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*Taihoro Nukurangi*

# Evaluation of eel enhancement in Lake Hawea

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## Final Research Report for
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# Final Research Report

**Report Title:** Evaluation of eel enhancement in Lake Hawea.

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## EXECUTIVE SUMMARY


In February 1998, Lake Hawea was stocked with about 9500 juvenile longfin eels (*Anguilla dieffenbachii*) sourced from the lower Clutha River for the purpose of enhancing the lake for Maori customary fishing. A sub-sample of 2010 transferred eels was tagged with coded wire tags. In February 2001 the eel population in Lake Hawea was sampled and this report examines the effectiveness of this transfer in terms of growth, survival and movement.

A total of 228 longfin eels were caught in Lake Hawea in February 2001, of which 12 were deemed to be resident (>84 cm) and 216 to be recaptures of juvenile eels released into the lake in February 1998. Of the recaptures, 19.4% (42) had tags (tag-recaptures) compared with 21.3% at release indicating good tag retention and/or low mortality due to tagging. Tags had no adverse effect on growth since length and weight of tag-recaptures were not different to that of untagged recaptures ($p>0.05$).

Mean length and weight at recapture were 56 cm and 498 g. During the three years at liberty, eels grew on average about 14 cm and 325 g (all recaptures). There was no difference between length or weight at recapture of tag-recaptures and recaptures without tags ($p>0.05$) indicating that tagging did not affect growth. Growth rate from tag-recaptures (mean annual length increment) was 4.1 $cm.yr^{-1}$, linear, and faster than at release when it was 2.4 $cm.yr^{-1}$ ($p<0.01$); mean annual weight increment from tag-recaptures was 99.1 $g.yr^{-1}$ and faster than at release when it was 10.9 $g.yr^{-1}$ ($p<0.01$). Mean eel condition (k) for all recaptures improved from 2.34 at release to 2.75 ($p<0.001$).

Eels dispersed throughout the lake but density was highest in the Neck, the point of release. Eels caught outside the Neck were larger (length and weight) and in better condition ($p<0.001$) than inside the Neck This was unrelated to length, weight, and condition at tagging indicating that the difference in growth occurred as a result of location within the lake ($p>0.2$).

Eels transferred into Lake Hawea experienced accelerated growth and mean annual increment in length almost doubled. Growth was one of the highest on record for the New Zealand longfin and suggests that eels released in 1998 into Lake Hawea are thriving. The fast growth was ascribed to low density and abundant food.

Recaptured eels were all females, indicating that either eels differentiated into females because density was low, or that males moved out of the lake to more preferred habitat downstream (juvenile eels were observed below Hawea Gates 17 months after release).

Although survival could not be quantified, based on a similar study, and notwithstanding the possible emigration of males out of the lake, we estimate that more than 80% of eels released into Lake Hawea have survived.

Given the very high growth rates experienced by longfin eels released into Lake Hawea we conclude that the stocking rate of 0.35 $kg.ha^{-1}$ for the littoral area of Lake Hawea was conservative. Estimate of current biomass, not taking into account the possible emigration of males but excluding resident eels, is 3753 kg (2.3 times biomass at stocking), which equates to a density for the littoral area of 0.8 $kg.ha^{-1}$. Based on the results of Lake Hawea enhancement, stocking of recruitment limited lakes in the Clutha River catchment is a viable option, and eels, at least from initial releases, will experience rapid and accelerated growth. Future transfers of immature juvenile longfins should, however, consider the implications of males moving out of the lake and downstream after transfer.

**Overall Objective**

To determine the effectiveness of transferring juvenile eels to productive environments to optimise growth and accelerate the recovery of customary fisheries.

**Specific Objective**

To measure the growth, survival and movement of juvenile eels transferred into *Coopers Lagoon (1997) and Lake Hawea (1998).

*This report deals only with Lake Hawea and Coopers Lagoon is covered in a separate report (Beentjes & Jellyman In press).

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|---|---|
| **Methods:** | See the attached report |
| **Results:** | See the attached report |
| **Conclusions:** | See the Executive Summary of this report and the Discussion section of the attached report |
| **Publications:** | Report attached. |
| **Data Storage:** | All electronic data are archived in NIWA Greta Point to the standards and specifications of NIWA data fisheries managers. |

## 1. INTRODUCTION

Lake Hawea was stocked with juvenile longfin eels (*Anguilla dieffenbachii*) in 1998 for the purpose of enhancing the lake for Maori customary fishing (Beentjes 1998); (MFish project EEL9702). The juvenile eels were caught in the lower Clutha River, which is fed by waters of Lakes Hawea, Lake Wanaka, and Lake Wakatipu. A sub-sample of the transferred eels was tagged and individual length and weight recorded before transfer. Three years later, in 2001, the eel population in Lake Hawea was sampled and this report examines the effectiveness of this transfer in terms of growth, survival and movement.

Historically, longfin eels in the Clutha River headwater lakes were fished by Maori (Mitchell & Davis-Te Maire 1996) and a [1]Nohoanga site was granted for Lake Hawea near the Neck in 1998 (Ngai Tahu settlement Act 1998, Schedule 95, site no. 28, Lake Hawea western shore, NM 447), recognising the importance of the eel fishery in this area to Maori. Although some commercial fishing still takes place in the headwater lakes, longfin eel numbers have declined markedly and this is reflected in dwindling commercial catches (Dave Richardson, commercial fisher, pers. comm.); only a small fraction of the virgin biomass remains. While commercial fishing has contributed to the decline in eel biomass from these lakes, barriers imposed by Roxburgh and Clyde Dams (completed in 1958 and 1992, respectively) have restricted recruitment of young eels. Even without the impact of fishing, the remnant population is ageing and declining, as mature eels that migrate to sea to spawn are not replaced by new recruits. Prior to stocking with juvenile longfin eels, abundance was very low and the remaining eels in Lake Hawea were large old females (Beentjes et al. 1997). Hence eels released into the lake were expected to achieve enhanced growth because of the low eel density.

This research was carried out by NIWA under contract to Ministry of Fisheries under Project EEL2000/02: *To measure the growth, survival and movement of juvenile eels transferred into *Coopers Lagoon (1997) and Lake Hawea (1998).*

*Coopers Lagoon is covered in a separate report (Beentjes & Jellyman In press).

The tag and release of eels into Lake Hawea in 1998 was carried out under contract to Ministry of Fisheries as part of Project Code EEL9702.

### 1.1 Description of Lake Hawea

Lake Hawea is a glacial, oligotrophic lake with a littoral[2] area of 4654 ha at average depth (Beentjes et al. 1997) which is 34% of total lake area (138 km$^2$). It lies at an altitude of 347 m, has a maximum and mean depth of 384 and 192 m. The catchment is largely tussock grassland growing on poor soils derived from schist (Flint 1975). The main water source is from the Hunter River and Dingle Burn at the north end and the lake drains via the Hawea Gates (weir structure) and Hawea River at the south end. The Neck is a shallow narrow bay on the west side midway up the lake (Figure 1). The littoral zone of the Neck is about 190 ha at average lake level, constitutes 4% of the total lake littoral area, and most of the bay is less than 20 m deep. Surface water temperature at the Neck in mid February 1998 and 2001 was 16.5 °C.

