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Don Jellyman
Iaean Cranwell

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Don Jellyman
Iaean Cranwell

NIWA
P O Box 8602
Riccarton
Christchurch

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EXECUTIVE SUMMARY

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Wairewa (Lake Forsyth) is a very important customary eel fishery to the Wairewa Rūnaka, who harvest migratory eels during the autumn heke (migration). To determine the species, size, and age composition of eels in the lake, and the effect of the present opening regime, juvenile eels were sampled by trawling and electrofishing, and adult eels by fyke netting. Migratory shortfin female eels were sampled during the heke. There was a relatively low abundance of juvenile eels in the lake, while the skewed size distribution of larger eels was indicative of low recruitment. The large average length of non-migratory eels (718 mm), the high proportion of females, and high CPUE were indicative of a non-harvested stock of immature eels; the growth rate of shortfins from the age-at-length relationship averaged 23 mm/yr, although annual growth increments of fyke-netted eels averaged 31 mm/yr. The minimum age of harvested eels, shortfin female migrants, was 16 years, with an average of 28 years. Age frequency distributions indicated intermittent and generally low recruitment over, perhaps, the past 20 years. The present age distribution of non-migratory eels lags behind that of migratory eels by a few years, and the predicted outcome of this is that there will be a marked decline in the heke eel fishery within a few years. Possibilities for enhanced recruitment are seen as changing the lake opening regime to include an opening during the main recruitment period, or the transfer of juvenile eels into the lake. Based on transfers from nearby Te Waihora (Lake Ellesmere) into a small coastal lake, growth rates of transplanted eels should be faster than that of resident eels, meaning that transplanted eels could contribute to the migratory fishery within 5 years. Failure to implement some management initiatives will mean that the present fishery will begin to decline within a few years, and that decline will continue for the foreseeable future.

1. INTRODUCTION

1.1 History and customary fishery

Tuna (eels) have been a major source of mahinga kai (traditional food) for Wairewa tangata whenua who have harvested them for centuries. Traditionally, the mahinga kai resources of Wairewa were regarded as 'the central food basket of Ngāi Tahu in the Canterbury region...' (Tau et al. 1990). Banks Peninsula was known as 'Te Pātaka o Räkaihautü or the storehouse of Räkaihautü. Tuna were, and continue to be, the principal source of mahinga kai.

As part of a vision to establish a Mahinga Kai Cultural Park (see www.ngaitahu.co.nz/tront-2025.html), Wairewa Rünaka have identified rehabilitation of Te Roto o Wairewa and mahinga kai species as the primary environmental, cultural, spiritual, and economic issue (Reid et al. 2004). While the overall concept involves integrated management of the whole catchment, understanding the extent and well-being of the tuna resource is an essential first step of this vision.

Te Roto o Wairewa (which can be translated as 'water lifted up') is one of the lakes referred to in the tradition of 'Ngä Puna Wai Karikari o Räkaihautü', which tells how the principal lakes of Te Wai Pounamu were dug by the rakatira (chief) Räkaihautü. Räkaihautü was the captain of the canoe, Uruao, which brought the tribe, Waitaha, to Aotearoa. Räkaihautü beached his canoe at Whakatü (Nelson). From Whakatü, Räkaihautü divided the new arrivals in two, with his son taking one party to explore the coastline south and Räkaihautü taking another south by an inland route. On his inland journey south, Räkaihautü used his famous "Ko" Tüwhakaröria (a tool similar to a spade) to dig the principal lakes of Te Wai Pounamu, including Te Roto o Wairewa.

There are place names connected with Te Roto o Wairewa which evoke earlier histories. One example is the mountain, which Te Roto o Wairewa lies in the lee of, 'Te Upoko o Tahumatä'. This name refers to the Käi Tahu ancestor Tahumatä who lived and fought in Hawke's Bay. Like many other lakes, Te Roto o Wairewa was occupied by a taniwha called Tü Te Rakihaunoa, whose origins stem back to the creation traditions. For Käi Tahu, traditions such as this represent the whakapapa links between the cosmological world of the gods and present generations. These histories reinforce tribal identity and solidarity, and continuity between generations, and document the events which shaped the environment of Te Wai Pounamu and Käi Tahu as an iwi.

The local hapü of this region are Käti Irakehu and Käti Makö. Irakehu was a descendant of Makö, the Ngai Tühaitara, and Käti Kuri chief who took Banks Peninsula with his cousin, Moki. Tradition has it that both Moki and Makö are buried near Te Roto o Wairewa. Poutaiki and Ötungakau are two principal urupä associated with Te Roto o Wairewa. These urupä are the resting places of Käi Tahu tüpuna and, as such, are the focus for whänau traditions. These are places holding the memories, traditions, victories, and defeats of Käi Tahu tüpuna, and are frequently protected by secret locations. These hapü are the kaitiaki (guardians) and exercise kaitiakitanga (guardianship) over the taoka (treasured resources) and rohe (area) of Wairewa.

The tüpuna had considerable knowledge of whakapapa, traditional trails, and tauraka waka (canoe landing places), places for gathering kai and other taoka, ways in which to use the resources of the lake, the relationship of people with the lake and their dependence on it, and tikanga for the proper and sustainable use of resources.

Te Roto o Wairewa has been used by the descendants of Räkaihautü ever since it was formed. It is famous for the tuna that it holds and which migrate out to sea in autumn. Käi Tahu gathers here annually to take the tuna. The attractiveness as a settlement site can be seen even today in the landscape with the remains of pä still discernible, such as Öruaka, Te Mata Hapuka, and Ngutu Piri Pä by the outlet of the lake.

Originally Te Roto o Wairewa (Lake Forsyth) was a hapua or estuary. In the late 1800s, alluvial drift caused the lake to close with a shingle bar, although the timing of this process is uncertain. Soons (1998) reviewed information from various sources, i.e., historic records (including maps), photographs, traditional and anecdotal evidence, and rate of sediment accumulation, and concluded that "...during the early part of the 19th century access to Lake Forsyth from the sea was possible for craft of some size, probably drawing over a metre. Use of the lake by whalers, canoes and coastal traders implies that the lake was frequently open. It is now closed more or less permanently. However, it is probable that in dry periods, when the lake level was low, a bar or exposed barrier would form across the outlet.....as the 19th century progressed, the Forsyth section of the barrier became a more solid feature."

Until Wairewa became closed to the sea, anecdotal evidence suggests that the lake was fished by a variety of means throughout the year, including the heke (seaward migration). The permanent closure of the lake meant that traditional practices and methods required modification. The practice of digging drains into Kaitorete Spit to harvest tuna during the seasonal heke was used extensively at Te Waihora (Lake Ellesmere). It is assumed that this was applied to Te Roto o Wairewa as a response and solution to the lake's closure. Over time, a new set of practices has evolved that has meant that harvesting tuna at Te Roto o Wairewa is solely during the heke and via drains dug into the shingle bar.

In modern times, Wairewa Rünanga as the kaitiaki of Te Roto o Wairewa have introduced permits for those wishing to participate in tuna harvesting. The purpose of the permits is to ensure that no great depletion in stock occurs and that traditional practices are followed, including protection of the immediate environment of the lake. The taking of the tuna is for whänau (family) consumption as there is no commercial tuna activity permitted. Photographs of customary fishing are shown in Appendix A.

This project is part of the long-term vision for Wairewa Rünanga based around the rehabilitation of Te Roto o Wairewa encapsulated in the whakataukï (proverb) below.

Ka hāhā te tuna ki te roto
Ka hāhā te reo ki te kāika
Ka hāhā te takata ki te whenua

This whakataukï can be translated two ways. Firstly, if the lake is full of tuna and the houses full of our reo (language), the people will be well. Secondly, if there are no tuna and no reo, the people will suffer.

Takuahi Research and Development Ltd (a subsidiary of Te Kete o Wairewa, a company owned by Wairewa Rūnanga Incorporated Society) is concerned about the overall well-being of the lake and its mahinga kai, and interested in exploring the possibility of additional management options on behalf of the Wairewa Rūnanga.

1.2 Objectives

The overall objective was: To assess the present status of eel stocks in Lake Wairewa (Forsyth). There were two sub-objectives (with commentary taken from MFish contract documents).

Objective 1. To determine the present species composition of eels in Lake Wairewa and the main tributaries.

Wairewa and inflows have particular value to the Wairewa Rūnanga as a customary eel fishery. No commercial fishing has occurred in the lake although some commercial harvest took place in the inflows before they were closed to commercial fishing in 1995. No specific assessment has been made of the eel population in the lake or inflows. The focus of this objective was to determine the species size composition of eels in the lake and main tributaries.

Objective 2. To determine the current age structure, growth rates, and sex composition of eels in Lake Wairewa.

This objective is designed to determine the age structure, growth rate, and sex composition of the eel population in Lake Wairewa. Specific analysis of the size and age frequency would determine evidence of intermittent recruitment possibly caused by the long periods of closure to the sea that might prevent the recruitment of glass eels into the lake. Local understanding is that glass eels might recruit into the lake via seepage through the shingle bar.

2. METHODS

2.1 Description of lake

Wairewa is a small (55.8 ha), shallow coastal lake. The maximum depth recorded during a 1978 bathymetric metric survey (Irwin 1979) was 4.1 m at a point about 200 m inland from the bar; within the main basin itself, the depth did not exceed 2 m. The lake is described as hypertrophic and slightly brackish (Woodward & Shulmeister in press). It has regular cyanobacterial blooms of *Nodularia,* although these blooms are not necessarily associated with the seasonally high nutrient concentrations (Main et al. 2003). The lake is separated from the sea by a gravel barrier bar, about 100 m wide, that is an extension of Kaiterete Spit that extends 30 km from Taumutu in the south to Banks Peninsula in the north. The lake is periodically mechanically opened to the sea when it rises to pre-determined summer and winter levels.

2.2 Lake opening date

The dates and durations of lake openings from 1954 to 2004 were obtained from Environment Canterbury (ECan). To determine the effect of lake openings on recruitment strength, two yearly indices of lake opening were generated. The first index listed the number of times a lake opening occurred between August and November inclusive, and then gave a weighting to each opening according to the perceived importance of that month for glass eel recruitment; thus, September and October, the main months of glass eel recruitment (Jellyman et al. 1999), received a weighting of 2, while August and November received a weighting of 1. For example, in 1974, the lake was opened twice in August (2 openings x weight of 1) and once in September (1 opening x weight of 2), giving a total index for the year of 4.

The second index multiplied each yearly total index by the average duration of openings for that year (in days). Again for 1974, the average duration of an opening was 3.2 days, so that the second index gave a value for 1974 of (4 x 3.2) = 12.8. These indices were then plotted against age frequencies (expressed by actual year of recruitment), to see whether there were any obvious relationships between these indices and the strength of yearly cohorts.

