MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

ISSN 1175-1584

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New Zealand Fisheries Assessment Report 2003/51
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New Zealand Fisheries Assessment Report 2003/51
October 2003

Published by Ministry of Fisheries
Wellington
2003

ISSN 1175-1584

Citation:
Jellyman, D.J.; Graynoth, E.; Beentjes, M.P.; Sykes, J.R.E. (2003).
A review of the eel fishery in Te Waihora (Lake Ellesmere).
New Zealand Fisheries Assessment Report 2003/51. 56 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Jellyman, D.J.; Graynoth, E.; Beentjes, M.P.; Sykes, J.R.E. (2003). A review of the eel fishery in Te Waihora (Lake Ellesmere).

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Te Waihora (Lake Ellesmere) sustains very important customary and commercial eel fisheries. As part of a review of management procedures on the lake, the National Institute of Water and Atmospheric Research Ltd. was contracted to provide a review of recent fishery information, principally available from published reports and papers.

The annual recruitment of glass eels into the lake is highly variable and is correlated with the duration and timing of the lake opening to the sea. Catch rates of different year classes in trawl surveys indicate recruitment was low from 1986 to 1990 and from 1993 to 1995. Growth rates of small juvenile eels dropped suddenly in the summers of 1996–97, 1997–98 and 1998–99. There is insufficient scientific information available on historical changes in the ecology of the lake and on factors influencing the diet, food supplies, and growth of juvenile eels to understand reasons for this decline. In contrast, growth rates of eels larger than about 530 mm (about 300 g) have increased markedly in recent years. This may be related to increased predation on common bullies.

For migrating eels, the main changes have been the virtual loss of migrating longfin eels, a change from a shortfinned female dominated migration to a male dominated one, a reduction in size of shortfinned males (eels are now becoming mature at a smaller size), a reduction in growth rates of shortfinned males, and an increase in size but a decrease in age of shortfinned females.

From a review of catch sampling for the 1995–96 to 1997–98 fishing years, most catches were 100% shortfin. The mean size of shortfin eels caught outside the Concession Area (excluding Kaitorete Spit) ranged from 52 to 60 cm, size increased each year, and eels were nearly all female. Length frequency distribution was variable between years, with length ranging from about 30 to 100 cm, skewed to the left with no clear modes. Eels sampled from the Concession Area were nearly all migrating males and mean size was consistent between years (39.5, 39.9, and 39.5 cm). Length frequency distribution was dominated by a strong mode at 35–45 cm. The mean annual length increments for shortfin eels were 35 $mm.yr^{-1}$ for Kaituna Lagoon (predominantly female) and 21 $mm.yr^{-1}$ in the Concession Area (predominantly males).

A catch-per-unit-effort analysis (CPUE) was conducted for Te Waihora for the fishing years 1990–91 to 1998–99. The number of net lifts per set has tended to decline as fishers have moved away from using large numbers of small fyke nets in favour of using fewer larger nets. Mean daily catches, however, although variable between years, have remained reasonably constant at about 200 kg per set. Between 99 and 100% of the total estimated catch was identified to species by fishers on CELR forms and the remainder was recorded as EEU (unidentified). Between 95 and 99% of all catch was shortfin. Apart from one very good year in 1992 and a poor year in 1994, shortfin catches have been stable at about 100 t annually. There was no trend in longfin catch.

Standardised CPUE analysis for shortfin showed no trend in CPUE. A second analysis on shortfin catch, excluding the Concession Area months (February and March for all years), gave a similar result. Permit followed by month explained about 30% of the variation in CPUE and indicated that catch rates are very dependent on fisher experience and/or ability and time of the year (season).

Overall, there were no statistically significant trends in CPUE in Te Waihora although there were some marked declines and increases which were related to the introduction of the Concession Area in 1996 and a minimum legal size (MLS) of 140 g at the start on the 1993–94 fishing year.

The administration of oestrogen can influence the proportion of female eels in a population. Although Te Waihora will receive environmental oestrogens from sewage and runoff from stock, it is considered unlikely that the concentration of oestrogens would be sufficient to have negative effects in the expression of sex of eels.

1. INTRODUCTION

The Ministry of Fisheries contracted NIWA to review the Te Waihora eel fishery, to better provide for customary fishing practices.

The specific objectives are:

1. to review the Te Waihora eel fishery using existing data sources to investigate claims by commercial fishers on potential recruitment into the fishery

2 review the extent to which the TACC and other management practices could be changed so as to provide larger eels for the customary fishery taken by customary methods

3 review the available literature on the potential effects of oestrogen in the environment on fish populations

Subsequent discussions agreed that it would be inappropriate for NIWA to make recommendations about specific levels of TACC, but comment about the implications of possible management practices.

The following information is taken from a range of NIWA publications on eels from Waihora, with some additional population modeling and CPUE analysis.

2. BACKGROUND

The following comments are taken from the Ministry of Fisheries contract document:

The Te Waihora eel fishery (ANG13) was introduced into the QMS on 1 October 2000. The TAC was set at 156.32 tonnes, with a customary allowance of 31.26 tonnes, and a recreational allowance of 3.13 tonnes. The fishery had previously been a Controlled Fishery with a commercial catch limit of 132 tonnes.

The fishery has been managed to maximise the catch of migrating eels by setting an arbitrary figure of 80–100 tonnes of migrating eels to be taken during the migration season, with the balance being caught as feeding eels.

Te Waihora has been commercially fished since the late 1960s. During the 1970s and early 1980s there was a heavy fish down period and the average size of eels caught reduced substantially. Few female eels escaped as migrants having been harvested at the feeding stage before migration. The catch of migrant eels can vary from year to year depending on growth and harvest of the feeding eels. Recruitment of juvenile eels into the fishery is not dependent on the migration of eels from the lake. As eels only home back to the sea to breed, recruitment into the lake is dependent on eels escaping to breed from throughout New Zealand.

Eels are highly valued by Maori through New Zealand as a food source. Customary fishing practices have required larger eels. The commercial fishery in Te Waihora has progressively reduced the average size of eels in the lake to the extent that Maori claim that their customary fishing practices cannot be maintained. Commercial fishers claim that there is a substantial number of undersized eels less that 220 g in the lake that will eventually improve customary access. The Te Taumutu Runanga have proposed a review of the TACC for ANG13, due to: a low harvest of customary eels using traditional fishing methods, reports from commercial fishers of poor catches, increased fishing pressure on feeding eels because of the 1 October fishing year, and the growing absence of the mass migration across the shingle bar.

In addition to the effect of the commercial fishing on the average size of eels available for customary use, habitat changes within the lake over the past 40 odd years have changed the species composition of eels in the lake. Before 1968 there were extensive macrophyte weed beds in the lake that provide extensive cover for eels. Before this time, the lake contained many larger longfin eels. Longfin eels are now virtually absent from the lake except as migrants that originate from the rivers and streams flowing into the lake. The change in the species composition in the lake would have significantly impacted on the customary in providing larger longfin eels.

In addition to habitat changes in the lake, there are claims that pollution from agricultural runoff and sewage have affected the lake ecosystem and consequently the eel population. In particular, there are claims that oestrogen might affect the sex ratio of eels in the lake.

The review of the TACC should include a review of available data sources to substantiate or otherwise the commercial fisher comments about the future recruitment into the customary fishery. The review should include comment on how realistic the objective is of restoring the customary fishery to provide better access using traditional methods such as koumu, hinaki, hau uruao patu, etc, given past environmental changes to lake and the effect of commercial fishing. Finally the review should include a review of available literature on the potential effects of oestrogen on fish populations.

The following review is largely drawn from existing literature, although some modelling has been carried out to integrate the outcomes from the various studies. As a consequence of the different sources of data, there are some inconsistencies in the units of length, being both millimetres and centimetres, and in the style of figures presented. The report is presented by sections (i.e., 3. Recruitment and growth trends; 4. Changes in the fishery for migrating eels; 5. Catch sampling and catch per unit effort analysis; 6. A review of the potential effects of environmental oestrogen on fish populations), with Sections 3–5 incorporating a discussion. The final section provides an overall summary and conclusions.

A brief history of the Te Waihora commercial fishery is as follows:

- significant commercial fishing began in 1971
- catches peaked at 847 t in 1976
- December 1977, national moratorium on issuing of new eel fishing permits
- December 1978, controlled fishery declared, with Total Allowable Catch (TAC) set at 256 t (excluding migrant eels)
- 1978–86, periodic reductions in TAC to present level of 136.5 t (including migrants)
- September 1993, minimum size set at 140 g, with annual increase of 10 g to 220 g
- 1995, formation of Te Waka a Maui me ona Toka Tuna (TWM), joint industry–iwi working party
- December 1996, publication of South Island Eel Management Plan by TWM, and formation of Te Waihora Eel Management Committee
- 1999, publication of Te Waihora Eel Management Plan
- October 2000, South Island eels introduced into Quota Management System

3. RECRUITMENT AND GROWTH TRENDS

This section reviews factors influencing the recruitment of glass eels (the stage at arrival from the sea), and the annual variations in growth of juvenile eels, and thereby provides information for the management of the lake and its eel fishery.

3.1 Methods

To obtain information on the size and age distributions of juvenile eels, small eels (99.5% shortfinned), were caught in 250 m long tows of a small, 2 m wide, beam trawl (Jellyman & Chisnall 1999), during summer from December 1994 to December 1999 (Table 1). From 1994–5 to 1996–7, a variety of locations was trawled during both day and night (Jellyman et al., 1995, Jellyman & Chisnall 1999). For the last three summers of the study, 1997–98 to 1999–2000, sampling was restricted to late November and early December in the western end of the lake (Timberyard Point) where there were few snags and catches were highest. Trawling began in the evening and finished past midnight, after the completion of 8–14 trawls. Although attempts were made to randomly sample the entire area each year, strong winds sometimes confined trawling to the lee of a small island. Sampling continued each year until sufficient juvenile eels (about 250) had been collected for ageing and length frequency analysis.

Catch rates of eels per trawl (CPUE) were calculated and used, with age data, to determine trends in year class abundance and to estimate survival rates. Because catches are influenced by differences in location, substrates, water depths, and light intensities (Jellyman & Chisnall 1999), only samples collected from the western area of the lake at night were examined (Table 1). Catch rates for different year classes were also adjusted for the influence of water temperature.

Eels were measured fresh to the nearest millimetres (total length), and representative samples aged. Ages determined from burnt otoliths (Hu & Todd 1981) were validated by length frequency analysis of strong year classes. Trends in length frequency and age composition from 1994 to 1999 were determined using samples collected from Timberyard Point. Trends in age composition, for fish under 300 mm and under 10 years, were measured using age length keys (Ricker 1975) and mixture analysis (MacDonald & Green 1988). Because high proportions (49%) of fish were aged, both methods gave similar results. Annual survival rates were estimated from trends in CPUE for eels of different year classes. Survival was estimated for ages 0 to 9, but older fish were pooled into a single class.

Average fish lengths at ages more than 0 were modelled using maximum likelihood techniques (Francis & Jellyman 1999). The length, L, and standard deviation, SD, of eels of age i is given by

$$L = a_1 + b_1 i \qquad SD = a_2 + b_2 i$$

where the parameters (a_1, b_1) define mean length as a linear function of age and (a_2, b_2) describe the standard deviation of length-at-age. Growth in the first year was faster than in later years and therefore a_1 and a_2 overestimated mean length and SD at age 0. Growth between sampling periods was determined using ANCOVA with the date of capture as a categorical variable and year class as a covariate. The difference in least square estimates of mean length between periods was used to estimate growth.

3.2 Results

3.2.1 Recruitment

The relative abundance of different year classes of juvenile eels varied (Table 2, Figure 1). The group of relatively large (300–450 mm) eels caught in 1994–95 and later summers, consisted of 10–18 year-old-fish of the 1976 to 1984 year classes. Their numbers declined rapidly, presumably because mature males migrated to sea (Jellyman & Chisnall 1999) and others were caught by eel fishers.

Recruitment was low from 1985 to 1990 and catch rates for individual year classes were generally under 0.1 fish per trawl (Table 3). The 1991 and 1992 year classes were of moderate size (0.5–1.0 eels per trawl) and these fish ranged from 100–200 mm in 1994–95 (Figure 1). Few glass eels entered the lake from 1993 to 1995, and in 1998, and CPUE for these year classes was low (0.08–0.24 eels per trawl). However, there was strong recruitment of glass eels into the lake in 1996, 1997, and to a lesser extent in 1999. Catches of yearling and older eels for the 1996 and 1997 year classes increased and did not decline due to natural mortality in later years.

Information on the strength of each year class and estimated growth rates (next section) were used to construct Table 3 which shows the dates when different year classes should enter the fishery. If growth rates remain low, then catches of migrant males in the fishery should remain at normal levels in 2002 and 2003. However, we suspect catches of migrating eels will decline over the next 10 to 15 years because of the low recruitment from 1985 to 1989.

On the other hand if growth rates return to normal (23 mm y^{-1}), then catches should improve from 2005 onwards, and peak in 2007, as fish of the moderate 1991 and 1992 year classes enter the fishery. The strong 1996 and 1997 year classes will enter the fishery about 4 years later.

There is good evidence that the duration and timing of the lake's opening to the sea influences the numbers of glass eels entering the lake. The strength of the 1986 to 1999 year classes was estimated using mean trawl catch rates over the study period. Catch rates were significantly correlated with the duration of the lake opening during September and October (Figure 2) ($n = 14$, $r = 0.56$, $P < 0.05$). This was mainly because the lake was open throughout September and October in 1996 when a large run of glass eels entered (Table 2, Figure 1). Natural variations in the size of glass eel runs to the Canterbury region had less influence on recruitment. Mean catch rates for each year class were not significantly correlated with glass eel densities in local streams and rivers (1994–99, $n = 5$, $r = 0.59$, $P > 0.1$) and were not related to estimated recruitment into a local stream (Pigeon Bay Stream 1992–98, $n = 7$, $r = 0.09$, NIWA unpubl. data).

3.2.2 Growth

Glass eels (0+ fish) averaged 63 mm ($n = 157$, $SD = 2.8$ mm) in November and December 1996 and 1997. They grew 22 mm in their first year of life, averaging 85 mm ($n = 79$, $SD = 9.5$ mm) at age 1.

Mean annual growth rates (mm y^{-1}) from age 1 onwards were approximately linear (Graynoth 1998, 1999) but varied between years. The fastest growth occurred during the 1995–96 summer when eels grew 21.1 mm from December 1995 to March 1996 (Table 4). Otoliths examined in March 1996 showed comparatively wide summer bands, averaging 63 mm in width (Graynoth 1999). Growth then slowed over winter and fish were only 1.8 mm longer by December 1996 (Table 4). Growth was particularly slow in the 1996/97 summer (6.3 mm y^{-1}) and was also poor in 1997–98 (Figure 4) and 1998/99 (13.9 and 14.3 mm y^{-1} respectively).

Growth over the entire study period was slow and averaged only 13.2 mm y^{-1} (Table 4). For example, the strong 1991 and 1996 year classes averaged 12.3 and 14.0 mm y^{-1} respectively (Table 4). Growth was faster in the decade prior to this study and averaged 23.2 mm y^{-1} based on age length plots of the fish caught in January and February 1995 (Table 5).

Growth rates appear to be higher in warm summers (unpublished data) but were unrelated to annual changes in density, as estimated by mean CPUE for all fish more than 70 mm combined (see Table 1) ($r = 0.14$, $n = 4$, $P = 0.85$).

There is strong evidence that juvenile eel growth rates have declined in Lake Ellesmere. Figures 3 to 5 show actual and predicted changes in mean length and weight of different sexes and age classes of eels from 1950 onwards. In the 1960s and 1970s, small (390–430 mm), mature males grew about 26 mm y^{-1} (Figure 3; data derived from Todd 1980) declining to about 23 mm y^{-1} in the 1980s and early 1990s (this study and Jellyman & Todd 1998). Growth rates of females have shown a slight increase over the 40 years, especially at lengths more than 500 mm over recent years (Figure 4); this accelerated growth is discussed more fully in Section 4.4). However, growth of juvenile eels from 1995 to 1999 was almost halved (Figure 6).

3.3 Discussion

3.3.1 Recruitment

This study showed that recruitment into Lake Ellesmere was variable and was correlated with the duration and timing of the lake opening to the sea (see Figure 2). This confirms earlier studies that indicated recruitment depended on the timing of the lake opening (Jellyman et al. 1995, Taylor & Graynoth 1996, Jellyman & Chisnall 1999).

3.3.2 Factors responsible for the decline in growth in recent years

Growth rates of shortfinned eels typically range from 20 to 30 mm y^{-1} (Jellyman 1997). The mean growth rates of 13 mm y^{-1} recorded during this study in recent years are exceptionally slow and have been recorded previously only from cool forested or springfed streams (Burnet 1969). It seems unlikely that low water temperatures are responsible for this decline in growth rates because there is no evidence for any long term historical trends and because growth rates were much less than the maximum achieved in the laboratory (Graynoth & Taylor 2000). We suspect the recent declines in growth rates were probably caused by changes in food supplies, competition, and possibly water quality.

In Lake Ellesmere, large juvenile eels (250–400 mm) eat chironomid larvae, snails, isopods, oligochaetes, and mysids (Ryan 1978). Based on their diet in other waters, small juveniles probably eat chironomid larvae, oligochaetes, amphipods, and possibly isopods. Historical changes in the benthic macroinvertebrate fauna of this lake have not been studied, though marked changes in the abundance of chironomid midges are strongly suspected. The lake has a restricted fauna, dominated by crustacea (amphipods, isopods, and mysids), snails, and chironomid larvae and oligochaetes (NIWA, unpub. data), which is of freshwater origin but tolerates brackish water. Euryhaline species of polychaetes, bivalves, gastropods, and amphipods, which dominate in the nearby Avon-Heathcote estuary (Knox 1992), are absent. The lake experiences marked long-term fluctuations in salinity which may have major, and as yet unstudied, effects on the fauna, and hence on eel food supplies.

After prolonged lake mouth openings, sea water (35‰) can penetrate to the centre of the lake and high salinity levels (more than 10‰) can persist for several months (Taylor 1996). Although high salinities are unlikely to directly affect eels, key food items such as chironomid larvae and amphipods could be diminished. For example, the amphipod *Paracalliope fluviatilis* becomes scarce when mean salinities exceed 5‰ in the Heathcote River (Robb & Voyce 1993), *Chironomus zealandicus* are scarce at salinities more than10‰. However, other foods such as snails and mysids are unlikely to be affected.

