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Enhancement of the New Zealand eel fishery by elver transfers

M. P. Beentjes, B. L. Chisnall, J. A. Boubée and D. J. Jellyman

New Zealand Fisheries Technical Report No. 45
ISSN 0113-2180
1997

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New Zealand Fisheries Technical Report No. 45
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Published by NIWA
Wellington
1997

ISBN 0-478-08407-2

Inquiries to:
Publication Services, NIWA
PO Box 14 901, Wellington, New Zealand

The *New Zealand Fisheries Technical Report* series in part continues the *Fisheries Research Division Occasional Publication* series. The *New Zealand Fisheries Occasional Publication* series contains mainly conference proceedings and bibliographies.

Edited by M. F. Beardsell
Set in 10 on 11 Times Roman
Printed by Madison Printing Company Limited

Cover photograph by Michael Beentjes

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Beentjes, M. P., Chisnall, B. L., Boubée, J. A., & Jellyman, D. J. 1997: Enhancement of the New Zealand eel fishery by elver transfers. ***New Zealand Fisheries Technical Report No. 45.*** **44 p.**

The scope of elver transfer programmes in New Zealand is reviewed and results of sampling programmes that intensively monitor manual and passive elver transfer in both the North and South Islands are provided.

In the North Island, five lakes (Lakes Karapiro, Arapuni, Matahina, Aniwhenua, and Rotorangi) were sampled to evaluate growth and productivity from previous elver transfers. The results indicate that both passive and manual transfer of elvers has been highly successful in re-establishing eel stocks in areas where access has been restricted by the construction of dams. Additionally growth rates were found to be exceptionally fast with estimates of two years to reach the current commercial minimum legal size (220 g).

An evaluation of South Island lakes (Lakes Wanaka, Dunstan, Wakatipu, and Hawea) as possible sites for eel enhancement was carried out by sampling age and growth of these eel populations, and by reviewing literature. Growth rates in these lakes, compared to the North Island lakes studied, were considered to be slow (20–25 years to reach 220 g) and size frequencies were skewed to the right, a characteristic typical of remnant populations where recruitment is restricted. A review of data on growth rates of eels from South Island high altitude oligotrophic lakes showed that 10–20 years is required to reach 220 g and that enhancement of these lakes should be regarded as a medium term investment.

Overseas stocking rates for eels and yields from important fisheries have been reviewed to provide a basis for determining stocking regimes in New Zealand. The size of eels used for stocking or enhancing varies between countries and includes glass eels, elvers, and juveniles. Stocking rates and potential yields depend on the water system productivity and are related to water type, nutrient status, temperature range, and bathymetry. It is estimated that stocking the 21 South Island lakes affected by hydro development could yield an additional 145 t of eels annually.

General introduction

Elver transfer in New Zealand has been carried out on an *ad hoc* basis by the eel fishing industry, the Department of Conservation (DoC), and Maori groups, with involvement from the Electricity Corporation of New Zealand (ECNZ), the Ministry of Fisheries (MFish), and the National Institute of Water and Atmospheric Research (NIWA). There is a need to determine if the transfer of elvers is resulting in significant survival and growth and to develop a strategy for future enhancement. To evaluate the success of transferring elvers, relative abundance and growth of elver cohorts subsequent to transfer are required to provide an indication of cohort survival and the relationship between eel density and growth for a given enhancement system. The data may also be used to determine potential yields, and therefore would be useful for making decisions on future allowable catch levels.

Elver is here defined as a juvenile eel with a length between 60 and 140 mm (Jellyman 1977). Elvers are distinct from the glass-eel stage in that they are darkly pigmented and undertake mass migrations upstream in summer.

Elver enhancement is here defined as the transfer of elvers into habitats which previously supported wild populations but to which recruitment is now severely limited. The transfer can be *passive*, as with elver passes which are man-made structures allowing elvers to negotiate dams and weirs, or *active*, where elvers are manually transferred.