2.3 Field sampling

2.3.1 Trawling

As the high conductivity of the water (a consequence of a periodic entry of salt water) meant that electric fishing would not be effective within the lake, trawling was used to capture juvenile eels. Trawling was used by Jellyman and Chisnall (1999) in nearby Te Waihora (Lake Ellesmere) to capture a wide size range of juvenile eels. The technique used in the present study was similar, i.e., a 2 m wide beam trawl (8 mm mesh, with an outer bag of 1 mm mesh) was towed from 4.5 m boat; each tow covered a distance of 250 m (500 m^2). The contents of the trawl were emptied into a fish box and sorted, any eels were anaethsetised (2–phenoxyethanol) and measured (to 1 mm), and the approximate number of other species was recorded. Apart from those few eels retained for ageing, all fish were released alive. For each trawl, the time of day, location (GPS), depth, and substrate type at the start of the trawl were recorded. Most trawling was done after dark when eels were known to be most active (Jellyman & Sykes 2003).

2.3.2 Electrofishing

Tributaries were sampled using electrofishing. Nine sites were electrofished, seven in the Okana River and three in the Okuti Stream. Electrofishing was done using a portable backpack shocker (Kainga EF300). In both catchments, the most workable downstream reach was the first site sampled, with other sites chosen by distance inland and ease of access. At each site, a representative reach that included a riffle was electric fished in an upstream direction. Because of the low velocity of water, a downstream stopnet was not used, but rather fishing was done in a series of small sweeps into a 1 m wide hand-held stopnet (2 mm mesh). Double passes were done at four sites to quantify capture efficiency.

Again, all eels caught were anaethsetised and measured, and a size-stratified sample was retained for later ageing. Information on fish caught and habitats were recorded on NIWA's Freshwater Fish Database forms. The maximum likelihood method of Carle & Strubb (1978), based on progressive removal of fish, was used to estimate total populations. For estimates of biomass, robust length-weight relationships (NIWA unpublished data) were used, i.e.,

longfin $W = 1.2508 \times 10^{-7} L^{3.4792}$ ($R^2 = 0.98$)

shortfin $W = 1.2313 \times 10^{-7} L^{3.4501}$ ($R^2 = 0.98$)

where W is weight in g and L is length in mm.

2.3.3 Fyke nets

A series of unbaited fyke nets (12 mm stretched mesh, 6 m leader, no escapement tubes) were set at locations around the lake, and in the lower Okana River. Nets were set overnight, placed at right angles to the shoreline, and emptied the following morning. Nets containing eels were transported by boat to a convenient shore station for processing of the catch. Captured eels were then transferred to keep bags that were immersed in a large bucket containing anaesthetic (either 2–phenoxyethanol when eel carcasses were retained for later identification of sex, or AquiS for those eel carcasses later given to local iwi for consumption). All eels were measured (to 1 mm). Eels retained for later ageing and sex identification were placed in individually numbered plastic bags in a chilly-bin with ice, and later transferred to a freezer at the laboratory. For eels given to local iwi, the head, guts, and gonads and a section of about 5 g of muscle tissue, were removed and placed in plastic bags as above. The muscle and internal organs were required for bioassay, to identify the extent of uptake of nodularin, the toxin associated with the blue-green alga *Nodularia* which undergoes seasonal blooms in the lake and leads to stock deaths and a prohibition of human body-contact recreation (Main et al. 2003). (Research on nodularin is being conducted by Dr Barbara Dollamore, Christchurch Polytechnic Institute of Technology, Christchurch.)

In addition to sampling with standard fyke nets, several fine-meshed fyke nets (0.72 mm square mesh; Chisnall & West 1996) were set in the lower Okana River to see whether they would capture smaller eels than standard fyke nets.

2.3.4 G-minnow traps

A line of 10 G-Minnow traps (20 mm apertures, 3 mm square mesh) was also set in the lower Okana River in an attempt to capture small eels. The trap line was 70 m in length, with traps located at 5 m intervals. The line was secured to the bank and the traps set at a right angle to the bank; traps were baited with marmite (Allibone & Chadderton 1992).

2.4 Ageing techniques

A size-stratified subsampling regime was used to obtain a representative range of otoliths of ageing – for this, otoliths from about 5 eels per 100 mm size group were collected. While otoliths were collected from both species of juvenile eels caught during trawling and electrofishing (under 400 mm), local iwi were not in favour of longfins over 500 mm being killed, as this species is not harvested during the annual heke.

Otoliths were stored dry and processed using the method of Hu & Todd (1981), subsequently modified by Graynoth (1999). A subjective 5-point scoring method was used to assess confidence in otolith readability, where 5 = clear demarcation of annuli and corresponding high confidence in ages, and 1 = very poor demarcation of annuli and corresponding very low confidence in ages. For age analysis, only otoliths scoring 4 or 5 were included. An age length key (Kimura 1977) was used to develop an age frequency for sampled eels, with individual lengths pooled into 50 mm size groups.

To estimate annual growth increments of individual eels, the average length of glass eels (60 mm) was subtracted from the total length (TL, mm) of each eel, and the resulting length then divided by the age of that eel.
i.e. mean annual growth increment (mm/y) = (TL - 60 mm)/age

Largely because sampling was curtailed by an outbreak of blue-green algae (described later), additional samples of otoliths from larger eels had to be obtained from the customary fishery for migratory shortfins that occurs during the autumn heke (migration). This customary fishery involves digging trenches into the lakeside of the gravel bar, and gaffing migrating eels that enter (Todd 1978), presumably stimulated by the seepage of saltwater. Photographs of aspects of this customary eel fishing are given in Appendix A.

Local iwi collected heads from eels before the carcasses were smoked. Heads were subsequently frozen. To estimate live total length, a relationship between frozen head length and frozen eel length was required, together with the relationship between frozen length and live length. Head length was defined as the length from the tip of the bottom jaw to the anterior margin of the operculum opening (being the longest clearly defined measure available from the eel heads). Frozen length was determined from freshly thawed eels, while comparisons of frozen and fresh lengths were made from those eels kept for ageing and sex determination. As a check that these eels were all migratory, the maximum eye diameter was measured using a digital micrometer, and compared with eye diameters from frozen non-migratory eels (i.e., eels captured during December fyke netting).

2.5 Identification of sex

Gonads were inspected in situ, except those from eels whose carcasses had been given to local iwi (where both guts and gonads had been frozen as described previously). Maximum gonad width was measured with digital callipers. Most gonads could be identified macroscopically using the stages of Beullens et al. (1997). For small or apparently undiffentiated gonads, a squash and staining technique (McCleave & Jellyman 2004) was used to identify sex.

3. RESULTS

3.1 Juvenile eel sampling

3.1.1 Trawling

Trawling was carried out on the nights if 16 and 17 November 2004. Sites were initially in the shallow margins in the "neck" of the lake, the region closest to the sea, although they later extended into the lake itself (Figure 1). A total of 27 trawls (Appendix B) caught 7 eels under 200 mm, 4 eels 200–399 mm, and 24 eels over 399 mm (Table 1). All eels were shortfins, apart from a single longfin (117 mm). Included among the seven smallest eels were four glass eels (61–63 mm). Average catches ranged from 0.15 (200–399 mm) to 0.89 (over 399 mm) eels per trawl (= eels/500 m^2). Catches of smelt (*Retropinna retropinna)* and common bullies (*Gobiomorphus cotidianus*) were much higher at 101 and 37 fish per trawl, respectively. No flatfish were caught.

3.1.2 Electrofishing

From the 9 sites electrofished (Table 2), 63 shortfins and 153 longfins were captured. Except at the lowest site on the Okana River, longfins were the dominant species. Overall, longfins made up 70% of the total eels sampled (n = 216). The proportion of shortfins declined significantly with distance inland, and at sites 8 and 9 on the Okuti Stream, shortfins were absent. Site 5 in the Okana River had a higher proportion of finer substrates than recorded at sites 4 and 6, and this may have been the reason for shortfins being present at that location.

For both species, the smaller size groups predominated in the lower reaches of both streams. The length frequency distributions indicated that while the 100–150 mm size group was well represented for both species, eels smaller than this were uncommon (Figure 2). A comparison of length of both species indicated that longfins (n = 153, mean = 335 mm, SE = 14 mm) were significantly longer than shortfins (n = 63, mean length = 254 mm, SE = 16 mm) (t-test, $p < 0.001$). Size of shortfins had a weak association with distance upstream of the sampling sites (linear correlation, P = 0.03), but there was no association for longfins (P = 0.18). Likewise, neither species showed any association between biomass and distance upstream of the sites ($P > 0.05$).

Results from the four reaches where two electric fishing passes were carried out were 29 and 8 shortfins caught in Runs 1 and 2 respectively, compared with 44 and 15 longfins. From the total estimated populations for these data, 38 shortfins (SE 1.23) and 64 longfins (SE 3.73) it was estimated that the first run captured 76% of shortfins and 69% of longfins. Apart from the lowest section in the Okana River where biomass of both species was virtually equivalent, longfins markedly dominated the biomass being 90.2% of the overall biomass recorded. There was a tendency for the biomass of longfins to increase with distance inland, indicative of the increase in average size upstream.

The overall densities of eels (estimated from first run catches at all sites, adjusted by capture efficiencies) gave the following densities:

Shortfins: all sizes = 4.5 eels /100 m^2 under 400 mm = 3.9 eels /100 m^2
Longfins: all sizes = 11.7 eels /100 m^2 under 400 mm = 8.3 eels /100 m^2

Selecting the three downstream sites for each waterway (sites 1–3, 7–9) where higher densities of shortfins might be expected, gave very similar results for both species, indicating that downstream densities were, in fact, not greater than average:

Shortfins: all sizes = 4.6 eels /100 m^2 under 400 mm = 4.3 eels /100 m^2
Longfins: all sizes = 10.4 eels /100 m^2 under 400 mm = 7.6 eels /100 m^2

3.2 Adult eel sampling

3.2.1 Catches

The original plan had been to minimise any temporal variability in fyke net catches by netting during December and mid January. Unfortunately, an unseasonally early bloom of the blue-green alga *Nodularia* occurred in early January after high rainfall necessitated opening of the lake. The consequent low lake levels and influx of saltwater precipitated an early algal bloom. Because of the extensive and dense nature of the bloom (Table 3), and the likelihood of the toxin being absorbed through contact with skin (as well as the possibility of inhaling the toxin from water vapour or wind-blown shoreline sediment), NIWA algal scientists advised that work not be carried out until the bloom had substantially subsided. Toxin levels were measured weekly by ECan, but "safe" levels did not occur until early May 2005. Because of the reduced sampling opportunities, little sampling carried out in the centre of the lake and along the northwest shoreline.

Shoreline netting in early December 2004 (Table 4) caught 691 shortfins and 227 longfins (75.3% shortfins, 24.7 % longfins). Similar species proportions were obtained from standard fyke nets in the lower Okana River, and the May 2005 sample from the northwest shoreline.