Macroinvertebrate food supplies, and eel growth rates, may be related to the proliferation of common bullies in recent years (Jellyman et al. 1995, Jellyman & Todd 1998). Common bullies are widely distributed (Glova & Sagar 2000) and were particularly abundant in 1996–97 (see Table 1). They eat similar food to eels in this lake (e.g., chironomid larvae, mysids, and snails), and competition for food, together with low summer water temperatures, may have been responsible for the slow growth rates of eels in the summer of 1996–97. Common bullies may have increased in abundance in recent years due to fishermen catching large piscivorous eels.

Although historical changes in water quality and increased eutrophication may have affected macroinvertebrate abundance and production in this lake, there are insufficient data available properly assess this issue. Eels do not depend upon vision for feeding and therefore the lake's high turbidity is unlikely to restrict foraging. Therefore it seems unlikely that changes in water quality will have direct effects on eel foraging behaviour and growth rates.

In conclusion, although changes to food supplies are probably responsible for recent declines in eel growth rates in this lake, more information on fish diets and food supplies is required to understand precisely why this has occurred and to model and predict growth rates in the future.

4. CHANGES IN THE FISHERY FOR MIGRATING EELS

Since observations on the eel fishery began in the 1940s, a number of significant changes in the species and size composition of stocks have been recorded. In brief these are:

- the virtual loss of longfinned migrating eels
- a change from a shortfinned female dominated migration to a male dominated one
- a reduction in size of shortfinned males
- a reduction in growth rates of shortfinned males
- an increase in size of shortfinned females
- a decrease in the average age of shortfinned females

4.1 Methods

Samples of migrating shortfinned male eels were caught in unbaited fyke nets (12 mm mesh), set overnight at Taumutu, Lake Ellesmere. During the 1970s, when an extensive research programme was underway, large samples were measured and aged. To compliment these and observe any changes over time, further samples were collected during 1992–96. For length-frequency data, eels were anaesthetised in the field, measured (to ±1 mm) and released. For subsamples retained for ageing, eels were taken to the laboratory where they were measured, weighed (to ±0.1 g), and otoliths collected. Otoliths were prepared by the cracking and burning method of Hu & Todd (1981). Condition was calculated using $k = w*10^6/l^3$ where w = weight in grams, and l = length in millimetres. Mean growth rates were calculated from mean length (or weight) /mean age for each year. Data on non-migratory eels came from extensive collections of eels made in the 1970s (NIWA unpublished data).

To compare changes in the size of female migratory eels, a sample of 66 migratory females from a commercial catch was measured on 25 March 1998. Eels were anaethsetised with clove oil, measured (mm), weighed (g), and released. Otoliths (n = 50) were obtained from a separate sample of females (30 March 1998) retained for commercial processing. These eels were aged, and individual growth rates estimated (using a back-calculation technique based on the widths of individual annual checks in each otolith). A further sample, 24 March 1999 (36 eels), was also measured alive from a commercial catch.

4.2 Results

4.2.1 The virtual loss of longfin migrant eels

Although it would be expected that the lake would have always been dominated by shortfins, there is little doubt that, historically, longfins made up a significantly higher proportion of the population than they do at present. For example, Cairns (1941) recorded a sample of eels from Lake Ellesmere (n =

305) that was 25% longfins, and 27% of a sample of 144 feeding eels examined by Shorland & Russell (1948) were also longfins. Since 1983, commercial fishing returns have recorded eel species; examination of returns for Lake Ellesmere show that for the 1983–84 and 1984–85 fishing years (1 October-30 September), longfins made up 1.9 and 1.0% of total catch, but numbers fell steadily over the following six seasons to be nil by 1990–91. Although 3.8% longfins were recorded during 1991/92, it seems unlikely that this quantity was taken from the lake, and it is more likely that most of these were longfins caught elsewhere but coded to the lake. Longfins are more susceptible to capture by fyke netting than shortfins (D. Jellyman, unpublished data); if a mixed population of both species is subject to commercial fishing, longfin numbers will become reduced more rapidly than shortfins. It is also possible that the loss of the extensive macrophyte beds in 1968 resulted in a less attractive environment for longfin eels.

In common with riverine populations of eels elsewhere in Canterbury, longfins are the numerically dominant species in the tributaries (data from Hardy 1989), although Burnet (1969) found that longfins in the Doyleston Drain made up only 31% of the population.

Although the data are "intermittent", collectively they show that the proportion of longfins in the catches has declined over time. Whereas reasonable numbers of longfins may have once been present within the lake, today most longfins will be encountered within tributaries rather than in the lake itself.

Hobbs (1947) marked a proportion of longfinned female migrants, and from subsequent recaptures he estimated a total of 3850 females (23 tons). No estimate of numbers of longfin males was attempted, but he commented that longfin females outnumbered males. Although no present-day estimates of numbers of longfin females are available, recent captures of females for use in pop-up tag experiments, would indicate that numbers would be a few hundred at most.

4.2.2 A change from a shortfinned female dominated migration to a male dominated one

Hobbs (1947) found that 82% of the migratory shortfins he trapped were females; although this percentage would have been biased towards females because of the period he fished, nevertheless his figures correspond to an estimated shortfin female migration of 801 140 which must be considered very large relative to present day numbers.

4.2.3 A reduction in size of shortfinned males and a reduction in their growth rate

Over the period for which samples are available, the mean length has reduced from 480 mm in 1942 (Hobbs 1947) to 394 mm in 1996 (Figure 7). The trend for a continued decline in mean length per season has been paralleled by a similar decline in weight until the early 1980s, after which weight has remained relatively constant. Condition, k, (calculated from $k = w*10^6/l^3$ where w = weight in grams, l = length in mm), was not correlated with length ($p>0.05$), and the mean condition of all yearly samples showed similar trends to weight, except that condition improved markedly over recent years (Figure 7).

Age distributions (Table 6) show a reasonably constant mean age over the 20 years for which data are available, although differences between years were significant (ANOVA, $F = 30.22$, $p<0.001$). Much of this difference will be due to variable age-class strengths – for example, age class 15 in 1978 also dominated the 1979 sample (as age class 16) and probably accounted for the greatest average age, 15.6, being recorded in that year; removal of the 1979 data from the age sample reduced the variability in age between years, but differences were still significant ($F = 11.56$, $p<0.001$). Of all aged males ($n = 2206$), 67% were 13–16 years old

The conclusion from the above analysis is that average size has declined over time, while age has stayed relatively constant – therefore the average growth rate will have declined also.

So, firstly, why has the average size declined? Todd (1980) assumed that the decline in length observed from 1942 to 1980 was due to commercial fishing selectively removing the larger males. If this were so and the larger males were caught when they exceeded the current minimum commercial size, then it should be evident from a changing skew in size frequency distributions, and there would be no reason to suppose a shift to smaller minimum sizes over time. Examination of size frequencies (Jellyman & Todd 1998) showed no evidence of changes in their shape over time, although the minimum size had declined. Further, the time-frame involved would seem to mitigate against commercial fishing being the mechanism involved, i.e., intensive commercial fishing began in 1971 (287 t; Jellyman et al. 1995), but by the following year (the first year since 1942 that length data were recorded) mean lengths had declined by 33 mm from those recorded by Hobbs (1947) in 1942. It seems unlikely that commercial fishing could have produced such a rapid decline within one year, and it is concluded that the decline in average size is mainly due to eels achieving maturity at a smaller size.

Secondly, why has the growth rate declined? Growth rates of New Zealand eels seem largely density dependent (Jellyman 1997). As Lake Ellesmere eels were heavily exploited during the mid 1970s (Jellyman et al. 1995), it might have been expected that growth rates would have increased as a result of commercial fishing. However, growth rates of male migrants (this study) and small non-migrant eels (Jellyman et al. 1995) have both declined. Suggested explanations for reduced growth rates are long-term environmental changes within the lake, or an increase in the abundance of small eels.

During the past 30–40 years, a number of significant ecological changes have occurred within the lake, with the most significant being increased eutrophication (Hughes et al. 1974), changes in salinity resulting from changed opening regimes in the 1960s (Gerbeaux 1993), and the loss of macrophytes during the 1960s with associated increased turbidity. Possibly some of these changes have been detrimental to eels. For example, they could have resulted in changes to food composition, similar to changes that accompanied increased turbidity in Lake Waahi (Hayes & Rutledge 1991). However, given the plasticity of eels diet, it seems unlikely that any changes in food composition would have disadvantaged eels.

Temporal changes in recruitment to the lake certainly occur, probably in response to annual differences in the timing and duration of the lake opening. A reduction in mortality of juvenile eels is also a distinct possibility as a result of the selective removal of larger eels of both species which are known predators of juvenile eels (Burnet 1952, Jellyman 1989). The scale of the reduced abundance of larger eels is apparent from comparing the estimate of Hobbs (1947) of 500 tons (=508 t) of shortfinned females migrating in 1942, with an estimate of only 2–3 t during 1996 (T.J. Gould, pers. comm.). Similarly the sex proportions of migratory eels have changed dramatically from a dominance by females (4.6:1; calculated from Hobbs 1947), to a dominance by males (1996 estimates = 235:1).

The reported increase in common bullies may also be a result of the reduction in the number of larger eels that would formerly have imposed some predatory constraints on bully numbers, because both bullies and juvenile eels frequent inshore areas and eat similar food, and might directly compete for food. The net result of increased survival of juvenile eels and limited food would be a reduction in growth rates of juvenile eels.

The Lake Ellesmere eel fishery is managed by a Total Allowable Commercial Catch. As virtually all migrating male eels are less than 220 g (96% in 1996), almost all eels harvested by the commercial fishery are, by definition, females. If the reduction in the number of large female eels is at least partly responsible for the proliferation of bullies (which in turn reduce the food available to small eels), then the fishery should maximise capture of male eels and minimise capture of females. To enable this, an exclusion zone was gazetted in March 1996 for that part of the lake where male eels congregate in their endeavours to leave the lake. Provided such a measure can be implemented annually, there should be a corresponding increase in the abundance of female eels, and perhaps an increase in both size and growth rates of males.

4.2.4 An increase in size and a decrease in the average age of shortfinned females

A sample of 50 migratory shortfin females captured in March 1998 was aged, and individual growth rates estimated (using a back-calculation technique based on the widths of individual annual checks in each otolith (Graynoth 1999)). Of these eels, 45 (90%) showed accelerated growth, 4 showed linear (straight-line) growth, and only one showed asymptotic growth (growth rate declining with age). The eels showing accelerated growth showed marked inflections, generally between 380 and 660 mm (Figure 8). The mean annual growth increment for all eels was 45.5 $mm.y^{-1}$ For eels showing accelerated growth, the increments below and above the point of inflection averaged 37.9 $mm.y^{-1}$ (SE = 1.0) and 89.5 $mm.y^{-1}$ (SE = 3.6) respectively.

Trends in the change in average length of migrating females eels from Lake Ellesmere (Figure 9) show an initial decline, but then an increase defining in 1979 which may have continued until the present. A comparison of the length distribution of eels collected from 1975 and 1998 (Figure 10) shows a marked shift from a left-skewed distribution in 1975, with a modal length of 540 mm, to a more normal distribution in 1998 with a modal length of 800 mm.

Thirty years before the advent of commercial eel fishing, Hobbs (1947) recorded an average length of migrating shortfin female eels from Lake Ellesmere of 680 mm. For the period 1972, 1974–80, Todd (1980) found that size had declined to a mean length of 609 mm (and a mean weight of 453 g, calculated from length-weight relationship given by Todd), and suggested that this was due to size-selective capture of non-migratory females eels by the commercial fishery. Average sizes recorded during 1998 and 1999 were significantly larger than those recorded by Todd (1980). Using fecundity data of Todd (1981), it was estimated that the increase in average size from the 1970s to the present has resulted in a corresponding 3.5 fold increase in egg production per female.

Migrating female shortfinned eels are therefore larger but younger than they were 20 or more years ago, and hence they grow faster. The questions that remain are "how has this been achieved?" and "why?". The most likely explanation is changes in food availability, either in absolute terms (sufficient/insufficient food to achieve maximum growth potential) or in relative terms (interactions with other fish may affect feeding).

As migratory eels do not feed, information on diet needs to be determined from non-migratory eels. In a study of the diet of non-migratory eels in Lake Ellesmere, Ryan (1986) noted major changes associated with size – eels under 400 mm fed principally on invertebrates, but larger eels were increasingly piscivorous, with eels more than 501 mm being almost entirely piscivorous; the smallest eel Ryan recorded that had eaten fish (common bullies, *Gobiomorphus cotidianus*) was 370 mm. As these lengths correspond well to those calculated from the growth inflections in the present study (i.e., 530 mm for most eels, and about 300 mm for the smallest), it is suggested that the reason for accelerated growth found in the present study is because of a change in diet to feeding on fish. It is of interest that previous back-calculations of growth of feeding eels in Lake Ellesmere during the late 1970s and early 1980s (Ryan 1978, Jellyman et al. 1995) failed to show any inflections in growth rate, indicating that such accelerated growth rates appear to be a more recent phenomenon, possibly associated with the recent increase in common bullies reported for the lake (Jellyman & Todd, 1998).

The energetic benefits of a change to piscivory are substantial, as the energy content of the common bully is four times that of the dominant invertebrate in the diet of Lake Ellesmere eels, the snail *Potamoprygus antipodarum* (Ryan 1982). Previously, in an study of size-related feeding of both New

Zealand main eel species, Cairns (1942) considered that the gape of eels under 400 mm was too small to enable them to catch fish. Hence, the growth inflections noted in the present study are considered to be associated with the adoption of piscivory, and result in a growth rate in length that is 2.4 times faster than the rate of eels considered too small to eat fish.

5. CATCH SAMPLING AND CATCH PER UNIT EFFORT ANALYSIS

A catch sampling programme to monitor the commercial freshwater eel stocks in the South Island, including Te Waihora, was conducted over three consecutive years from 1995–96 to 1997–98 fishing years. The main goal was to develop a time-series of data on size, age, and species composition. This research was carried out by NIWA under contract to the Ministry of Fisheries as part of Monitoring of eel fisheries (MFish Project Nos. INEE01, EEL9701), and the following data are largely extracted from that report.

A catch-per-unit-effort analysis (CPUE) was conducted for freshwater eels throughout New Zealand including Te Waihora, for the fishing years 1990–91 to 1998–99. The main goal was to examine trends in relative abundance of eels catches over time. This research was carried out by NIWA under contract to the Ministry of Fisheries as part of MFish Project No. EEL1999/02: "To Analyse the CPUE data for 1990 to 1998 as a measure of stock abundance" (see Beentjes & Bull 2002).

5.1 Methods

5.1.1 Commercial catch sampling

The commercial catch sampling programme was based at Mossburn Enterprises Ltd (Invercargill). Te Waihora was divided into four areas, Selwyn River to Halswell River, Kaituna Lagoon, Kaitorete Spit, and the Concession Area for migrating males (Figure 11). Catches from these areas were kept separate because eel size and species distribution can vary within a catchment. At the factory, landing weight (species unsorted) was recorded and a randomly selected sample of about 100–200 free-swimming eels was taken. For smaller landings the entire catch was sampled. Care was taken to ensure that samples were representative of the landing. Eels were deslimed before being processed, with a resultant weight loss estimated at about 3%. Species, length, weight, sex (1996–97 and 1997–98), and maturity were recorded for all individual eels in the sample. The sample usually contained a mix of the two species, and these were sorted as the sample was analysed.

Shortfin otoliths were collected from a stratified subsample representative of the size range in 1995–96 and 1996–97. In 1997–98 otoliths were collected from shortfins within two weight ranges (22–260 g and 450–550 g). Annual length increments were calculated from length minus size at recruitment into freshwater (50 mm), divided by age.

5.1.2 Catch per unit effort (CPUE)

Data extraction

Fishers record estimates of catch and effort for each day's fishing on catch effort landing return (CELR) forms and these data are entered into the Ministry of Fisheries (MFish) catch effort database. For each daily record for the years 1990–91 to 1998–99, the following variables were extracted:

- Date nets were lifted
- Permit number (encoded)

- Eel Return Area (ERA)
- Number of net lifts
- Target species (SFE = shortfin eel, LFE = longfin eel, EEU = species not recorded)
- Total weight (weight of SFE, LFE, EEU, and by-catch)
- Weight of individual species (includes SFE, LFE, and bycatch species)

Permit numbers extracted from the catch effort database were encoded by MFish, ensuring anonymity of fishers.

Catch effort data were error checked and groomed using the criteria of Beentjes & Willsman (2000). Errors were corrected where possible, or the record was deleted.

Analyses

Analyses were conducted for total estimated catch (shortfin, longfin, and unidentified) and for shortfin catch separately because catches were well identified and estimates of catches were dominated by shortfin (98.5% shortfin).

Before the analysis, the number of net lifts per set and catch per set (where set was the duration of a fishing trip, usually overnight) were examined since it was thought that gear practises had changed over the 1990s with a tendency to use larger and fewer nets. The number of net lifts per set in Te Waihora has declined between 1990–91 and 1998–99 as fishers moved away from using large numbers of small fyke nets in favour of using fewer larger nets (Clem Smith, Te Waihora commercial fisher, pers. comm.). For this reason it was not sensible to use catch per lift as an index of CPUE since the change in gear type and subsequent reduction in the number of nets required to sustain the same catch would introduce a bias. Unfortunately, as changes in gear were gradual, it was not possible to use gear type as a variable, and it is recognised that there is some bias associated with the assumption of uniformity of gear used. Therefore, for Te Waihora, we used catch per day (kg/day) as an index of CPUE with the assumption that fishers optimise effort to take their annual quota, whereas for Eel Return Areas outside Te Waihora, an index of kg/lift was appropriate.

Two types of CPUE analyses were carried out, *unstandardised* using raw catch data, and *standardised* where variables that can affect catch rates are taken into account in a mathematical model.

Before standardised analysis, a selection criterion was applied to each dataset restricting data for analysis to fishers with at least 30 landings and total landings greater than 1000 kg over the nine fishing years. For shortfin analysis, data were further restricted to fishers that identified more than about 60% of their catch each year to species level. The winter months (May to August) were excluded because catch was usually very low compared to other months. Standardised analyses were also conducted including and excluding the Concession Area months (February and March for all years) and thus the confounding influence of migrating male catches on CPUE. The Concession Area, introduced in 1996, allows undersize migrating shortfinned males to be legally harvested during February-March (Annala et al. 2001); Te Waihora fishers choosing to fish in the Concession Area during this time must register with MFish and are not permitted to fish outside the Concession Area during this period.