Lake Hawea is subject to water level fluctuations of 10 m as a result of hydro storage. The submerged aquatic vegetation has been shown to be impoverished and has only two plant communities with a notable absence of vascular and other shallow water plants (Clayton et al. 1986). By comparison, neighbouring Lake Wanaka undergoes a fluctuation of only 1.0 m and

[1] A Nohoanga site is an area recognised by the Crown as being of historical customary importance to Maori for mahinga kai.

[2] The zone where there is sufficient light to maintain growth of rooted plants and where most of the benthic food production occurs.

has five plant communities. The difference between these lakes appears to be a result of extreme water level fluctuations in Lake Hawea (Clayton et al. 1986). Because the Neck is affected by even small water level changes, a drop in water level of 10 m would reduce its area by about one half.

Koaro (*Galaxias brevipinnis*), common bully (*Gobiomorphus cotidianus*), brown trout (*Salmo trutta*), and rainbow trout (*Onchyrynchus mykiss*), and Chinook salmon (*Onchyrynchus tshawytscha)* are all common throughout Lake Hawea (Jellyman 1984), with upland bullies (*Gobiomorphus breviceps*) found only in a few tributaries of the lake (Allibone 1997). Invertebrates of Lake Hawea have not been studied.

## 2. METHODS

### 2.1 Catch of juvenile eels and transfer to Lake Hawea (1998)

In February 1998 an estimated 1630 kg (9421) of juvenile eels were caught in the Matau and Koau branches of the lower Clutha River and, with the exception of 96 eels retained for aging, were transferred to Lake Hawea where they were released at the Neck (Figure 1). The stocking rate estimates were 8 kg $ha^{-1}$ for the littoral area of the Neck and 0.35 kg. $ha^{-1}$ for the littoral area of Lake Hawea. Before transfer, a sub-sample of 2010 longfinned eels (21.3%) was tagged with sequentially coded wire tags inserted in the top of the head, and length and weight were recorded. Each stainless steel tag (1.25 x 0.25 mm) was etched with a unique 6-bit binary code. During tagging two shortfin eels were found and therefore the total number of shortfin eels transferred was estimated at about nine (for more details of methods used see Beentjes (1998)).

Otoliths from a length stratified sub-sample of transferred eels were removed for ageing from 96 longfin eels (4 otoliths per centimetre length class) and prepared using the crack-and-burn method (Hu & Todd 1981). Otolith halves were mounted in silicone rubber sealant on microscope slides and observed under X10–100 magnification using a compound microscope with side illumination. The central area of oceanic larval growth was ignored (Jellyman 1979) and age was expressed as years spent in fresh water and was determined by the number of complete hyaline zones or winter rings in the otolith. Using age, annual growth was calculated as follows: mean annual length increment ($cm.yr^{-1}$)=(length–5)/age, where 5 is total length (cm) at recruitment into fresh water; mean annual weight increment ($g.yr^{-1}$)=weight/age. Eel condition (k) was calculated from $k=W*10^6/L^3$, where W=weight (g) and L=length (mm).

### 2.2 Lake Hawea resident eel population

Prior to stocking Lake Hawea was surveyed using baited commercial fyke nets set overnight in December 1995 (Beentjes et al. 1997) and February 1998 (Beentjes 1998), when lengths and weights of all captured eels were recorded, and otoliths removed for ageing and processed as for transferred juvenile eels. Sampling of Lake Hawea in 2001 also resulted in captures of resident eels, distinguishable from stocked eels by size. Eel condition (k) was calculated as for transferred juvenile eels.

### 2.3 Re-sampling Lake Hawea after stocking (2001)

Between 18–23 February 2001, Lake Hawea was re-sampled with the aim of recapturing eels that were released at the Neck in February 1998. For the purposes of the survey the lake was broken into three areas: Neck, South, and North (Figure 1). Fishing occurred on five consecutive nights of which three were in the Neck, and one each were in the South and North ends. Thirty commercial fyke nets designed for targeting longfin eels, were baited and left overnight with escape tubes blocked to retain small eels. Nets were placed in locations considered to be favoured eel habitat such as weed beds, log jams and overhanging willows,

spaced throughout each area in 3 to 10 m depth. Nets were checked each following morning and all captured eels were taken ashore, anaesthetised with 2-phenoxyéthanol, and measured and weighed. Eels were also checked for the presence of coded wire tags using a hand-held tag detector wand; eels found to have tags were killed, and the heads taken for dissection of the tags in the laboratory. The sex and gonad stage of these tagged eels were also recorded. All other eels were retained in holding bags in the water and returned alive to the Neck at the end of the last days sampling to avoid catching the same eels twice
In the laboratory, tags were removed from heads and the unique binary code on the tag read using a binocular microscope. It was then possible to match details of individual weight and length at recapture with those at release.

Surface water temperature in the middle of the Neck was recorded with a hand-held temperature probe (Minitherm, HI8053).

The length–weight relationship was determined from the linear regression model: logW=b(logL)+log(a), where W=weight (g), L=length (cm), and logs are natural logarithms.

Annual growth rates for tag-recaptures were estimated as follows: mean annual length increment ($cm.yr^{-1}$)=(length at recapture–length at tagging)/years at liberty; mean annual weight increment ($g.yr^{-1}$)=(weight at recapture–weight at tagging)/years at liberty. Eel condition (k) was calculated as for transferred juvenile eels.

### 2.3.1 Relative abundance

Relative abundance was measured as catch per unit effort (CPUE) and expressed as catch per net (kg/net) or eels per net (no.eels/net).

### 2.3.2 Statistical analysis

Statistical analyses were conducted to compare growth characteristics of juvenile eels at time of release into Lake Hawea with those at recapture, and also to compare growth variation within the lake (Statsoft 1999). The following questions were addressed:

*Did eels grow after release into Lake Hawea ?*
To determine if eels were significantly larger at recapture than at release, a t-test for independent samples was used to compare length and weight at release (N=2010) and at recapture (N=216). Similarly, a t-test for dependent samples was used for tag-recaptures (N=41). To determine if tagging affected growth a Mann-Whitney U non-parametric test was used to compare length, weight and condition at recapture of tag-recaptures (N=41) and recaptures without tags (N=174). Non-parametric statistics were used because datasets were unbalanced.

*Did eel annual growth and condition change after release into Lake Hawea ?*
To determine if eel growth rates at release were significantly different at recapture a t-test for independent samples was used to compare annual length increments ($cm.yr^{-1}$); length increments at release were determined from length at age (N=96) and recaptures from growth over the three years at liberty (N=41).