3.2.2 Sizes of eels

Lengths of both species of eels from the lake were significantly greater than those of eels from the Okana River (t-test; $P < 0.001$); there were no significant differences between the average sizes of eels caught by standard fyke nets or fine-meshed fykes nets during the sampling in May 2005 (t-test, shortfin: $P = 0.10$; longfin $P = 0.71$), and shortfins were significantly longer than longfins (t-test, $P < 0.001$). The length frequency distribution for shortfins was near-normal, with the size groups 720–780 mm being strongly represented; in contrast, longfins showed a more skewed distribution with a higher representation of fish under 650 mm (Figure 3). The mean length of shortfins migrants was significantly greater than shortfins non-migrants ($P < 0.01$; Table 5).

3.2.3 CPUE

During December 2004, a total weight of 920 kg of eels was captured, with an average catch-per-unit-effort (CPUE = kg/net/night) of 54.1 kg (excluding one net that was holed; Table 4. Appendix C). For the lake itself, CPUE per net was reasonably consistent during December, with a cv of only 0.29, compared with 0.97 for riverine eels caught during the same month. While CPUE did not vary between successive nights (ANOVA, $P > 0.05$), it did vary between 7 and 9 December (ANOVA, $P = 0.021$). River catches (14 December) were not significantly different to lake catches of the nearest fishing day, 9 December (ANOVA, $P = 0.571$). December lake catches (7–9 December) were significantly greater than in May 2005 lake catches (ANOVA, $P < 0.000$). May 2005 CPUE averaged 5.15 kg/net/night, and the highly variable catches had a cv of 1.51.

3.2.4 Age and growth

Plots of the relationships of frozen head length:total frozen length and total frozen length: total fresh length were linear, and regressions were as follows:

Frozen head length:total frozen length
Shortfins: total frozen length = 24.945 + 8.149 (frozen head length) N = 17, $R^2 = 0.91$
Longfins: total frozen length = 23.676 + 7.246 (frozen head length) N = 24, $R^2 = 0.98$

Total fresh length:total frozen length
Shortfins: Total fresh length = 10.317 + 1.018 (frozen total length) N = 17, $R^2 = 0.99$
Longfins: total fresh length = 4.529 + 1.032 (frozen total length) N = 24, $R^2 = 0.99$

Thus, for both species, as eels grow, the ratio of head length:total length increases slightly, and the relative head length of longfins is slightly greater than for shortfins, e.g., at 350 mm, head length of shortfins averaged 11.4% of total length, compared with 12.9% for longfins; at 700 mm, the relative percentages were shortfin 11.9%, longfin 13.3%.

The average size of migratory shortfin females was estimated from 203 heads taken from migratory eels caught between 1 and 3 April 2005. The resulting length-frequency distribution (Figure 3) was normal, with an estimated length range of 561–988 mm, and a mean length of 771 mm (Table 5). The eye diameter of migratory eels was larger than that of non-migratory eels (paired t-test, $P < 0.01$), but for any given length group, especially eels under 800 mm, there was some overlap (Figure 4), meaning that eye diameter alone was insufficient to differentiate between migratory and non-migratory eels. However, in the present study, migratory eels were all collected at the drains as they attempted to exit the lake, and it was this behaviour that finally differentiated them from non-migratory eels.

All otoliths that scored 4 or 5 were considered readable. Ages of both species (Table 6) ranged from 0 to 36 for shortfins, and 1 to 16 for longfins. The distribution of age at length (Figure 5) indicated that growth was linear for both species, although eels from the tributaries showed a slower growth rate than eels from the lake. Age-length relationships (Table 7) were all highly significant. During reading of otoliths, there was no evidence of a consistent change in widths of annuli within individual otoliths that would indicate a growth inflexion. Consequently, no measurements of individual annuli were carried out.

Annual length increments for fyke netted or migratory shortfins, ranged from 18 to 45 $mm.y^{-1}$ (see Table 6). These increments for lake eels (i.e., excluding eels from tributaries) were inversely related to length:
shortfins length increment = - 0.982 (age) + 51.159, n = 94, $R^2 = 0.45$, $P < 0.01$

Increments of electrofished shortfins and longfins were not significantly different ($P > 0.05$), whereas increments of non-migratory shortfins (from fyke nets) were significantly different ($P < 0.05$) from increments from migratory shortfins (see Table 6).

Age class distributions

The distributions of age classes of juvenile eels (Table 8) shows a good correlation between strong recruitment years of both species. Age classes 3 and 4 (= recruitment years 2001 and 2000 respectively), and 9 (recruitment year 1995) are well represented for both species; other strong age classes are 13 for shortfins and 14 for longfins.

The age-class distributions generated from the age-length key (Figure 5) showed considerable variability, presumably partly because of the relatively few non-migratory eels caught by fyke nets that were aged (n = 31). There were suggestions of strong cohorts recruiting about 20 years ago (age class 19), and also 26–27 years ago, and 31–32. For migrant eels, strong cohorts were 23–24, 27, 29–30, and 33.

A 5-point moving average was used to smooth the variability on age-frequencies of non-migrant and migrant shortfins generated from the age-length key. Results (Figure 6) showed that there was considerable alignment of the two distributions, with the age distribution of non-migratory eels lagging about 6 years behind that of migratory eels. Comparison of the mean lengths of the two groups was 53 mm (see Table 5), which, at a mean growth rate of 35 $mm.y^{-1}$ for non-migratory shortfins (see Table 4), represents less than two years before the mean lengths overlap.

To look for any correlation between strong year classes and lake opening frequencies, the lake opening indices were plotted against the strength of recruitment cohorts (i.e., age frequencies adjusted to year of recruitment). No trend was apparent, with low indices in some years sometimes associated with high recruitment and vice versa. Regressions of both indices against recruitment strength were not significant (index I; P = 0.80, index II, P = 0.40)

3.2.5 Sex composition

Of the 39 shortfins where gonads were categorised, 3 were undifferentiated, 1 was a male, and the remaining 35 were females (Table 9). As sex in shortfins, is differentiated by about 270 mm in males and 320 mm in females (Todd 1980), and male shortfins achieve a maximum size of 550 mm (Jellyman & Todd 1982), the sex distribution over a range in length of 320 to 550 mm was examined as this would remove the bias of larger eels being female. The sex distribution here was 10 females to a single male. For longfins, all eels were within the length range for both sexes with the sex ratio being 9 females to 2 males.

For shortfin females, there was a linear relationship between total length and gonad width, i.e., total length = 18.119 (ovary width) + 465.163 (n = 34, $R^2 = 0.71$).

4. DISCUSSION

4.1 Juvenile eels

Results from trawling indicated a low abundance of juvenile eels in Wairewa. In comparison, in nearby Te Waihora (Lake Ellesmere), a total of 549 trawls made between 1994 and 2000 gave an average catch of 4.4 eels/ trawl, with the average catch of eels under 300 mm being 3.4 eels/trawl (Graynoth & Jellyman 2002); ignoring the first 2 years, when some experimental fishing was undertaken, increased the average catch to 6.2 eels/trawl, of which 5.7 were over 300 mm. Thus, the overall mean catch from Wairewa of 0.4 eels over 400 mm per trawl was substantially less than the 5.7 eels/trawl (under 300 mm) from Te Waihora.

Catches of smelt from Wairewa (average of 101 per trawl) substantially exceed smelt catches from Te Waihora (3.3/trawl), while common bullies were less abundant in Wairewa (37/trawl) than in Te Waihora (184/trawl).

Densities of eels in the tributaries were also relatively low at 4.5 shortfin /100 m^2 and 11.7 longfins/100 m^2. Jowett & Richardson (1996) provided densities of native fish for 38 rivers and streams throughout New Zealand – their densities (fish/100 m^2 for single-pass electric fishing) for small rivers (under 3.2 m^3/s) range from 0.2 to 3.1 shortfins/100 m^2 and 5.0 to 40.2 for longfin /100 m^2. Given that most of these waterways were substantially larger than either the Okuti or Okana in the present study, a better comparison is provided by data of Glova et al. (2001), where spatial densities of juvenile eels are estimated for three small coastal streams – in the lower reaches of these streams, densities of shortfins averaging about 20/100 m^2, with densities of longfins between 5 and 15/100 m^2. Thus, while densities of longfins in the present study are about equivalent to those of Glova et al. (2001), the densities of shortfins are substantially less.

4.2 Adult eels

The average length of fyke-netted shortfins, 718 mm, is extremely large. For instance, it exceeds the mean length for any of the 21 sites from 17 South Island catchments sampled by Beentjes & Chisnall (1997) and the 27 sites from 16 South Island catchments sampled by Beentjes (1999). As only the migratory eels are harvested in Wairewa, the stock of feeding eels represents an unexploited one. The average length of Wairewa shortfins exceeded those from two studies of unexploited shortfins stocks, i.e., Five Mile Lagoon, Westland, where the mean length of 122 shortfins (caught be fyke nets) was 637 mm (SE 14, range 260–990 mm; NIWA unpublished data) and Lake Pounui, Wairarapa where the mean length of 971 fyke-netted shortfins was 526 mm (SE 3, range 201–1042 mm; NIWA unpublished data).

The shape of the Wairewa length-frequency distribution has a pronounced skew to the left (negative skewness), which is unlike length-frequencies for either regularly or seldom-fished stocks (e.g., Beentjes & Chisnall 1997, Beentjes 1999). The large average size of shortfins is partly a result of the small number of eels in the 500–600 mm range, being the group that is usually best represented in commercial catches of shortfins (Beentjes & Chisnall 1997, Beentjes 1999), but also in the unexploited population from Lake Pounui (NIWA unpublished data). The few shortfins under 600 mm in Wairewa is indicative of restricted recruitment.

Data for an earlier length distribution of shortfins from Wairewa are available (Jellyman et al. 1995). Comparison of the two distributions from samples collected 30 years apart (Figure 7), shows that in 1975 the size distribution was bimodal, with peaks at 520–540 mm and 720–740 mm (mean length 570 mm). In 1975, there was a strong representation of eels under 600 mm, unlike the present population. Given present-day average growth increments of 31 $mm.y^{-1}$, then eels corresponding to the strong length groups in the 1975 sample would no longer be present in the population.

Fyke nets of similar mesh size used in Waihora, caught shortfins as small as 250 mm, but well-represented size groups were over 350 mm (Jellyman et al. 1995). Using the data for fyke-netted shortfins from Wairewa (see Figure 3), it can be estimated that the age classes corresponding to the size range of 350–700 mm (the latter being the length at which the right-hand side of the length-frequency distribution begins to decline) range from 8–23. Also, from the trawling and electrofishing data, the smaller size and age classes are also poorly represented. In other words, there is evidence that recruitment has been less than optimal for the last 20 years.

