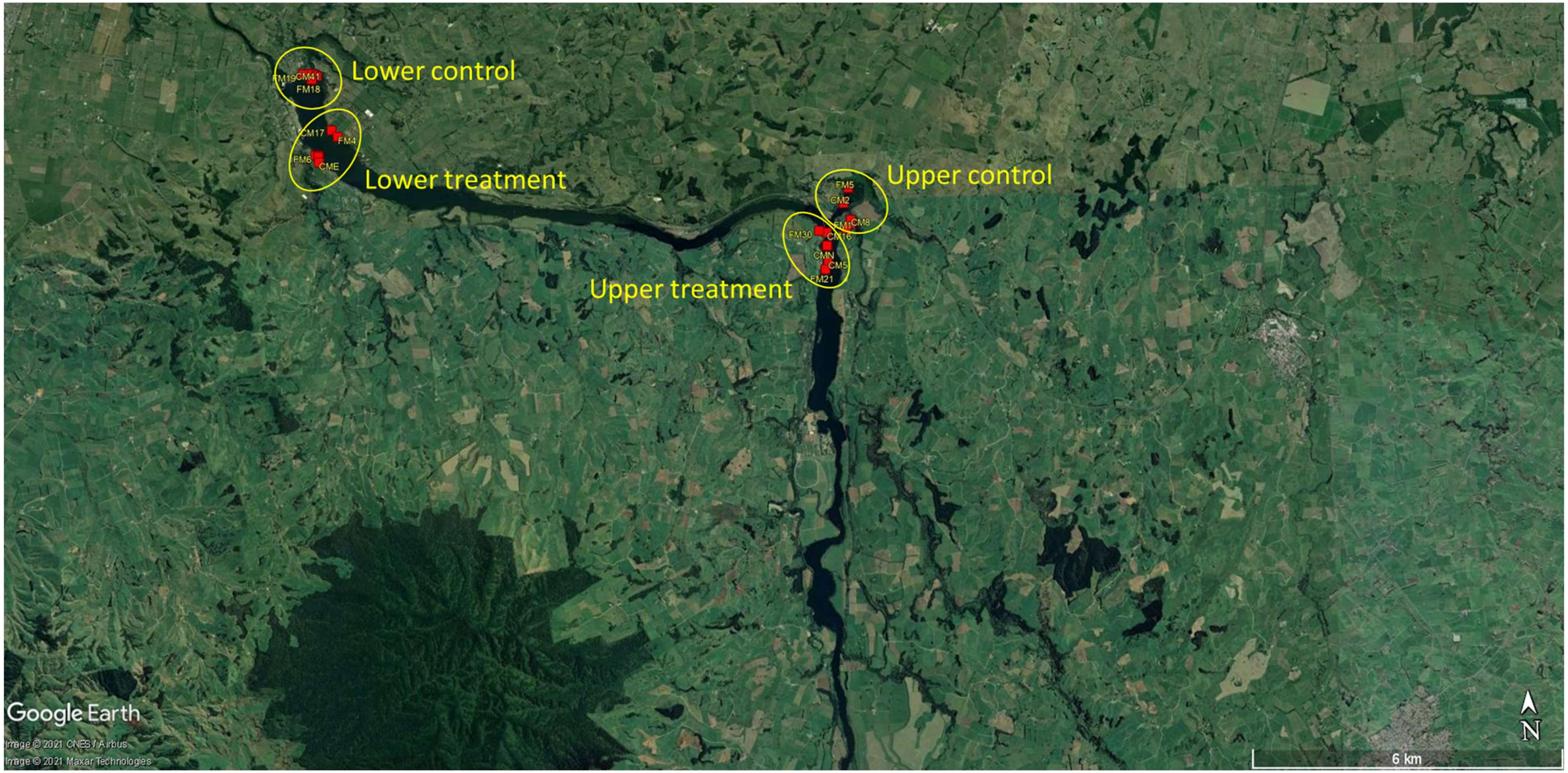

Figure 9: Location of the fyke nets set in Lake Karāpiro for LINZ weed control monitoring surveys between 2007–2010. (Map Source: Google Earth)

2.4 Data analysis

To establish the distribution and the population structure of eels in the tributaries, and compare these with records obtained in the reservoirs, the following attributes were examined: Species distribution, size distribution, and relative abundance in term of number and biomass. For the purpose of the present eel catch analysis, catches from the sprayed zones were omitted.

Length-weight relationships

Length versus weight plots were used to identify outliers. These were point-checked against field records and excluded where the source of the error could not be resolved. Once groomed for errors, data were transformed (natural log, ln) and the length-weight relationship was derived for each eel species using the least squares linear regression method. Where actual weights were not measured in the field, the length-weight relationships were used to calculate individual eel weights to derive catch biomass estimates.

Relative abundance

Catch per unit effort (CPUE) is an index of abundance that is commonly used to examine and compare the status of eel fisheries (Jellyman & Graynoth 2005). Two CPUE indices were derived: one for electric fishing data (from the tributaries) and one for fyke net data. Electric fishing data were expressed as number and weight of eels per 100 m^2 of stream, and fyke net data were expressed as the number and weight of eels captured per fyke net per night for each species caught. Where several reaches within one tributary were fished, CPUE was derived by combining all records for that stream. For fyke nets, CPUE was derived for each net type, and also for the combination of all the nets. All double-cod sets (DC, DF, and DCO) were treated as one net for CPUE calculations because one of the nets always captured more fish than the other.

Size distribution

Eel size distribution is influenced by the mesh size of the fyke nets used, while with electric fishing, habitat type and the ability to see and retrieve the fish will influence the size of fish caught. Habitat dictated what type of nets could be deployed, but as far as possible the aim was to standardise effort. For reporting size distribution of the fish captured, all the catch was amalgamated and the numbers of shortfins and longfins in 50-mm size classes were plotted.

Length-at-age

Eel growth was calculated from length-at-age data obtained from the otoliths that were extracted during the study. As described by Beentjes & Chisnall (1998), freshwater growth rates for eels were then calculated for each fish as mean annual length (millimetres) increase per year (i.e., total length at capture minus length at entry into fresh water divided by the estimated age of fish). For longfins, an arrival length of 63 mm was used and 60 mm for shortfins (Jellyman 1977). These calculations assumed that growth rate was not dependent on age given that growth rates have been shown to be linear in shortfin and longfin eels (Jellyman 1997).

3. RESULTS

3.1 Species distribution and total catch

Tributaries

Both fyke netting and electric fishing were used to determine the presence/absence of eels in the Karāpiro, Arapuni, and Whakamaru (electric fishing only) tributaries. Several of the tributaries accessed from the Karāpiro and Arapuni hydro-reservoirs by boat had waterfalls a short distance from the lake shore (Figure 10) and these were expected to restrict the upstream passage of fish, including eels. Generally, instream habitats below such waterfalls were mostly shaded, with gravelly substrates, and easily accessible to elvers from the reservoir (e.g., Makomako Stream, Figure 11). In contrast, upstream of the waterfalls the tributaries ran through mostly open pasture, had lower gradients, and the substrates consisted of sand and silt (e.g., Huihuitaha Stream**,** Figure 12).

Across all methods used (electric fishing and fyke netting), a total of 21 eels (81% longfin) were caught from five Lake Karāpiro tributaries. In comparison, 89 eels (88% longfin) were caught from eight tributaries surveyed around Lake Arapuni, and 37 eels (97% longfin) were caught from eleven Lake Whakamaru tributaries. The highest numbers of eels (mostly elvers) were observed from Makomako Stream in the Lake Arapuni catchment. Across the 47 reaches fished (12 reaches in Karāpiro; 14 reaches in Arapuni; 21 reaches in Whakamaru), a total of 55.9 kg of eels were caught, the majority (52%) coming from Arapuni tributaries. Where both eel species were present in the tributaries, longfins generally dominated the catch by number and by weight (Table 4). Longfins were also far more widely distributed than shortfins (Figure 13). Full details of eel catches obtained by electric fishing in the tributaries are provided in Appendices 1 and 2.

In addition to eels, common bullies (*Gobiomorphus cotidianus*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and kōura (*Paranephrops planifrons*) were observed in the hydro-reservoir tributaries. Cran's bullies (*G. basalis*) may have been present at some sites, but this could not be confirmed.

Figure 10: The Te Rimu Stream waterfalls taken from Lake Arapuni. (Photo: J. Smith)

Figure 11: The Makomako Stream, where the highest density of longfin eels (mostly elvers) was caught. This site is only a short distance from the edge of Lake Arapuni. (Photo: J. Smith)

Figure 12: Fine-mesh fyke net set in the Huihuitaha Stream. (Photo: B. Bartels)

Table 4: Total catch and species composition of eels caught using electric fishing and fyke netting from tributaries surveyed in the Karāpiro, Arapuni, and Whakamaru hydro-reservoir catchments between December 2011 and November 2012.