To determine if eel condition (k) at release and recapture was significantly different a t-test for dependent samples was used for tag-recaptures (N=41), and a t-test for independent samples was used to test between release (N=2010) and recaptures (N=216).

*Was growth and condition of recaptures variable within Lake Hawea ?*
To determine if eel growth varied within the lake, growth and condition (k) of all recaptures at the Neck (N=178) were compared (Mann-Whitney U test) with those in areas outside the

Neck (South and North combined) (N=38). The same test was used to compare the length, weight and condition of eels at tagging and recapture (Neck=34, outside Neck=7).

*Was growth linear ?*
Linear regression analysis was used to test the assumption of linear growth by plotting length at tagging (independent variable) against growth increment ($mm.yr^{-1}$) (dependent variable) for tag-recaptures (N=41).

## 3. RESULTS

### 3.1 Transferred juvenile eels (1998)

The length frequency distribution representative of the estimated 9500 longfin juvenile eels released into Lake Hawea in 1998 is shown in Figure 2 (Beentjes 1998). Eels at release were too small to determine sex since longfin eels do not differentiate until about 50 cm (Beentjes & Chisnall 1998). The length distribution was unimodal, size ranging from 30 to 55 cm with a mean length of 42 cm (Table 1). Weight ranged from 55 to 380 g with a mean of 173 g. The bulk (77%) of these eels were less than the commercial minimum legal size of 220 g. The mean age was 15 years and mean annual growth was 2.45 $cm.yr^{-1}$ and 10.9 $g.yr^{-1}$ (Table 2).

### 3.2 Resident eels

The two surveys (1995 and 1998) (Beentjes et al. 1997, Beentjes 1998) of the resident eel population of Lake Hawea before stocking, yielded only three longfinned eels on each of the surveys and these data were combined because the data were few and three years is not long relative to the size and age of these eels. The mean length of eels from both surveys combined was 112 cm and mean weight 4880 g (Table 3). There was no overlap in size and age of resident eels in Hawea and those juveniles that were released into the lake. All eels had well developed ovaries. The mean age of resident eels was 56 years although most otoliths were difficult to read and confidence in these ages is low. The width between annuli did not indicate accelerated growth in recent years despite the low eel density in the lake.

Twelve of the eels sampled in February 2001 were over 84 cm and were deemed to be resident eels, clearly distinguishable from the recaptures based on size alone (Figure 3). The descriptive statistics of these eels are shown in Table 4.

### 3.3 Recaptures

A total of 228 longfin eels was caught in Lake Hawea in February 2001, of which 12 were resident and the remainder (N=216) were recaptures of juvenile eels released into the lake in February 1998 (Figure 3). No shortfin eels were caught. Of the 216 recaptures, 19.4% (42) had tags (tag-recaptures) compared with 21.3% at release. One tagged eel could not be included in the analyses because details of its weight were incorrect.

Macroscopic examination of the gonads of the 42 tag-recaptures showed that they were all females at an early stage of development.

#### 3.3.1 Distribution and abundance

Recaptures, including tag-recaptures were caught in all three areas (Neck, North, South) indicating that some eels had moved from the Neck to the extreme north and south ends of the lake as well as across to the east side of the lake. Catch per unit effort for the entire lake, and for the Neck and outside the Neck separately, is shown in Table 5. Eels were nearly twice as abundant (kg/net) in the Neck than outside and the contrast may have been greater had we not repeat fished the Neck causing some local depletion over the sampling period.

For comparison, CPUE is also shown for the lower Clutha River where juvenile eels were caught in 1998. The relative abundance of eels (kg/net) in Lake Hawea post stocking is less than the lower Clutha River by a factor of about four by weight and seventeen by number.

### 3.3.2 Growth

The length distribution of recaptures has remained unimodal but the range of lengths increased due to variable growth rates (Figure 3). Mean length and weight of all recaptures (N=216) was 56 cm and 498 g (Table 1) and for tag recaptures (N=41) 56 cm and 485 g (Table 6). During the three years at liberty, eels grew on average about 14 cm and 325 g (all recaptures) and both length and weight were significantly larger at recapture ($p<0.001$)). For the tag-recaptures, length and weight increase was comparable to that of all recaptures (13 cm and 300 g) (see Tables 1 and 6) and length and weight were also significantly larger at recapture ($p<0.001$)). Length at tagging and recapture are plotted for the tag-recaptures (Figure 4). There was no difference between length and weight at recapture of tag-recaptures (N=41) and recaptures without tags (N=175) ($p>0.05$).

Mean annual length increment ($cm.yr^{-1}$) was 2.45 $cm.yr^{-1}$ at release (N=96) (see Table 2) compared to 4.1 $cm.yr^{-1}$ at recapture (N=41 tag-recaptures) (see Table 6) and was significantly different ($p<0.001$). Results of the linear regression analysis of length at tagging (independent variable) against annual growth increment ($cm.yr^{-1}$) (dependent variable) indicated that the slope was not significantly different from zero and therefore growth, in terms of length, was linear. Therefore the increase in mean annual length increment since transfer to Lake Hawea was the same for all eels regardless of tagged length.

### 3.3.3 Condition

Eel condition (k) improved from a mean of 2.24 at release (N=2010) to 2.75 for all recaptures (N=216) (Table 1), and the difference was statistically significant ($p<0.001$). For the 41 tag-recaptures, condition improved at recapture (2.26 at tagging and 2.70 at recapture) (Table 6) and the difference was also significantly different ($p<0.001$). Condition at release and for all recaptures is plotted in Figure 5 and condition at tagging and recapture (N=41) in Figure 6. Condition of tag-recaptures (N=41) and recaptures without tags (N=175) was significantly different at the 0.05 significance level (see Table 6).

### 3.3.4 Within-lake growth variation

All eels were released into the Neck in February 1998 and after three years at liberty eels dispersed throughout the lake (see Table 5). Comparison of recapture length, weight, and condition of eels caught in the Neck (N=178) and outside the Neck (N=38) (Table 7) indicated that eels from outside the Neck were significantly larger (length and weight) and in better condition. ($p<0.001$ for all three variables, Mann-Whitney U non-parametric test). The difference in growth inside and outside the Neck was corroborated by tag-recapture data where recaptured length and weight, annual length and weight increments, and condition were all significantly greater outside the Neck ($p<0.05$ for all variables, Mann-Whitney U non-parametric test). Length, weight, and condition at tagging of eels caught inside (N=34) and outside the Neck (N=7) were not significantly different ($p>0.2$ for all three variables) indicating that the difference in growth occurred as a result of location within the lake and not size at release.