4.3 CPUE

The large average size also contributes to high CPUE. Average nightly CPUE for the lake and lower Okana River for standard fyke nets in December 2005, ranged from 36 to 67 kg/net/night; CPUE from shoreline sites in Wainono Lagoon, a shallow coastal lake, ranged from 3.2 to 8.0 kg/net/night (Jellyman & Sykes, 1998), while average CPUE from commercial fishers in Marlborough and North Canterbury for the years 1990–91 to 1998–99, range from 6.3 to 8.0 kg/net/night (Beentjes & Bull, 2002). Although individual net catches in December were also high; as expected, May CPUE was markedly lower, reflecting a seasonal reduction in temperature and hence activity of eels. Water temperature is a significant correlate of fyke net catches of shortfins (Jellyman 1991). Water temperature during the May sampling was 11° C (compared with 24.2°C on 8 December at 1800 h), and as eel activity ceases at temperatures of 5–6 ° C (Jellyman 1991, 1997), lower seasonal CPUE will result from decreasing temperatures.

4.4 Age and growth

Overall growth rates (age at length data) were linear, although there was a reduction in annual length increment with increasing age, indicating that the growth rate of shortfins slowed with increasing age. Linear growth rates are common in New Zealand eels (Jellyman 1997, Beentjes & Chisnall 1998); growth rates also vary within catchments (Beentjes 1999), so differences in growth rates between the lake tributaries and the lake itself in the present study are not unusual. Beentjes (1999) also used annual growth increments to compare growth rates between various South Island catchments, and the average growth rate for shortfins from 14 South Island rivers was 33 $mm.y^{-1}$, very similar to the 31 $mm.y^{-1}$ in the present study. Values for Te Waihora (Lake Ellesmere, the only lake in the Beentjes study) ranged from 30 to 35 mm/yr, again similar to present values. Likewise, in a New Zealand-wide review of growth rates, Jellyman (1997) found that growth rates for eels over 300 mm were typically 20 to 30 mm/yr; he noted that such growth rates were slow compared with those for other temperate eel species.

4.5 Age class distributions

Although younger age classes were not well represented overall, there was evidence that the years of "better than average recruitment" were the same for both species. Although 2001 had a single opening during the recruitment period of August–November, there were four openings in 2000, and three in 1995, all "better than average" years. From the age-frequency analysis, of larger eels, there was some evidence that stocks of female eels (i.e., eels over 500 mm) were maintained by periodic strong recruitment of particular year classes. Given that the harvested component of the fishery, migrant eels, comprises an age range of 20 years, then such "intermittent" recruitment of strong year classes is probably adequate to maintain the fishery. As previously mentioned, there is evidence of generally low recruitment for the past 20 years, something of considerable concern for the well-being of the fishery. In the absence of population estimations, it is not possible to say with certainty how long the present migratory eel fishery can be sustained. However, as there is a difference of only a few years between the size and age distributions of non-migrant and migrant eels, it is anticipated that substantial declines in the fishery will become evident within a few years.

Although the diet of eels was not investigated during the present study, it was often noted during processing that stomachs contained fish. This was confirmed from additional information collected as part of NIWA's Lowland Lakes programme, where stomachs of six shortfins (611–847 mm) were examined, and of the five that contained food, all had fish or fish remains in their stomach; the next most common food were mysid shrimps (four of five stomachs), followed by snails and chironomids (both two of five stomachs; Dave Kelly, NIWA, pers. comm.). In nearby Te Waihora, a length-related change to feeding on fish is accompanied by acceleration in growth rate (Jellyman 2001), something not evident in the present study.

4.6 Sex composition

The sex composition was highly skewed in favour of females. Although the customary fishery is selective for shortfin females, few shortfin males are seen (I. Cranwell, pers. obs.), a further indication that the sex ratio favours females. The development of sex in freshwater eels is not determined genetically, but rather is an expression of the environment in which the eels live. Density of eels is the primary determinant (Davey & Jellyman in press), with low densities favouring development of females. Whether there have been changes in the sex composition in Wairewa over time is uncertain. However, in nearby Waihora, there is evidence that historically there were large numbers of migrating shortfin females (Hobbs 1947), but shortfin males dominate the present fishery. A possible reason for this is that with the selective fishing removal of larger predatory eels of both species, survival of juvenile eels has increased, and this would influence sex ratios in favour of females. The continued decline in the Wairewa fishery will mean an increased likelihood of small eels developing as females, something advantageous to the customary fishery.

4.7 Recruitment

Although there is a local belief that glass eels may recruit into the lake when the bar is closed by wriggling through the gravel bar in response to freshwater seepage, it is considered unlikely that this takes place. Examination of the seepage areas has shown the presence of significant quantities of coarse sand, meaning that the interstitial spaces are very small and hence it would be difficult for glass eels to squeeze through. There is also a local understanding that glass eels can enter the lake when the bar is overtopped during large southerly swells. If correct, it would be a serendipitous mechanism, and no substitute for a regular lake opening regime.

The relationship between lake openings (timing and duration) and the associated strength of recruitment is not a simple one, as no correlation was found between cohort strength and two indices of lake opening. This is not surprising for several reasons. Firstly, the quality of the lake opening records is uncertain. Secondly, there is considerable variation in both the diel and seasonal timing of glass eel recruitment, with timing associated with such variables as hours of darkness, proximity to spring tides, and discharge (Jellyman & Lambert 2003), while numbers of glass eels often vary between years by a factor of 10 (Francis & Jellyman 1999). Thirdly, ageing is not exact with repeat readings of the same otoliths often giving ages that vary by ± 2 or more years (Jellyman et al. 1995), which would further compromise any correlation between opening records and cohort strength.

Records of the lake opening times of the lake for the past 50 years, were examined – these records are missing lake opening times for 1990 and 1991, while the number of days that the lake remained open per opening is unrecorded from 1992 onwards. The current Memorandum of Understanding is that the lake will be opened in summer (December to April inclusive) when the level reaches 8 feet (2.44 m), and in winter (May to November) at 7 feet (2.13 m) (T. Loy, Banks Peninsula District Council, pers. comm.) - higher levels create drainage problems for pasture and septic tanks. Once opened, lake levels can fall dramatically (Appendix D). The frequency of lake opening per month (Figure 8) shows that July and August are when most openings occur (51% of all openings), and there is a low probability of an opening being required during the heke season of March and April (6% of openings). Of more concern is the lack of openings during the main glass eel arrival in September and October (Jellyman et al.1999), with only 18% of openings recorded during these months. Further, the average duration of openings is low at 4.0 days (SE 0.4, range 1.7–9.0 days). As glass eels are thought to arrive in "waves" associated with the 14-day tidal cycle (Tesch 2003), the combined probability of a wave corresponding to a brief opening during September or October is obviously low.

4.8 Future management

How might the low recruitment of eels over past years be mitigated? When discussing the formation of Lake Forsyth and changes in the barrier bar, Soons (1998) indicated that accumulation of gravel along the barrier is continuing, and the present barrier width is "not less than 100 metres wide, depending on lake level". She also calculated an accretion rate "of the order of 1.6–2.0 metres per year for the last 150 years", which contrasts with the general loss of gravel occurring at Te Waihora (Lake Ellesmere) and shorelines further south, e.g., the shoreline of Wainono Lagoon appears to be reducing at about 1 m. y^{-1} (Mark Dickson, NIWA, pers. comm.). Soons (1998) also recorded that an attempt was made as recently as the 1960s to form a permanent canal "running obliquely from a point near the outlet of the lake to the end of the barrier against the cliffs" – seemingly this closed at the seaward end as a result of gravel movement. She concluded that "a century or more of effort has demonstrated the problems of control on the lake, and suggest that the present policy of creating an artificial opening from time to time may have to continue indefinitely".

Although installing a permanent outlet for the lake would provide the best option for ensuring recruitment of glass eels and flounders (provided, of course, it could kept open during the required periods in spring), it seems likely that the cost and ongoing maintenance would prohibit this option in the immediate future. Unfortunately, as the bar continues to grow wider each year costs of such an installation will increase over time. Until any further engineering feasibility study is commissioned, alternative means of recruitment must be investigated. These are:

- changing the lake opening regime to attempt to include a substantial period (e.g., 7 days) during the main recruitment period of September and October each year;
- installing a small capture facility near seepage areas to catch glass eels for subsequent transfer into the lake;
- the transfer of glass eels or juvenile eels collected at another location

The first of these options might be able to be implemented, but would have implications for water levels and farming, septic tank drainage, etc. It would mean a fundamental change in the current lake opening regime that is determined by predetermined water levels.

Although low-technology ladders are used to capture juvenile eels (elvers) at the base of many hydro dams throughout New Zealand (Boubée et al. 2002), the use of such apparatus at Wairewa would be risky. Arrival of glass eels into freshwater occurs after dark, and usually on an incoming tide (Jellyman & Lambert 2003), meaning that fishing would be at night, and there is also see the uncertainty of exposure to heavy seas with attendant risk to equipment and personnel. In addition, a source of fresh/brackish water would be required to attract glass eels – this could either be from the lake itself (requiring a hose of over 100 metres), or maybe "tapping" the seepage in such a way that it could be made to flow down an outlet pipe. Before this option was taken further, further observations and preferably some pilot fishing would need to be done to explore feasibility.

The third option is theoretically possible but might raise issues of the whakapapa of tuna for local iwi. If it was decided to proceed with this option it would be difficult to source the required quantity of glass eels within Canterbury, or indeed the South Island, with the most and reliable source of supply being the lower Waikato River where glass eels have previously being caught in large numbers (Jellyman 1979). At present, commercial capture of glass eels is prohibited (although they can be captured under a customary fisheries permit), plus there would need to be resolution of customary issues with Tainui. A more realisable option would be the transfer of juvenile eels from Te Waihora (Lake Ellesmere) into Wairewa, in a similar way that eel stocks in Muriwai (Coopers Lagoon) were augmented from Te Waihora (Jellyman & Beentjes 1998). Because of the low density of resident eels in Muriwai, growth rates of the transplanted eels were almost 2.5 times faster than they exhibited in Waihora before transfer (Beentjes & Jellyman 2002). Similar accelerated growth would be expected in Wairewa, assuming average size at stocking of about 400 mm (200 g) and an average growth rate of 80 mm/yr (similar to the accelerated growth experienced by transferred shortfins in Muriwai; Beentjes & Jellyman 2002), then time for such eels to enter the customary fishery would average 5 years, and would coincide with the start of the projected decline in the present Wairewa fishery.

One caution with such transfers is the possibility that Waihora eels are principally males. Sex in eels is primarily determined by density (Davey & Jellyman 2005), and sexual differentiation in shortfins can be achieved by270 mm. To ensure that transferred eels were females, it would be necessary to restrict the minimum size at transfer to over 45 cm, as recommended by Beentjes & Jellyman (2002) for transfers of shortfins into nearby Muriwai.

Failure to carry out some management initiatives will mean that the present fishery will begin to decline within a few years, and that decline will continue for the foreseeable future.

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Table 1: Results from trawl surveys, November 2004.