		Electric fishing				Fyke netting			Total eel catch		% longfin	
Hydro-reservoir	Tributary name	No. of reaches	Total area fished (m^2)	No. of shortfin	No. of longfin	No. nets	No. of shortfin	No. of longfin	No.	Weight (kg)	By number	By weight
Karāpiro	Huihuitaha Stream	5	407	3	1	14	1	2	7	9.90	43	65
	Mangakara Stream	1	60	0	0	11	0	12	12	30.38	100	100
	Raparahi Stream	3	60	0	0	7	0	0	0	0.00	–	–
	Unnamed tributary K1	1	30	0	0	–	–	–	0	0.00	–	–
	Waipā Stream	2	120	0	0	2	0	2	2	10.92	100	100
	Waitete Stream	–	–	–	–	2	0	4	4	3.34	100	100
	All Karāpiro tributaries	**12**	**677**	**3**	**1**	**36**	**1**	**20**	**25**	**54.54**	**84**	**94**
Arapuni	Makomako Stream	1	90	2	47	–	–	–	49	1.83	96	99
	Mangare Stream	4	258	7	6	2	0	11	24	21.29	71	91
	Mangawhio Stream	3	165	0	1	–	–	–	1	0.01	100	100
	Ngautaramoa Stream	3	159	4	2	–	–	–	6	0.36	67	97
	Te Rimu Stream	1	90	0	2	–	–	–	2	0.12	100	100
	Tumai Stream	1	30	0	1	–	–	–	1	1.11	100	100
	Unnamed tributary A1	1	90	0	3	–	–	–	3	0.85	100	100
	All Arapuni tributaries	**14**	**882**	**13**	**62**	**2**	**0**	**11**	**86**	**25.58**	**85**	**93**
Whakamaru	Mangatutu Stream	1	75	0	1	–	–	–	1	0.95	100	100
	Maraemanuka Stream	2	276	0	9	–	–	–	9	2.66	100	100
	Mokautere Stream	2	285	0	2	–	–	–	2	2.15	100	100
	Okama Stream	3	264	0	2	–	–	–	2	0.51	100	100
	Ongarahu Stream	1	30	0	0	–	–	–	0	0.00	–	–
	Opareiti Stream	3	330	0	13	–	–	–	13	2.24	100	100
	Potungutungu Stream	2	95	0	0	–	–	–	0	0.00	–	–
	Te Rakau Stream	1	45	0	8	–	–	–	8	0.04	100	100
	Unnamed tributary W1	1	20	0	0	–	–	–	0	0.00	–	–
	Waiharuru Stream	1	20	0	0	–	–	–	0	0.00	–	–
	Waipāpa Stream	4	560	1	1	–	–	–	2	0.59	50	98
	All Whakamaru tributaries	**21**	**2 000**	**1**	**36**	**0**	**0**	**0**	**37**	**9.14**	**97**	**100**

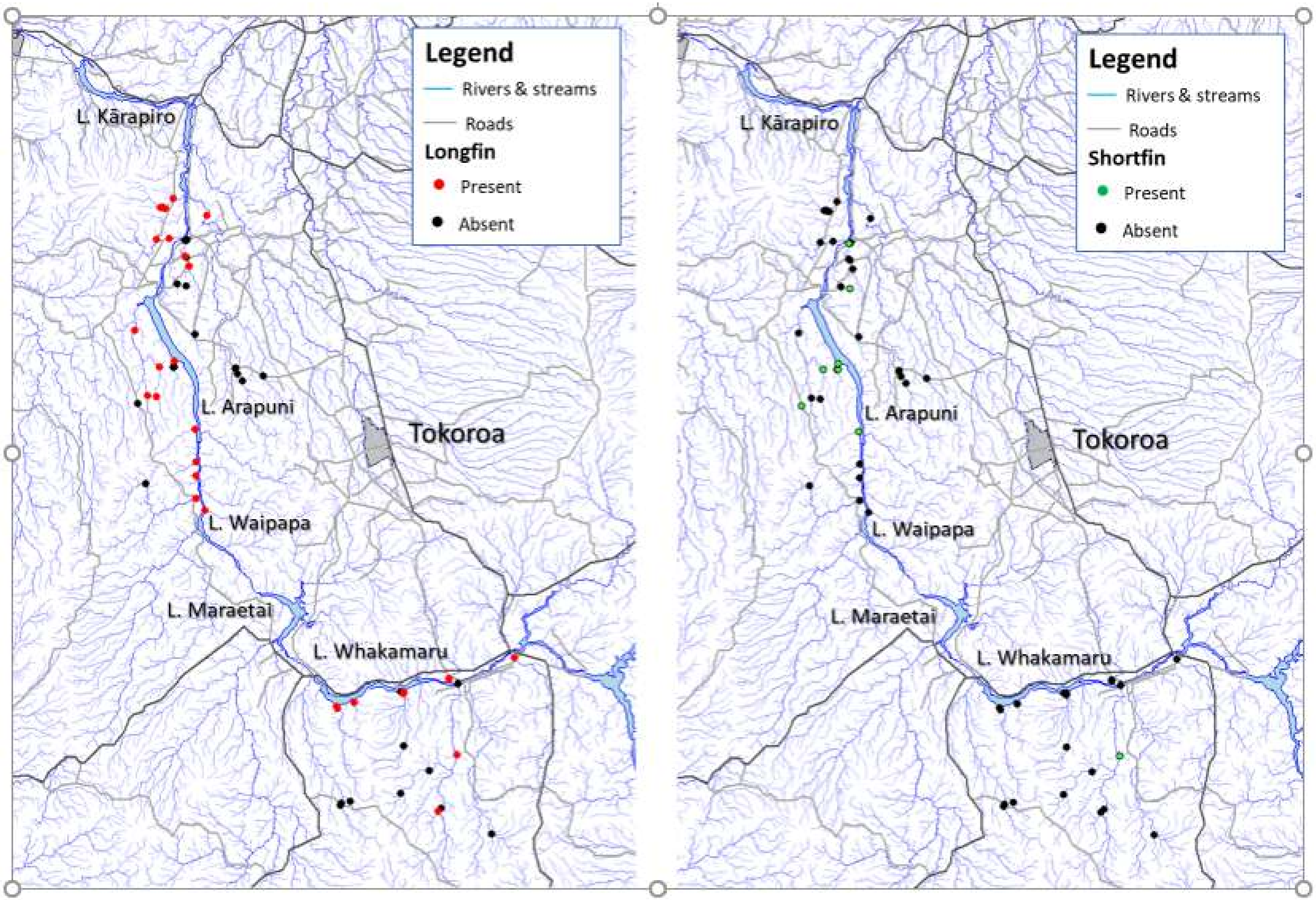

Figure 13: Locations of tributary reaches fished where longfins (left) and shortfins (right) were observed during electric fishing only between December 2011 and November 2012.

Hydro-reservoirs

In Lake Arapuni, a total of 4446 eels (1394 kg; 29% longfins by number) were caught over 12 nights with fyke nets. In Lake Whakamaru, 1102 eels (404 kg; 18% longfins by number) were caught over two nights. In Lake Ātiamuri, 277 eels (149 kg; 36% longfins by number) were caught after one night fishing. In Lake Karāpiro, a total of 1004 eels (417 kg; 5.7% longfins by number) were caught over ten sampling occasions between May 2007 and May 2010 (Matheson et al. 2010). In Arapuni, Whakamaru, and Ātiamuri hydro-reservoirs, shortfins generally dominated the catch by weight and number (Tables 5 and 6). In addition to eels, common bullies, brown trout, catfish (*Ameiurus nebulosus*), goldfish (*Carassius auratus*), and rudd (*Scardinius erythrophthalmus*) were captured in the reservoirs.

Table 5: Number of shortfins and longfins, total weight and species composition of eels captured in fyke nets set in the Arapuni, Whakamaru, and Ātiamuri hydro-reservoirs between February 2012 and February 2013.

Hydro-reservoir	Date	No. of nets	Number		Total eels		% Longfins	
			Shortfin	Longfin	Number	Weight (kg)	By number	By weight
Arapuni	Dec 2012	111	2 417	1 053	3 470	1 124	30	27
	Feb 2013	75	759	217	976	270	22	27
Whakamaru	Feb 2012	43	907	195	1 102	404	18	15
Ātiamuri	Feb 2012	15	177	100	277	149	36	50

Table 6: Number of shortfins and longfins, total weight and species composition of eels captured in fyke nets set in the Karāpiro hydro-reservoir between May 2007 and May 2010. (Data courtesy of LINZ, see Matheson et al. 2010.)

Hydro-reservoir	Date	No. of nets	Number		Total eels		% Longfins	
			Shortfin	Longfin	Number	Weight (kg)	By number	By weight
Karāpiro	May 2007	24	74	5	79	41.9	6.3	5.6
	Jun 2007	12	1	1	2	1.0	50	14.4
	Aug 2007	24	55	6	61	34.5	9.8	8.7
	Oct 2007	12	51	5	56	31.7	8.9	8.1
	May 2008	24	148	13	161	63.0	8.1	5.2
	Jun 2008	12	36	2	38	19.3	5.3	13.2
	May 2009	24	118	6	124	51.9	4.9	3.1
	Jun 2009	12	41	3	44	17.5	6.8	3.3
	Apr 2010	24	331	8	339	121.6	2.4	1.9
	May 2010	6	100	8	100	34.4	8	7.2

3.2 Catch per unit effort

Tributaries

In tributaries, electric fishing CPUE in terms of numbers varied from 0.00–52.22 longfins per 100 m^2 and 0.00–2.52 shortfins per 100 m^2. For biomass, the CPUE varied from 0–2.72 kg longfins per 100 m^2 and 0–0.73 kg shortfins per 100 m^2 (Table 7). CPUE, both in terms of numbers and weight, was markedly higher for longfins than for shortfins in tributaries of the Arapuni and Whakamaru catchments, but shortfins dominated electric fishing catches from the Karāpiro catchment.

Fyke net catches were extremely variable, but where eels were present, longfins dominated catches (Tables 8 and 9). Coarse-mesh fykes tended to catch more longfins than fine-mesh ones, but this difference is most likely due to where each type of net could be set rather than mesh size.

Examining the records from both electric fishing and fyke netting, it appears that habitat type, access for recruits, and size of eels present affects CPUE the most. The effect of access was particularly evident in the Waipā Stream where no eels were caught in the upper reaches (the Waipā Stream flow underground in its lower reaches).

Table 7: Catch per unit effort (CPUE, by number and by weight) for eels caught by electric fishing the tributaries of Karāpiro, Arapuni, and Whakamaru reservoirs between December 2011 and November 2012.

Reservoir	Tributary name	Number per 100 m^2		Weight (kg) per 100 m^2	
		Shortfin	Longfin	Shortfin	Longfin
Karāpiro	Huihuitaha Stream	0.74	0.25	0.692	0.313
	Mangakara Stream	0.00	0.00	0	0
	Raparahi Stream	0.00	0.00	0	0
	Unnamed tributary K1	0.00	0.00	0	0
	Waipā Stream	0.00	0.00	0	0
	All Karāpiro tributaries	**0.44**	**0.15**	**0.416**	**0.183**
Arapuni	Makomako Stream	2.22	52.22	0.007	2.030
	Mangare Stream	2.71	2.33	0.729	2.722
	Mangawhio Stream	0.00	0.61	0	0.008
	Ngautaramoa Stream	2.52	1.26	0.007	0.218
	Te Rimu Stream	0.00	2.22	0	0.136
	Tumai Stream	0.00	3.33	0	3.690
	Unnamed tributary A1	0.00	3.33	0	0.944
	All Arapuni tributaries	**1.47**	**7.03**	**0.215**	**1.280**
Whakamaru	Mangatutu Stream	0.00	1.33	0	1.267
	Maraemanuka Stream	0.00	3.26	0	0.965
	Mokautere Stream	0.00	0.70	0	0.754
	Okama Stream	0.00	0.76	0	0.192
	Ongarahu Stream	0.00	0.00	0	0
	Opareiti Stream	0.00	3.94	0	0.679
	Potungutungu Stream	0.00	0.00	0	0
	Te Rakau Stream	0.00	17.78	0	0.097
	Unnamed tributary W1	0.00	0.00	0	0
	Waiharuru Stream	0.00	0.00	0	0
	Waipāpa Stream	0.18	0.18	2	0.104
	All Whakamaru tributaries	**0.05**	**1.80**	**1**	**0.457**

Table 8: Catch per unit effort (CPUE, by number) for eels caught in fyke nets set in Lake Karāpiro and Arapuni tributaries between December 2011 and February 2012.