Elver transfer in the North Island began in 1983 when elvers were manually transferred within the Rangitaiki River above Matahina Dam. The most effective and coordinated programme has been based on the Waikato River where, since 1992–93, 2.5 t (2.5 million elvers) have been collected and transferred to the hydro lakes above Karapiro Dam. In 1993 MFish issued the first special permit authorising the North Island Eel Industry Association, in cooperation with Tainui (these groups worked together as the Tainui Tuna (Eel) Working Group), NIWA, and ECNZ, to relocate elvers from the base of Karapiro Dam to enhance parts of the Waikato River catchment. Between 1992–93 and 1995–96, elvers have been manually transferred into Lakes Karapiro, Arapuni, Waipapa, Maraetai, and Waikare. NIWA assisted with all of these transfers under contract to ECNZ, and in 1995–96 monitored the transfer as part of an MFish research contract. In the 1995–96 season, ECNZ collaborated with NIWA and the Tainui Tuna (Eel) Working Group to build permanent collection and transfer facilities at Karapiro Dam.

Other significant initiatives have involved installation of elver passes by ECNZ on the Patea River (Taranaki) and Rangitaiki River (Bay of Plenty), and an *ad hoc* manual transfer programme on the latter. Most of the manual transfer on the Rangitaiki River has been by DoC and local Maori and does not fall within the MFish authorised programmes of elver transfer like those on the Waikato River.

Before 1995–96, elver transfer in the South Island was limited to passive transfer through elver passes on the Waitaki River. In February 1996, acting under an MFish special permit, the South Island Eel Industry Association and NIWA attempted to collect elvers from below Roxburgh Dam with the intention of transferring them to Lake Wanaka.

This report reviews the scope of elver transfer programmes in New Zealand and the results of intensive elver transfer monitoring programmes. In the North Island, five lakes were sampled to evaluate growth and productivity from elver transfers. South Island lakes were evaluated as possible sites for eel enhancement by reviewing literature and sampling the age and growth of eel populations in the Clutha River lakes. Overseas stocking rates for elvers/juvenile eels and yields from important fisheries are reviewed to provide a basis for determining stocking regimes in New Zealand.

North Island elver transfers

Lake Karapiro

Introduction

Lake Karapiro, constructed in 1947–48, is nearest the sea of the eight dams on the Waikato River. There is limited elver recruitment into Lake Karapiro and virtually none beyond the next dam at Lake Arapuni. Eels have been recorded as far upstream as Ohakuri (Coulter 1977), presumably arriving by natural means before construction of the hydro dams on the Waikato. There are no elver passes on Karapiro Dam, but in wet weather elvers can ascend the spillway and adjacent siphon tubes. (Originally, electric fields were installed on both the siphon and spillway to prevent elvers reaching the reservoirs where a trout fishery was being developed.)

To help mitigate the affects of the Karapiro Dam on eel passage and the upstream eel fishery, an elver trapping and transfer programme has been established at the dam. In 1995–96, permanent elver collection facilities were installed and the efficiency of operation and design was monitored by ECNZ during the elver migration period. Transportation and transfer of the elvers was undertaken by the Tainui Tuna (Eel) Working Group under a special permit issued by MFish. ECNZ also held a special permit for transfer of elvers to Lake Karapiro during times when the group undertaking the main transfer was not available. The MFish special permit allowed for the maximum release of 1150 kg of elvers into Lake Waikare, 550 kg into Lake Arapuni, 100 kg into Lake Waipapa, 250 kg into Lake Maraetai, and 100 kg into the eastern drainage system, Aka Aka. No limits were set for Lake Karapiro. NIWA was responsible for collecting data on elver quantities, numbers, species composition, size and age distribution, and release details.

This research was done under contract to the Ministry of Fisheries as part of Eel Fisheries and Enhancement (MFish Project No. INEE01). The programme objectives were to document eel enhancement projects, and the location and likely effectiveness of elver transfer; and monitor the effects of elver transfers in selected enhancement projects.

Methods

Trapping and transfer of elvers

Five different elver traps were installed at the base of Karapiro Dam. They were of two types, floating and land-based. The floating trap was constructed of a porous fabric, to ensure that adequate water flow was maintained, supported by a frame of aluminium or stainless steel. Floats ensured buoyancy at the appropriate height. A ramp with stones or artificial grass glued to the surface was floated to overhang over the trap. Water running down the ramp attracted elvers, which ascended the ramp and dropped into the trap. A larger running water source directed near the ramp provided the initial attraction to elvers. The land-based trap was essentially the same, except that the trap was a solid tank, the ramp extended from the river on to land where it connected with the tank, and the ramp was generally steeper (*see* Boubée & Barrier (1996) for details of the types and locations of traps used).