Standardised CPUE indices (year effects) were obtained using a stepwise Generalised Linear Model (GLM) method (McCullagh & Nelder 1989). The GLM model used the log-link and constant coefficient of variation. This implies a multiplicative model, i.e., the combined effect of two predictors is the product of their individual effects. The predictor variables used in the model were fishing year, permit number (fisher), month (season), and moon-phase (where the fishing dates were assigned the appropriate quarter of moon phase). All variables were entered into the model as categorical.

A stepwise regression procedure was used to fit the GLM of CPUE (catch/day) on these predictor variables.

For total catch (shortfin, longfin and unidentified) analysis the stepwise fitting method used forwards selection, i.e., began with a basic model in which the only predictor was the year, and iteratively added the best predictor, until no predictors made a sufficient improvement. For analyses of both eel species combined, the improvement in R^2 was used as the criterion for including predictors. In the GLM model, the R^2 is defined as the proportional improvement in the residual deviance, (new deviance – old deviance) / (saturated deviance – null deviance). The predictor with the greatest improvement in R^2 was included, providing that the improvement was at least 0.005. For shortfin catch analysis this method was not appropriate because the catch per lift data contained zeros, as a result of which the saturated deviance is undefined. As a substitute, Akaike's Information Criterion (AIC) (Venables & Ripley 1999) was used. The AIC is defined as the residual deviance plus twice the number of predictors (the latter term acts to penalise models with many predictors). The predictor with the greatest decrease in AIC was included, and the stepwise procedure finished when there was no predictor whose inclusion decreased AIC. Unlike the R^2 statistic the AIC is not an indication of the proportion of variance or deviance explained.

Model fits were investigated using standard residual diagnostics. Plots of residuals and fitted values were investigated for evidence of departure from model assumptions, but for simplicity are not presented here (see Beentjes & Bull 2002). Linear regression was used to determine if trends in CPUE were statistically significant.

5.2 Results

5.2.1 Catch sampling

Detailed results of the catch sampling programme for Te Waihora and the key fisheries throughout New Zealand can be found in Beentjes & Chisnall (1997, 1998) and Beentjes (1999).

Species composition

Shortfin were the predominant species landed from all areas in Te Waihora and most catches were 100% shortfin (Table 7); over the three years of sampling only 44 longfin eels were caught compared with 4600 shortfin (Table 8).

Size and length frequency

Shortfin eels were largest in Kaituna Lagoon, followed by Selwyn to Halswell River, Kaitorete Spit, and the Concession Area (Table 8). The small size of eels in the Concession Area is understandable because these are males congregating before migration. Similarly, size of eels from Kaitorete Spit in 1995–96 was small compared to the Kaituna Lagoon and the Selwyn to Halswell because samples contained more migrating males; this indicates that migrating males sometimes congregate along the spit as well as in the Concession Area. Size of eels in the Concession Area was consistent between year (39.5, 39.9, and 39.5 cm), but for the other areas size increased each year.

Length frequency distributions of shortfins are given by area in Figures 12–14. Outside the Concession Area, shortfin length frequency distributions are variable between years but indicate a wide size range from about 30 to 100 cm, skewed to the right, and no clear modes are present. The Concession Area and Kaitorete Spit (1995–96 only) distributions are dominated by a strong mode (35–45 cm) of migrating shortfin males. In 1997–98 Kaitorete Spit had length frequency distribution similar to Kaituna Lagoon and Selwyn to Halswell with fewer migrating males than in 1995–96. Longfin length frequency distributions are not shown because too few longfin eels were caught.

Sex and maturity

Outside the Concession Area catches were nearly all female and inside they were nearly all male (Table 9). Most shortfinned males had mature or maturing gonads and these eels exhibited the morphological signs of migration. Shortfinned males do not grow large and the results on maturity are consistent with previous studies that have shown that males migrate out of Te Waihora at about 40 cm (Jellyman et al. 1995). Females were mostly maturing (stage 2 of 4) and few showed the morphological signs of migration.

Age and growth

Shortfin otoliths from the full size range were aged for Te Waihora from otoliths collected in 1995–96 and 1996–97. Scatterplots of length and age reveal considerable scatter, indicating that length or weight at age is highly variable (Figure 15). Mean annual length increments were 35 mm.yr^{-1} for Kaituna Lagoon (predominantly female) and 21 mm.y^{-1} in the Concession Area for males (Table 10). Mean annual length increments from two defined weight categories in 1997–98 for shortfins from Kaitorete Spit and Selwyn to Halswell were similar to the above annual length increment for Kaituna (35 mm.y^{-1}), being about 30 and 34 mm.y^{-1}, and growth rate increased slightly at greater size (Table 11).

5.2.2 Catch per unit effort (CPUE)

Descriptive analysis

Descriptive data by fishing year (Table 12) include 4449 fishing days, 905 481 kg of catch, and 145 800 net lifts from 1990–91 to 1998–99. The number of net lifts per set (the duration of a fishing trip, usually overnight) in Te Waihora has declined between 1990–91 and 1998–99 as fishers use fewer but larger nets than formerly (Figure 16). The mean number of nets per set dropped from about 50 in the period 1990 to 1992 to about 15 in the last three years. In contrast the mean daily catch from 1991 to 1999 displays no similar declining trend (Figure 17) and mean catches, although variable between years, have remained at about 200 kg per set.

Fishers' catch estimates

Catch data used in the catch effort analyses are from fishers' estimated weights taken from the catch-effort section of the CELR form. Comparison with catch landing weights taken from processors' data (Licensed Fish Receivers, LFR), indicates that fishers' estimates of catch were on average about 67% that of LFR weights (Figure 18). Fishers' estimates of catch follow the same general trend as LFR weights, indicating that the data were acceptable for catch effort analyses.

The annual estimated catches of shortfin and longfin individually are plotted in Figure 19. Between 99 and 100% of the total estimated catch was identified to species and the remainder was recorded as EEU (unidentified). Between 95 and 99% of all catches were shortfin. There was no trend in longfin catch and apart from one very good year in 1992 and a poor year in 1994 shortfin catches have been stable.

CPUE analyses

Results of unstandardised CPUE analyses for total catch are plotted in Figure 20. CPUE for total catch fluctuated between 113 and 269 kg/day. CPUE declined markedly in 1993–94 followed by a marked increase in 1995–96, although there was no consistent trend in CPUE.

The number of records, number of fishers, and catch used in standardised GLM CPUE analyses together with details of excluded records, are presented in Table 13. Results of these analyses, including predictor variables used and included in the model, and R^2/AIC values are presented in Tables 14 and 15.

Total catch–standardised CPUE analysis for total catch followed the same general pattern as unstandardised CPUE (Figure 20). The slope was not significantly different from zero and therefore there is no trend in increasing or declining CPUE. The variables permit followed by month explained nearly 31% of the variation in CPUE and were included in the model (see Table 14).

Total catch (excluding Concession Area)–a second analysis on total catch, excluding the Concession Area months (February and March for all years), gave a similar result (slope not significantly different from zero), but rather than the marked increased in CPUE in 1995–96, it remained flat for several years and increased gradually. The variables permit followed by month explained nearly 30% of the variation in CPUE and were included in the model (see Table 14).

Shortfin catch–standardised CPUE analysis for shortfin catch followed the same general pattern as unstandardised CPUE and standardised analysis for total catch with no trend in CPUE evident (Figure 21) as the slope was not significantly different from zero. Permit followed by month explained the most variation in CPUE and were included in the model (see Table 15).

Shortfin catch (excluding Concession Area)–A second analysis on shortfin catch, excluding the Concession Area months (February and March for all years), gave a similar result but only up until and including 1994–95; like the analysis for total catch excluding the Concession Area, CPUE was flat between 1993–94 and 1996–97, although there was a small peak in 1997–98. Overall though, the slope was not significantly different from zero and therefore there was no overall trend in CPUE. Permit followed by month explained the most variation in CPUE and were included in the model (see Table 15). The results of the shortfin analyses were essentially the same as the equivalent analysis for total catch, a result of the high proportion of shortfin in catches from Te Waihora.

5.3 Discussion

Catch sampling

The results of the commercial catch sampling programme indicate that shortfins are the predominant species in Te Waihora (99.1% of eels measured). Before 1993, the commercial fishery in Te Waihora was based on both shortfin females and migrating males as there was no minimum legal size and eels as small as 110 g were taken (Town 1985). In 1993–94 a minimum legal size of 140 g was introduced, thereafter increasing by 10 g per year until it was equivalent to the national minimum legal size of 220 g in September 2001.

Shortfinned eels landed from the Te Waihora Concession Area were predominantly migratory males as they displayed clear morphological characteristics of migrating eels and had gonads that were maturing, presumably in preparation for migration. The mean length and weight were also similar to those of Te Waihora migrating eels recorded in 1993–95 (Jellyman et al. 1995). In contrast, outside of Te Waihora, commercial catches of shortfin were nearly all immature (sex could not be determined) or female, as males are not vulnerable to capture because they migrate at a size below the national minimum legal size (220 g).

Growth was characteristically variable for shortfin in Te Waihora and the time for females to reach 220 g, the national minimum legal size including Te Waihora in 2001–2002, was about 13 years. This is about average for shortfin female growth rate throughout the South Island where the mean time to reach 220 g was about 12.8 years (Beentjes & Chisnall 1998). The shortfinned migratory males from Te Waihora were aged between 12 and 21 years and grew more slowly than females.

Catch per unit effort

The results in this report represent the first attempt at a standardised CPUE analysis for the commercial freshwater eel fishery in Te Waihora and are part of a more comprehensive report that includes analyses for all Eel Return Areas in New Zealand (Beentjes & Bull 2002). These results should be viewed as the first step in analysing stock abundance of eels using catch per unit effort data.

Te Waihora fishery constitutes the largest shortfin fishery in New Zealand. The proportion of the national catch contributed by Te Waihora between 1990–91 and 1998–99 was 8.5%, similar to the proportion in the 1980s (Jellyman 1994). Similarly the proportion of catch contributed by the key areas (Northland, Waikato, Southland, and Te Waihora) throughout New Zealand has remained consistent over the last 20 years.

Reporting of target species, and catch identification of catch by species, is of a high standard in Te Waihora compared to many other Eel Return Areas in New Zealand (Beentjes & Bull 2002). To a large extent this is because all targeting is on shortfin and shortfin dominate catches, thus simplifying reporting requirements. The introduction of South Island freshwater eels into the Quota Management System in October 2000 has required fishers to be more diligent in completing the CELR form and should see an improvement in quality of catch effort data throughout New Zealand. In addition, the CELR form, which had been shown to be inappropriate for the freshwater eel fishery (Beentjes & Chisnall 1998), was replaced by an eel fishery specific catch effort reporting form on 1 October 2001. These changes should also improve the quality of catch effort data, and thereby future CPUE analyses, by providing more accurate catch data by individual species.

Fishers; estimates of daily catch were 67% of LFR weights (see Figure 18). The data extract used in these analyses contained all Te Waihora eel catch data for the period 1990–91 to 1998–99, and the shortfall in fishers' estimates of catch compared to LFR weights were wholly a result of fishers' under-estimating catch when completing the catch effort section of the CELR. The finding that the trend in fishers' estimates and LFRs weights was similar indicates that the data were acceptable for CPUE analyses.

The unstandardised and standardised CPUE analysis pattern for total catch is essentially the same. Standardised CPUE analyses using the GLM model accounted for the effects that variables fisher, season, and moon-phase had on catch rates. The variables permit and month were included in the model and explained about 30% of the variability in CPUE (see Tables 8 and 9). Moon phase has been shown to affect eel catch rates (Jellyman 1991), although for Te Waihora the explanatory power of moon phase was negligible. In contrast, fisher experience and/or ability are important influences of catch rates. The finding that month (season) was an important variable affecting catch rates is understandable since water temperature varies seasonally and eel catch rates are related to water temperature (Jellyman 1991, 1997).

Overall, there were no statistically significant trends in CPUE in Te Waihora although there were some marked declines and increases. Interpretation of CPUE analysis in Te Waihora needs to consider 1) the introduction of the Concession Area in 1996 to harvest undersized migrating males between February and March each year, and 2) the introduction of a minimum legal size (MLS) of 140 g at the start of the 1993–94 fishing year and thereafter increasing annually by 10 g per year until it was equivalent to the national MLS of 220 g (which occurred in September 2001). Before 1993–94 there was no MLS and eels as small as 110 g were taken (Town 1985). Results of the CPUE analyses that include the Concession Area data are consistent with the introduction of the MLS, initially causing CPUE to decline, followed by an increase in 1995–96 coinciding with the introduction of the Concession Area in February 1996. By contrast the CPUE analysis that excludes the Concession Area data may only reflect the effect of the MLS. The latter includes catches of female feeding eels and the results indicate a gradual increase in abundance following the decline in CPUE after the introduction of the MLS; this is also complicated by the incremental increase in MLS by 10 g per year. Catch data also mirror the main trends in CPUE and therefore were also affected by the introduction of the MLS and Concession Area (Figures 18 and 19). Thus the fisheries management regulations have affected both catches and CPUE in Te Waihora, rendering the results difficult to interpret.

A separate CPUE analysis was not feasible for the Concession Area fishery because we could not obtain accurate information from MFish on which fishers elected to fish in the Concession Area each year. CPUE analyses for the Concession Area, if the data were available, would highlight any trends in abundance of migrating males and would be desirable in future analyses. Additionally, the target MLS of 220 g in Te Waihora was to be reached on 1 October 2001 and thereafter not change annually. This will provide some stability for future CPUE analyses.

6. A REVIEW OF THE POTENTIAL EFFECTS OF ENVIRONMENTAL OESTROGEN ON FISH POPULATIONS

Eel fishers have expressed some concern about possible effects of environmental oestrogen on the sex of eels in Waihora. The suggestion has been made that oestrogen, originating from domestic sewage or agricultural runoff, may be persistent in the lake, be ingested by eels, and then affect sex ratios. The following section provides results from a brief literature search of this topic.

The impact of environmental oestrogens takes two forms – either the partial feminisation of males by exposure to oestrogens, or the oestrogen-mimicking effect caused by various phenyl breakdown products.

6.1 Manipulation of sex in eels

Chemical manipulation of sex in the European eel has been studied by Colombo & Grandi (1995), using 17*a* methyltestosterone (MT) and 17*a* ethynylestradiol (EE). In a control group of untreated eels, 98% matured as males. For the MT treatments, most matured as males meaning that no effect of masculinisation could be shown. The EE treatments were administered at a dose of 10 ppm to two size groups of eels, 6–8 cm and 15–18 cm. In the former group, ovarian differentiation was induced in 90% of the eels, while in the latter, a 65% ovarian differentiation occurred. From a control, less than 5% of females were recorded. For a further group of 22–25 cm eels a much more reduced effect of feminisation was observed. The outcomes of this study indicate that administration (or the presence) of hormones can profoundly influence sex in young eels.

6.2 Feminisation of male fish

Unfortunately, there are no observations on the effect of environmental oestrogens on eels. However, the use of the serum levels of the female egg protein vitellogenin (VTG) has become an important biomarker in the review of the oestrogenic effects of environmental contaminants such as PCB, dioxin, pesticides, and other surfactants, on the reproductive organs of fish and their subsequent reproductive success. Feminised responses of fish to the effluent from sewage discharge, stormwater, and other urban discharges, have been the subject of a few studies in the United Kingdom (Jobling &

Sumpter 1993, Lye et al. 1998, Allen et al. 1999,). Most of these studies have investigated the effect of environmental oestrogens on the synthesis of VTG.

Under normal conditions, VTG should be present only at low levels in males. However, in a study of male flounders (*Platichthys flesus*) in the United Kingdom, Lye et al. (1998) recorded a 94% incidence of VTG in serum flounders from the Tyne estuary (polluted), compared with 27% from control males in the Solway Firth (less polluted). Similarly, both Simpson et al. (2000) and Allen et al. (1999) found high concentrations of vitellogenin in serum of male flounders from the River Mersey compared with control fish, suggesting exposure to endocrine disrupting chemicals. Further examinations revealed liver tumours, abnormal kidneys, and intersexual gonads. Testicular abnormality in flounder was also investigated by Lye et al. (1997), who found a 53% incidence in Tyne flounder compared to none in the Solway Firth control population.

Allen et al. (1999) also found that the artificial induction of VTG by a synthetic oestrogen (ethynylestradiol) in male flounder was slower than that in rainbow trout, indicating a higher sensitivity to environmental oestrogens for rainbow trout. Female flounders from the River Tyne were found to have increased VTG levels and a higher proportion of degenerating oocytes when compared to Solway Firth controls (Lye et al. 1998).

6.3 Oestrogen mimicking agents

Synthesis of VTG by 4-tert-octylphenol (OP, an environmental oestrogen) was shown to impair the reproduction of the Japanese medaka (*Oryzias latipes*) (Gronen et al. 1999). Fertilised egg counts from control females mated with males exposed to OP reduced by 50%. Significant differences in embryo survival and incidence of embryo abnormality were also found. Carlson et al. (2000) investigated sexual development in salmonids following the microinjection of endocrine-active contaminants into rainbow trout and quinnat salmon embryos – their results showed that embryonic development was not consistently altered, i.e., treatments using both 80 mg/kg and 160 mg/kg xenoestrogen showed an increased ratio of males to females, but a later experiment using more fish and the 80 mg/kg treatment showed no effect on sex ratio.

The absorption by river sediments of the oestrogen 4-tert-octylphenol (OP) was also investigated by Johnson et al. (1998), who reported that suspended sediment (clays and silts) with a high total organic carbon ratio probably plays a key role in the dispersal of OP in English rivers.

6.4 Implications for Te Waihora

Te Waihora receives inflows from many small catchments that variously contain silt, raw sewage, surfactants, pesticides, and other contaminants. Given sufficient time and mixing, environmental oestrogens can adsorb to suspended solids and hence become deposited in lake bed sediments (Johnson et al. 1998), so some of these pollutants could potentially affect the eel population within the catchments and the lake itself.