Reservoir	Tributary	No. of nets[a]		CPUE (number/net/night)					
				Shortfin		Longfin		All nets	
		SC	SF	SC	SF	SC	SF	Shortfin	Longfin
Karāpiro	Huihuitaha	–	14	–	0.07	–	0.14	0.07	0.14
	Mangakara	6	5	0.00	0.00	1.67	0.40	0.00	1.09
	Raparahi	–	7	–	0.00	–	0.00	0.00	0.00
	Waipā	2	–	0.00	–	1.00	–	0.00	1.00
	Waitete	2	–	0.00	–	2.00	–	0.00	2.00
	All Karāpiro tributaries	**10**	**26**	**0.00**	**0.04**	**1.60**	**0.15**	**0.03**	**0.56**
Arapuni	Mangare	1	1	0.0	0.0	5.0	6.0	0.0	5.5

[a] SC = Single coarse-mesh fyke; SF = Single fine-mesh fyke; and –, type of net not deployed.

Table 9: Catch per unit effort (CPUE, by weight) for eels caught in fyke nets set in Lake Karāpiro and Arapuni tributaries between December 2011 and February 2012.

Reservoir	Tributary	No. of nets[a]		CPUE (kg/net/night)					
				Shortfin		Longfin		All nets	
		SC	SF	SC	SF	SC	SF	Shortfin	Longfin
Karāpiro	Huihuitaha	–	14	–	0.05	–	0.37	0.05	0.37
	Mangakara	6	5	0.00	0.00	4.73	0.40	0.00	2.76
	Raparahi	–	7	–	0.00	–	0.00	0.00	0.0
	Waipā	2	–	0.00	–	5.46	–	0.00	5.46
	Waitete	2	–	0.00	–	1.86	–	0.00	1.86
	All tributaries	**10**	**26**	**0.00**	**0.03**	**4.30**	**0.28**	**0.02**	**1.40**
Arapuni	Mangare	1	1	0.00	0.00	4.19	8.20	0.00	6.19

[a] SC = Single coarse-mesh fyke; SF = Single fine-mesh fyke; and –, type of net not deployed.

Hydro-reservoirs

The highest CPUEs both in terms of numbers and weight were recorded in Lake Arapuni in December 2012 and Lake Whakamaru in February 2012, respectively (Tables 10 and 11). The lowest CPUE for number and weight was in Lake Arapuni during February 2013 (for both species). In all reservoirs fished in 2012 and 2013, generally the highest CPUEs were obtained in the deeper sets where two nets were attached end to end (i.e., net types DC, DCO, DF). However, there was large variability in catches across all net types. The higher catches of these double-net arrangements was possibly because they were treated as a single net in CPUE calculations, but habitat differences are also likely (note for example that in Ātiamuri the highest CPUE was in the single fine-mesh fyke nets). Longfins tended to be more numerous in areas with a rocky bottom and near the dam; for example, one net set below Waipāpa Dam (i.e., in the Arapuni reservoir) in December 2012 caught 115 longfins (32 kg), but only 6 shortfins.

A close examination of Arapuni 2012 catch records showed that the area that could not be fished in 2013 due to high public use of this area, was productive, especially for shortfins (i.e., in 2012 the average CPUE in the middle reaches of Lake Arapuni was 31.8 shortfins per net and 8.5 longfins per net, whereas for the rest of the lake it was 18.4 and 9.8 respectively). Therefore, the decline in average CPUE observed between 2012 and 2013 could be explained by the inability to fish the most productive Lake Arapuni habitats.

Catches in Karāpiro reservoir between 2007 and 2010 (via the LINZ study) tended to be lower than the records collected in 2012 and 2013 from the next three reservoirs using the same type of nets (cf. Table 12 vs. Tables 10 and 11). Fewer habitats were included in the LINZ surveys compared to this study, but more importantly the LINZ surveys were completed mostly in autumn and winter when lower temperatures would have made the eels less active and less prone to capture. Therefore, it is unlikely that the density of eels in the Karāpiro reservoir is lower than in the next three reservoirs.

The percentage of longfins captured in the Karāpiro reservoir between 2007 and 2010 was also much lower than in the next three upstream reservoirs in 2012–2013. Again, it is anticipated that this difference is largely a function of habitat since the LINZ study was limited to a lower and middle reach of Lake Karāpiro, whereas this study covered the full extent of other reservoirs, including reaches with rocky substrates favoured by longfins.

Table 10: Catch per unit effort (CPUE, by number) for eels caught using a combination of six fyke net types set in lakes Arapuni, Whakamaru, and Ātiamuri between February 2012 and February 2013.

Hydro-reservoir	Year	Species	CPUE (number/net/night)[a]						All nets combined
			CO	DC	DCO	DF	SC	SF	
Arapuni	2012	Shortfin	12.4	29.5	20.8	25.2	15.9	16.9	21.8
		Longfin	4.3	12.4	5.4	10.9	11.3	6.8	9.5
Arapuni	2013	Shortfin	–	21.8	7.9	–	9.4	8.2	10.1
		Longfin	–	1.4	7.1	–	2.6	2.4	2.9
Ātiamuri	2012	Shortfin	6.0	13.4	–	20.5	3.0	30.0	11.8
		Longfin	8.2	4.2	–	6.5	14.0	3.0	6.7
Whakamaru	2012	Shortfin	21.6	26.4	–	13.5	–	16.0	21.1
		Longfin	3.3	6.5	–	3.0	–	4.2	4.5

[a], Net types used: CO = Commercial eel coarse-mesh fyke; DC = Double coarse-mesh fyke nets set leader to leader; DCO = Double commercial eel coarse-mesh fyke nets set leader to leader; DF = Double fine-mesh fyke nets set leader to leader; SC = Single coarse-mesh fyke; and SF = Single fine-mesh fyke.

Table 11: Catch per unit effort (CPUE, by weight) for eels caught using a combination of six types of fyke nets set in lakes Arapuni, Whakamaru, and Ātiamuri between February 2012 and February 2013.

Hydro-reservoir	Year	Species	CPUE (kg/net/night)[a]						All nets combined
			CO	DC	DCO	DF	SC	SF	
Arapuni	2012	Shortfin	6.6	9.5	12.1	7.7	5.5	5.4	7.4
		Longfin	1.7	3.3	2.9	2.7	3.4	1.9	2.7
Arapuni	2013	Shortfin	–	4.3	4.7	–	2.4	1.8	2.6
		Longfin	–	0.4	3.2	–	0.7	0.8	1.0
Ātiamuri	2012	Shortfin	3.7	3.8	–	10.1	1.1	11.0	4.9
		Longfin	8.3	1.2	–	3.6	10.2	2.1	5.0
Whakamaru	2012	Shortfin	11.9	7.4	–	3.8	–	4.6	8.0
		Longfin	1.6	1.7	–	0.7	–	1.1	1.4

[a], Net types used: CO = Commercial eel coarse-mesh fyke; DC = Double coarse-mesh fyke nets set leader to leader; DCO = Double commercial eel coarse-mesh fyke nets set leader to leader; DF = Double fine-mesh fyke nets set leader to leader; SC = Single coarse-mesh fyke; and SF = Single fine-mesh fyke.

Table 12: Catch per unit effort (CPUE, by number and by weight) for eels caught using two types of fyke nets set in the Karāpiro reservoir between 2007–2010. (Data courtesy of LINZ, see Matheson et al. 2010.)

Date	No. of each type of net	Species	CPUE (by number and kg/net/night)[a] No. SC	No. SF	Wt.(kg) SC	Wt.(kg) SF	All nets No.	All nets Wt. (kg)
May 2007	12	Shortfin	1.6	4.6	0.96	2.33	3.1	1.65
		Longfin	0.3	0.2	0.1	0.1	0.2	0.10
Jun 2007	6	Shortfin	0.0	0.2	0.00	0.14	0.1	0.07
		Longfin	0.2	0.0	0.02	0.00	0.1	0.01
Aug 2007	12	Shortfin	3.3	1.2	1.98	0.64	2.3	1.31
		Longfin	0.5	0.0	0.25	0.00	0.3	0.12
Oct 2007	6	Shortfin	4.7	3.8	2.64	2.21	4.25	2.43
		Longfin	0.5	0.3	0.21	0.22	0.4	0.21
May 2008	12	Shortfin	6.8	5.5	2.92	2.32	6.2	2.62
		Longfin	0.4	0.7	0.11	0.18	0.5	0.15
Jun 2008	6	Shortfin	3.5	2.5	1.86	0.93	3.0	1.39
		Longfin	0.2	0.2	0.30	0.12	0.2	0.2
May 2009	12	Shortfin	3.3	6.6	1.45	2.74	4.9	2.09
		Longfin	0.0	0.5	0.00	0.13	0.3	0.07
Jun 2009	6	Shortfin	2.8	4.0	1.16	1.66	3.4	1.41
		Longfin	0.5	0.0	0.10	0.00	0.3	0.05
Apr 2010	12	Shortfin	12.0	15.6	4.50	5.44	13.7	4.97
		Longfin	0.2	0.4	0.1	0.13	0.3	0.10
May 2010	6	Shortfin	5.2	10.2	1.87	3.46	7.7	2.67
		Longfin	1.0	0.3	0.27	0.14	0.7	0.20

[a] SC = Single coarse-mesh fyke; SF = Single fine-mesh fyke.