Elvers from the traps were either flushed out into a dip net through the flush valve in the bottom of the tank (land-based traps), or removed with a scoop net (floating traps), weighed, and emptied into aerated transporting tanks. Volumes were assessed at the beginning of the programme. (The conversion was $W = 0.33 + 0.91L$, where W is weight (kg) and L is litres ($r^2 = 0.86$; n = 58. i.e., 1 litre is equivalent to about 1 kg of elvers).)

Plastic bins with close fitting lids and battery-operated air compressors were initially used to transfer elvers, but as the air pumps proved unreliable a petrol-driven compressor was used. The open bins were replaced with plastic containers fitted with screw top lids.

Siphon tubes

Siphon tubes were installed at the top of the dam to direct a small trickle of water down the face of the dam into two channels, one covered and one uncovered, to determine whether elvers would use these channels to reach Lake Karapiro. Monitoring consisted of night observations and installation of an infra-red sensitive video camera at the siphon crest.

Size and species composition

About 50 elvers were collected from the traps at weekly intervals from 28 December 1995 to 17 March 1996 by making random scoops in the traps with a dip net. Samples were immediately frozen, and length, weight, and species composition were determined in the laboratory.

Age determination

The otoliths of a representative size range were extracted for age determination. Otoliths were mounted in Crystal Bond and ground and polished with a gemstone polisher, treated with a 1% solution of EDTA for 5 min, washed and then stained with a 5% toluidine blue solution. This technique has been used overseas as an alternative to burning otoliths for revealing annuli and is particularly useful with small otoliths that cannot easily be split in half as required by the burning technique.

Otolith marking

Chemical marking of fish otoliths is often used in age and growth studies. Alizarin red and tetracycline are useful for mass marking of juvenile fish (Beckman & Schulz 1996, Ward & Boubée 1996) and were tested to determine if it was possible to mass mark elvers.

About 15 elvers were placed in two containers holding 1 l of water in which 200 mg of alizarin red was dissolved. The pH in the bins had previously been adjusted as recommended by Beckman & Schulz (1996). Elvers from one bin were removed after 2 h immersion, and the others after 19 h. The elvers were then held outside in 1000 l troughs where they were fed daily. The elvers were sacrificed after about 2 months, and the otoliths extracted, ground, and polished before examination under a compound microscope.

About 15 elvers were placed in four plastic containers with mesh lids containing 1 l of aged water. Each container was aerated and 200 or 750 mg of tetracycline added. Elvers were left in the solution for 2 or 19 h and then placed in separate rearing troughs.

Results

Catch rates and species composition

From 23 December 1995 to 20 March 1996, 1217.85 kg of elvers were collected from below Karapiro Dam and transferred to the four upstream reservoirs (Figure 1). From mean length and species proportion data, this equates to about 1.2 million elvers. ECNZ, with the help of the Tainui Tuna (Eel) Working Group, transferred 564.25 kg of elvers to Lake Karapiro (an unknown number of elvers successfully climbed the siphon tube to this lake), 442.75 kg to Lake Arapuni , 131.8 kg to Lake Waipapa, and 79.05 kg to Lake Maraetai.

Catch rates were highest on 23 December 1995. An overall decline in catch rate occurred from the end of January (*see* Figure 1). The percentage of longfinned elvers ranged

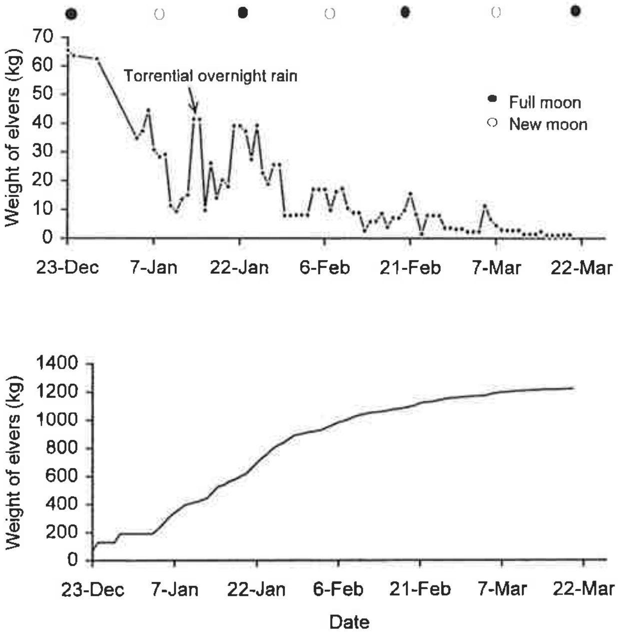

Figure 1: Catch of elvers from below Karapiro Dam in 1995–96. *Top*, total catch per day; *bottom*, cumulative catch.