For eels in the lake, these environmental oestrogens could conceivably result in unnatural feminising of elvers and yellow (feeding) eels, as well as reducing eventual spawning success by endocrine disruption and gonad deformation. Over recent years though, the trend has been for an increase in males rather than females, the opposite of what would be expected if environmental oestrogens were affecting the expression of sex.

The persistence of synthetic oestrogens can be relatively high in aquatic environments, and, in addition to adhering to sediment particles, they can be in solution in the water column. However, their dilution is likely to be high in the lake, to the extent they are unlikely to be affecting eel sex ratios (Lois Tremblay, environmental toxicologist, Landcare, pers. comm.). However, with the increase in dairying in the catchment, there is certainly the potential for oestrogens to affect fish stocks, and some monitoring would be prudent. There is also a group of chemicals that act as androgen disruptors that could conceivably affect sex of males.

7. SUMMARY AND CONCLUSIONS

7.1 Recruitment and growth trends

- The recruitment of glass eels into the lake is variable and is correlated with the duration and timing of the lake opening to the sea. Catch rates of different year classes in trawl surveys indicate recruitment was low from 1986 to 1990 and from 1993 to 1995.

- Growth rates of small juvenile eels dropped suddenly and substantially in the summers of 1996–97, 1997–98 and 1998–99

- Possible causes for this decline were investigated, but no firm conclusions could be reached. This was because there is insufficient scientific information available on historical changes in the ecology of the lake, and on factors influencing the diet, food supplies and growth of juvenile eels. For these reasons we are also unable to predict future growth rates.

- Growth rates of eels longer than about 530 mm (about 300 g) have increased markedly in recent years. This may be related to increased predation on common bullies.

7.2 Migrating eels

Main trends are:

- the virtual loss of migrating longfin eels over past decades

- a change from a shortfinned female dominated migration to a male dominated one

- a reduction in size of shortfinned males – eels are now becoming mature at a smaller size

- a reduction in growth rates of shortfinned males – possibly as a result of large numbers of small eels (reduction in predation by large longfins), competition for food with bullies, and/or changes to the benthic invertebrates of the lake

- an increase in size of shortfinned females – apparently due to a diet shift to eating fish at lengths more than 500 mm.

- a decrease in the average age of shortfinned females – female shortfins now migrate at a larger size but younger age. This appears to be a response to low mortality and the opportunity to maximize fecundity.

7.3 Commercial catch sampling

- A catch sampling programme to monitor the commercial freshwater eel stocks in the South Island, including Te Waihora, was conducted over three consecutive years from 1995–96 to 1997–98 fishing years (Ministry of Fisheries funded research programme). The main goal was to develop a time-series of data on size, age and species composition.

- Samples of Te Waihora commercial catches were taken from Selwyn to Halswell Rivers, Kaituna Lagoon, Kaitorete Spit, and the Concession Area for migrating males.

- Shortfin were the predominant species landed from all areas in Te Waihora and most catches were 100% shortfin; only 44 longfin eels were caught compared with 4600 shortfin.

- Mean size of shortfin eels caught outside the Concession Area (excluding Kaitorete Spit) ranged from 52 to 60 cm, size increased each year, and eels were nearly all female. Length frequency distribution was variable between years with length ranging from about 30 to 100 cm, skewed to the right with no clear modes.

- Mean size of eels in Kaitorete Spit in 1995–96 was only 42 cm due to the presence of migrating males. In 1997–98, however, eels from Kaitorete Spit were nearly all females of similar size to those from Kaituna Lagoon and Selwyn to Halswell Rivers.

- Eels sampled from the Concession Area were nearly all migrating males and mean size was consistent between years (39.5, 39.9, and 39.5 cm). Length frequency distribution was dominated by a strong mode at 35–45 cm.

- Most shortfinned males had mature or maturing gonads and exhibited the morphological signs of migration. Females were mostly maturing and few showed the morphological signs of migration.

- Mean annual length increments for shortfin eels were 35 $mm.y^{-1}$ for Kaituna Lagoon (predominantly female) and 21 $mm.y^{-1}$ in the Concession Area (predominantly males). These increments are in good agreement with those estimated from separate studies of migrating eels

7.4 Catch per unit effort analysis (CPUE)

- A catch-per-unit-effort analysis (CPUE) was conducted for freshwater eels throughout New Zealand, including Te Waihora, for the fishing years 1990–91 to 1998–99 (Ministry of Fisheries funded research programme). The main goal was to examine trends in relative abundance of eel catches over time.

- The catch effort data include 4449 fishing days, 905 481 kg of catch, and 145 800 net lifts from 1990–91 to 1998–99.

- The number of net lifts per set in Te Waihora declined between 1990–91 and 1998–99 as fishers moved away from using large numbers of small fyke nets in favour of using fewer larger nets. Mean daily catches, however, although variable between years, have remained reasonably constant at about 200 kg per set.

- Catch per day was used as an index of CPUE because gear specifications have changed over time, with the assumption that fishers optimise effort to take their annual quota.

- Fishers' estimates of catch (catch effort landing forms, CELR) were on average about 67% that of Licensed Fish Receivers' weights, indicating that fishers' underestimate catch.

- Between 99 and 100% of the total estimated catch was identified to species by fishers on CELR forms and the remainder was recorded as EEU (unidentified). Between 95 and 99% of all catch was shortfin.

- Apart from one very good year in 1992 and a poor year in 1994, shortfin catches have been stable at about 100 t annually. There was no trend in longfin catch.

- Mean annual catch rates (unstandardised CPUE) of *total catch* (SFE, LFE and EEU) fluctuated between 113 and 269 kg/day.

- *Standardised CPUE analysis for shortfin* showed no trend in CPUE. A second analysis on shortfin catch, excluding the Concession Area months (February and March for all years), gave a similar result.

- Permit followed by month explained about 30% of the variation in CPUE and indicate that catch rates are very dependent on fisher experience and/or ability and time of the year (season).

- Overall, there were no statistically significant trends in CPUE in Te Waihora although there were some marked declines and increases which were related to the introduction of the Concession Area in 1996 and a minimum legal size (MLS) of 140 g at the start on the 1993–94 fishing year.

- A separate CPUE analysis was not feasible for the Concession Area fishery because we could not obtain accurate information from MFish on which fishers elected to fish in the Concession Area each year.

7.5 Potential effects of environmental oestrogen on fish populations

- Environmental oestrogens can influence the proportion of female fish in a population

- Environmental oestrogens arise from both sewage and farm runoff (from livestock)

- It is considered very unlikely that the concentration of oestrogens in Te Waihora would be sufficient to affect the expression of sex of eels – any influence would be to feminisation of males and thus would not account for the predominance of migratory male eels

7.6 Management implications

- From an analysis of the strengths of different year classes, we predict that catches of migrant males in the fishery should remain at normal levels in 2002 and 2003. Therefore, the migrant male fishery could continue under the present rules for 2002 and 2003. There might be a small increase in mean size as the remnants of the strong 1984 and 1985 year classes are caught.

- Because of low recruitment from 1985 to 1989, we anticipate that catches of migrating eels will decline over the next 10 to 15 years. If growth rates remain low (13 mm y^{-1}), this will increase the mean age and reduce still further the size at which mature male eels migrate to sea.

- If growth rates return to normal (23 mm y^{-1}), then catches should improve from 2005 onwards, and peak in 2007, as fish of the strong 1990 to 1993 year classes enter the fishery. The strong 1996 and 1997 year classes will enter the fishery about 4 years later.

- To maintain native fish and eel recruitment, and the fishery for mature males, the lake should be opened to the sea in spring each year. However, the "downside" of this could be the dewatering of the productive littoral (shallow) margin of the lake, with consequent loss of feeding opportunities for small eels. Also, the effect of saline water on the chironomid populations is not understood.

- The fishery for immature and adult female eels should be largely unaffected by variable recruitment because it relies on c. 30 age-classes (Jellyman et al. 1995).

- We recommend that fishing effort not be diverted from migrant males back to the feeding eel (female) fishery because this could reduce eel predation on common bullies and further decrease macroinvertebrate food supplies, and hence juvenile eel growth rates

- Further, Te Waihora is the only fishery in New Zealand that targets migrating shortfinned males – this is only possible through gazetting of the concession area. Nothing is known about the ability of such small eels to swim the several thousand kilometres to the presumed spawning grounds, but any density dependent bottleneck at spawning is much more likely to be due to limited numbers of females than males.

- With regard to Maori harvest for customary purposes poses something of a management dilemma. Maori are principally interested in being able to harvest eels substantially larger than the present minimum commercial size of 220 g. Although the preferred size has not been explicitly determined, it is likely to be more than 400–500 g. All shortfinned eels of these sizes will be female, and hence any management proposal that maximises production of females will potentially benefit Ngai Tahu.

- We suggest that the harvest of feeding eels (females) should not be increased. Overfishing of feeders could reduce eel predation on common bullies and further decrease macroinvertebrate food supplies, and hence juvenile eel growth rates.

- The most obvious way to achieve larger average size, yet not increase the number of eels harvested, is to impose a larger minimum size for feeding eels. Before such a management tool is implemented though, a yield-per-recruit analysis should be carried out, to establish what benefits would accrue from such a decision.

- It is recognised that any such change in the minimum size would have significant implications for the commercial fishery. Further, the well-being of the commercial fishery seems vulnerable in that a substantial part of the annual catch comprises of migrating male eels – if their average size continues to decline, this could conceivably result in marketing difficulties.

7.7 Lake and fisheries management investigations

- Research key features of the lake on an annual or seasonal basis (temperature, salinity, water levels, plankton, benthic macroinvertebrates, fish stocks).

- Monitor fishers catches on a annual basis (includes total crop, species and sex composition, length and weight frequencies)

- Every 3 years, access the recruitment of juvenile eels (using trawls), and the age composition, growth rates and length frequency of feeders and migrating males.

- Develop computer models designed to predict the size and age composition of fishers' catches and the effectiveness of different fisheries management options. The models could be easily adapted from those developed for longfinned eels and would use and integrate information from all the research and management investigations listed above.

8. ACKNOWLEDGMENTS

This research was carried out by NIWA under contract to the Ministry of Fisheries (Project Code EEL2000/03F). We thank Paul Taylor for reviewing this report, and Mike Beardsell for editorial assistance.

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Table 1: Trawl fishing effort by location in Lake Ellesmere from 1994/95 to 1999/00 and catch of common bullies, smelt and different size classes of shortfinned eels.

	Days		Trawls west	Total number of eels				
Summer	fished	Total	at night	<70 mm	70–300 mm	>300 mm	Bullies	Smelt
1994/95	12	151	55	0	291	241	10 468	1 284
1995/96	10	98	51	0	114	123	8 520	479
1996/97	10	96	88	158	101	63	29 790	430
1997/98	8	88	83	44	322	54	17 040	161
1998/99	5	64	49	5	414	18	5 105	148
1999/00	4	52	43	35	394	24	2 425	263
Total	49	549	369	242	1636	523	73348	2765

Table 2: Percentage age composition of eels (<300 mm) from 1994/95 to 1999/00. All November and December samples with the exception of January and February 1995.

Age	94/95	95/96	96/97	97/98	98/99	99/00
0	2.2	0.0	40.2	7.8	0.7	6.8
1	6.4	1.0	13.6	49.4	14.8	0.9
2	36.8	3.3	2.9	8.5	49.5	28.7
3	26.2	13.8	1.6	3.0	3.8	32.7
4	10.1	42.4	7.0	3.1	6.1	4.0
5	6.6	18.9	11.7	8.7	2.6	1.4
6	4.1	9.5	6.9	7.0	7.4	2.3
7	4.1	1.2	2.0	5.4	10.7	9.3
8	1.9	2.7	6.5	1.1	1.2	8.7
9	0.7	2.4	2.4	2.5	2.1	0.0
10+	0.9	4.7	5.2	3.8	1.1	5.2
No. aged	212	70	90	147	212	109
No. measured	250	77	180	363	419	430

Table 3: Duration of mouth openings, strength of different year classes, and estimated dates when migrant males will enter the fishery

				Year males are caught		
Year class	Days open Sep/Oct	Mean catch rate per 100 trawls	Year class strength	First enter the fishery	Mid point	Run ends
1976	–	–	High?	1988	1990	1991
1977	–	–	High?	1989	1991	1993
1978	–	–	High?	1991	1993	1995
1979	–	–	High?	1993	1995	1997
1980	–	–	High?	1993	1996	1998
1981	–	–	High?	1995	1997	1999
1982	–	–	High?	1996	1999	2001
1983	–	–	High?	1998	2000	2002
1984	–	–	High?	1999	2002	2004
1985	–	–	High?	2001	2003	2006
1986	33	5	Low	2002	2005	2007
1987	26	8	Low	2004	2006	2009
1988	0	10	Low	2005	2008	2010
1989	30	12	Low	2005	2008	2012
1990	17	18	Low	2008	2011	2013
1991	0	60	Moderate	2011	2014	2015
1992	35	57	Moderate	2011	2014	2016
1993	15	14	Low	2012	2015	2018
1994	14	12	Low	2014	2016	2020
1995	33	24	Low	2015	2018	2021
1996	61	255	High	2018	2020	2023
1997	17	138	High	2018	2021	2024
1998	0	8	Low	2020	2022	2026
1999	14	70	Moderate	2021	2024	2027

Table 4: Growth rates of shortfinned eels aged 1 to 9 years in Lake Ellesmere, 1994 to 1999. * Summer growth rate, **, Autumn and winter growth rate.

Year	Month captured	Number aged	Summer of growth	Growth period (years)	Length increment (mm)	SE (mm)	Growth rate ($mm.y^{-1}$)
1995	Jan-Feb	209	–	–	–	–	–
1995	Dec	66	94–95	0.87	6.6	1.5	7.2**
1996	Mar	67	95–96	0.28	21.1	2.5	75.5*
1996	Dec	87	95–96	0.74	1.8	2.3	2.5**
1997	Dec	139	96–97	0.96	6.1	2.0	6.3
1998	Nov	210	97–98	0.98	13.6	1.1	13.9
1999	Dec	100	98–99	1.04	14.9	1.1	14.3
Totals		878		4.87	64.1		13.2

Table 5: Growth rates derived from length at age plots for selected samples and year classes. a_1,y intercept; b_1, growth rates (mm y^{-1}); a_2, standard deviation at age 0; b_2, increase in SD with age.

Samples selected		Year		Growth rate			
Months	Year	class	N	a_1	b_1	A_2	b_2
January-February	1995	all	212	96.5	23.2	14.9	2.9
Nov-Dec	1995–99	all	601	63.6	22.2	5.9	4.1
Nov-Dec	all	1991	139	123.5	12.3	26.3	0.08
Nov-Dec	all	1996	123	72.2	14.0	6.6	2.19

Table 6: Age distribution (%/year) of migrating shortfinned males from Waihora 1975–1995. < = < 0.1.

Age (years)								Year	Total (%)
	1975	1978	1979	1980	1981	1982	1994	1995	
8						0.4			<
9		0.3	0.2	0.3		0.7		1.8	0.3
10	0.9	0.9	0.8	1.0	1.2	3.6	2.0	0.9	1.3
11	2.3	4.0	1.2	5.2	4.3	7.3	9.8	2..7	3.9
12	8.2	8.9	4.3	8.6	6.5	18.1	9.8	9.8	8.6
13	12.3	16.9	9.1	16.6	14.2	23.6	23.5	18.8	15.3
14	29.2	21.5	14.0	23.6	19.4	19.9	15.7	18.8	20.1
15	21.9	24.9	17.7	16.9	16.7	10.5	11.8	19.6	18.0
16	12.3	11.4	19.7	13.5	17.6	6.9	9.8	11.6	14.1
17	4.6	4.9	16.2	8.3	11.4	6.9	15.7	7.1	9.7
18	3.2	3.1	9.7	3.9	6.5	1.1		2.7	4.9
19	2.7	2.2	4.7	1.6	1.2	0.7		0.9	2.3
20	0.5	0.3	2.1	0.3	0.6	0.4	2.0	2.7	1.0
21	1.4	0.3		0.3	0.3			1.8	0.2
22		0.3	0.4					0.9	<
23	0.5								
24									
N	219	325	514		324	276	51	112	2206
Mean	14.6	14.4	15.6		14.8	13.5	14.1	14.6	14.7
SE	0.13	0.11	0.09		0.11	0.12	0.30	0.24	0.05
CV	0.14	0.13	0.13		0.14	0.14	0.15	0.18	0.14

Table 7 : Commercial catch sampling in Te Waihora (1995–96, 1996–97 and 1997–98). Percentage of shortfin in each location expressed by numbers measured and landing weight.

		Percent shortfin	
Year	Location	Numbers	Weight
1995–96	Kaituna Lagoon	98	95
	Kaitorete Spit	100	100
	Concession Area	98	97
1996–97	Kaituna Lagoon	100	100
	Selwyn-Halswell	100	100
	Concession Area	100	100
1997–98	Kaituna Lagoon	100	100
	Kaitorete Spit	99	99
	Selwyn-Halswell	100	100
	Concession Area	100	100

Table 8: Commercial catch sampling (1995–96, 1996–97 and 1997–98). Length, weight, and regression coefficients for shortfin and longfin from Te Waihora. s.e., standard error.

Year	Location	Species	N	Mean length (cm)	s.e.	Range	Mean weight (g)	s.e.	Range	a	b	r2
1995–96	*Kaituna Lagoon*	Shortfin	1 070	51.7	0.29	37–92	348.5	7.75	120–2 005	0.0008	3.25	0.96
	Kaitorete Spit		414	41.6	0.32	30–79	163.4	5.96	55–1 175	0.0013	3.13	0.91
	Concession Area		705	39.5	0.09	34–72	129.8	1.40	70–855	0.0035	2.86	0.66
	Kaituna Lagoon	Longfin	25	61.9	2.30	47–89	631.4	78.9	205–1 740	0.0017	3.08	0.97
	Concession Area		12	44.2	1.04	38–51	228.8	20.0	135–400	0.0006	3.41	0.93
1996–97	Kaituna Lagoon	Shortfin	576	56.4	0.37	38–99	458.2	12.70	145–2255	0.0004	3.41	0.96
	Selwyn-Halswell		540	55.7	0.36	37–89	435.6	11.00	80–1785	0.0005	3.35	0.96
	Concession Area		506	39.9	0.10	34–49	128.0	1.01	70–260	0.0048	2.76	0.72
	Kaituna Lagoon	Longfin	1	52.0	–	–	345.0	–	–	–	–	–
1997–98	Kaituna Lagoon	Shortfin	128	59.9	0.85	45–86	539.9	29.77	205–1665	0.0003	3.49	0.98
	Kaitorete Spit		623	55.9	0.44	31–96	453.1	13.32	50–2285	0.0005	3.39	0.97
	Selwyn-Halswell		485	58.5	0.36	42–91	481.4	11.52	165–1850	0.0008	3.25	0.96
	Concession Area		626	39.5	0.11	32–56	116.1	1.32	60–365	0.0008	3.22	0.78
	Kaitorete Spit	Longfin	6	49.5	2.09	44–57	287.5	39.85	195–455	0.0023	3.00	0.92

Table 9: Commercial catch sampling (1996–97 and 1997–98). Percentage of longfins and shortfins in Te Waihora by location that were male (M), female (F), or immature (I). –, no data.