### 3.3.5 Length-weight and length-age relationship

The length-weight (cm and g) relationships at release and recapture were:

At release* weight = $0.001087(\text{length})^{3.1926}$ (N=2010, $R^2=0.93$, $p<0.001$)
At recapture weight = $0.000886(\text{length})^{3.2809}$ (N=216, $R^2=0.92$, $p<0.001$)

The length-age (cm and years) relationship at release was:

At release* length = 1.1852(age)+23.08 (N=96, $R^2$=0.45, $p<0.001$)

* data from Beentjes (1998)

## 4. DISCUSSION

This report presents the results of a stocking experiment where juvenile longfin eels from the lower Clutha River were released into Lake Hawea, a recruitment-limited lake that historically contained a healthy population of eels, but density was very low at the time of stocking. This provided a unique opportunity to study the effects of stocking in terms of growth, movement and potential survival. In addition, the utility of deploying coded wire tags on eels was gauged.

### 4.1 Movement

Tagging studies on both shortfin and longfin eels in New Zealand have shown that movement of non-migratory eels is limited and tagged eels were often recaptured near or at the tagging site (Burnet 1969b, Chisnall & Kalish 1993, Jellyman et al. 1996). Tagging studies on the American eel (*Anguilla rostrata*) also indicates that movement is restricted within a home range of about 1 ha (Bozeman et al. 1985) and 100 m (Ford & Mercer 1986), and *A. australis* in Australia to about 400 m (Beumer 1979). From this we can assume that adult eels establish territories or home ground ranges which are adequate to meet food requirements. During the three years since release, eels in Lake Hawea dispersed throughout the lake but density was highest in the Neck, the point of release. It is not possible to know the time frame over which dispersal occurred but it was probably not as a result of competition from Lake Hawea resident eels as these were present in only very low numbers. Eels probably migrated out of the Neck and around the lake to avoid overcrowding and to exploit under-utilised food resources. Periodic low water levels as a result of hydro storage demands may also have encouraged eels to move out of the Neck. This finding indicates that eels placed into a largely eel free environment will eventually occupy all suitable habitat. It is notable that while some eels remained in Lake Hawea after transfer 200 km upstream the proportion cannot be determined since eels can exit the lake via the Hawea Gates. Indeed, large numbers of juvenile eels were reported below Hawea Gates in an irrigation canal about 17 months after release in July 1999 (Richard Hewitt, pers. comm.). Unlike the American eel (*Anguilla rostrata*) (Helfman et al. 1987) New Zealand longfin males are not restricted to coastal and estuarine areas, however, the proportion of longfin males in the Clutha River tends to decline slightly from the coast to inland areas, indicating a preference for coastal areas (Beentjes 1999). It is likely that the eels observed below Hawea Gates were males attempting to return to preferred downstream habitat and the 17 month delay between release and departure may represent the time between immaturity and differentiation into males. Homing behaviour is known to occur in some Anguillids, for example, *A. australis* (New Zealand shortfin) (Jellyman et al. 1996) and *A. rostrata* (Lamothe et al. 2000). The observation that some eels departed Lake Hawea, is not convincing evidence of homing as males may simply be moving in response to a preference for downstream habitat.

### 4.2 Growth

Because eel growth in length is generally linear, assuming no significant changes in density and food availability (Jellyman 1995, Jellyman 1997, Beentjes & Chisnall 1998), annual growth increment is more appropriately expressed in $cm.yr^{-1}$. Weight increases exponentially and is strongly correlated with size as larger eels accrue more weight annually than smaller eels. Annual weight increments were also estimated, as weight is the parameter of more importance to the eel industry. Eels transferred into Lake Hawea experienced accelerated growth to the extent that the annual increment in length almost doubled from 2.45 at release to around 4 $cm.yr^{-1}$ at recapture. Longfin growth (females only) in length over the three years at liberty was found to be linear (slope of regression of length at tagging on annual length increment was not different from zero) and therefore regardless of length at transfer eels grew at the same rate. This indicates that the increase in annual growth since transfer to Lake Hawea is not a function of length (i.e., larger eels growing faster than smaller eels) but a result of the transfer to more favourable habitat. CPUE analyses indicated that density of eels in Lake Hawea was substantially less than in the lower Clutha River where eels were sourced. Growth in eels is often density dependent (Tesch 1977, Horn 1996, Jellyman 1997) and high-density in the lower Clutha River was probably a constraint on growth. In contrast, in the low-density environment of Lake Hawea, growth has been enhanced. Slower growth rates of eels in the Neck compared to the north and south of the lake is further evidence of the density dependent growth. Eels caught outside the Neck were larger and in better condition and statistical analyses confirmed that the difference in growth occurred as a result of location within the lake and not size at release.

High growth rate is often a feature of eels in hydro lakes where density is very low because of barriers to recruitment. For example, longfins released into Lake Arapuni, the second hydro impoundment on the Waikato River, achieved annual growth of 21 $cm.yr^{-1}$. Similarly, in Lake Matahina on the Rangitaiki River, growth was 5.7 $cm.yr^{-1}$; in both cases the exceptionally high growth was considered to be due to very low density and an abundant food source (Beentjes et al. 1997). As part of a research programme to monitor commercial eel catches in New Zealand, length and age were determined for commercial catches of longfin from more than 21 major rivers in the South Island, including the Clutha River (Beentjes & Chisnall 1998, Beentjes 1999). The mean annual length increment from these rivers was 2.3 $cm.yr^{-1}$ (s.e.=0.13, range 1.6–3.1); this figure is similar to the value of 2.45 $cm.yr^{-1}$ estimated for the juvenile eels taken from the lower Clutha River to stock Lake Hawea in 1998 (Beentjes 1998). This comparison demonstrates the magnitude of accelerated growth experienced by eels after release into Lake Hawea–they grew faster than longfins from South Island rivers as well as longfin from 13 other South Island locations (Jellyman 1997). In addition, from a review of longfin growth throughout New Zealand, apart from the extremely fast growth of longfins from North Island hydro lakes described above, growth of eels introduced into Lake Hawea was one of the highest on record for the New Zealand longfin (Cairns 1941, Burnet 1969a, Chisnall 1989, Chisnall & Hicks 1993, Chisnall & Kalish 1993, Jellyman 1995, Beentjes et al. 1997, Jellyman 1997).

Longfins greater than 40 cm are piscivorous (Jellyman 1989) which would indicate that diet of eels probably changed from exclusively invertebrates to include fish, some time after transfer into Lake Hawea. Although stomachs were not examined, common bully (*Gobiomorphus cotidianus*) was present in large numbers and was frequently caught in the fyke nets. Fish provide a high energy diet (Ryan 1982) and the change to piscivory may partly explain the accelerated growth of eels after transfer.