	No. of trawls	Depth range (m)	Shortfins <200 mm	200-399 mm	> 399 mm	Total	Longfins < 200 mm	Total	Smelt	Bullies
16/11/2004	16	0.8 - >2.0	5	2	6	13	1	1		
17/11/2004	11	0.8 – 1.6	2	2	18	22		0	1060	565
Mean fish/trawl (SE)			0.26 (0.08)	0.15 (0.09)	0.89 (0.52)		0.04		101 (12.0)	37 (7.8)

Table 2: Results from electrofishing, November 2004. Note that the total biomass and density (g/m^2) have been calculated for the total estimated population.

River	Site	Distance to lake (km)	Area (m^2)	No. passes	Shortfins <200 mm	200-399 mm	>399 mm	Total	Total biomass	Density (g/m^2)	Longfins <200 mm	200-399 mm	> 399 mm	Total	Total biomass	Density (g/m^2)
Okana	1	2.6	400	2	13	13	4	30	1819	4.5	3	0	2	5	1862	4.7
Okana	2	3.6	280	1	13	4	3	20	958	3.4	21	7	4	32	2432	8.7
Okana	3	5.7	160	2	0	0	0	0	0	0.0	5	18	9	32	3204	20.0
Okana	4	7.7	86	1	0	0	0	0	0	0.0	2	1	3	6	1819	21.2
Okana	5	4.8	141	1	2	2	3	7	1143	8.1	3	12	11	26	9779	69.4
Okana	6	7.0	90	2	0	2	0	2	224	2.5	0	3	7	10	1966	21.8
Okuti	7	2.2	150	2	4	0	0	4	14	0.1	4	1	7	12	5082	33.9
Okuti	8	2.7	192	1	0	0	0	0	0	0.0	2	11	5	18	2652	13.8
Okuti	9	3.9	180	2	0	0	0	0	0	0.0	0	8	4	12	9361	52.0
Totals (SE)					32 (1.8)	21 (1.4)	10 (0.6)	63	4157		40 (2.1)	61 (2.0)	52 (1.0)	153	38157	

Table 3: Concentrations of *Nodularia* collected from Wairewa (data from ECan)

Date	*Nodularia* sp. Cells/ml	Nodularin mg/kg
28 September 2004	No result	<0.03
11 October 2004	No result	<0.03
29-October-04	No result	<0.03
08 November 2004	No result	<0.03
06 January 2005	34,000	220
12 January 2005	101	41
20 January 2005	320	42
24 January 2005	70	38
03 February 2005	12,000	28
17 February 2005	47	870
21 February 2005	4,500,000	91,000
02 March 2005	46	29
17 March 2005	47	2.2
22 March 2005	153	210
30 March 2005	7500	1,700
07 April 2005	310	7.4
11 April 2005	19	7.6
18 April 2005	830	85
29 April 2005	42	28
02 May 2005	8	1
09 May 2005	2	2.6
16 May 2005		<0.1
Nodularin toxicity MACV (New Zealand drinking-water standards)		1 g/L
Microcystin toxicity guideline (stock drinking water		2.3 g/L
Microcystin cell count guideline (stock drinking water		11 500 cells/ml

Table 4: Numbers and sizes of both species of eels caught by fyke- netting of Wairewa and lower Okana River, and total CPUE (kg/net/night)

			Shortfin			Longfin			
				Length			Length		
Date	Location	No. nets	No.	Mean (SE)	Range	No	Mean (SE)	Range	Total CPUE
7/12/2004	Lake – SE shoreline	6	290	735 (5)	446–946	103	664 (15)	481–1308	66.6
8/12/2004	Lake – SE shoreline	6	228	745 (6)	340–1001	77	645 (12)	467–914	50.7
9/12/2004	Lake – SE shoreline	6	173	706 (7)	472–935	47	721 (23)	468–1148	36.1
14/12/2004	Lower Okana River	5	218	667 (6)	436–911	83	678 (13)	503–1295	48.8
4/5/2005	Centre of lake	3	0			0			
	Lake – NW shoreline	7	37	758 (11)	462–867	12	676 (36)	491–967	7.3
Total				953		329			

Table 5: Numbers and lengths of eels caught by various types of sampling gear in Wairewa and tributaries. Note that "Gaffed' eels are migratory eels where total length was estimated from headlength (see Methods).

Sampling gear	Shortfin			Longfin		
	No.	Mean (SE)	Range	No.	Mean (SE)	Range
Trawl	17	369 (67)	61–800	1	117	
Electrofish	63	254 (16)	111–562	153	335 (14)	84–1100
Standard fyke net	945	718 (3)	340–1001	332	671 (8)	322–1308
Fine mesh fyke net	7	631 (18)	570–708	7	665 (30)	578–795
G-minnow traps				1	595	
Gaffed	203	771 (6)	561–988			

Table 6: Mean, range, and SE of ages and mean annual length increment ($mm.y^{-1}$) of eels. Comparisons (ANOVA) of increments indicated as † = P>0.05; ‡ = P<0.05

		Age				Annual length increment			
Species	Method	No.	Mean	Range	SE	No.	Mean	Range	SE
Shortfin	Trawl	12	3.7	0–10	1.1	8	34.5	24.5–41.0	2.2
	Electrofish	29	8.7	2–14	0.8	29	$22.5^{\dagger}$	13.4–41.9	1.2
	Fyke	31	19.4	9–32	1.0	31	$31.2^{\ddagger}$	21.4–44.7	0.8
	Migrants	55	27.7	16–36	0.6	55	$26.3^{\ddagger}$	18.4–34.9	0.6
Longfin	Trawl	1	2			1	28.5		
	Electrofish	36	8.9	1–19	0.9	36	$21.2^{\dagger}$	13.1–40.0	0.9
	Fyke	4	14.3	13–16	0.8	4	34.4	31.4–39.3	1.8

Table 7: Statistics for age and length regressions. * = P< 0.01

Species	Location	No.	Constant	Slope	R^2
Shortfin	All	127	94.760	24.941	0.86*
	Tributaries	29	75.791	20.072	0.69*
	Lake	98	171.628	22.695	0.81*
Longfin	All	41	77.138	19.739	0.66*
	Tributaries	36	92.197	15.649	0.84*

Table 8: Age class distribution (%) of juvenile eels (age classes ≤15).

	Age class																N
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Shortfins	10	2	2	10	20	0	2	0	7	12	5	0	10	15	5	0	41
Longfins	0	7	3	16	16	7	3	0	3	13	3	3	0	3	13	0	31

Table 9: Sex composition and size ranges of non-migratory eels.

	Undifferentiated			Male			Female		
	N.	Mean length (SE)	Length range	N.	Mean length (SE)	Length range	N.	Mean length (SE)	Length range
Shortfin	3	316 (18)	292-351	1	395		35	639 (26)	340-895
Longfin	13	262 (31)	178-575	2	385 (7)	378-392	9	440 (37)	325-583

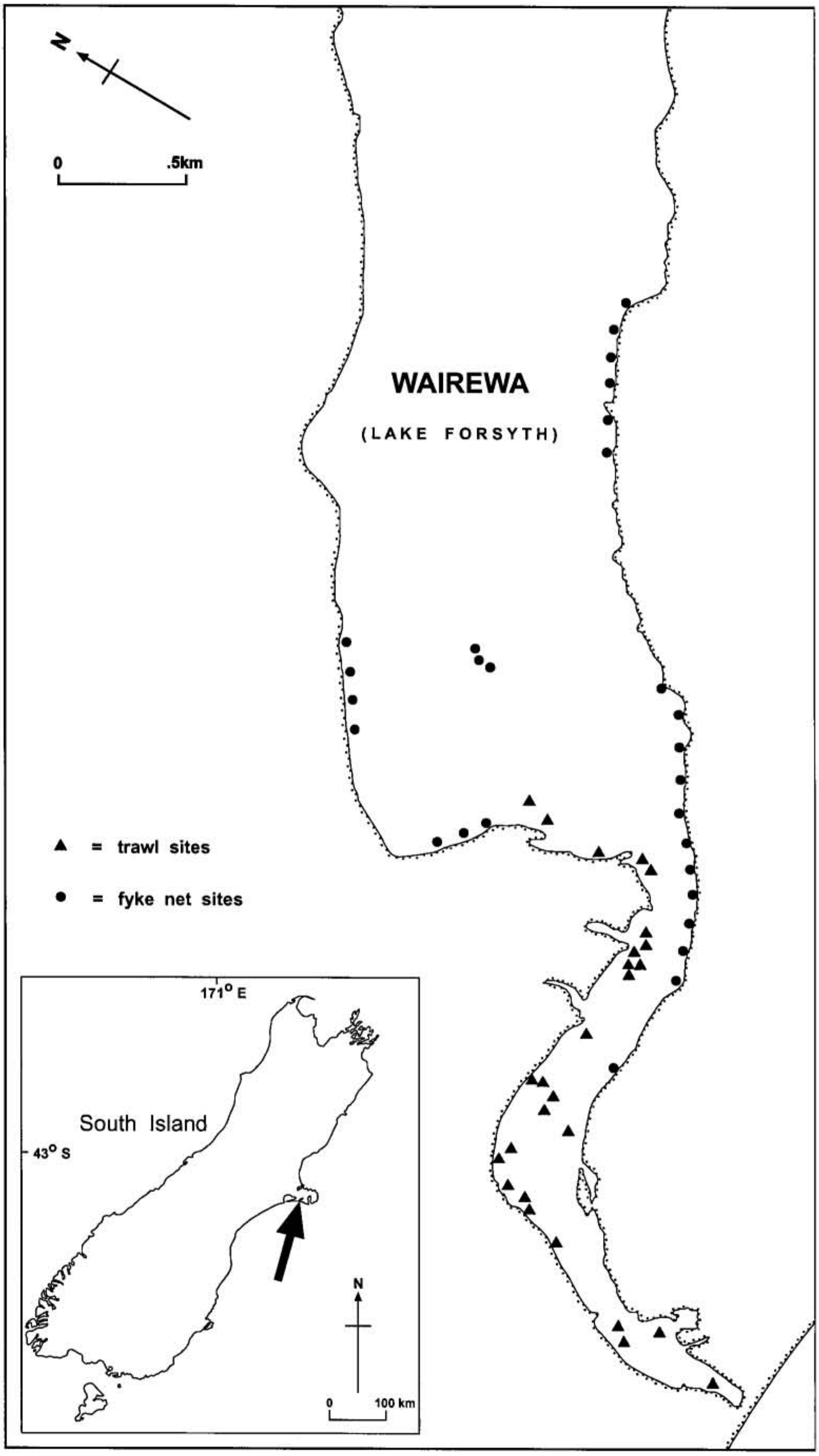


Figure 1: Map of Wairewa showing trawling and fyke netting sites.