		Longfins				Shortfins			
Year	Location	M	F	I	Total	M	F	I	Total
1996–97	Kaituna Lagoon	–	–	–	0	1.0	98.3	0.7	576
	Selwyn-Halswell	0.0	0.0	100	1	2.4	96.7	0.9	540
	Concession Area	–	–	–	0	100.0	0.0	0.0	416
1997–98	Kaituna Lagoon	–	–	–	0	0.0	100.0	0.0	128
	Kaitorete Spit	16.7	33.3	50.0	6	7.2	91.3	1.4	623
	Selwyn-Halswell	–	–	–	0	0.2	99.6	0.2	485
	Concession Area	–	–	–	0	96.3	3.0	0.6	626

Table 10: Commercial catch sampling (1995–96, 1996–97). Length, age and annual length increments for shortfins from Te Waihora from a representative length range.

Year	Location	N	Length range (mm)	Age range (y)	Mean annual length increment ($mm.yr^{-1}$)
1995–96/1996–97	Kaituna Lagoon	115	370–920	9–23	35.3
	Concession Area	43	340–480	12–21	20.8

Table 11: Commercial catch sampling 1997–98. Length, age and annual length increments for shortfins from Te Waihora for two weight categories, 220–260 g and 450–550 g.

Year	Location	N	Weight category	Mean length (cm)	Mean age (yr)	Age range	Mean annual length increment ($mm.yr^{-1}$)
1997–98	Kaitorete Spit	20	220–260	48.8	14.9	9–20	30.6
		20	450–550	59.9	16.6	10–20	33.9
	Selwyn/Halswell	20	220–260	48.5	14.9	11–20	29.8
		21	450–550	60.1	16.4	11–20	34.5

Table 12: Summary of catch and effort data for Te Waihora. EEU, unidentified; LFE, longfin; SFE, shortfin.

				Target species (%)		
Fishing Year	No. fishing days	Total estimated catch (kg)	No. of lifts	EEU	LFE	SFE
1990–91	457	94233	22956	0.0	0.2	99.8
1991–92	683	168957	37349	0.0	1.3	98.7
1992–93	510	119726	21506	2.0	0.0	98.0
1993–94	329	47315	8097	0.0	3.6	96.4
1994–95	773	87390	24924	0.0	1.8	98.2
1995–96	453	101939	12747	0.0	0.4	99.6
1996–97	332	89356	4639	0.0	0.0	100.0
1997–98	373	87571	4990	0.0	0.0	100.0
1998–99	539	108994	8592	0.0	0.6	99.4
Total	4449	905481	145800	0.2	0.9	98.9

Table 13: All data and subsets of data used in standardised CPUE analyses. Subsets were restricted to fishers with at least 30 landings and total landings greater than 1000 kg, and for shortfin analyses the data were further restricted to fishers that identified more than about 60% of their catch each year to species level. Months 2 and 3 are the Concession Area period (February and March).

Dataset	No. records	No. fishers	Catch (kg) in analysis	Months excluded
All data	4449	14	905481	
Total catch	2381	14	396506	2,3, 5–8
Total catch	4402	14	898105	5–8
Shortfin	1929	10	297005	2,3, 5–8
Shortfin	3663	10	717121	5–8

Table 14: Predictor variables used in the GLM stepwise regression analysis for total catch standardised analysis. Only variables with borders were entered into the final model.

Analysis	Variable	r-square
Total catch (including Concession Area)	Year	0.0996
	Permit	0.2775
	Month	0.3063
	moon phase	0.3076
Total catch (excluding Concession Area)	Year	0.0939
	Permit	0.2772
	Month	0.2970
	moon phase	0.2973

Table 15: Predictor variables used in the GLM stepwise regression analysis for shortfin standardised analysis. Only variables with borders were entered into the final model. AIC, Akaike's Information Criterion.

Analysis	Variable	AIC
Shortfin (including Concession Area)	Year	-257.91
	permit	-698.6002
	month	-778.7847
	moon phase	-776.3747
Shortfin (excluding Concession Area)	year	-81.76
	permit	-252.77
	month	-261.43
	moon phase	-256.01

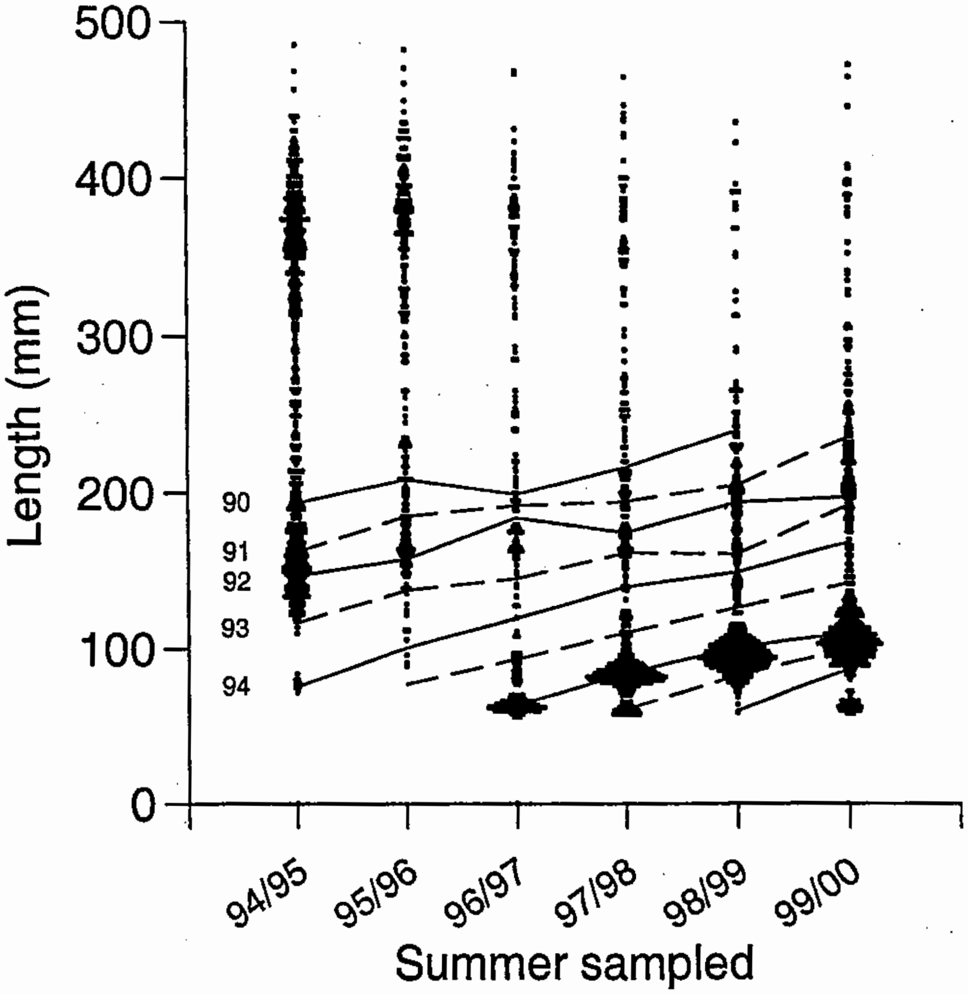


Figure 1: Length frequency (dot density plot) of all shortfinned eels caught in Lake Ellesmere from the 1994–95 to 1999–2000 summers. Fifteen eels >500 mm were excluded. Lines show mean lengths of 1990 to 1999 year classes.

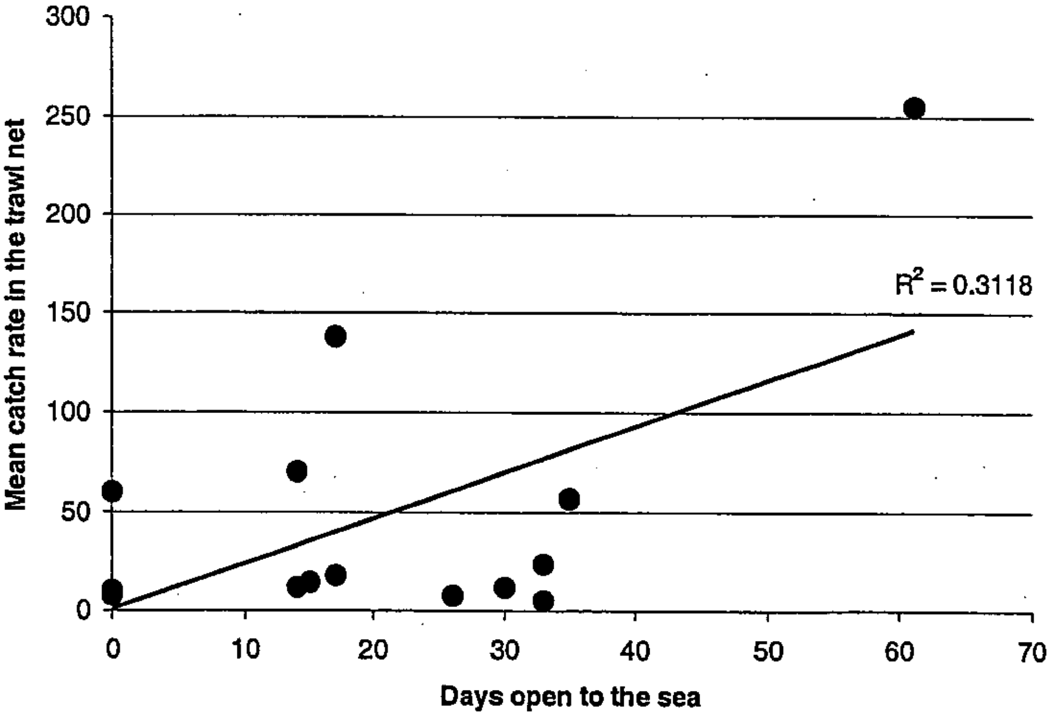


Figure 2: Correlation between the catch of different year classes (per 100 trawls) and the number of days the lake was open in September and October (1986–1999)

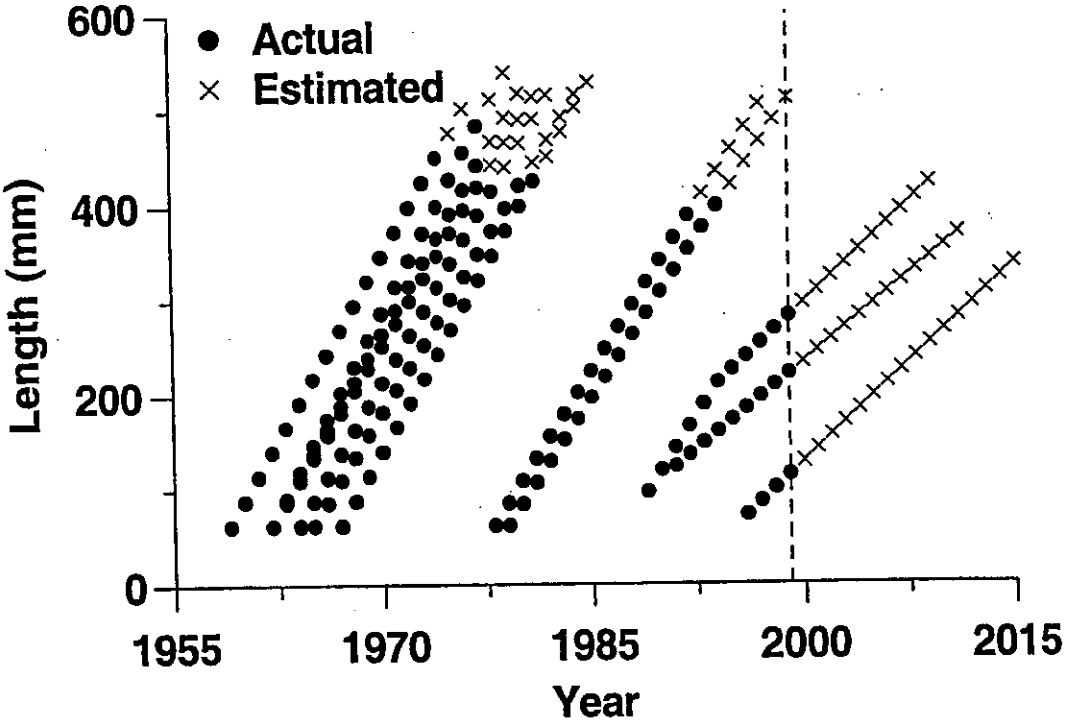


Figure 3: Growth rates of migrant males and unsexed juveniles. Estimated growth rates beyond 2000 assume slow growth rates will continue.

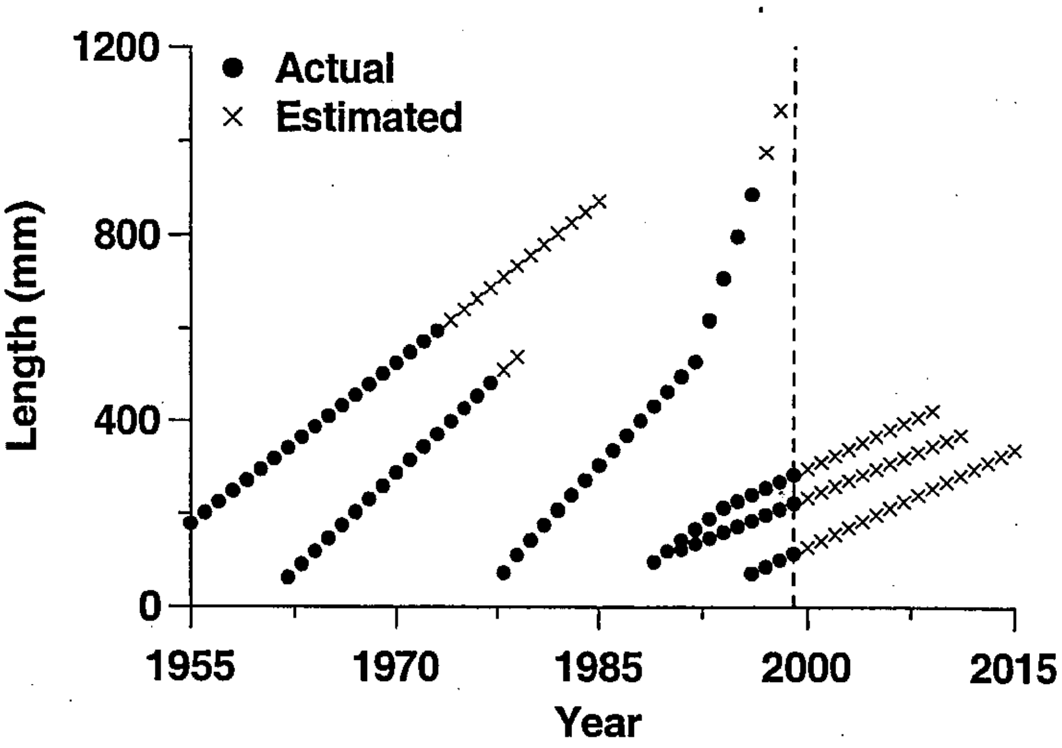


Figure 4: Growth rates of migrant females and unsexed juveniles. Estimated growth rates beyond 2000 assume slow growth rates will continue.

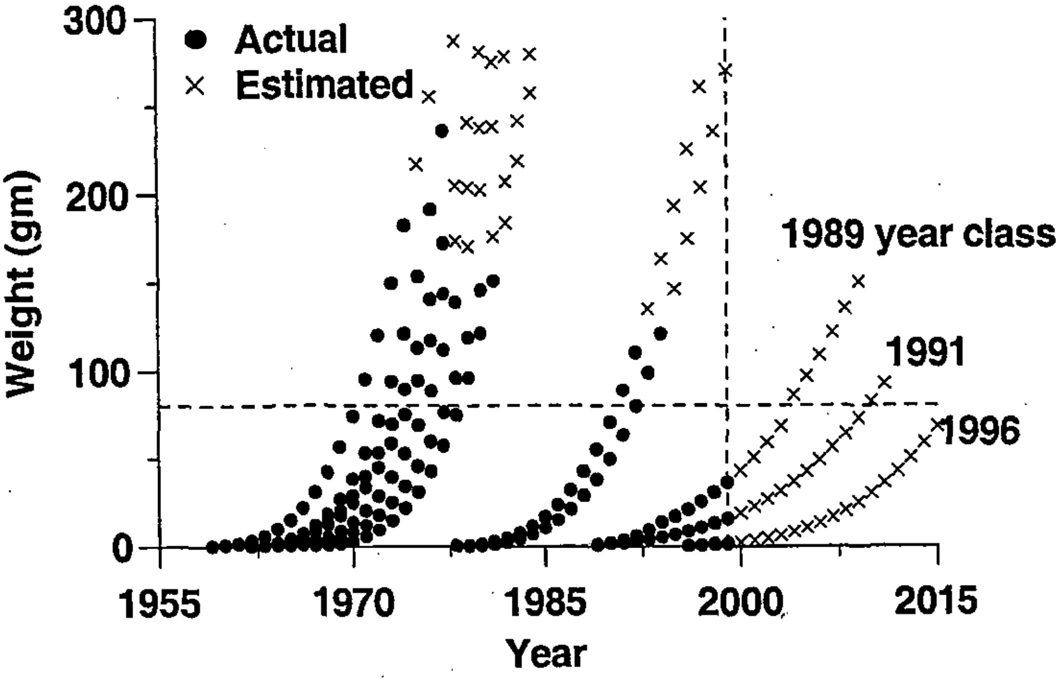


Figure 5: Trends in the mean weight of males and unsexed juveniles. The horizontal line at 80 gms indicates the minimum commercial size for migrant male eels (Trevor Gould pers. comm.)