Along with density and food, water temperature has been shown to be one of the most important variables affecting growth with warm temperatures enhancing growth (Jellyman 1991, Chisnall & Hicks 1993, Horn 1996, Jellyman 1997). Given the relatively cool water temperatures characteristic of glacial oligotrophic lakes such as Hawea, the fast growth rates of eels in Lake Hawea were unexpected, and indicates that historic growth rates of resident eels in the lake (about 2 $cm.yr^{-1}$, see Table 3) were not constrained by water temperature and were probably density dependant. A significant reduction in the density of eels in Lake Hawea would have occurred over time given the limited recruitment of juvenile eels beyond Roxburgh Dam (Pack & Jellyman 1988) and the commercial harvest of eels from Lakes Wakatipu, Hawea, and Wanaka where annual catches were estimated at 40 t per annum (Jellyman 1984).

## 4.3 Sex ratio

The sex of eels transferred into Lake Hawea in 1998 could not be determined because eels were immature or undifferentiated. In 2001 all tag-recaptures were found to be female (N=42). Male longfin migrate to sea to spawn at about 65 cm and 0.7 kg and females 94 cm and 2.5 kg (Todd 1980, Jellyman & Todd 1982, Beentjes & Chisnall 1998, Beentjes 1999) and given the size of recaptures (see Table 1) we would have expected that only a small proportion of male eels would have been large enough to have migrated. Although recruitment into Lakes Wanaka and Wakatipu has been greatly reduced since 1958 when Roxburgh Dam was built (Pack & Jellyman 1988) analysis of length and ages of eels from these lakes indicates that limited recruitment has occurred since this time but only females are present (Beentjes et al. 1997, Beentjes 1999). Given the size range of longfinned eels in Lakes Wanaka and Wakatipu we would also have expected to have found some males.

Several studies on *Anguilla anguilla* and *A. japonica* indicate that the expression of sex is partly dependent on the environment (Tesch 1977, Krueger & Oliveira 1999). Eel populations of low density tend to be largely female and dense populations tend to be predominantly male. The absence of males in Lake Hawea is consistent with the concept that transferred eels differentiated into females in response to low density. Alternatively, as large numbers of juvenile eels were reported below Hawea Gates about 17 months after release, we cannot rule out the possibility that these were males attempting to move downstream to preferred male habitat. Either theory would provide an explanation as to why only females are found in Lake Hawea and in the other headwater lakes of the Clutha River.

## 4.4 Tagging

Of the eels released into Lake Hawea, 21.3% were tagged and about the same proportion of recaptures (19.4%) was found to have tags. This suggests that even after three years at liberty, tag retention of coded wire tags in eels is good and/or mortality due to tagging is low. Tags had no adverse effect on growth since length and weight at recapture of tag-recaptures and recaptures without tags were not significantly different. Condition was significantly different but the level of significance was low ($p<=0.05$) and this result seems questionable given that weight and length were unaffected by tagging.

## 4.5 Survival

Without a regular longterm monitoring programme it will not be possible to quantify survival of eels released into Lake Hawea, particularly when the lake is open to emigration. There are few estimates available of longterm survival post stocking and most estimates of survival are based on elvers or glass eels as seed stock and are not directly comparable. Pederson (2000) however, estimated survival using wild juvenile eels (*A. anguilla*, mean length 25 cm) as seed stock released into a productive lake in Denmark at 55–75% over eight years. The lake was closed to immigration and all migrating eels exiting the lake were caught in traps at the outlet. Survival using juvenile eels as seed stock is greater than that using elvers or glass eels. Mortality estimates (M) of unexploited populations of the New Zealand longfin are very low (0.04) (Jellyman 1994) and similar to that for *A. anguilla*. Based on this and after only three years since release, we estimate that more than 80% of eels released into Lake Hawea have survived, not withstanding eels that emigrated

## 4.6 Stocking

Given the very high growth rates experienced by longfin eels released into Lake Hawea it seems reasonable to conclude that the stocking rate of 0.35 $kg.ha^{-1}$ for the littoral area of Lake Hawea was conservative. Given our inferred estimate of 80% survival, based on mean recapture weight (498 g), the current biomass of transplanted eels in the lake would be 3753 kg (2.3 times biomass at stocking), which equates to a density for the littoral area of the lake of 0.8 $kg.ha^{-1}$; this estimate does not take into account the possible emigration of eels, presumed to be males, 17 months after release. Nonetheless, this is only a fraction of the biomass density estimates from 12 riverine locations in New Zealand, which range from 66–965 $kg.ha^{-1}$ (Jellyman 1997) and indicates that the stocking potential of Lake Hawea has not been optimised. Density and growth were inversely related and therefore it might be more sensible to base future stocking rates on the desired growth of eels rather than density. Any subsequent stockings should also incorporate a tagged sub-sample in order to monitor annual growth after transfer. Tagging will assume more importance in future stockings because it may not be possible to distinguish eels from different releases, as we were able to do in this case.

### 4.7 Future enhancement

Based on the results of Lake Hawea enhancement, stocking of recruitment limited lakes in the Clutha River catchment is a viable option and at least from initial releases, eels will experience rapid and accelerated growth. Lake Wanaka has only a third of the littoral area of Hawea but is likely to be more productive than Lake Hawea as it has minimal lake level fluctuations, warmer water temperatures and a more diverse aquatic vegetation. There is evidence that longfin recruitment and abundance are declining (Jellyman et al. 2000, Beentjes & Bull In press) and alternative fisheries for longfin in stocked lakes such as Hawea, Wanaka, Wakatipu, and Dunstan may relieve some pressure on downstream stock. However, female and to a lesser extent male longfins are unlikely to contribute to future spawning stock because of the high mortality incurred during turbine passage through Clyde and Roxburgh Hydro Dams as they attempt to migrate to sea (Mitchell & Davis-Te Maire 1996). All future transfers of immature juvenile longfins should consider the implications of males moving out of the lake and downstream after differentiation into sex has occurred.

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**Table 1: Descriptive statistics for juvenile longfin eels tagged and released into Lake Hawea in 1998 and recaptured in 2001. Recaptures include 42 tagged eels.**

| Variable | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| **Release length (cm)** | | | | | |
| Release length (cm) | 2010 | 42.0 | 30.0 | 55.0 | 0.10 |
| Recapture length (cm) | 216 | 55.8 | 40.0 | 74.0 | 0.39 |
| Release weight (g) | 2010 | 173 | 55 | 380 | 1.33 |
| Recapture weight (g) | 216 | 498 | 136 | 1040 | 11.80 |
| Release condition (k) | 2010 | 2.24 | 1.37 | 3.55 | 0.00 |
| Recapture condition (k) | 216 | 2.75 | 1.98 | 3.62 | 0.02 |