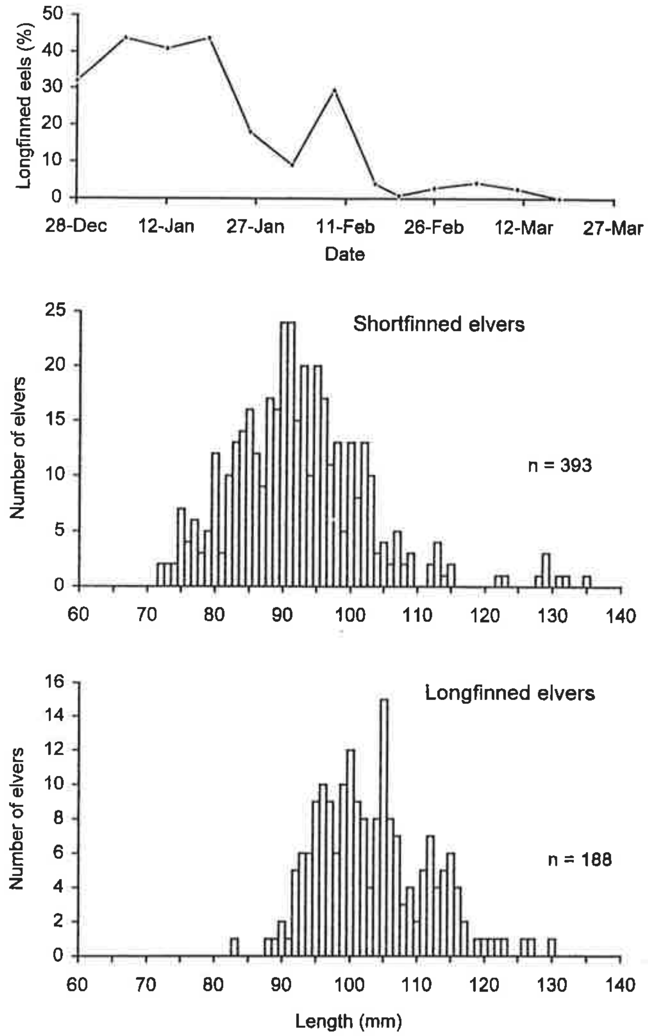

Figure 2: Species composition (*top*) and size distribution of shortfinned elvers (*centre*) and longfinned elvers (*bottom*) trapped below Karapiro Dam.

from 0 to 43.7% (Figure 2). More longfinned elvers were present early in the season: their proportion in the catch was below 5% from mid February.

Length and weight distribution

The mean length and weight of shortfinned elvers were 92.3 mm and 0.92 g (ranges 72–135 mm and 0.29–2.86 g) (Figure 2). Longfinned elvers were larger with mean lengths and weights of 103.4 mm and 1.46 g (ranges 83–130 mm and 0.7–3.27 g). Selective sampling produced juvenile eels up to 271 mm in length. Elvers longer than 120 mm were unable to climb the ramps to the traps.

Age

A total of 30 shortfinned elvers and 1 juvenile shortfinned eel were aged (Figure 3). Length ranges of age groups were: year 0 (previous year's glass-eels), 75–84 mm; year 1, 76–110 mm; year 2, 105–110 mm; year 3, 108–111 mm; and year 4, 107–129 mm. The 148 mm eel examined was estimated to be 5 years old. A total of 23 longfinned elvers and 2 juvenile longfinned eels were aged (Figure 3): length ranges were year 0, 83 mm; year 1, 88–116 mm; year 2, 89–122 mm; and year 3, 115–127 mm. Eels 241 mm and 271 mm long were examined and estimated to be 8 and 10 years old, respectively.