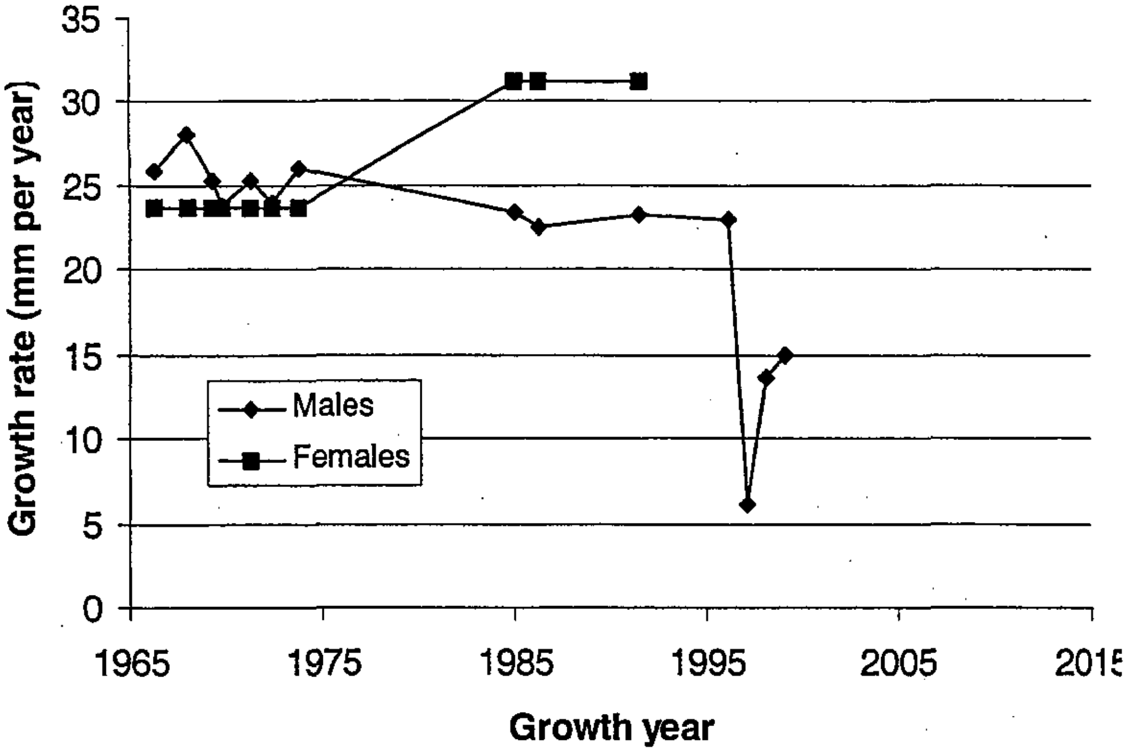


Figure 6: Trends in mean annual growth rate in length (mm) of male (and immature) eels and female eels. Excludes fast growing (90 mm y^{-1}), large (>530 mm) females caught in recent years.

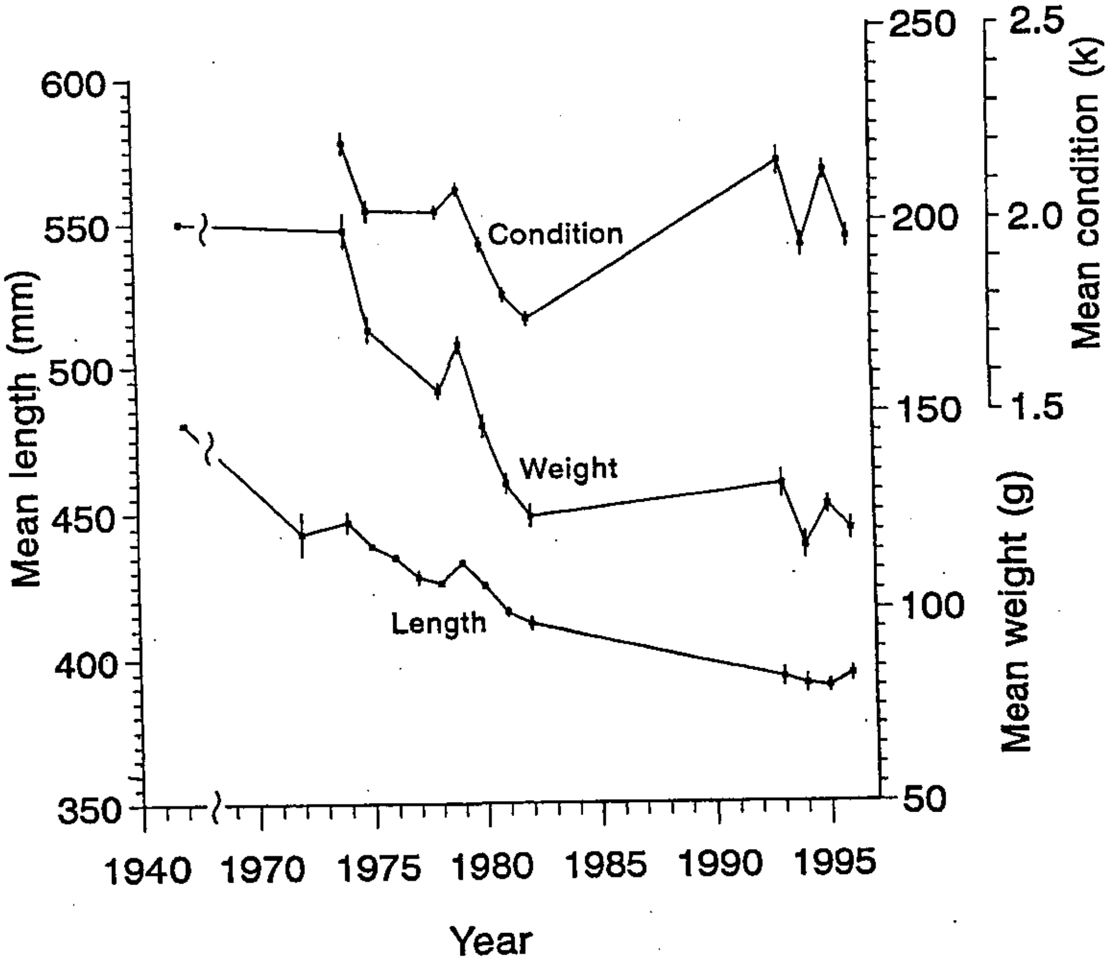


Figure 7: Mean length, weight, and condition (+/- 2 SE) of migrating shortfinned males from Waihora for various years from 1942–1996

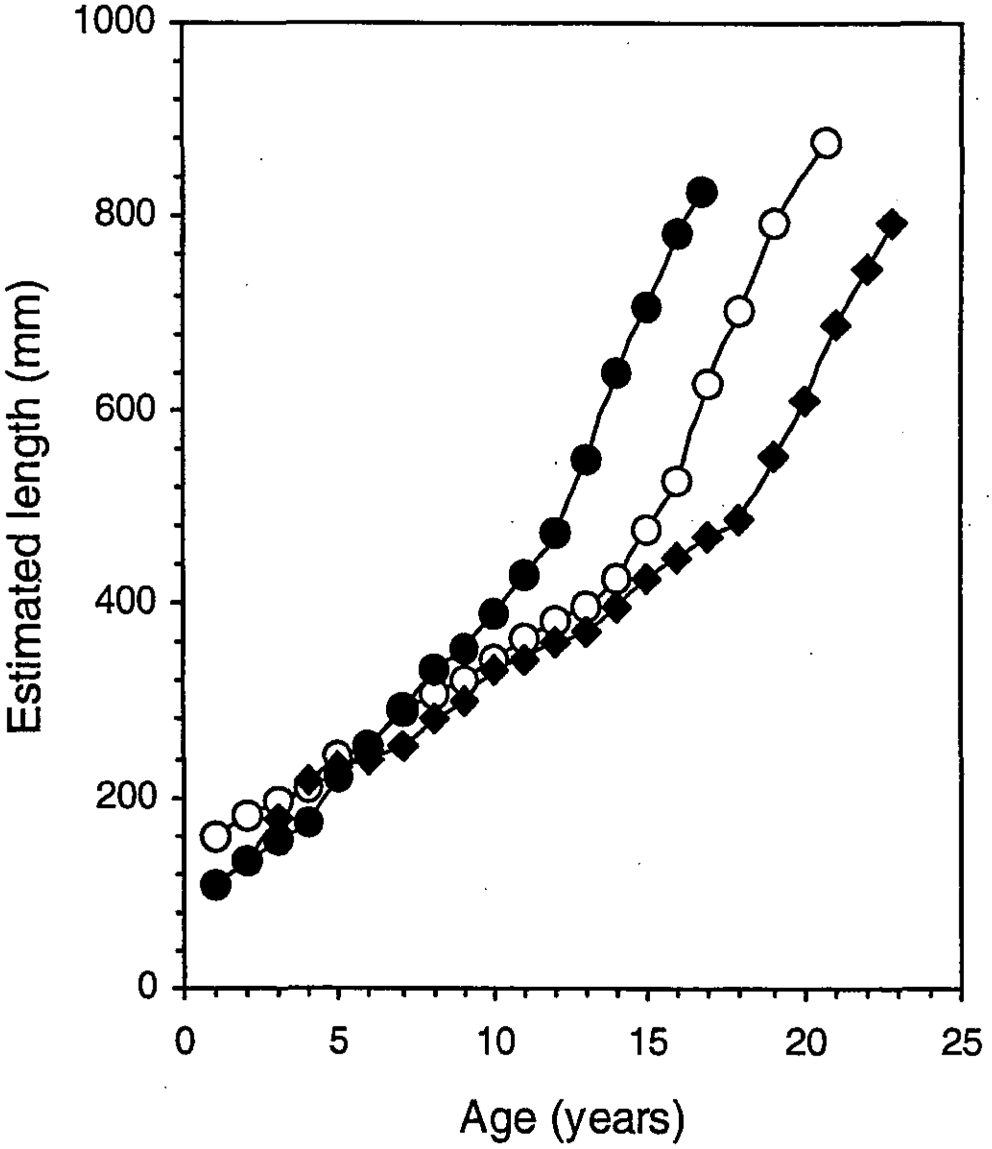


Figure 8: Back-calculated growth rates of three representative migrating shortfinned females, March 1998 .

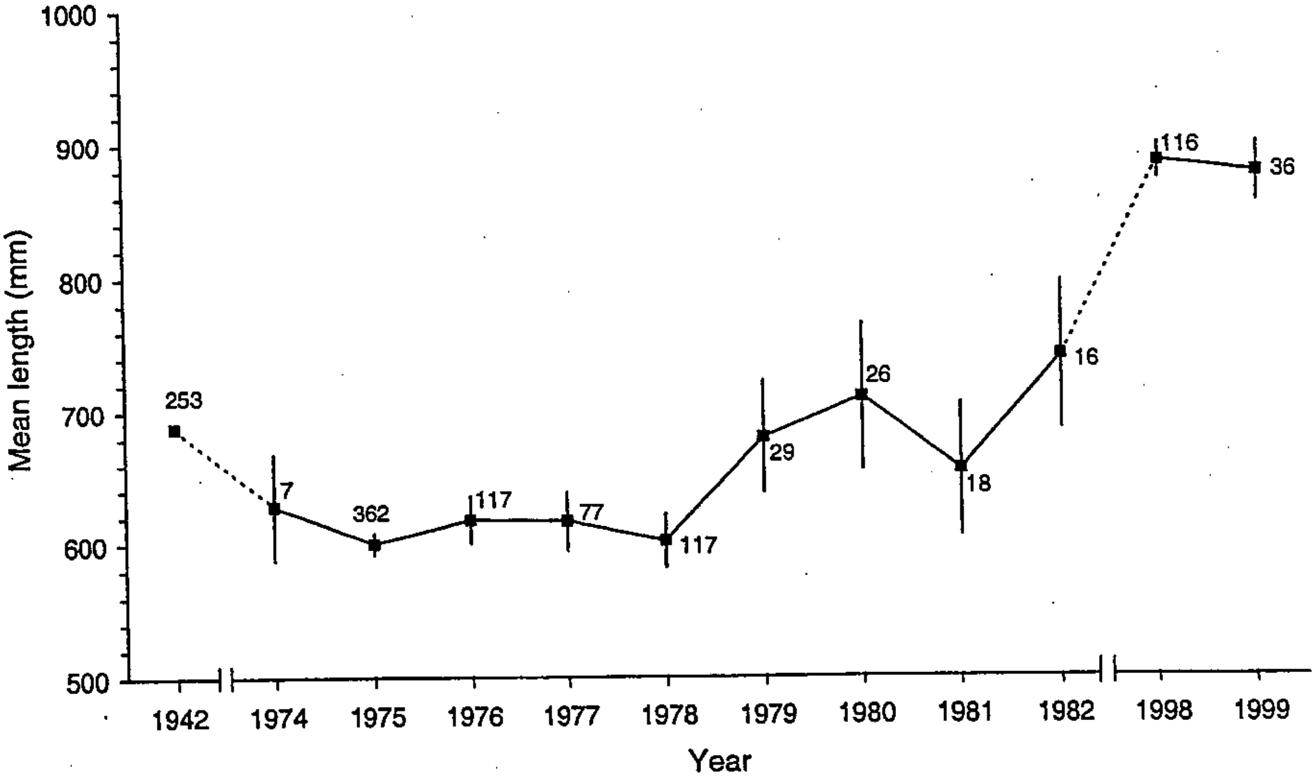


Figure 9: Length trends of migrating female shortfinned eels, 1942 – present. Mean length, SE, and sample numbers shown

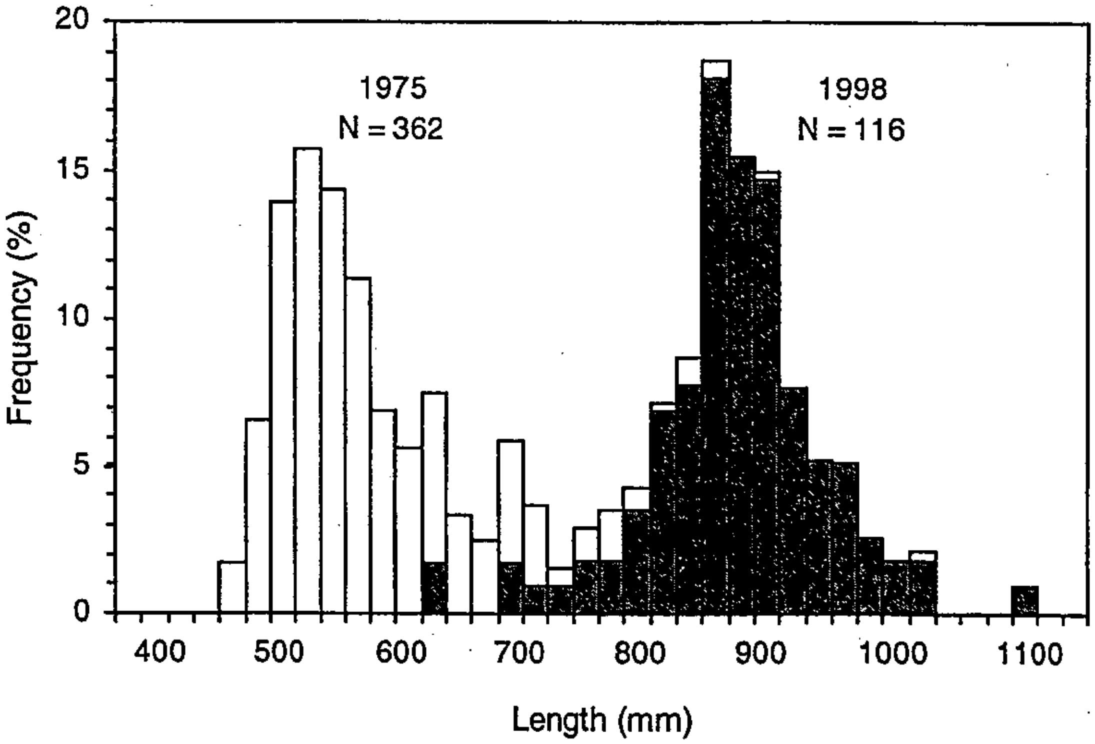


Figure 10: Length-frequency distributions of migrating shortfinned female eels from Lake Ellesmere, 1975 (open bars, n = 362) and 1998 (hatched bars, n=116)

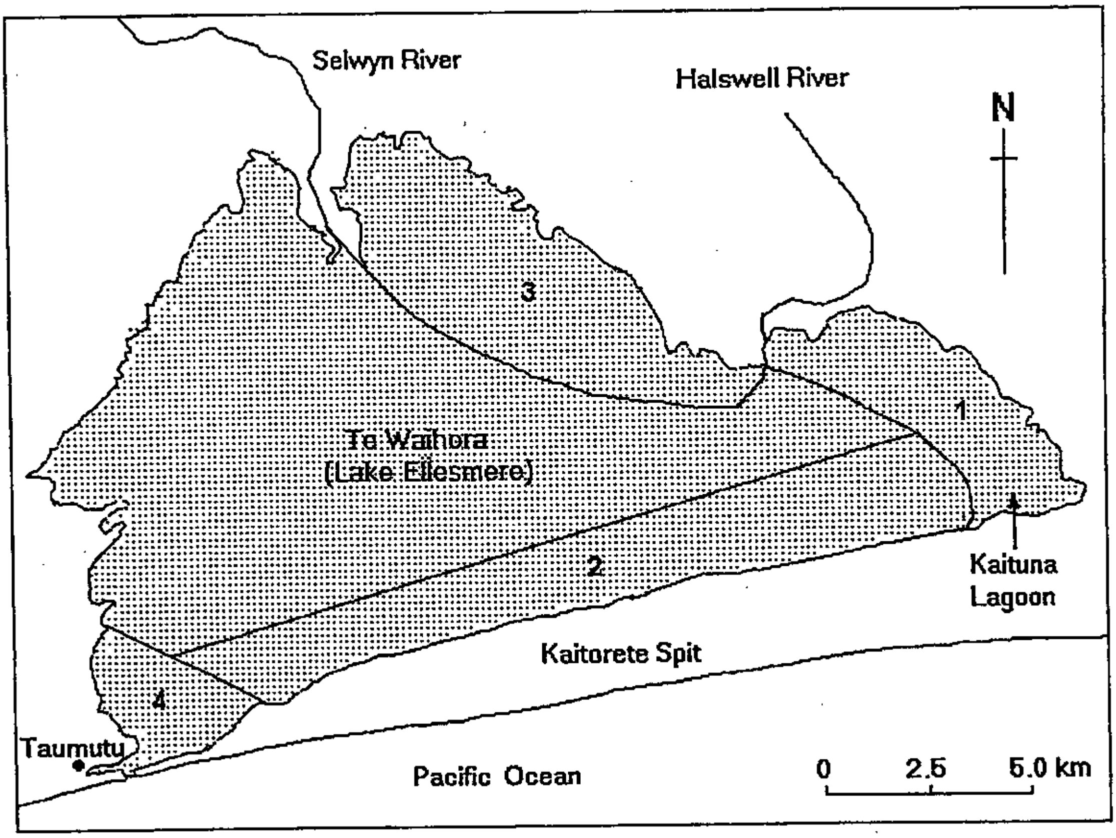


Figure 11: Te Waihora showing locations used in commercial catch sampling in 1995–96, 1996–97, and 1997–98.1= Kaituna Lagoon, 2=Kaitorete Spit, 3=Selwyn to Halswell, 4=Concession Area.