3.3 Length-weight relationships

The derived length-weight relationships for eels captured in the reservoirs surveyed between 2011 and 2013 are presented in Appendix 3. The slope of these relationships provides a measure of condition of the eels captured (i.e., how fat they are for a given length). As expected, the slope of the derived regressions was greater for longfins than for shortfins, indicating a greater weight for that species at any given length (i.e., better condition). Very little differences were observed between reservoirs, although shortfins from Lake Ātiamuri tended to be in better condition than in the other two reservoirs surveyed.

Records obtained in 2007–2010 through the LINZ study gave the derived length-weight relationship for shortfins in Lake Karāpiro as Ln (weight) = -14.121+3.1579*Ln (length). Shortfins in Karāpiro were therefore in very similar condition to those captured in the next three reservoirs between 2011 and 2013 (see Appendix 3). In contrast, the derived relationship for longfins in the LINZ study was Ln (weight) = -16.191+3.5226*Ln (length) indicating that they were in better condition than in the three reservoirs surveyed between 2011 and 2013.

3.4 Population structure

The length and weight characteristics of all the eels measured (i.e., all net types combined) are presented in Tables 13 and 14. Length distributions are shown in Figures 14 and 15. Although elvers (i.e., less than 150 mm) were present at most of the sites in tributaries where eels were found, juvenile eels (i.e., less than 400 mm) represented less than 5% of the eels captured in the Karāpiro tributaries, but represented 70% and 62% of the catches from the Arapuni and Whakamaru tributaries, respectively.

Large longfins are piscivorous. They will feed on elvers and will also displace juveniles (Chisnall & Kalish 1993). The relatively high abundance of eels over 800 mm in the Karāpiro tributaries compared with the Arapuni and Whakamaru streams surveyed may, therefore, at least partially explain the lack of juveniles observed in the Karāpiro tributaries.

There was considerable variability in the size distribution of eels between reservoirs and between years. For example, in Lake Arapuni the proportion of juvenile eels (under 400 mm) in the catches was around 27% in 2013 but only 11% in 2012. In lakes Ātiamuri and Whakamaru that proportion was around 9% and 12%, respectively. With the exception of Lake Whakamaru, very few eels over 800 mm were observed across the reservoirs surveyed. These results cannot be attributed solely to differences in the proportion of fine-mesh nets used because, in Lake Arapuni for example, out of 111 nets set in 2012, 41% were fine mesh and in 2013 out of 75 nets, 36% were fine mesh. It was observed, however, that when large eels were present in a net, smaller eels tended to be less numerous. It appears, therefore, that small eels will avoid nets already holding large eels, but this observation needs to be fully tested. Commercial harvest, which currently targets larger eels, would of course also affect population densities and size structures.

Table 13: Length characteristics of all eels (irrespective of capture method) measured from selected Waikato River hydro-reservoir habitats between December 2011 and February 2013. Records obtained from the Karāpiro reservoir between 2007 and 2010 are also shown.

Catchment	Habitat	Shortfin length (mm)				Longfin length (mm)			
		Number	Average ± SD	Median	Range	Number	Average ± SD	Median	Range
Karāpiro	Tributaries	4	745 ± 71	715	700–850	17	873 ± 270	940	130–1 200
	Reservoir[a]	1111	574 ± 110	577	250–910	77	491 ± 79	475	316–780
Arapuni	Tributaries	13	281 ± 208	155	90–650	77	296 ± 236	157	97–880
	Reservoir	3176	515 ± 111	514	186–930	1269	471 ± 78	468	218–1 016
Whakamaru	Tributaries	1	172	–	–	36	348 ± 194	305	110–750
	Reservoir	907	574 ± 122	554	212–957	195	482 ± 93	480	300–910
Ātiamuri	Reservoir	177	559 ± 122	565	235–920	100	598 ± 161	552	300–1 145

[a], LINZ records 2007 to 2010 (Matheson et al. 2010).

Table 14: Weight characteristics of all eels (irrespective of capture method) measured from selected Waikato River hydro-reservoir habitats between December 2011 and February 2013. Records obtained from the Karāpiro reservoir between 2007 and 2010 are also shown.

Catchment	Habitat	Shortfin weight (g)				Longfin weight (g)			
		Number	Average ± SD	Median	Range	Number	Average ± SD	Median	Range
Karāpiro	Tributaries	1	635	–	–	15	3 098 ± 1 862	2 900	720–6 772
	Reservoir[a]	111	432 ± 260	400	30–1 520	77	320 ± 222	250	50–1 425
Arapuni	Tributaries	5	372 ± 256	240	140–660	20	1 138 ± 701	880	140–2 400
	Reservoir	3171	322 ± 228	275	10–1 785	1 259	291 ± 218	250	17–3 380
Whakamaru	Tributaries	1	11	–	–	27	209 ± 231	160	2–880
	Reservoir	907	377 ± 252	340	15–1 740	195	317 ± 300	265	50–2 560
Ātiamuri	Reservoir	176	415 ± 280	375	40–1 770	100	782 ± 917	453	30–4 830

[a], LINZ records 2007 to 2010 (Matheson et al. 2010).

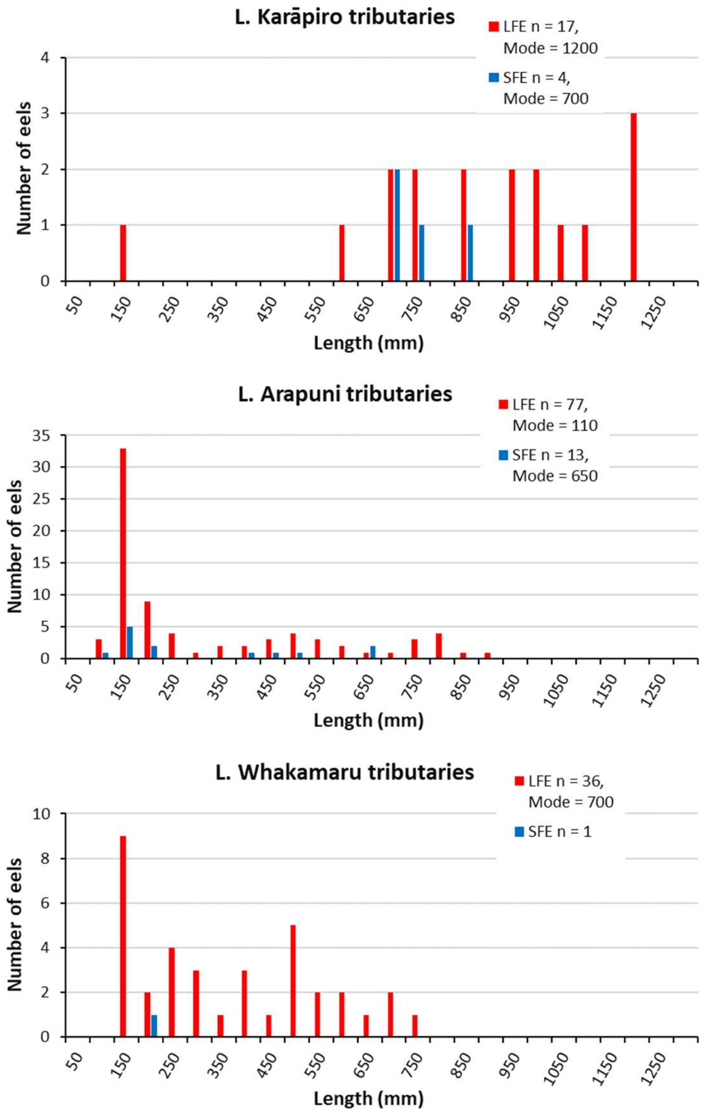

Figure 14: Length distribution of longfins (LFE) and shortfins (SFE) captured in tributaries of lakes Karāpiro, Arapuni, and Whakamaru between December 2011 and February 2013.

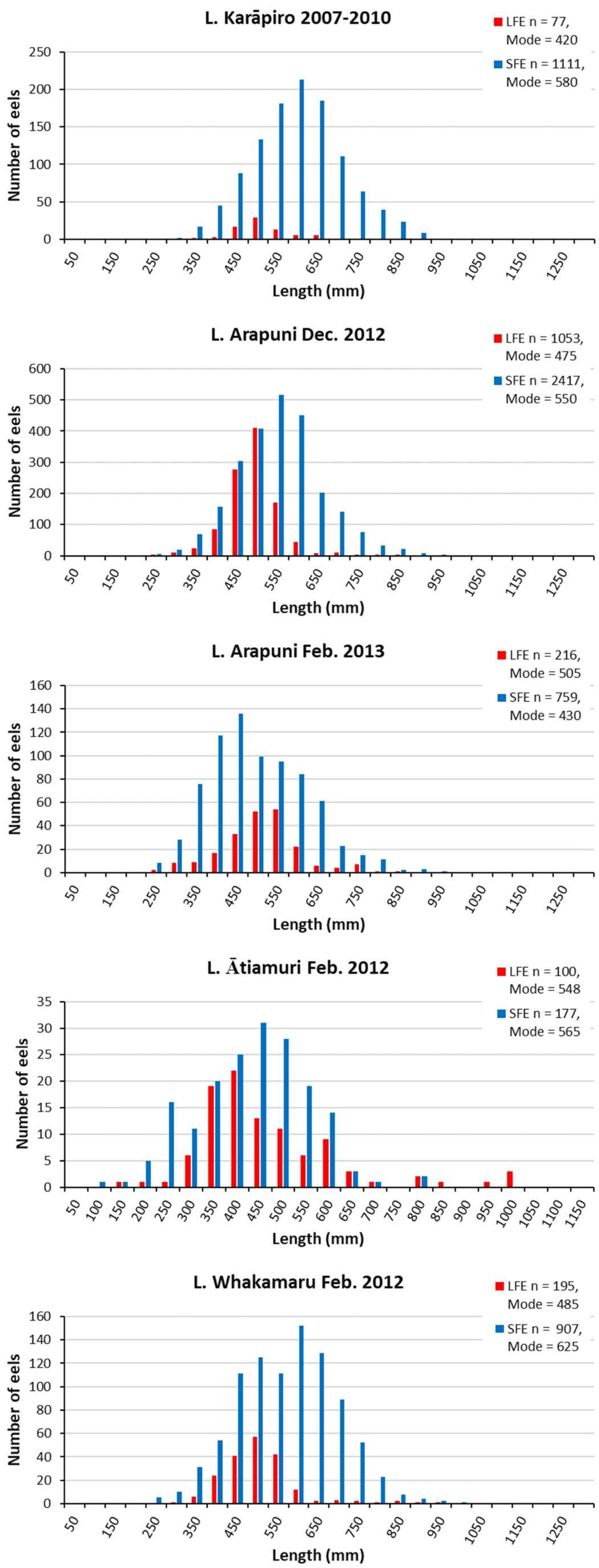

Figure 15: Length distribution of longfins (LFE) and shortfins (SFE) captured in lakes Arapuni, Ātiamuri, and Whakamaru between December 2011 and February 2013.