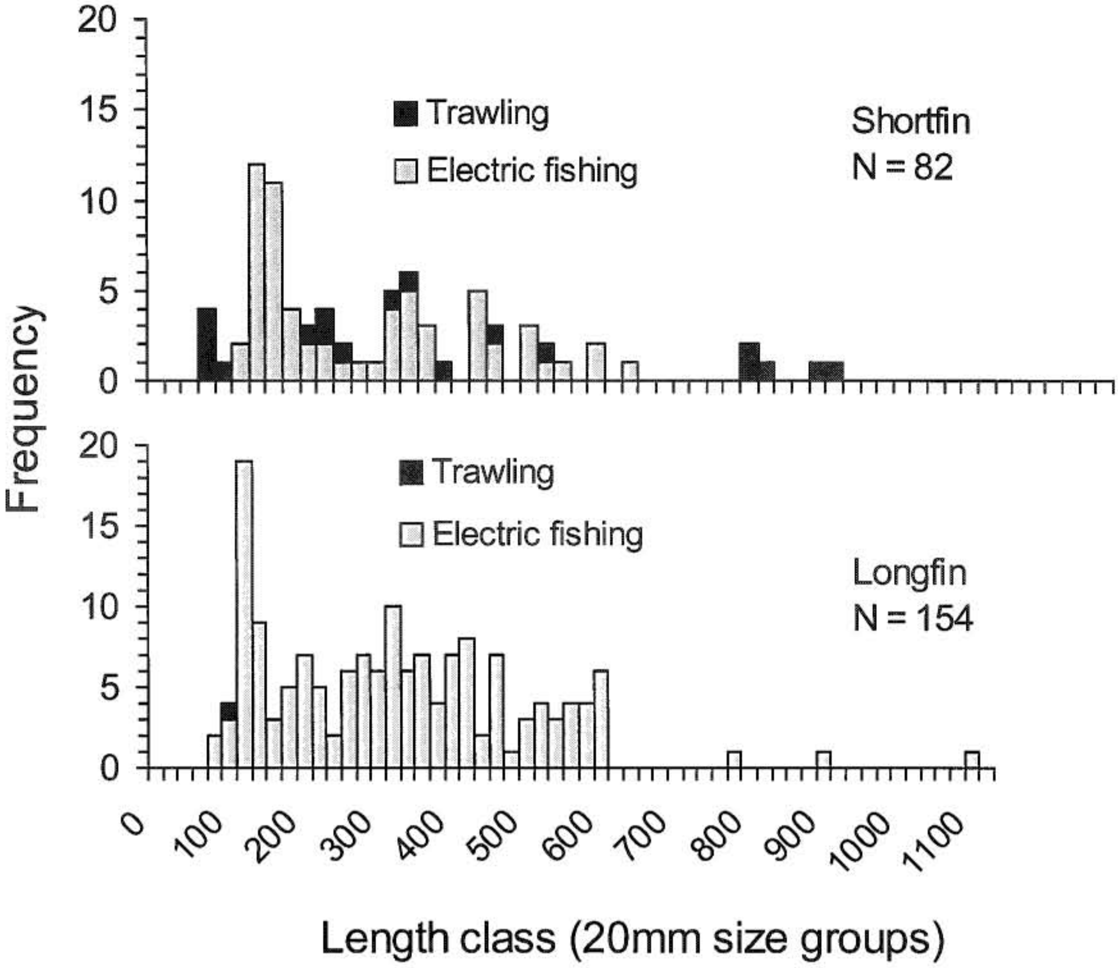


Figure 2: Length frequency of trawled and electrofished eels of both species.

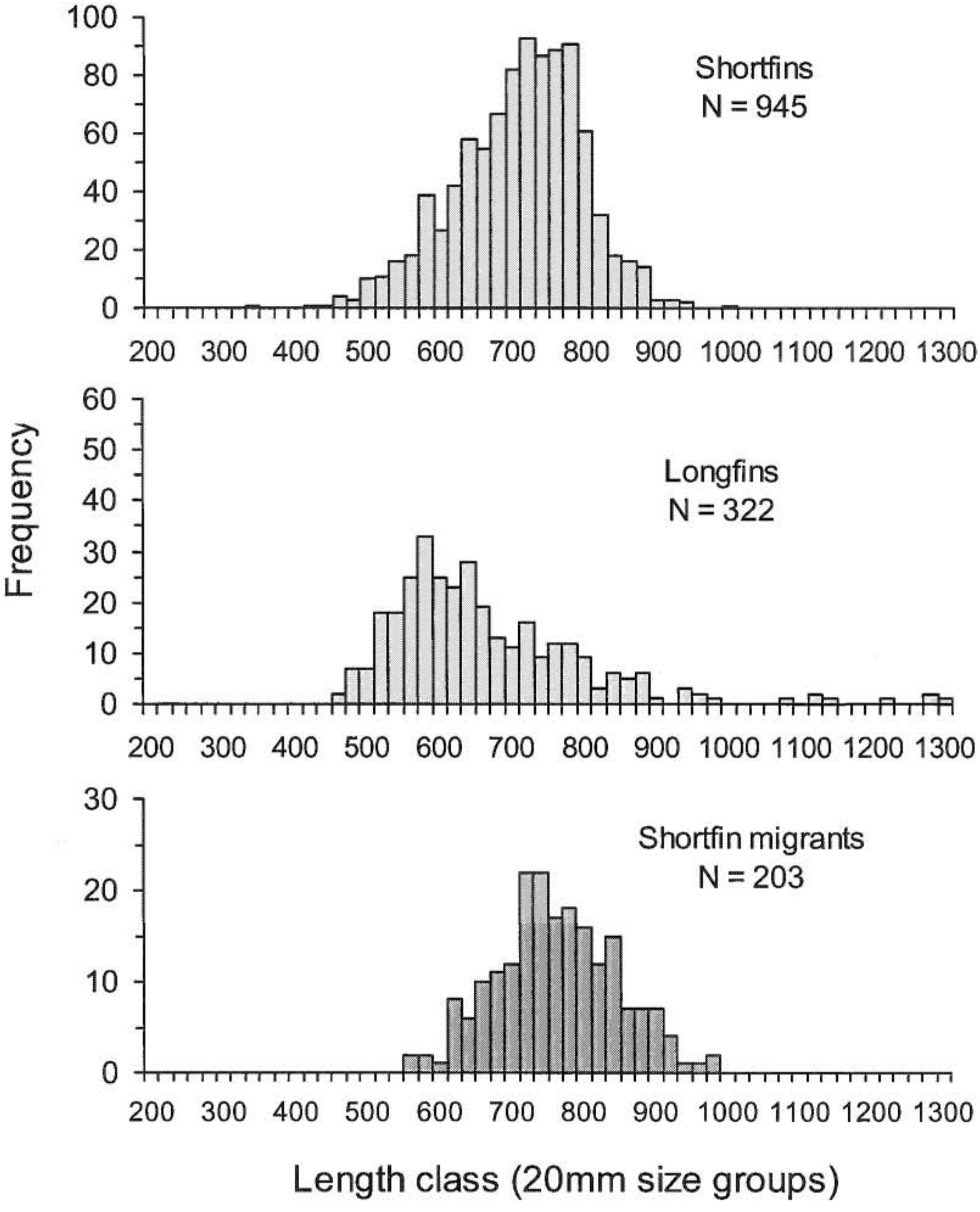


Figure 3:Length frequency of fyke netted non-migratory eels of both species, and migratory shortfins.

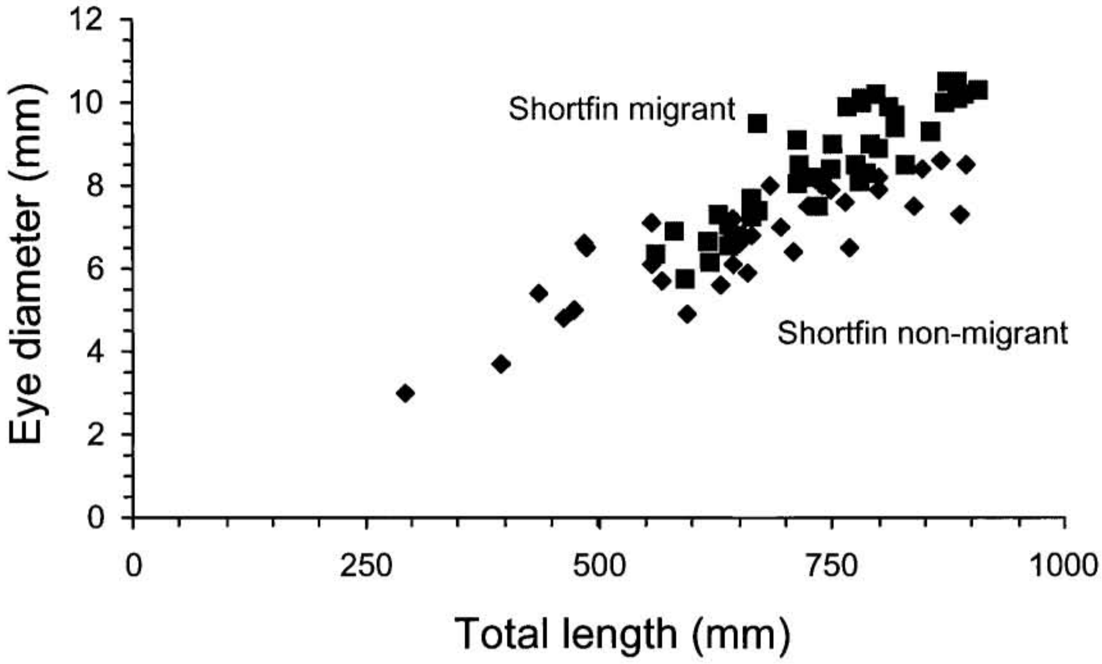


Figure 4: Relationship between eye diameter and total length of non-migratory and migratory shortfin eels.