**Table 2: Age and annual growth for a sub-sample of eels released into Lake Hawea in 1998**

| | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| Age (yr) | 96 | 15.4 | 6.0 | 32.0 | 0.42 |
| Length (cm) | 96 | 41.3 | 29.0 | 57.0 | 0.74 |
| Weight (g) | 96 | 172 | 45 | 455 | 9.57 |
| Annual growth ($g.y^{-1}$) | 96 | 10.9 | 3.6 | 23.6 | 0.48 |
| Annual growth ($cm.y^{-1}$) | 96 | 2.45 | 1.48 | 4.50 | 0.06 |

**Table 3: Descriptive statistics for longfin eels resident in Lake Hawea prior to stocking. (Three eels sampled in 1995 and three in 1998).**

| Variable | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| Length (cm) | 6 | 112 | 101 | 124 | 3.79 |
| Weight (g) | 6 | 4880 | 3260 | 7640 | 704.92 |
| Age (yr) | 5 | 56 | 42 | 61 | 3.58 |
| Condition (k) | 6 | 3.35 | 2.91 | 4.01 | 0.15 |

**Table 4: Descriptive statistics for longfin eels resident in Lake Hawea during sampling in 2001. Eels were deemed to be residents if >84 cm.**

| Variable | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| Length (cm) | 12 | 109.3 | 85.0 | 130.0 | 4.09 |
| Weight (g) | 12 | 4253 | 1770 | 6506 | 431.87 |
| Condition (k) | 12 | 3.15 | 2.05 | 3.77 | 0.13 |

**Table 5: Catch per unit effort for Lake Hawea in 2001 (including all 216 recaptures and 12 residents), and from the lower Clutha River in 1998.**

| Location | No. nets | Catch (kg) | No. eels | CPUE kg/net | CPUE No.eels/net |
|---|---|---|---|---|---|
| Lake Hawea (2001) | 150 | 159 | 228 | 1.06 | 1.5 |
| The Neck (2001) | 90 | 118 | 187 | 1.31 | 2.1 |
| Outside Neck (2001) | 60 | 41 | 41 | 0.68 | 0.7 |
| Lower Clutha River (1998) | 380 | 1682 | 9722 | 4.43 | 25.6 |

**Table 6: Descriptive statistics for longfin tag-recaptures from Lake Hawea in 2001. Length, weight and condition of recaptures without tags are also shown.**

| Variable | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| **Tagged recaptures** | | | | | |
| Tagged length (cm) | 41 | 43.1 | 34.0 | 50.0 | 0.56 |
| Recapture length (cm) | 41 | 55.7 | 47.0 | 67.0 | 0.80 |
| Length increment (cm) | 41 | 12.5 | 2.0 | 22.0 | 0.67 |
| Annual growth ($cm.yr^{-1}$) | 41 | 4.13 | 0.66 | 7.26 | 0.22 |
| Tagged weight (g) | 41 | 185 | 90 | 315 | 7.47 |
| Recapture weight (g) | 41 | 485 | 214 | 906 | 27.58 |
| Weight increment (g) | 41 | 300 | 47 | 706 | 24.89 |
| Annual growth ($g.yr^{-1}$) | 41 | 99.1 | 15.5 | 232.6 | 8.20 |
| Tagging condition (k) | 41 | 2.26 | 1.70 | 2.85 | 0.03 |
| Recapture condtion (k) | 41 | 2.70 | 2.06 | 3.46 | 0.05 |
| **Untagged recaptures** | | | | | |
| Recapture length (cm) | 175 | 55.9 | 40.0 | 74.0 | 0.44 |
| Recapture weight (g) | 175 | 500 | 136 | 1040 | 13.09 |
| Recapture condition (k) | 175 | 2.77 | 1.98 | 3.62 | 0.02 |

**Table 7: Descriptive statistics for all recaptures (N=216) from inside and outside the Neck.**

| Variable | N | Mean | Minimum | Maximum | Standard error |
|---|---|---|---|---|---|
| Length (cm) inside Neck | 178 | 54.9 | 40.0 | 74.0 | 0.42 |
| Length (cm) outside Neck | 38 | 59.7 | 53.0 | 68.0 | 0.73 |
| Weight (g) inside Neck | 178 | 464 | 136 | 1040 | 11.86 |
| Weight (g) outside Neck | 38 | 653 | 410 | 956 | 25.49 |
| Condition (k) inside Neck | 178 | 2.70 | 1.98 | 3.62 | 0.02 |
| Condition (k) outside Neck | 38 | 3.02 | 2.59 | 3.61 | 0.05 |