3.5 Growth

Because relatively few eels were captured in the tributaries, none were euthanised for the purposes of ageing at the request of the Waikato River hapū/iwi partners.

In the reservoirs, a total of 203 shortfins and 133 longfins were aged (Table 15). Growth rates were similar across the hydro-reservoirs (Figure 16), with both species of eel in Whakamaru showing a slightly faster growth rate than the other two hydro-reservoirs (Table 15). Growth in terms of length was linear but variability increased with age. For example, the length of a 16-year-old shortfin varied from 400 to 800 mm while a longfin of the same age could be 350 to 800 mm (Figure 16). Some of the Arapuni longfin age data suggest that growth is slower for fish above 12 years of age, but more data are required to verify this given the high amount of variability in length for fish older than 12 years.

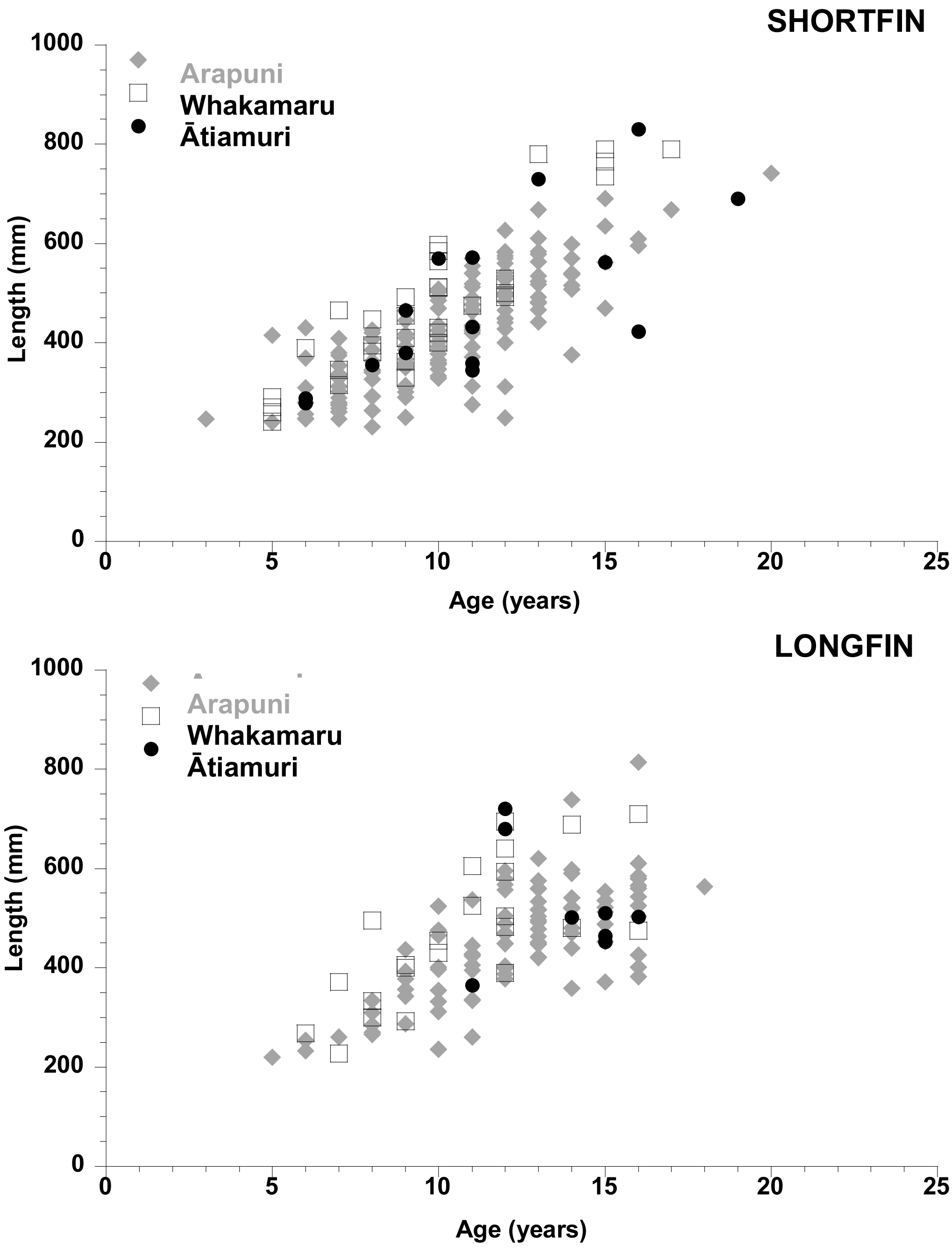

Figure 16: Age-length relationships for shortfins and longfins captured from the three hydro-reservoirs surveyed between February 2012 and February 2013.

Table 15: Growth (as mean annual length increment) and standard error (SE) of eels aged from three hydro-reservoirs surveyed between February 2012 and February 2013.

Reservoir	Shortfin					Longfin				
	Number aged	Length range (mm)	Age range (year)	Mean growth (mm/year)	SE	Number aged	Length range (mm)	Age range (year)	Mean growth (mm/year)	SE
Arapuni	153	231–742	3–20	36.0	0.6	100	220–814	6–18	31.8	0.6
Ātiamuri	15	279–830	6–19	37.7	2.3	9	365–720	11–16	33.9	3.7
Whakamaru	35	227–710	6–16	43.0	1.2	24	241–790	5–17	37.6	1.8

3.6 Comparison between tributaries and hydro-reservoirs

There is no single survey method that can sample all eel size classes effectively across the range of freshwater habitats they occupy. To meet the objectives of this study, the aim was to set fine and coarse-mesh fyke nets in both the reservoirs and the tributaries. Unfortunately, most tributaries proved too small to set fyke nets effectively and records were collected from only five tributaries in the Karāpiro catchment and one tributary in the Arapuni catchment (Table 8). No fyke nets could be set in the tributaries of Ātiamuri and Whakamaru. Where a tributary could be fished with fyke nets, invariably the space available to set a net was very restricted. Furthermore, the hapū/iwi partners requested that all eels captured in the tributaries be returned to live at the place of capture, so no ageing was possible. Therefore, given the limited datasets available, the comparison between tributaries and reservoirs focused on the Karāpiro catchment only.

This survey was undertaken in summer when eels are most active. Consequently, for the comparison between reservoirs and tributaries, only the April/May 2010 records from the LINZ survey of the Karāpiro reservoir were used (Tables 16 and 17). Although it was expected that fine-mesh nets would capture more juvenile eels than coarse-mesh fykes, records from Karāpiro reservoir indicated that the size distribution of shortfins (the most numerous of the two eel species present) in the two types of nets deployed was very similar (Figure 17). Furthermore, there were no statistical differences in CPUE between the two types of nets set in the reservoir (two sample t-Test with unequal variance, df = 164, t = 1.008, p = 0.157). On that basis, catches from both net types were treated as similar for further comparisons between the two habitats.

Table 16: Catch per unit effort (CPUE, by number) for eels caught in fyke nets set in Lake Karāpiro reservoir and tributaries (reservoir dataset courtesy of LINZ, Matheson et al. 2010).

Habitat	Year fished	No. of nets		CPUE (number/net/night)[a]					
				Shortfins			Longfins		
		SC	SF	SC	SF	All	SC	SF	All
Hydro-reservoir	2010	18	18	9.72	13.78	11.75	0.5	0.39	0.44
Tributaries	2011–2012	10	26	0.00	0.04	0.03	1.60	0.15	0.55

[a] SC = Single coarse-mesh fyke; SF = Single fine-mesh fyke.

Table 17: Catch per unit effort (CPUE, by weight) for eels caught in fyke nets set in Lake Karāpiro reservoir and tributaries (reservoir dataset courtesy of LINZ, Matheson et al. 2010).

Habitat	Year fished	No. of nets		CPUE (kg/net/night)[a]					
				Shortfins			Longfins		
		SC	SF	SC	SF	All	SC	SF	All
Hydro-reservoir	2010	18	18	3.62	4.78	4.20	0.13	0.14	0.13
Tributaries	2011–2012	10	26	0.00	0.02	0.02	4.30	0.28	1.40

[a] SC = Single coarse-mesh fyke; SF = Single fine-mesh fyke.

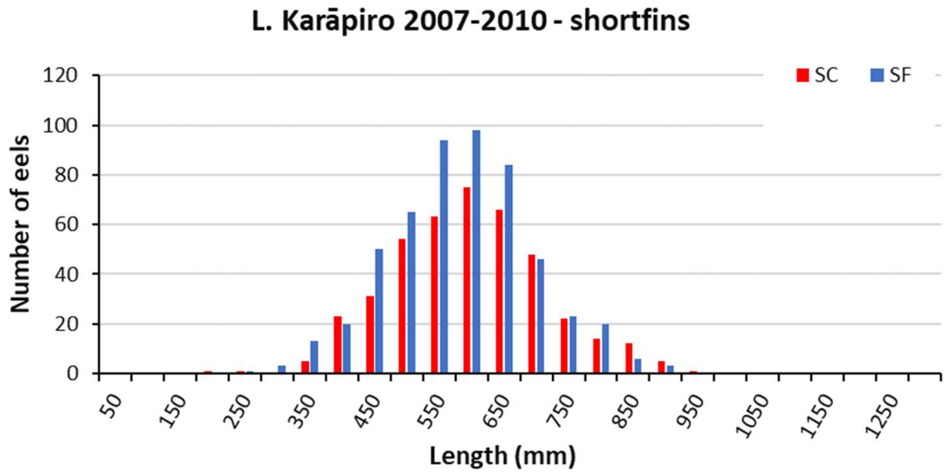

Figure 17: Length distribution of shortfins captured in single wing coarse-mesh (SC) and fine-mesh (SF) fyke nets set in the Karāpiro reservoir between 2007 and 2010. (Data courtesy of LINZ, Matheson et al. 2010.)