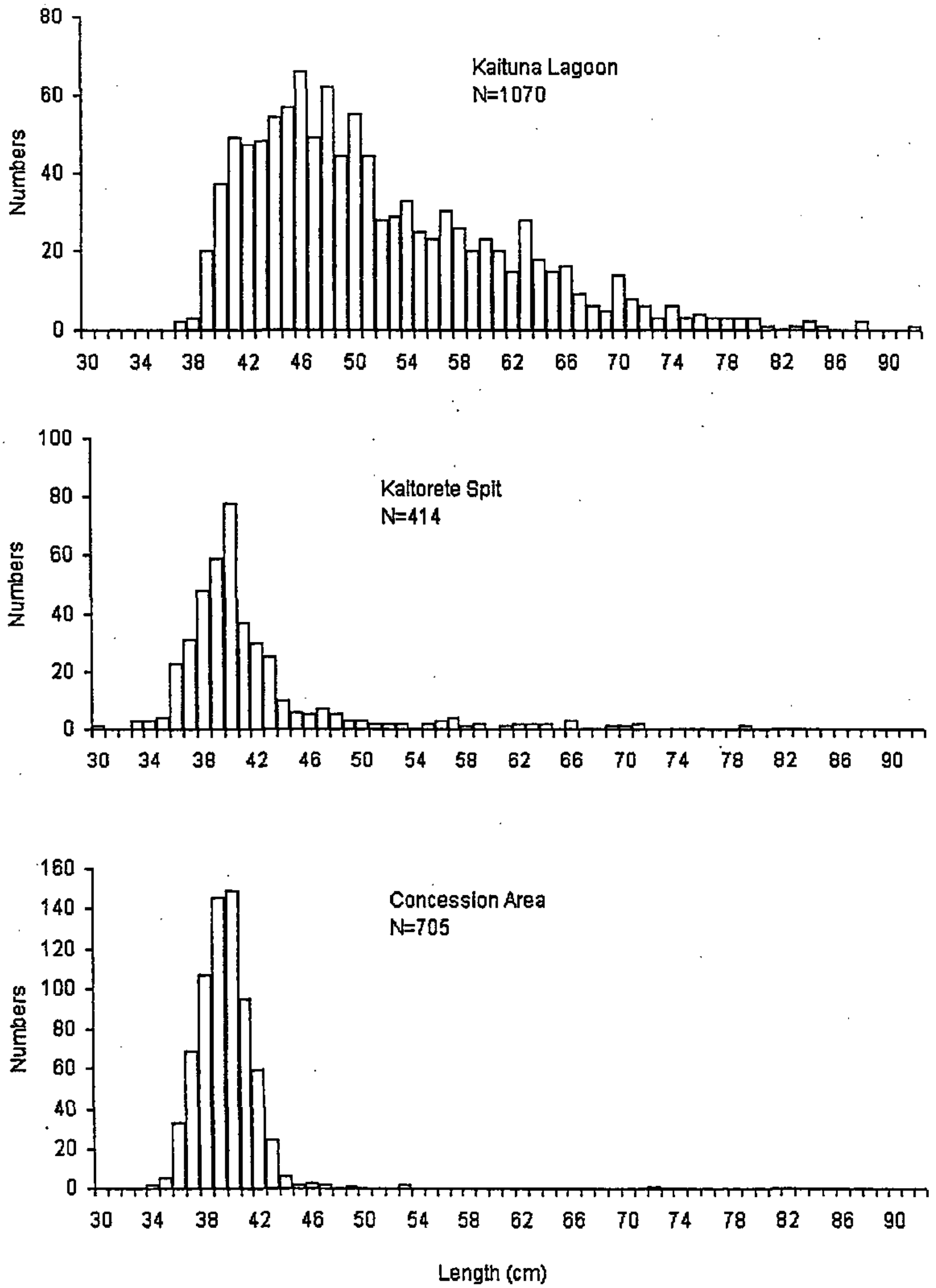


Figure 12: Length frequency of shortfin eels from Te Waihora from commercial catches in 1995–96 fishing year. (eels are unsexed).

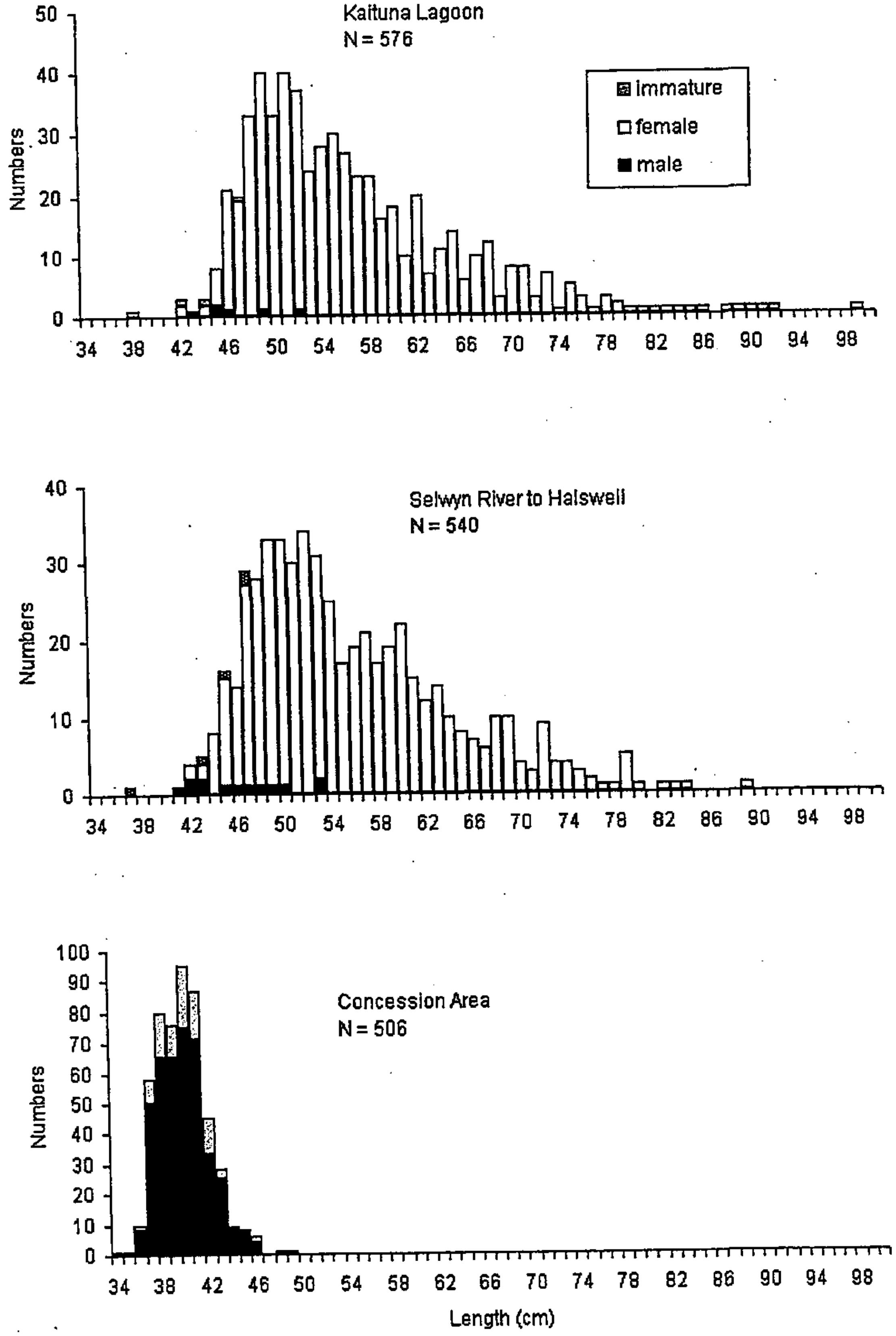


Figure 13: Length frequency of shortfin eels from Te Waihora from commercial catches in 1996–97 fishing year

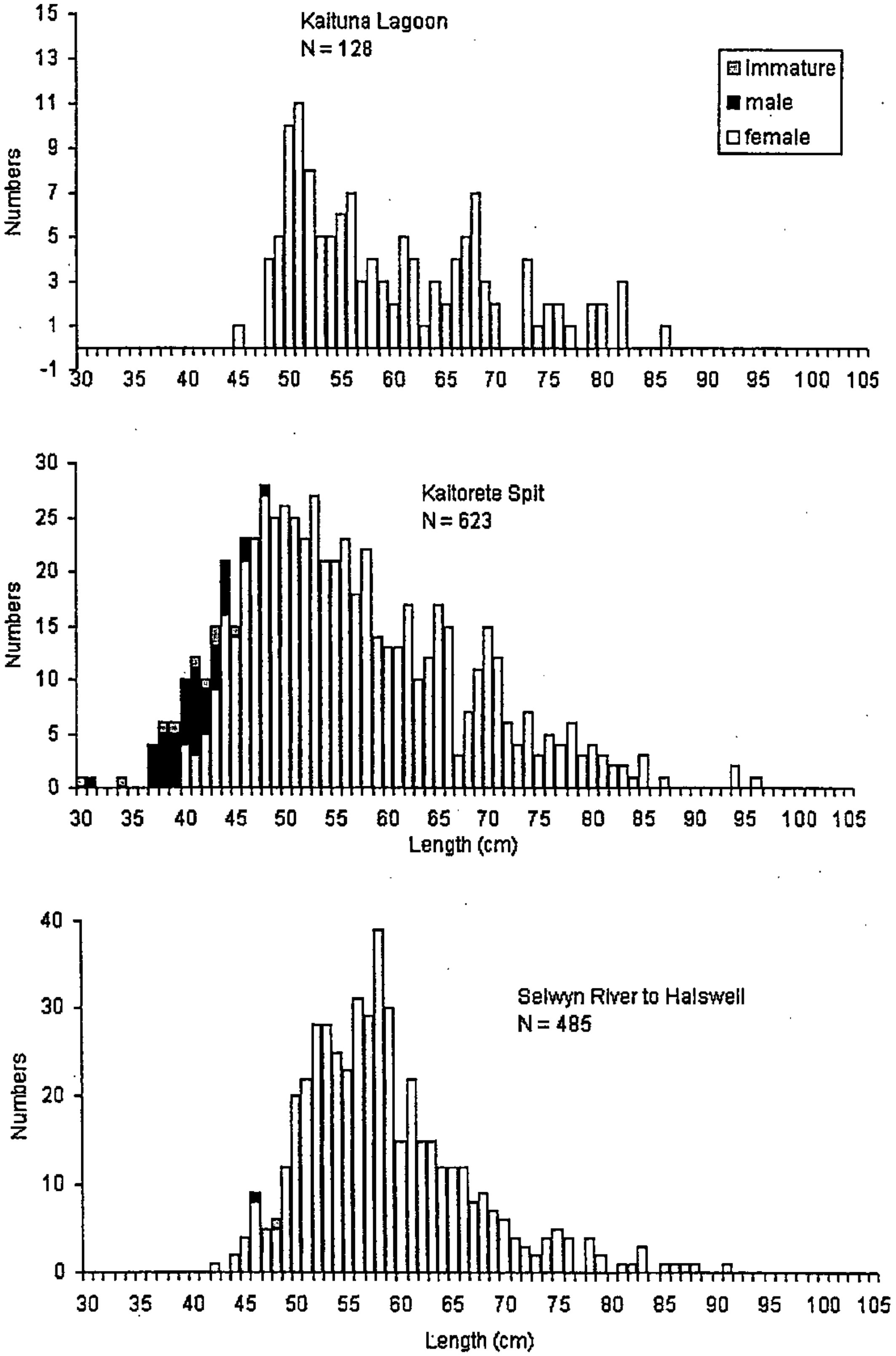


Fig. 14: Length frequency of shortfin eels from Te Waihora from commercial catches in 1997-98 fishing year.

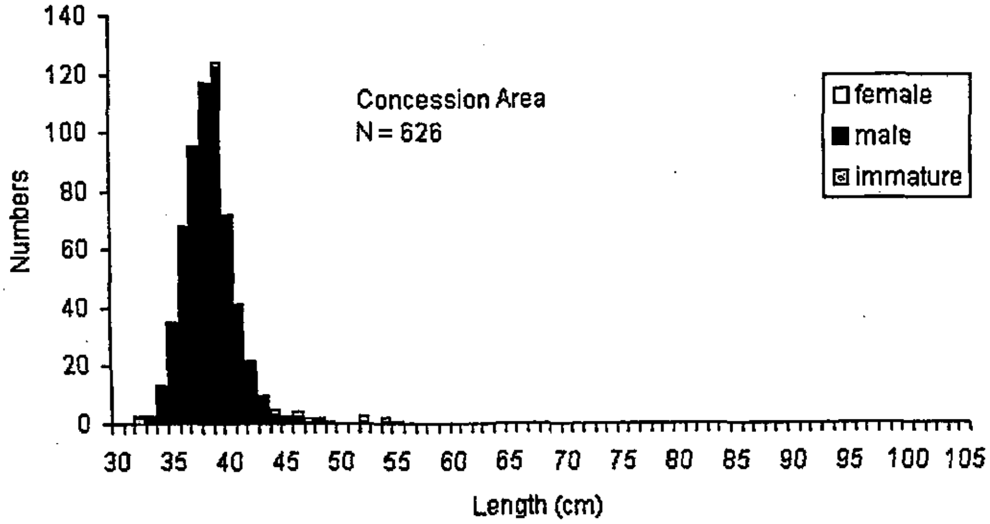
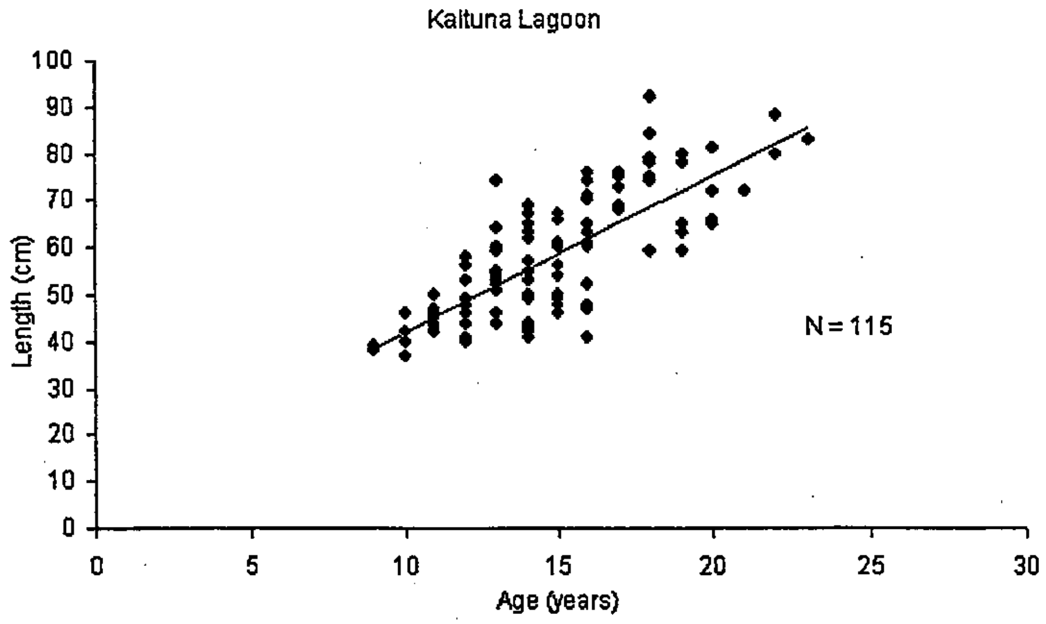


Figure 14 continued.