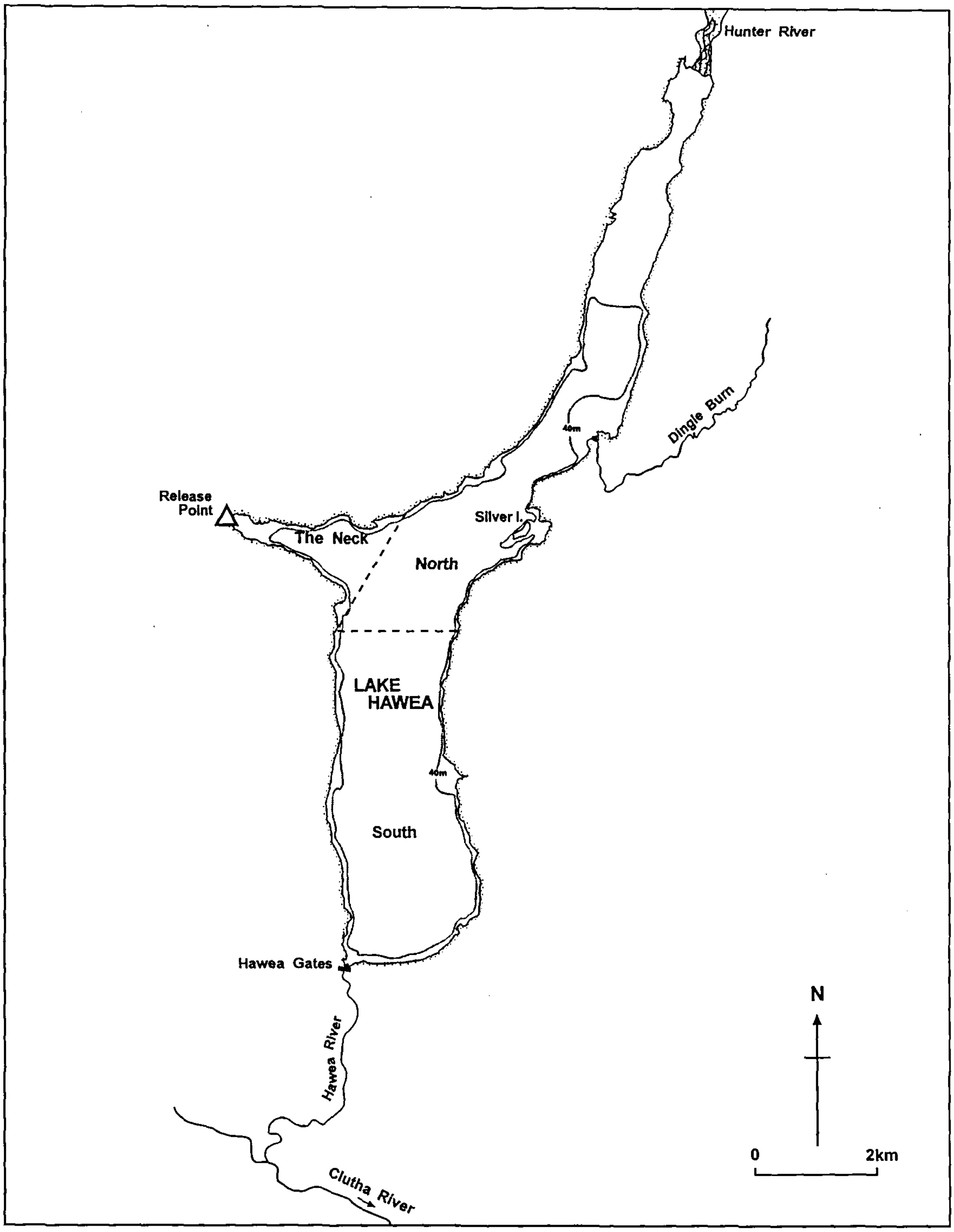


**Figure 1: map of Lake Hawea showing release point in 1998 and the three areas surveyed in 2001 (Neck, South, & North).**

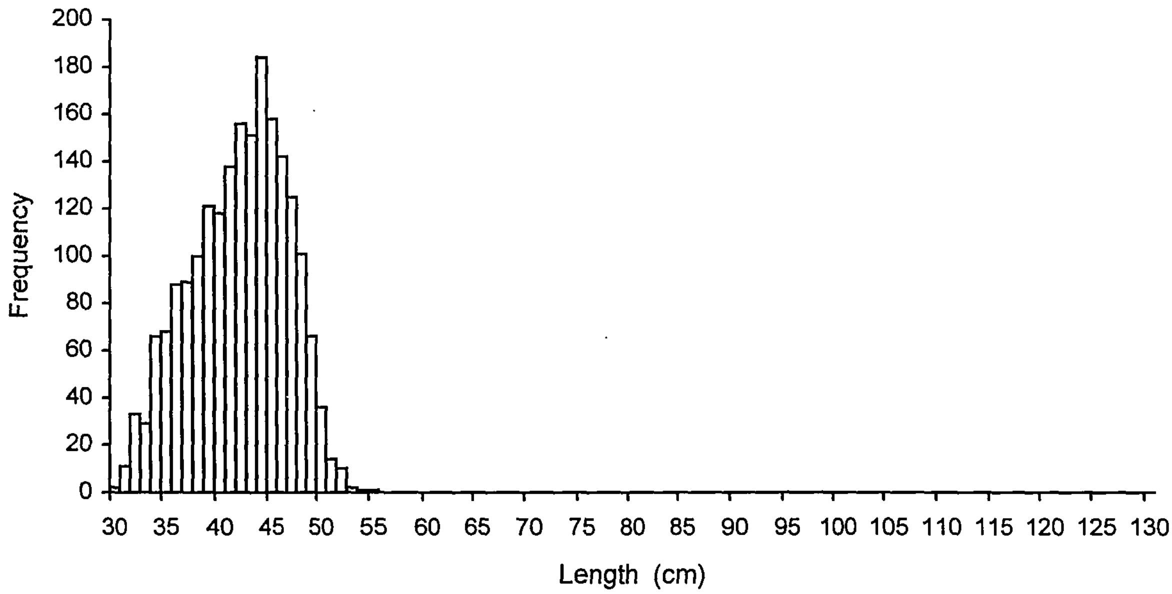


***Figure 2:*** **Length frequency of longfin eels released into Lake Hawea in 1998 (N=2010).**

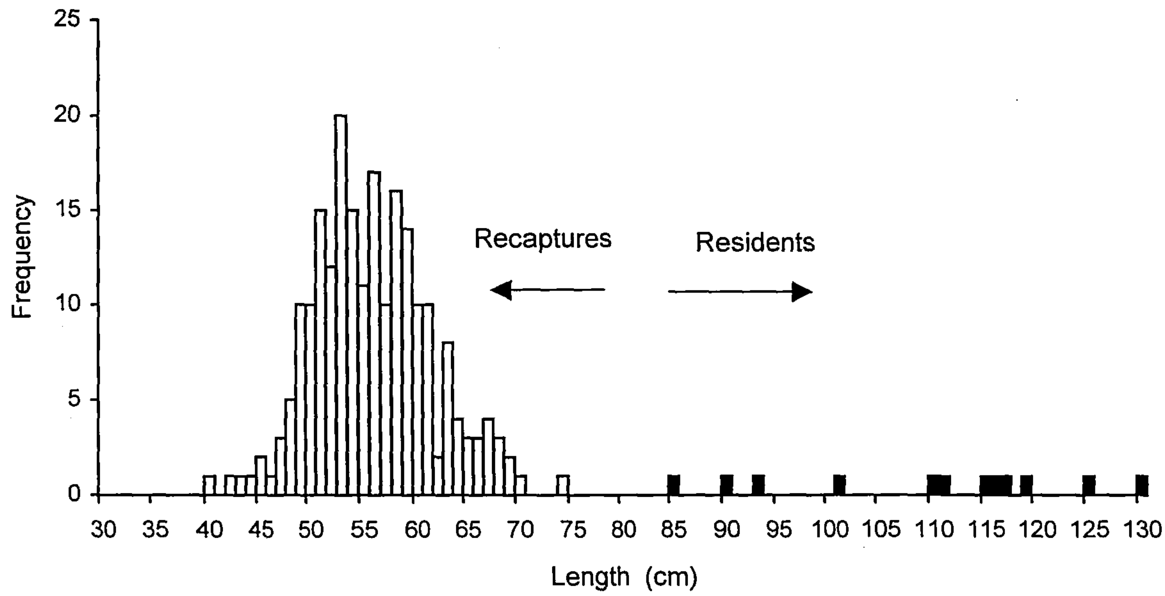


***Figure 3*****: Length frequency of longfin recaptures (N=216) in Lake Hawea in 2001 and 12 resident eels (>84 cm). Recaptures include 42 coded wire tagged eels.**