The average CPUE (by number) of shortfins in the reservoir was over 440 times greater than in tributaries. In contrast, the average longfin CPUE (i.e., 0.55 in the streams and 0.44 in the lake) was not significantly different (two sample t-Test with unequal variance, df = 70, t = 0.486, p = 0.31). However, in terms of biomass, longfin CPUE was significantly higher in the tributaries (i.e., 1.38 kg/net in tributaries vs. 0.13 kg/net in the reservoir) (two sample t-Test with unequal variance, df = 36, t = 2.478, p = 0.009).

Thus, although the average longfin fyke net catch was similar between the stream and the reservoir, the longfins were markedly larger in size from the stream, and this is clearly shown in the length distribution (Figure 18).

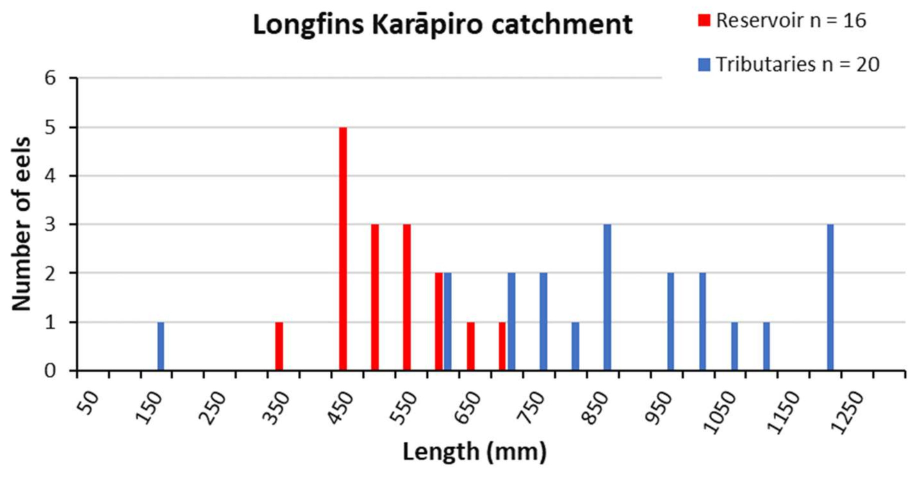

Figure 18: Length distribution of longfins captured in single wing fyke nets set in the Karāpiro reservoir in 2010 and tributaries between 2011 and 2012. (Reservoir data courtesy of LINZ, Matheson et al. 2010.)

4. DISCUSSION

4.1 Eel distribution and density changes through time

Tributaries

Bioresearches (1994) carried out an extensive fyke netting and electric fishing survey of tributaries of the two lowermost Waikato hydro-reservoirs (i.e., Karāpiro and Arapuni) in 1992 and only found eels in streams within the Karāpiro catchment (Figure 19). In contrast, the current survey found eels in tributaries of not only Lake Karāpiro but also in those of lakes Arapuni and Whakamaru (Figure 13). There are now eels in most accessible permanent tributaries of the Waikato hydro system (Mike Holmes, EECo pers. comm., J. Boubée pers. obs.). This increase in eel distribution can be attributed to the elver trap-and-transfer programme that began in earnest in 1994 for Arapuni and 1996–1997 for the upper reservoirs, including Whakamaru.

Longfins were the dominant species in the tributaries surveyed, but this, in part, could be because tributary streams tend to have a rock bottom and/or are lined with trees such as willows which are favoured by longfins. Longfins also tend to be the dominant species where there is little or no fishing pressure (e.g., Chisnall & Kalish 1993). However, for both species, access to upstream habitat from the reservoirs where most of the elvers are released is often severely limited by the presence of waterfalls and other migration barriers such as underground passages and overhanging culverts. Consequently, if eel stocks in tributaries and associated habitats, including ponds, is to increase rapidly, seeding of elvers above these natural barriers would be required.

Hydro-reservoirs

Similar to the results observed for the tributaries, habitat in the hydro-reservoirs plays a very important role in determining the size and species composition of the catch. Visual field observations indicated that longfins tended to be captured where the lakebed was rocky and water currents were high, so they tended to be more prevalent in deep sets and immediately downstream of the dams.

Comparisons of Lake Arapuni catch rates in this study with those reported in 1992 by Bioresearches (Table 18) indicate that there has been a considerable increase in CPUE over time (Table 19). This study did not survey Karāpiro, but the LINZ study between 2007 and 2010 reported CPUE estimates from Karāpiro that were well above those recorded by Bioresearches in 1992 (Table 19). Studies carried out for Kinleith Mill in 1995 (Boubée et al. 1995) also observed a marked increase in eel numbers in Waipāpa, Maraetai, and Whakamaru after elvers were released in these reservoirs (Table 19). For all, not only have catches increased markedly over the years, but shortfins now dominate the catch in all the reservoirs.

The current survey also identified that some areas of the hydro-reservoirs are more productive than others, and that not including these areas (as was necessary in Lake Arapuni during the February 2013 survey because of high public use at the time) can have major effects on average catch rates. Commercial fishing effort and environmental factors such as water temperature (i.e., timing of survey), water level, weather, and moon phase will also influence catch rates, so these factors need to be considered when comparing catches between years and hydro-reservoirs.

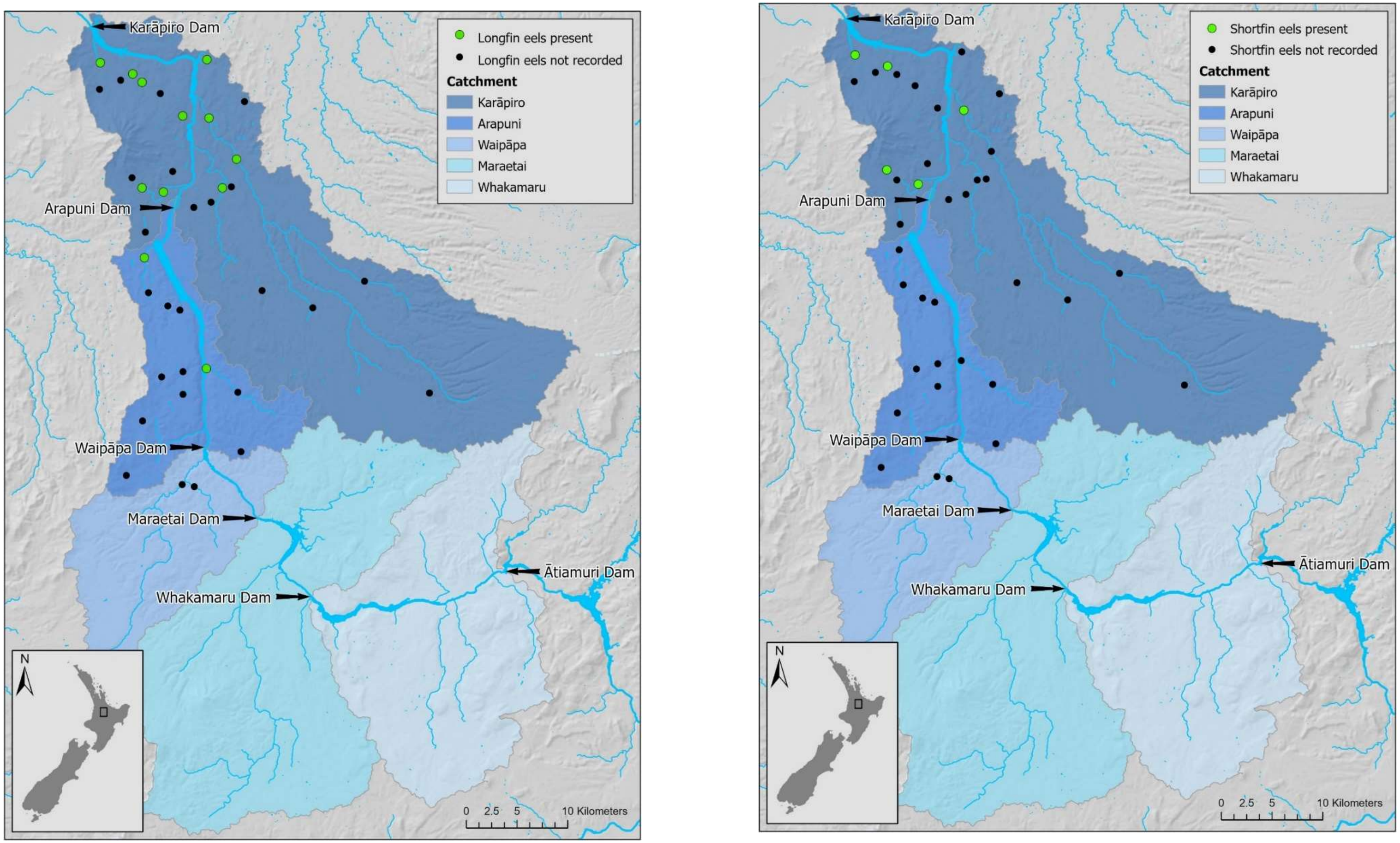

Figure 19: Locations of tributary reaches fished where longfins (left) and shortfins (right) were observed during the 1993–94 electric fishing and fyke netting survey (Bioresearches 1994).

Table 18: Catches of eels obtained in commercial fyke nets (equivalent to CF of this study) set in the Waikato hydro-reservoirs in November 1992. Note in this study trains of up to 30 nets were set at some sites (source: Bioresearches 1994).

Hydro-reservoir	No. of sites	No. of nets	Total catch		CPUE (number/net/night)		CPUE (weight/net/night)	
			Shortfin	Longfin	Shortfin	Longfin	Shortfin	Longfin
Karāpiro	39	65	110	53	2.82	1.36	2.68	1.29
Arapuni	37	195	11	11	0.30	0.30	0.06	0.06
Waipāpa	22	41	1	8	0.05	0.36	0.02	0.20

Table 19: Catch per unit effort (CPUE, by number) of eels for coarse-mesh fyke nets set in lakes Karāpiro, Waipāpa, Maraetai, and Whakamaru between 1992 and 2013.