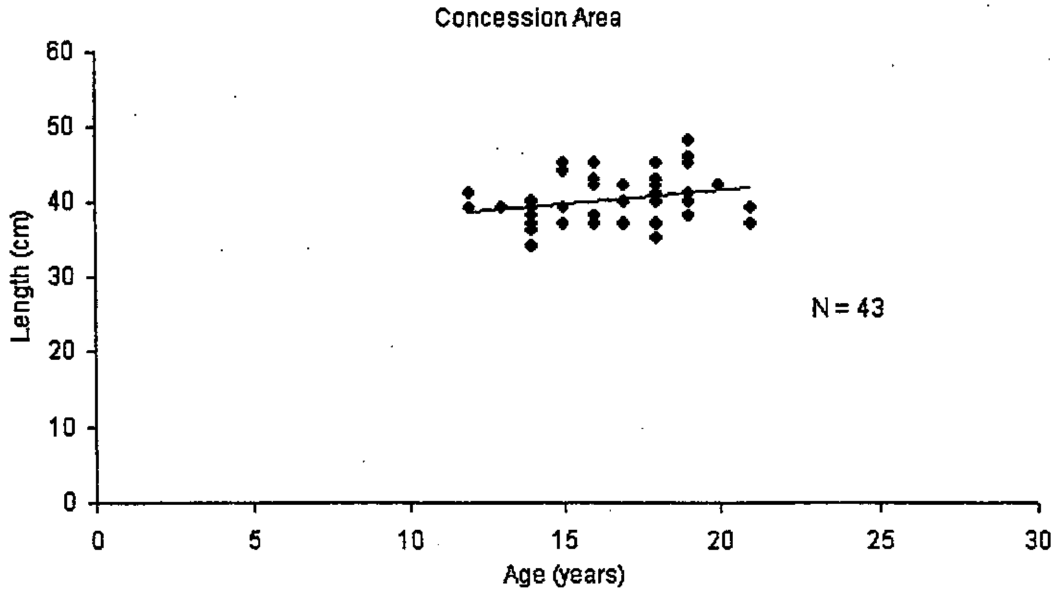


Figure 15: Age against length for Te Waihora shortfin eels from Kaituna Lagoon and the Concession Area. Kaituna Lagoon eels are females and the Concession Area migrating males

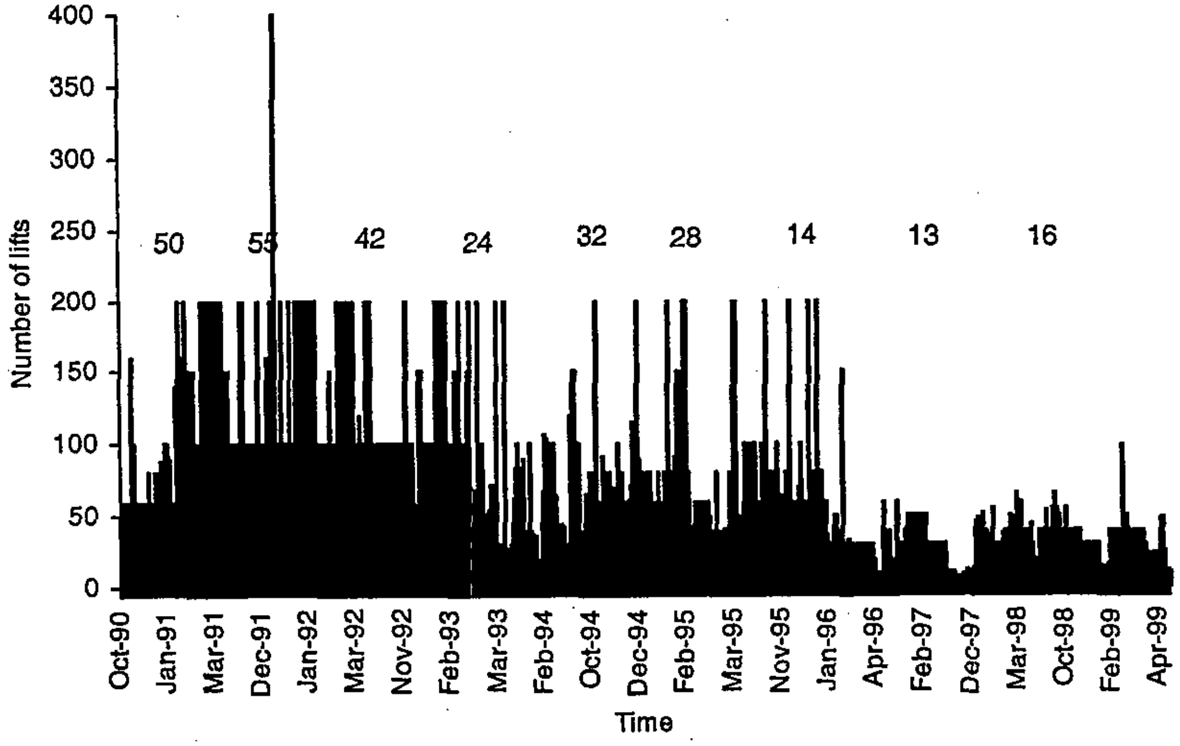


Figure 16: Number of lifts per set for fishing years 1990–91 to 1998–99 for Te Waihora. Numbers represent mean number of lifts per set for each fishing year. Total sets=145800.

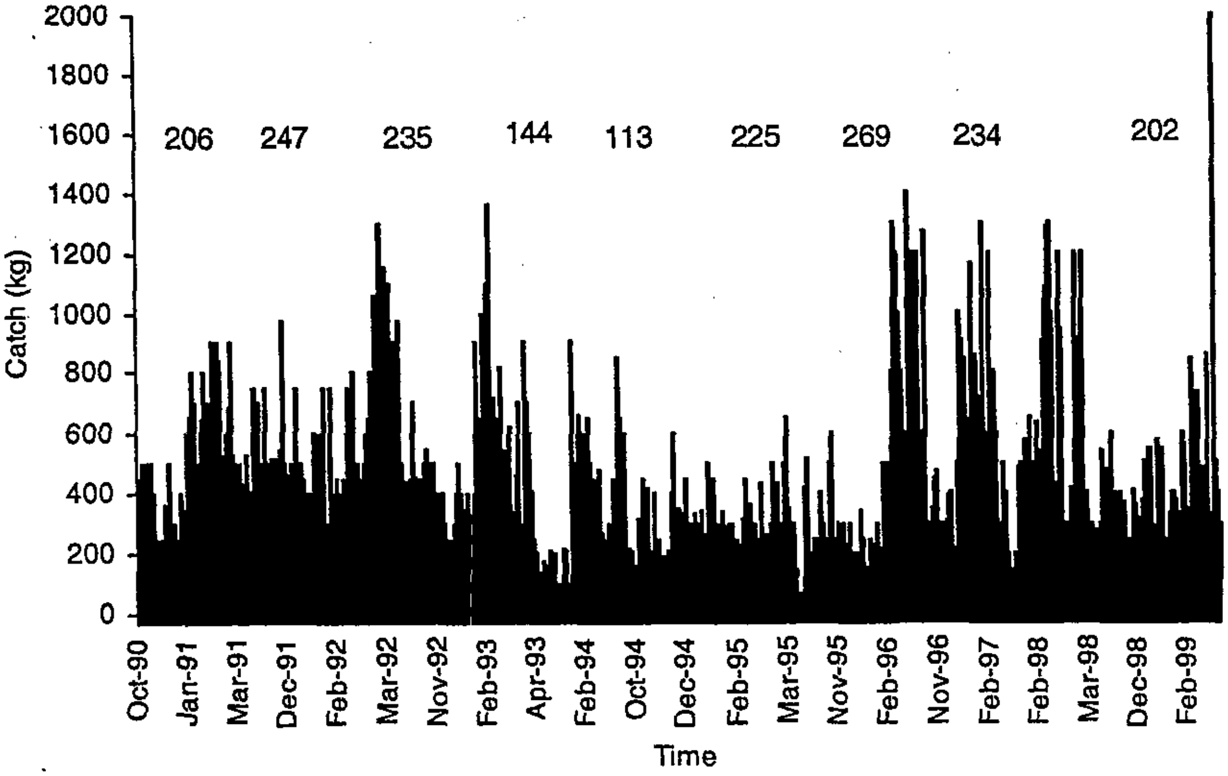


Figure 17: Catches per set for fishing years *1990–91* to *1998–99* for Te Waihora. Numbers represent mean daily catch for each fishing year. Total catch = 904581kg.

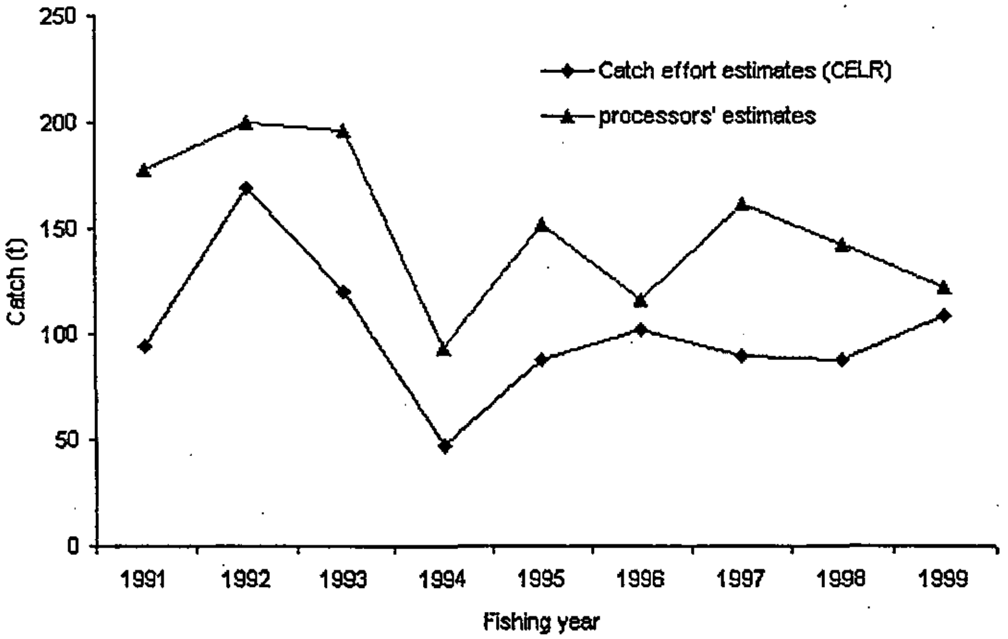


Figure 18: Comparison of total estimated annual eel catch (CELR) with processors' catch for Te Waihora. 1991 represents 1990–91 fishing year. CELR, catch effort landing return.

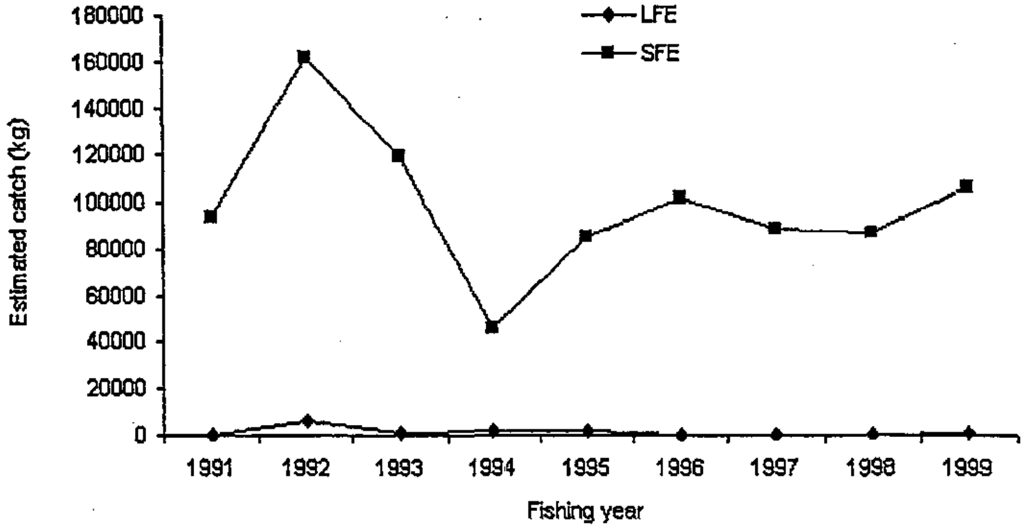


Figure 19: CELR estimates of shortfin (SFE) and longfin (LFE) catch and total estimated catch for Te Waihora. 99% of catch identified to species. 1991 represents 1990–91 fishing year. CELR, catch effort landing return

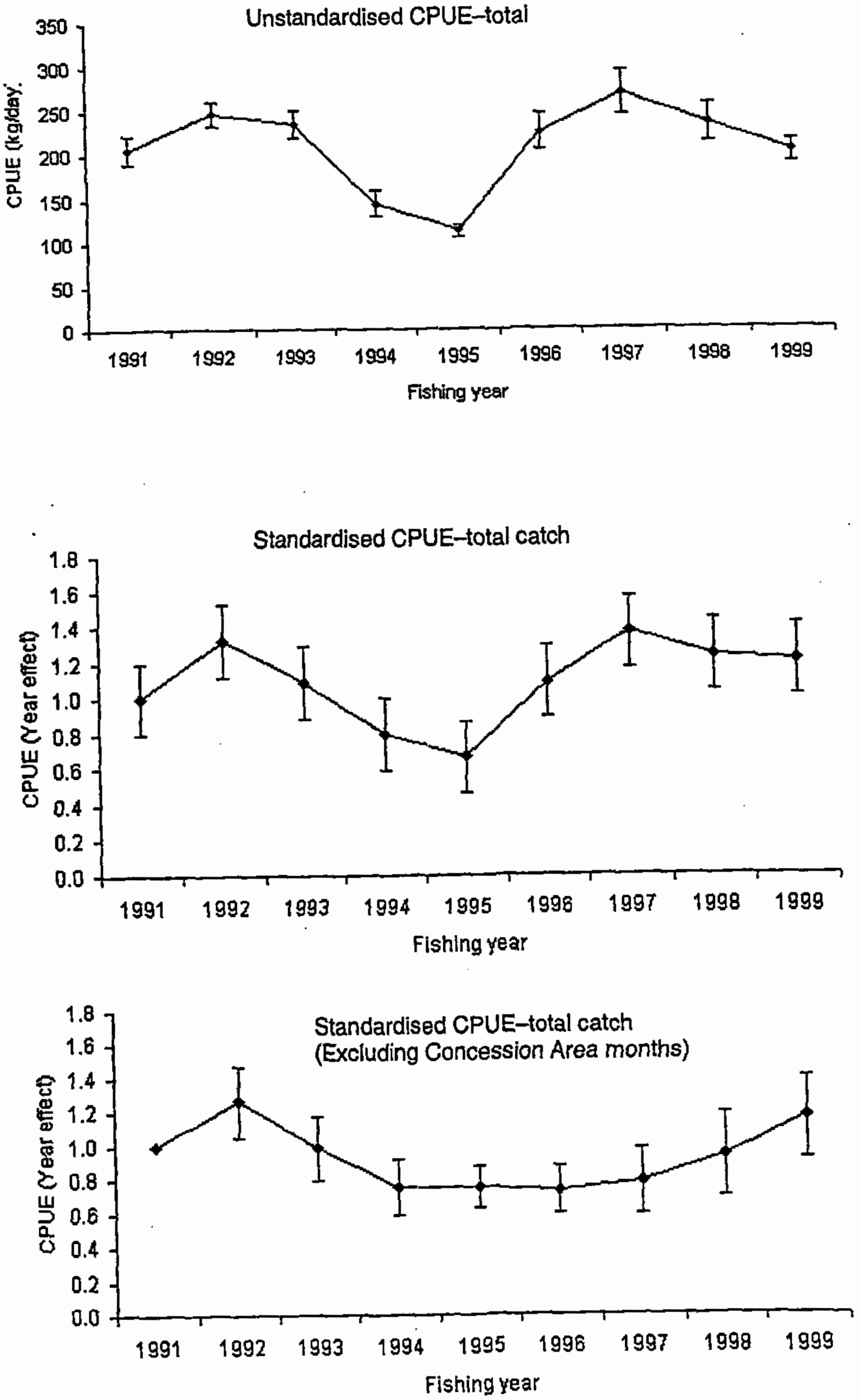


Figure 20: Unstandardised and standardised CPUE indices for Te Waihora. 1991=1990–91 fishing year. CPUE, catch per unit effort.

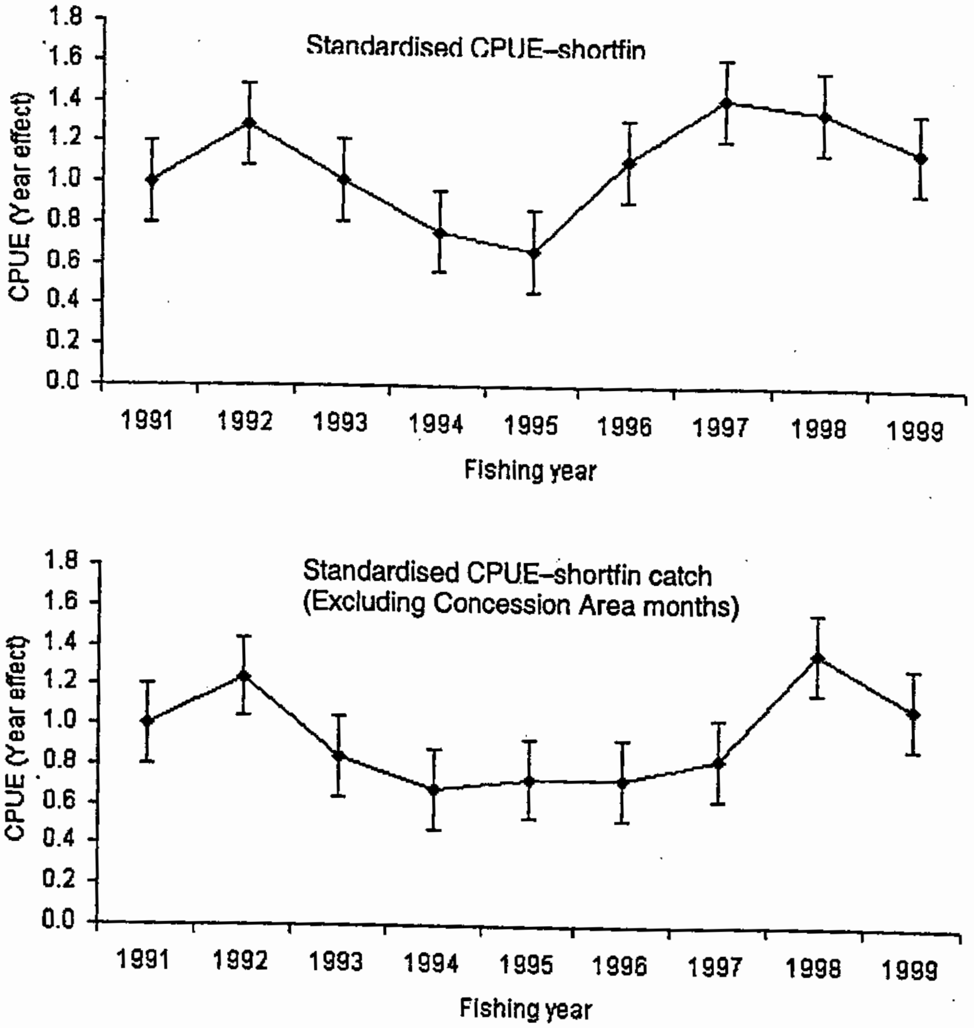


Figure 21: Standardised CPUE indices for Te Waihora shortfin catch. 1991=1990–91 fishing year. CPUE, catch per unit effort.