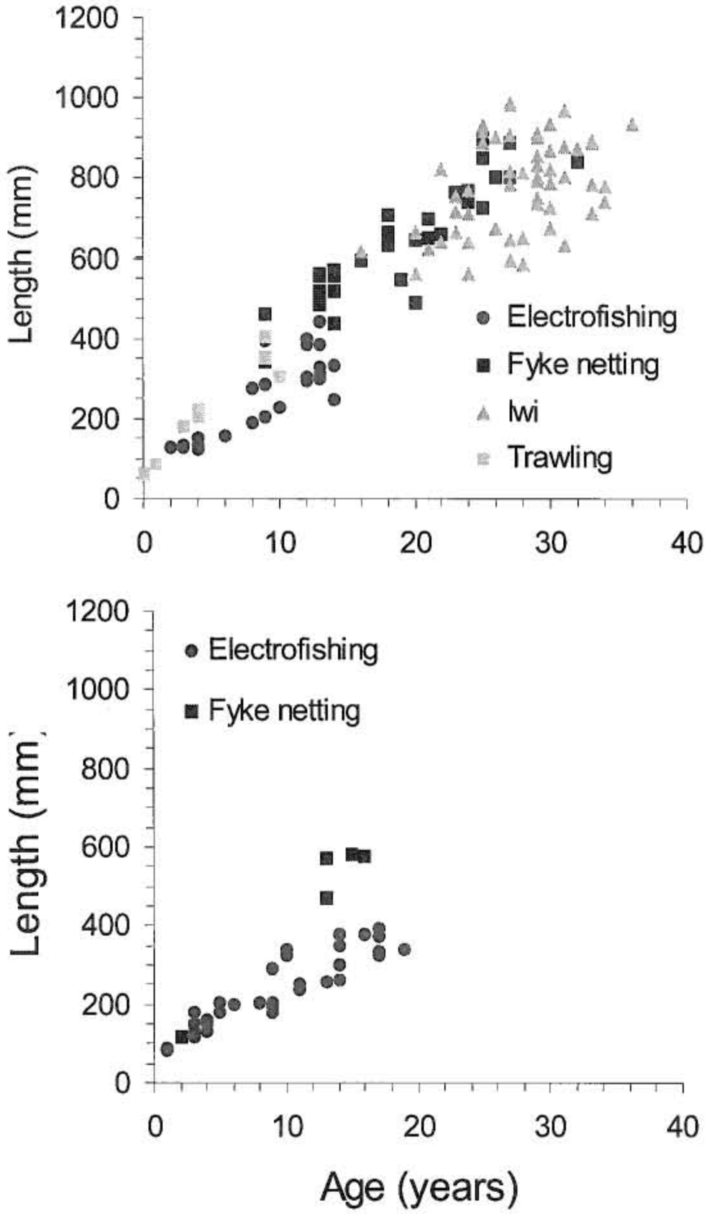


Figure 5: Length-at-age relationship of shortfin and longfin eels for different capture methods.

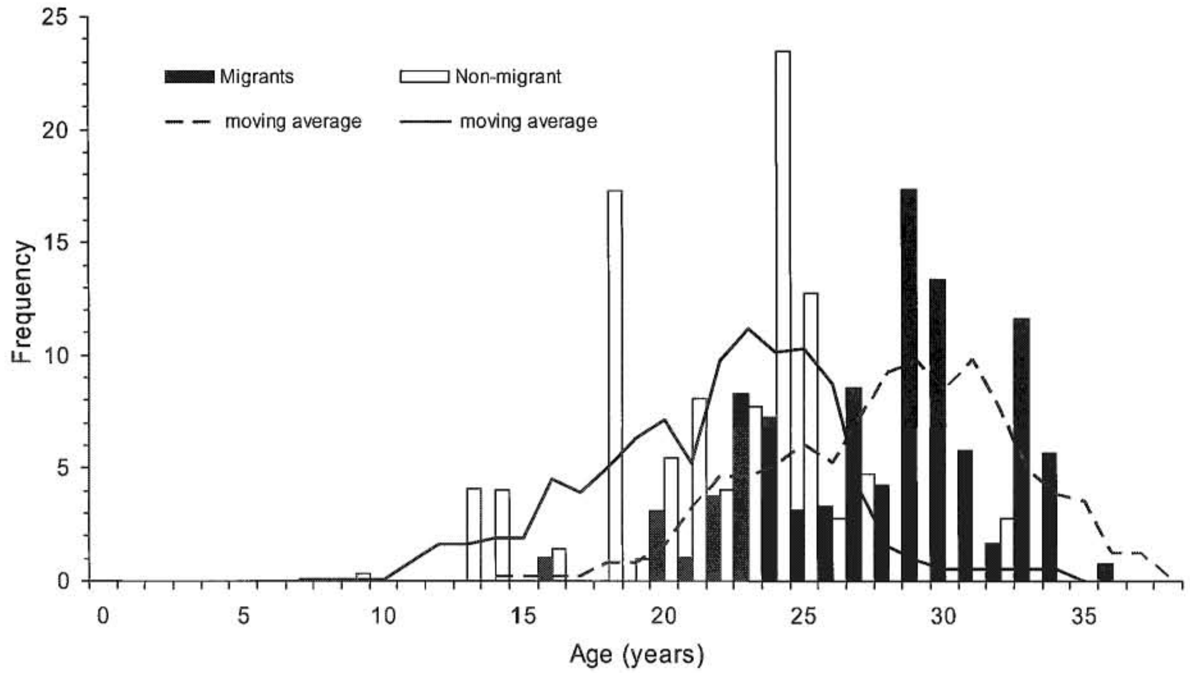


Figure 6: Age class distributions of non-migratory and migratory eels, and 5-point moving average distributions.

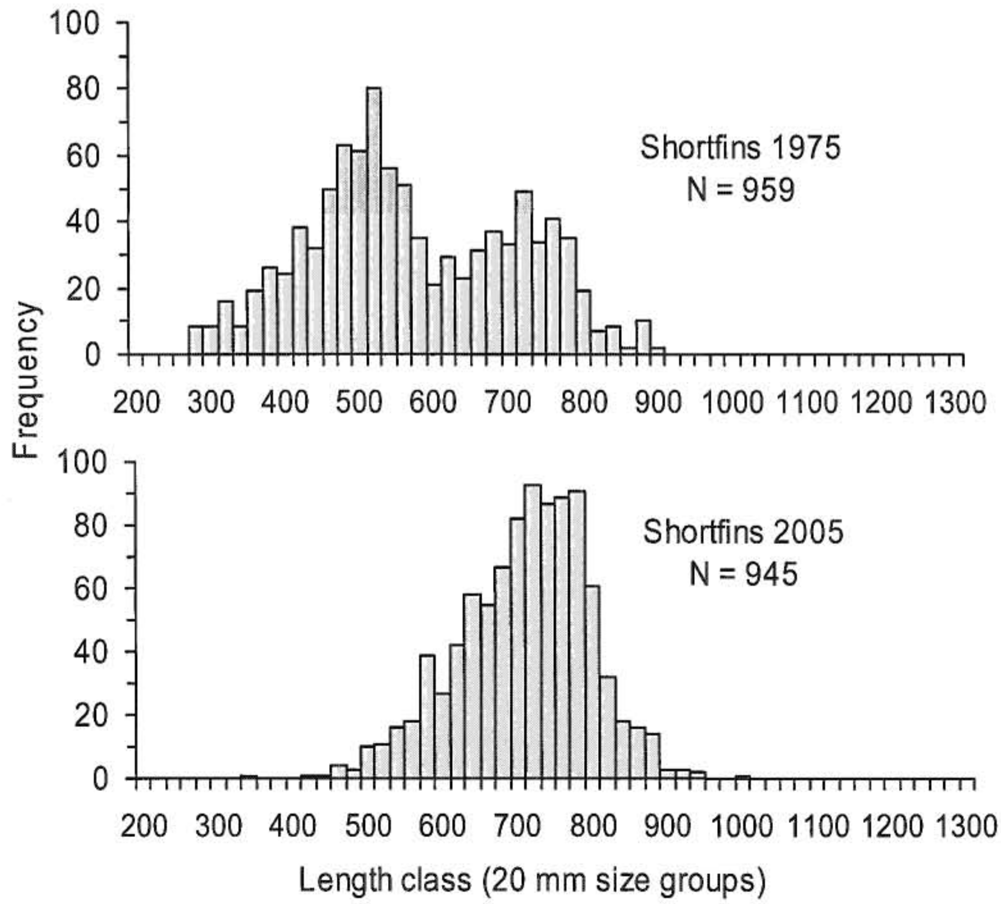


Figure 7: Length frequency of fyke netted shortfin eels, 1975 and 2005.

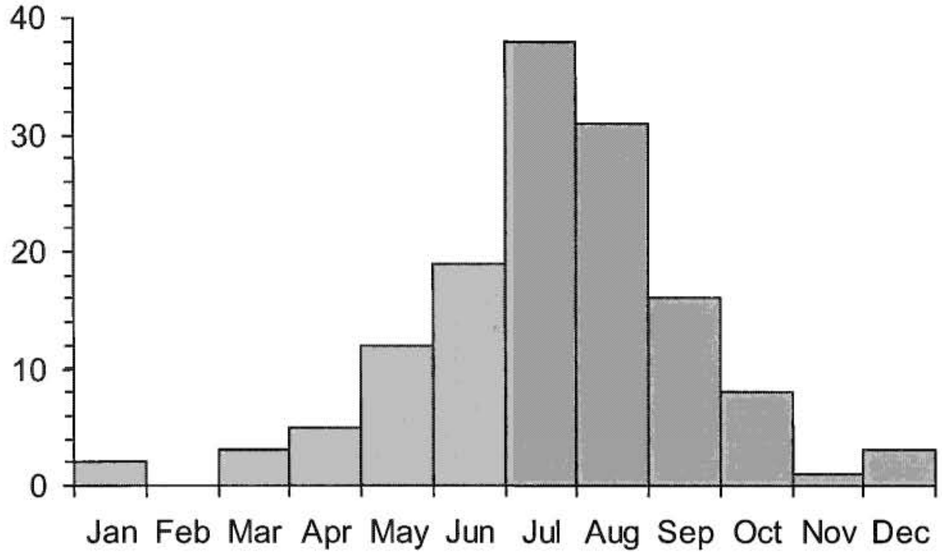
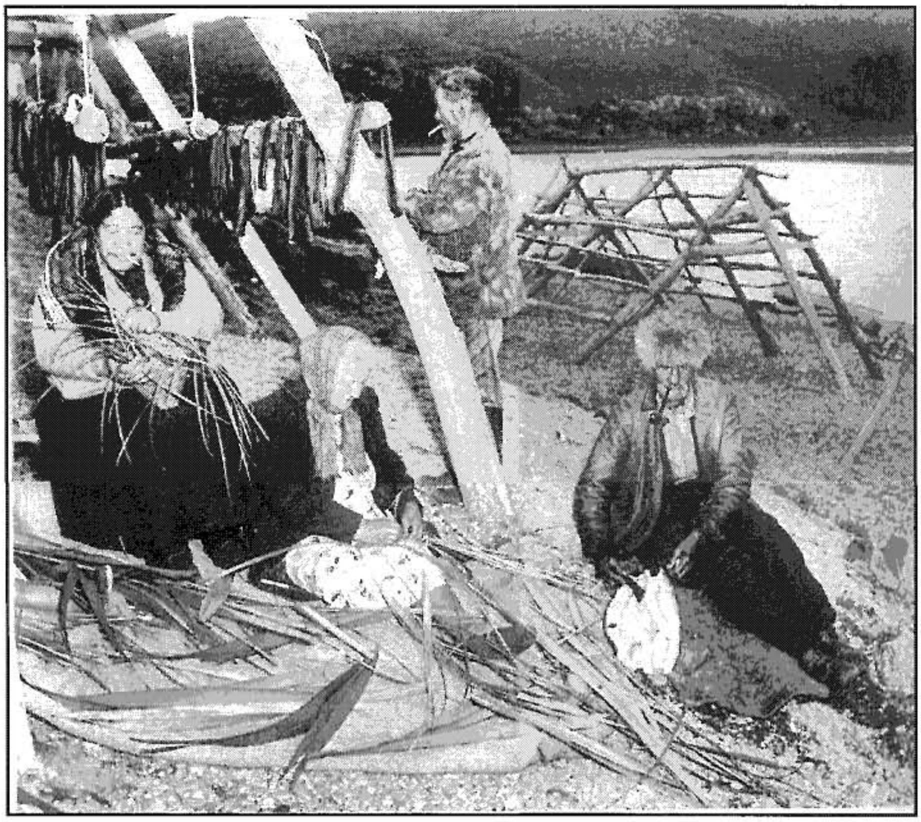


Figure 8: Frequency of lake openings per month, 1955 – 2004.