Hydro-reservoir	Year	No. of nets	CPUE (number/net/night)		Authors
			Shortfin	Longfin	
Karāpiro	1992	65	2.68	1.29	Bioresearches 1994
	1999	24	4.83	0.50	Boubée et al. 2000
	2009	18	4.42	0.25	Clayton et al. 2009[a]
	2010	18	11.77	0.73	Matheson et al. 2010[a]
Arapuni	1992	195	0.06	0.06	Bioresearches 1994
	1999	8	5.25	0.88	Boubée et al. 2000
	2012	15	15.87	11.27	This study
	2013	32	9.41	2.59	This study
Waipāpa	1992	41	0.02	0.20	Bioresearches 1994
	1995	18	0.00	0.20	Boubée et al. 1995
	2006	14	10.1	3.5	Richardson et al. 2006
	2008	21	4.90	2.40	Depree et al. 2008
Maraetai	1995	43	0.00	0.00	Boubée et al. 1995
	1999	14	0.00	0.00	Richardson & Boubée 1999
	1999	9	0.78	0.11	Boubée et al. 2000
	2006	42	2.74	1.90	Richardson et al. 2006
	2008	21	3.50	1.90	Depree et al. 2008
Whakamaru	1995	18	0.00	0.00	Boubée et al. 1995
	1999	9	2.11	0.56	Boubée et al. 2000
	2012	15	21.60	3.33	This study
Ātiamuri	1999	9	0.22	0.78	Boubée et al. 2000
	2012	6	6.00	8.17	This study

[a], Part of LINZ weed spraying study. Only catches from pre spraying and reference (i.e., non-sprayed) sites are reported here.

4.2 Size distribution changes through time

Tributaries

The numbers of eels in the tributaries have increased markedly since elvers have been transferred to the hydro-reservoirs, and longfins remain the dominant species. Large longfins (i.e., greater than 800 mm) are present in the Karāpiro tributaries and occasionally in the Arapuni tributaries, but not in Whakamaru tributaries. Conversely, this study found that small longfins were only common in the Whakamaru catchment. This information alongside historical catch records indicates that longfins had access to the Karāpiro tributaries before the elver trap-and-transfer programme began. Some longfins also reached the Arapuni catchment, but access to the Whakamaru catchment was more limited. Furthermore, where large longfins are present smaller eels were sparse. It is expected that as eels in the Whakamaru streams continue to grow, smaller eels will become less common and the population structure will resemble that of Karāpiro streams.

Hydro-reservoirs

In 1992 shortfins were less numerous and smaller than longfins in the reservoirs (Table 20). In contrast, in this study longfins were less numerous than shortfins and both species tended to be about the same size (Tables 13 and 14). The study undertaken in Lake Karāpiro between 2007 and 2010 for LINZ showed similar results (Table 14). Therefore, since elver seeding of the hydro-reservoirs was implemented and the eel population has been commercially fished, smaller eels have become more numerous, and shortfins now dominate the species composition.

Table 20: Size of eels obtained in commercial fyke nets set in the Waikato hydro-reservoirs in November 1992 (source: Bioresearches 1994).

Hydro-	Number measured		Average length ±SD (mm)		Average weight ±SD (g)	
reservoir	Shortfin	Longfin	Shortfin	Longfin	Shortfin	Longfin
Karāpiro	10	45	662±75	895±143	744±201	2 736±1 491
Arapuni	11	11	920±160	1 022±159	1 951±1 090	3 532±1 645
Waipāpa	1	8	930	1 089±218	1 640	4 961±2 872

4.3 Age and growth changes through time

Tributaries

Although this study could not age any of the eels captured in the tributaries to determine growth rates, Chisnall (1993) provided records for eels examined in 1992. The ageing methods used by Chisnall (1993) were similar to those used in this study and there have been no major changes in land use that could have affected growth rates over time. Eel densities in the Karāpiro and Arapuni tributaries have also remained relatively low. Consequently, the records of Chisnall (1993) should still be pertinent. Based on Chisnall (1993), the growth rates of longfins in the tributaries of lakes Karāpiro and Arapuni were slightly lower than the growth rates obtained for reservoirs during this study (Table 21). However, these growth rates were also relatively high compared with those from tributaries of the lower Waikato River (Chisnall 1993).

According to Chisnall (1993) longfins grow about 30 mm/year so any elvers released during the first transfer in 1994 would be expected to be around 600 to 700 mm in 2012. This is supported by length distribution records from the Whakamaru catchment where the largest eel captured was 750 mm (Table 13, Figure 14). Similarly, the larger eels present in both the Karāpiro and Arapuni catchments must have recruited before the elver trap-and-transfer programme began.

Hydro-reservoirs

Chisnall (1993) noted that the otoliths obtained from the hydro-reservoirs in 1992 had conspicuously narrow central growth bands followed by wider bands (i.e., faster growth), something he did not observe in eels from the lower Waikato River. The change in growth was attributed to the eels passing over the dam. Furthermore, Chisnall (1993) estimated that in the lower river, shortfin eels took 16–18 years to reach a commercial size of 220 g and longfins 14–16 years, whereas in Lake Karāpiro both eel species reached this harvestable size at around 3–7 years. Even higher growth rates were measured in the reservoirs further upstream where eel densities were lower than in Lake Karāpiro (Table 21). Chisnall (1993) speculated that the low eel density and high food availability that existed in the reservoirs at the time likely promoted fast growth rates.

Growth rates obtained subsequently show that prior to 1999 eels were growing markedly faster in Lake Maraetai than at present, with a 700-mm eel being about 6–7 years of age in 1999 but more than 16 years in 2008 (KMA 1999; Depree et al. 2008). This slower growth rate is now prominent in the reservoirs (Figure 16, Table 21), but is still considerably faster than in the lower Waikato River.

Table 21: Mean annual growth and standard deviation (SD) of shortfins and longfins aged from the Waikato hydro-reservoirs and tributaries 1989 to 2012.

Location	No. aged	Length range (mm)	Age range (yr)	Average age (yr)	Mean growth (mm/yr ±SD)	Source
Shortfins						
Lake Karāpiro (1989)	18	460–960	6–29	–	–	Chisnall 1993
Lake Arapuni	10	665–1 170	8–17	13.5	64.6±3.6	Chisnall 1993
	153	231–742	3–20	10.3	36.0±7.6	This study
Lake Waipāpa	1	930	23	23	37.8	Chisnall 1993
	2	540–565	8–9	8.5	51.8±6.1	KMA 1999
	11	520–770	10–17	14.9	38.5±5.1	Depree et al. 2008
Lake Maraetai	15	345–765	9–3	6.7	86.3±24.0	KMA 1999
	15	508–912	10–19	14.5	39.8±4.7	Depree et al. 2008
Lake Whakamaru	7	540–745	14–17	15.7	36.7±4.4	Depree et al. 2008
	35	227–710	6–16	17.0	43.0±6.8	This study
Lake Ātiamuri	15	279–830	6–19	11.4	37.7±9.0	This study
Longfins						
Lake Karāpiro (1989)	62	345–980	6–30	–	19±4.4	Chisnall 1993
Lake Arapuni	11	705–1 280	6–35	19.8	55.0±6.6	Chisnall 1993
	100	220–814	6–18	12.3	31.8±6.1	This study
Lake Waipāpa	8	680–1 350	25–48	33.5	31.4±2.3	Chisnall 1993
	4	535–625	8–10	–	–	KMA 1999
Lake Maraetai	2	478–505	28–31	14.5	29.4±2.7	Depree et al. 2008
Lake Whakamaru	4	458–565	13–18	15.8	28.4±5.2	Depree et al. 2008
	24	241–790	5–17	10.8	37.6±8.5	This study
Lake Ātiamuri	9	365–720	11–16	13.9	33.9±11.1	This study
Lakes Karāpiro & Arapuni tributaries	9	965–1 260	26–47	35.8	30.4±2.1	Chisnall 1993

–, Records not provided by the author(s).

4.4 Comparison between tributaries and hydro-reservoirs

The Waikato hydro-reservoirs are stocked with elvers and commercially fished so the changes observed through time in population size and size structure reflects these activities. Harvest and stocking are also expected to affect populations in the tributaries, but recruitment into these habitats is mostly due to reservoir stocking (some elver releases may have taken place in the tributaries, but it is expected that this has been confined to associated ponds). Migration barriers do have a significant effect on eel populations in the tributaries and there would be value in directly stocking these tributaries (e.g., the Waipā stream which runs underground or the numerous tributaries with waterfalls).

Harvest in the reservoirs currently controls the number of large eels present, but because the tributaries are either not fished or lightly fished (commercially and for customary take), the number of large longfins present is considerably higher than in the reservoirs. The hydro-tributaries, therefore, currently support a sizable population of large longfin eels. Currently, these large longfins most likely pre-date the present elver trap-and-transfer programme.

In time, all eels will mature and will attempt to reach spawning grounds at sea so will invariably be killed by the hydro turbines (Beentjes et al. 2005). Consequently, there would be benefits in ensuring eels in the hydro-reservoirs are intensively harvested, and also in enhancing harvest in the tributaries. However, given that the hydro-reservoirs are now dominated by a large population of small shortfins and that growth rate has declined since seeding of the hydro-reservoirs has taken place, there may be benefits in targeting shortfins as soon as they reach a marketable size. Doing this could reduce the risk of males developing into migrants and out-migrating through the turbines, but these postulates need to be field tested in at least one of the hydro-reservoirs before being implemented in all the reservoirs.

5. MANAGEMENT IMPLICATIONS

Trap-and-transfer of elvers from below Karāpiro Dam to upstream habitats has developed a fishery in the hydro-reservoirs and has also restocked tributaries that are preferred fishing grounds for hapū/iwi fishers. Most Waikato River iwi have seen the change as positive but remain concerned by the lack of provision for downstream migrants. One option to address this is to ensure that harvests (commercial and customary) in the reservoirs are maximised to reduce the numbers of downstream migrant females passing through the hydro-electric turbines. In addition, a downstream migrant catch-and-transfer operation could also be established to help with the safe downstream passage of adult migrant eels. These programmes have been established in other hydro catchments across the country and could be a valuable way of helping ensure fewer eels are killed by the turbines.