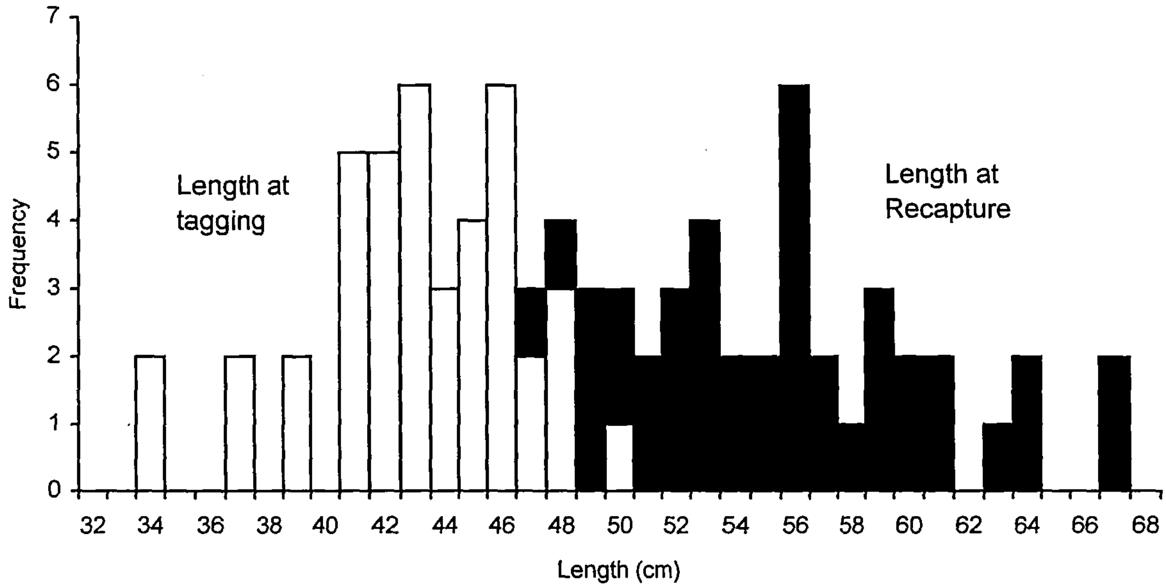


***Figure 4:*** **Length frequency of longfin tag-recaptures at tagging (1998) and recapture (2001). (N=41).**

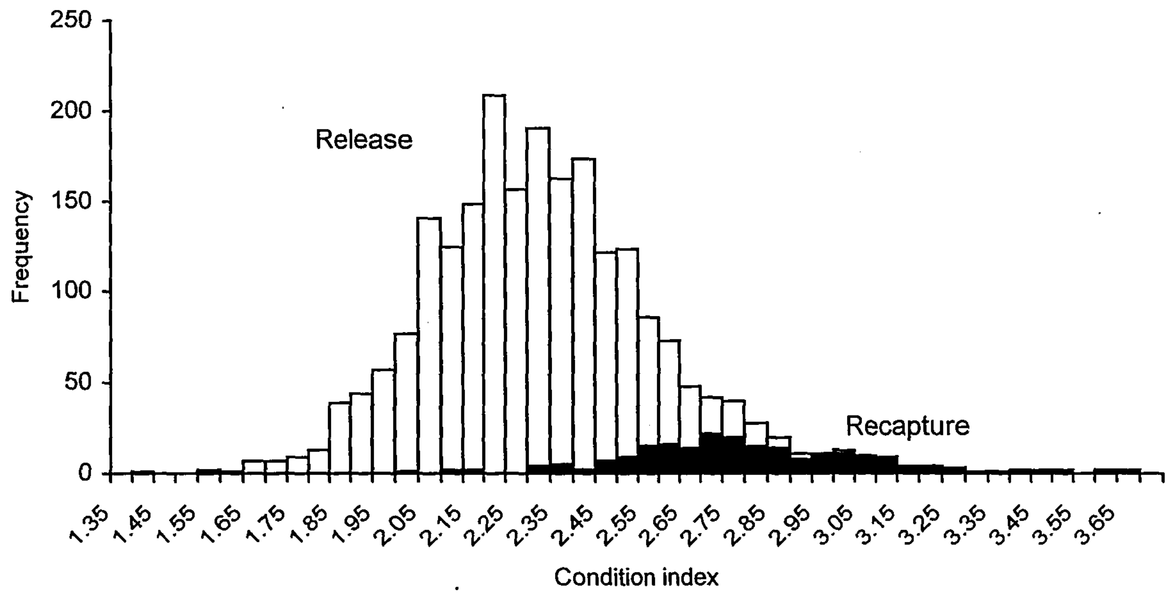


*Figure 5:* **Conditon frequency of longfins at release (1998) and recapture (2001). N=2010 release eels and 216 recaptures (excluding residents >84 cm). Ranges: 1.35=1.301–1.35, 1.40=1.351–1.40, etc.**

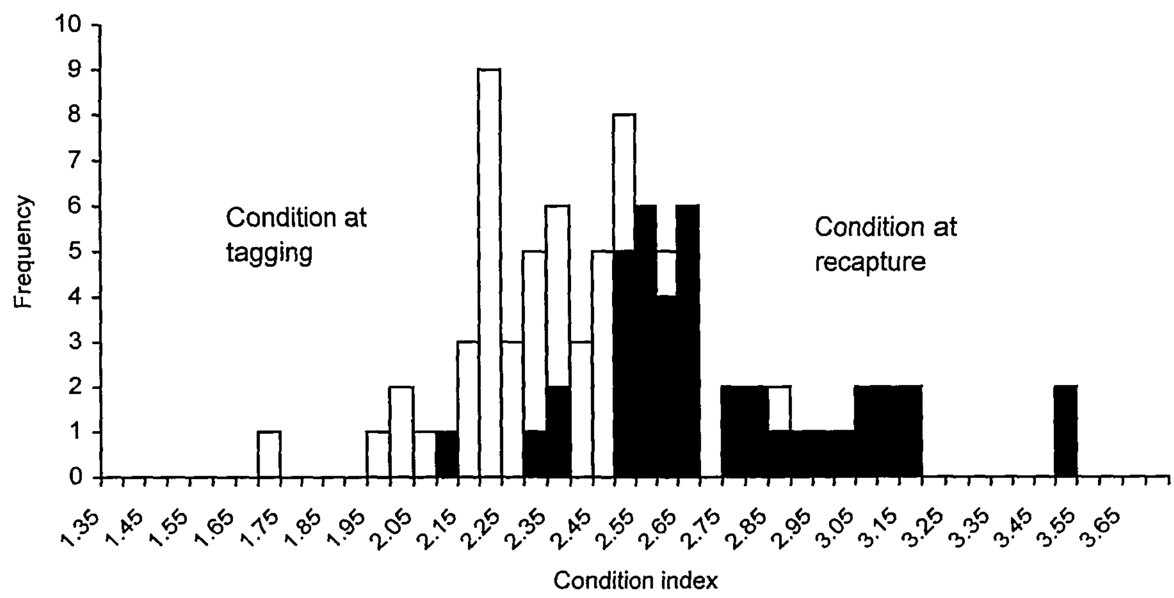


*Figure 6:* **Condition frequency of longfin tag-recaptures at tagging (1998) and at recapture (2001). N=41. See Figure 5 for ranges.**