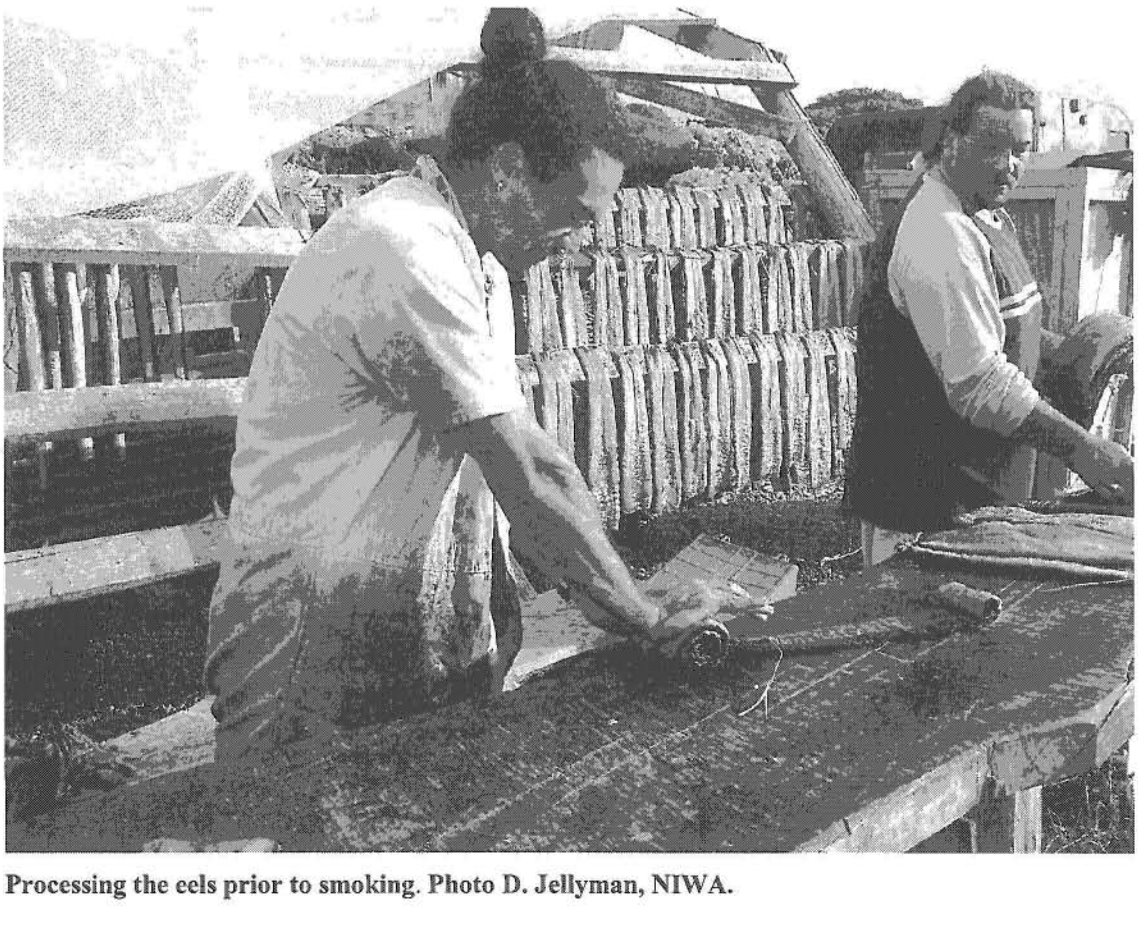
Appendix A Photographs of historic and present day customary fishing practices.



Wairewa whānau at Te Roto o Wairewa processing tuna (1940s).

Digging the trenches (drains) before to the annual heke. Note the shallow pit where the person on the left is standing – these are the parau, the dry trenches, into which the gaffed eels are thrown. (Photo courtesy Jack Jacobs, Wairewa Rūnaka.)

Gaffing eels into the parau at night. Photo courtesy Jack Jacobs, Wairewa Rünaka.



Processing the eels prior to smoking. Photo D. Jellyman, NIWA.

Appendix B. Catches of fish from trawls

Date	Time	Trawl #	Easting	Northing	Water temp	Depth (m)	substrate	eels			smelt	bullies
								< 200	200-399	> 399		
16/11/2004	2000	1	2487250	5710082	17.2	1.8	soft mud				50	10
16/11/2004	2015	2	2487336	5710133		1.4	soft mud				80	3
16/11/2004	2035	3	2486655	5709400		2	black smelly mud				25	
16/11/2004	2100	4	2486716	5709017		> 2.0	stony				90	2
16/11/2004	2105	5	2486649	5709456		1.4	stony				20	4
16/11/2004	2115	6	2486772	5709299		1.5	soft mud			1	200	50
16/11/2004	2140	7	2486758	5709899		0.9	stony				150	40
16/11/2004	2145	8	2486948	5710121		1	stony	2		1	230	40
16/11/2004	2200	9	2487092	5710202		1	stony		1	1	100	50
16/11/2004	2215	10	2487359	5710199		1	stony	1			80	40
16/11/2004	2228	11	2487360	5710205		1	stony				80	30
16/11/2004	2242	12	2487270	5710130		1.1	stony/soft mud		1	1	100	50
16/11/2004	2255	13	2487928	5710144		1.2	soft mud	1		2	150	30
16/11/2004	2315	14	2488314	5710253		0.9	stony				100	40
16/11/2004	2330	15	2486884	5709999		0.8	stony				120	20
16/11/2004	2345	16	2486954	5710095		1.2	soft mud	1			100	20
Total								**5**	**2**	**6**	**1675**	**429**

Mean/trawl								**0.3**	**0.1**	**0.4**	**104.7**	**26.8**
17/11/2004	2115	1	2487591	5710158	17.8	1	stony			1	100	20
17/11/2004	2127	2	2487955	5710137		1.2	mud				30	80
17/11/2004	2140	3	2487908	5710070		1.5	soft mud		2		30	200
17/11/2004	2155	4	2488210	5710101		1.6	soft mud			1	50	100
17/11/2004	2213	5	2488359	5710292		0.9	stony				70	10
17/11/2004	2225	6	2488260	5710701		0.8	stony	1			200	20
17/11/2004	2240	7	2488223	5710466		0.8	stony	1		1	140	60
17/11/2004	2257	8	2488316	5710801		2	soft mud				250	20
17/11/2004	2315	9	2488076	5711422		1.8	soft mud			14	60	5
17/11/2004	2330	10	2487944	5711264		1.4	mud			1	30	20
17/11/2004	2348	11	2487617	5710136		1.1	mud				100	30
Total								**2**	**2**	**18**	**1060**	**565**
Mean/trawl								**0.2**	**0.2**	**1.6**	**96.4**	**51.4**
Overall means								0.26	0.15	0.89	101.29	36.81

Appendix C. Results from fyke net fishing. F, standard fyke net; FM, fine-meshed fyke net;

				Shortfin		Longfin		Total		
Date	Net	Easting	Northing	No.	kg	No.	kg	No.	kg	Comments
7/12/2004	F	2487588	5710044	57	60.4	25	23.8	82	84.3	
	F	2487982	5719904	36	40.7	11	26.9	47	67.6	
	F	2488083	5719941	32	31.9	16	21.4	48	53.3	
	F	2488195	5709990	50	49.1	8	8.5	58	57.6	
	F	2488300	5710039	71	65.6	38	24.9	109	91.5	
	F	2488383	5710114	44	43.0	5	3.3	49	46.3	
				290	**290.8**	**103**	**108.8**	**393**	**399.6**	
8/12/2004	F	2488470	5710180	28	33.5	16	18.8	44	52.3	
	F	2488545	5710248	35	34.2	16	11.5	51	45.7	
	F	2488663	5710307	52	51.5	25	15.7	77	67.2	
	F	2488769	5710369	40	46.1	4	4.4	44	50.5	
	F	2488865	5710443	28	29.9	13	10.5	41	40.4	
	F	2488923	5710549	45	44.7	3	3.5	48	48.2	
				228	**239.8**	**77**	**64.4**	**305**	**304.3**	
9/12/2004	F	2489622	5711260	19	19.2	15	24.7	34	43.9	
	F	2489729	5711303	42	43.0	1	1.1	43	44.1	
	F	2489841	5711329	43	36.1	11	8.0	54	44.1	
	F	2489932	5711429	1	1.7	1	1.7	2	3.4	Hole in net
	F	2490035	5711429	36	27.0	4	2.9	40	29.9	

Date	Net	Easting	Northing	Shortfin No.	Shortfin kg	Longfin No.	Longfin kg	Total No.	Total kg	Comments
	F	2490144	5711428	32	25.5	15	25.5	47	51.0	
				173	**152.6**	**47**	**64.1**	**220**	**216.6**	
14/12/2004	F	2492169	5713065	86	65.4	59	64.0	145	129.4	
	F	2492215	5713144	10	8.1	1	2.2	11	10.3	
	FM	2492206	5713171	5	2.8	2	2.7	7	5.5	
	F	2492281	5713202	34	24.9	4	3.7	38	28.6	
	FM	2492380	5713266	2	1.3	5	3.4	7	4.7	
	F	2492493	5713305	50	35.2	17	14.3	67	49.5	
	F	2492638	5713503	38	24.7	2	1.2	40	25.9	
				225	**162.4**	**90**	**91.6**	**315**	**254.0**	
14/05/2005	F	2488473	5711733	6	6.8	4	5.3	10	12.1	
	F	2488372	5711655	21	21.6	3	1.6	24	23.2	
	F	2488280	5711599	7	6.8	3	3.2	10	10	
	F	2488198	5711524	2	2.9	1	1.2	3	4.1	
	F	2488651	5711210	0	0	0	0	0	0	
	F	2488655	5711211	0	0	0	0	0	0	
	F	2488659	5711212	0	0	0	0	0	0	
	F	2487948	5711013	0	0	0	0	0	0	
	F	2488010	5710943	0	0	0	0	0	0	
	F	2488101	5710889	1	1.3	1	0.8	2	2.1	
				37	**39.4**	**12**	**12.1**	**49**	**51.4**	

Appendix D. Effect of lake openings on water level of Wairewa in 2000. Note that the lake was opened in January, May, August (2), September, October, and December