Tributaries are more difficult to fish than the hydro-reservoirs because of access issues (e.g., private land), and the increased fishing effort required. However, this study showed that these tributaries are supporting some large longfins, particularly in the Karāpiro catchment, that will need to be either harvested or moved (e.g., downstream trap-and-transfer) before they mature, out-migrate, and get killed passing through the turbines. Therefore, more fishing effort could be focused in stream habitats upstream of hydro dams. Such fishing could include the transfer of large females downstream of Karāpiro Dam where they will have free access to the sea. To make tributaries more attractive to fishers, releasing elvers directly into these streams, especially upstream of natural migration barriers, is needed, so available biomass increases more quickly than through natural recruitment processes.

Under the present quota management system, seeding of hydro-reservoirs and their tributaries has increased the population of eels available for harvest. Since the quota has been reduced, and there are now more eels available for harvest through stocking of the reservoirs, there should be lower pressure on downstream habitats where migrant eels have free access to the sea.

Although seeding of the hydro-reservoirs (and incidentally of the tributaries) has benefited the fishery, Ngāti Tahu-Ngāti Whaoa Runanga Trust have raised concerns about the loss of kōura (*Paranephrops planifrons)* from the hydro-reservoirs. Clearwater et al. (2014) speculated that the demise of kōura in the hydro-reservoirs was the result of eel enhancement and predation by eels. Indeed, fish surveys undertaken for Kinleith Pulp and Paper Mill show that the numbers of kōura captured declined markedly between 1995 and 1999 and have not recovered (Depree 2008). Consequently, the current Fisheries New Zealand special permit issued to EECo for the transfer of elvers no longer allows elver releases to the two most upstream reservoirs (lakes Ohakurī and Ātiamuri). On refection, it seems improbable that a mere four years after the release of elvers they could have grown enough to have resulted in the demise of the entire kōura population of the hydro-reservoirs. It is to be noted that Boubée et al. (1995) recorded kōura with growths on their limbs in Lake Maraetai and this disease may well have also contributed to a population collapse. The increased use in forestry and cropping of insecticides such as Alpha-Scud (Cypermethrin), that are known to be lethal to kōura at very low doses, may also have contributed to the loss of kōura. A combination of other factors may also be contributing to the loss of kōura and require further investigation, such as a decline in water quality, possible changes to trout abundance, the invasion by catfish and rudd, a decline in palatable aquatic plants, and replacement by hornwort, and perhaps even the introduction of a new pathogen.

6. CONCLUSIONS AND RECOMMENDATIONS

The seeding of elvers into the Waikato River hydro-reservoirs has created or at least re-instated an eel fishery upstream of the dams. It has improved the population of eels in hydro-tributaries that are now again available for customary and recreational take. Eel populations in hydro-tributaries are dominated by longfins, whereas shortfins are most common in the hydro-reservoirs. In the Karāpiro and Arapuni tributaries there are still large longfins that recruited before the present elver trap-and-transfer programme began. These large longfins appear to control the number and size of other eels present.

Although the elver trap-and-transfer programme has improved eel numbers in the reservoirs, not all tributaries have benefited because of the presence of natural barriers. Consequently, there would be benefits in releasing elvers directly into the tributaries. However, before doing so the interactions between kōura and eels needs to be better understood, and where kōura harvest is valued by hapū/iwi it may be prudent not to enhance the eel population.

Longfins are dominant in tributaries with a rocky bottom and/or with an abundance of woody cover. Few shortfins are present in these habitats, but it is possible that in streams running through open pasture or in associated ponds, shortfins will thrive. A better understanding of habitat availability and use by the two species is therefore required to inform management of the fishery.

By increasing the population of eels upstream of the dams, the number of eels maturing and killed while passing through the turbines will continue to increase. To minimise this impact, a range of options could be considered including maximising harvest, changing size limits and catch limits in the reservoirs, and/or the establishment of a downstream migrant catch-and-transfer programme.

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APPENDIX 1

Electric fishing records for tributary reaches of the hydro-reservoirs Karāpiro and Arapuni surveyed between 21 December 2011 and 8 February 2012.

Hydro-reservoir	Reach name	NZMG Coordinates		Area fished (m^2)	No. of passes	Total catch				Catch per 100 m^2 (CPUE)			
						By number		By weight (kg)		By number		By weight (kg)	
		Easting	Northing			Longfin	Shortfin	Longfin	Shortfin	Longfin	Shortfin	Longfin	Shortfin
Karāpiro	Mangakara Stream A	2742345	6349171	60	1	0	0	0	0	0	0	0	0
	Huihuitaha Stream A	2743792	6343033	105	1	1	0	1.27	0	0.95	0	1.21	0.00
	Huihuitaha Stream B	2743443	6343869	105	1	0	0	0	0	0	0	0.00	0.00
	Huihuitaha Stream C	2744299	6336774	105	1	0	0	0	0	0	0	0.00	0.00
	Huihuitaha Stream D	2743440	6345381	52.5	1	0	0	0	0	0	0	0.00	0.00
	Huihuitaha Stream E	2743481	6341228	40	1	0	3	0	2.82	0	7.50	0.00	7.04
	Raparahi Stream A	2748162	6333135	20	1	0	0	0	0	0	0	0.00	0.00
	Raparahi Stream B	2748170	6333130	20	1	0	0	0	0	0	0	0.00	0.00
	Raparahi Stream C	2747971	6333724	20	1	0	0	0	0	0	0	0.00	0.00
	Waipā Stream A	2747968	6333723	60	1	0	0	0	0	0	0	0.00	0.00
	Waipā Stream B	2750521	6332978	60	1	0	0	0	0	0	0	0.00	0.00
	Unnamed tributary K1	2742624	6341386	30	1	0	0	0	0	0	0	0.00	0.00
Arapuni	Makomako Stream	2744335	6328095	90	2	46	2	1.83	0.01	51.11	2.22	2.03	0.01
	Mangare Stream A	2739945	6331189	135	2	1	0	2.2	0	0.74	0.00	1.63	0.00
	Mangare Stream B	2739067	6330429	33	2	0	1	0	0.01	0.00	3.03	0.00	0.03
	Mangare Stream C	2740795	6331105	39	2	2	0	4.50	0	5.13	0.00	11.54	0.00
	Mangare Stream D	2741006	6333823	51	2	3	6	0.32	1.87	5.88	11.76	0.64	3.66
	Mangawhio Stream A	2744374	6321775	15	1	1	0	0.01	0	6.67	0.00	0.07	0.00
	Mangawhio Stream B	2739741	6323084	120	1	0	0	0	0	0.00	0.00	0.00	0.00
	Mangawhio Stream C	2739729	6323113	30	2	0	0	0	0	0.00	0.00	0.00	0.00
	Ngautaramoa Stream A	2742362	6333828	57	2	0	1	0	0.001	0.00	1.75	0.00	0.00
	Ngautaramoa Stream B	2742328	6333778	51	2	0	0	0	0	0.00	0.00	0.00	0.00
	Ngautaramoa Stream C	2742372	6334329	51	2	2	3	0.35	0.01	3.92	5.88	0.68	0.02
	Te Rimu Stream	2744370	6325082	90	2	2	0	0.12	0	2.22	0.00	0.14	0.00
	Tumai Stream	2745185	6320640	30	1	1	0	1.11	0	3.33	0.00	3.70	0.00
	Unnamed tributary A1	2744385	6323866	90	2	3	0	0.85	0	3.33	0.00	0.94	0.00

APPENDIX 2

Electric fishing records for tributary reaches of the Whakamaru hydro-reservoir surveyed between 26–30 November 2012.

Hydro-reservoir	Reach name	NZMG Coordinates		Area Fished (m^2)	No. of passes	Total catch				Catch per 100 m^2 (CPUE)			
						By number		By weight (kg)		By number		By weight (kg)	
		Easting	Northing			Longfin	Shortfin	Longfin	Shortfin	Longfin	Shortfin	Longfin	Shortfin
Whakamaru	Mangatutu Stream	2773572	6307193	75	2	1	0	0.95	0	1.33	0.00	1.27	0.00
	Maraemanuka Stream A	2757340	6302605	126	2	5	0	2.02	0	3.97	0.00	1.60	0.00
	Maraemanuka Stream B	2757257	6302722	150	3	4	0	0.64	0	2.67	0.00	0.43	0.00
	Mokautere Stream A	2766789	6293469	105	1	0	0	0	0	0.00	0.00	0.00	0.00
	Mokautere Stream B	2766596	6293130	180	2	2	0	2.15	0	1.11	0.00	1.19	0.00
	Okama Stream A	2763415	6304101	120	2	1	0	0.48	0	0.83	0.00	0.40	0.00
	Okama Stream B	2763355	6303965	120	2	1	0	0.03	0	0.83	0.00	0.03	0.00
	Okama Stream C	2763427	6299109	24	1	0	0	0	0	0.00	0.00	0.00	0.00
	Ongarahu Stream	2771477	6291104	30	2	0	0	0	0	0.00	0.00	0.00	0.00
	Opareiti Stream A	2767584	6305326	105	2	2	0	0.41	0	1.90	0.00	0.39	0.00
	Opareiti Stream B	2767585	6305326	120	2	1	0	0.28	0	0.83	0.00	0.23	0.00
	Opareiti Stream C	2767584	6305226	105	2	10	0	1.61	0	9.52	0.00	1.53	0.00
	Potungutungu Stream A	2757637	6293736	75	2	0	0	0	0	0.00	0.00	0.00	0.00
	Potungutungu Stream B	2757675	6293910	20	1	0	0	0	0	0.00	0.00	0.00	0.00
	Te Rakau Stream	2758883	6303110	45	3	8	0	0.04	0	17.78	0.00	0.10	0.00
	Unnamed tributary W1	2763095	6304101	20.4	1	0	0	0	0	0.00	0.00	0.00	0.00
	Waiharuru Stream	2758470	6294096	20	1	0	0	0	0	0.00	0.00	0.00	0.00
	Waipāpa Stream A	2768370	6304815	250	1	0	0	0	0	0.00	0.00	0.00	0.00
	Waipāpa Stream B	2763150	6294825	18	1	0	0	0	0	0.00	0.00	0.00	0.00
	Waipāpa Stream C	2768323	6298318	180	2	1	1	0.58	0.01	0.56	0.56	0.32	0.01
	Waipāpa Stream D	2765730	6296849	112.5	2	0	0	0	0	0.00	0.00	0.00	0.00

APPENDIX 3

Length-weight relationships of shortfin and longfin eel for the three hydro-reservoirs fished in 2012–13