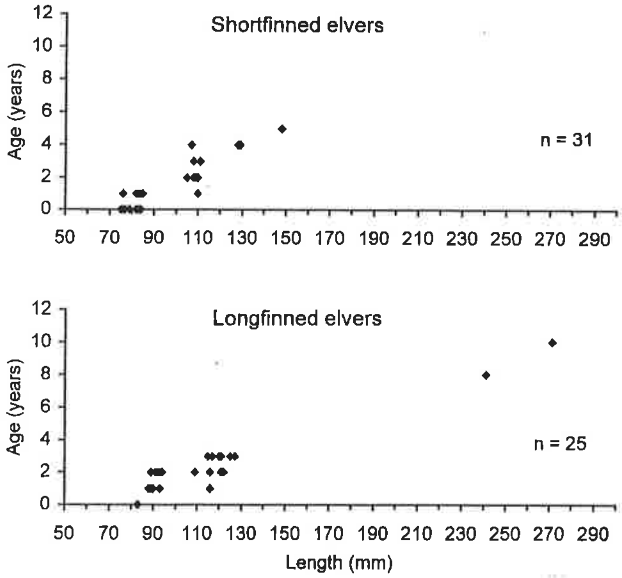

Figure 3: Estimated age for a selected size range of shortfinned (*top*) and longfinned (*bottom*) elvers collected in traps below Karapiro Dam, 1995–96.

Age validation

None of the 15 elvers treated with alizarin showed any sign of marking. A few elvers treated with tetracycline were examined under a fluorescent microscope after about 2 months in the rearing tank. No fluorescent rings were noted. The tetracycline used (the same batch successfully used by Ward & Boubée (1996)) may have been too old and no longer fluorescing. The remaining elvers were maintained in the rearing trough for examination at a later stage.

Siphons

The open channel nearest the spillway appeared to be more successful than the closed channel. On nights around full and new moons in January and early February the whole floor of the open channel was teeming with elvers. The siphon crest was monitored by video, but it was not possible to view the entire siphon floor and walls.

Elver movement at the hydro dams

Maraetai and Whakamaru Dams were visited between 2100 and 2300 h on 21 February 1995. Elvers were seen below Maraetai I, Maraetai II, and Whakamaru Dams wherever they had the opportunity to climb. Three elvers collected from the seepage outlet below Whakamaru Dam had lengths and weights of 100, 89, and 86 mm, and 0.90, 0.73, and 0.47 g, respectively.

Similar observations were made at Karapiro and Arapuni Dams on the evening of 25 January.

Other fish

Three juvenile common bullies of 25, 28, and 29 mm total length (TL) were captured in the floating traps in January. The occasional bully may have been present at other times as a number were sighted on the lower section of the ramps. One adult smelt of 88 mm TL was captured in a trap in February. Although rudd were observed during low-flow periods, none were observed in the catches.

Discussion

The trial catch and transfer programme at Lake Karapiro in 1995–96 was very successful as 1218 kg of elvers (about 1.2 million fish) were trapped and transferred to lakes above Lake Karapiro. The floating traps were more efficient than the land-based traps, but the catch was smaller than eel fishers anticipated. Whether this was caused by the operation of the spillway during the peak migration period, a poor season, or a general decline in the number of elvers arriving at Karapiro Dam, will be determined only after several years of monitoring. ECNZ and interested parties plan to install and monitor additional catching and transfer facilities at Karapiro in 1996–97.

The transfers to Lake Waipapa exceeded the permitted quota by about 30 kg because of an emergency release of a load of elvers en route to Lake Maraetai caused by aeration problems with the transporting equipment.

Jellyman (1977) reported that elvers arrived at Karapiro Dam in mid January. The present catch records indicate that the migration can begin at least 1 month earlier. Unseasonably warm temperatures in December may have caused this shift. Whitebait behaved similarly: Raglan residents captured kahawai full of whitebait, and observed whitebait running, a month earlier than usual in 1995–96.

The siphon tube was successful as an elver pass with video monitoring showing that many elvers successfully reached the lake. Without additional equipment, it will not be possible to estimate the numbers of elvers entering Lake Karapiro by this route. Some elvers re-entered the siphon from the lake, so modifications to the siphon will be required to improve its efficiency.

Shortfinned elvers were the predominant species in all samples, and by mid February catches were almost exclusively of shortfins. Most longfinned elvers arrived during the first month of trapping in January with another smaller migration in February, possibly coinciding with the full moon. Species composition should continue to be obtained to fix the timing of migration of the two species more accurately and to determine if the proportion of longfinned elvers in the catch is changing.

Longfinned elvers were much larger than shortfinned elvers of the same age. The lack of elvers over 120 mm in the north trap (land-based) is probably a result of their smaller surface area to body weight ratio making them less efficient at climbing steep faces. Jellyman (1977) reported that 120 mm is the maximum elver length for vertical climbing. Some larger eels, up to 300 mm long, were caught in the floating traps. Ageing showed that they were older than their size would indicate, suggesting that growth rate below the dam is poor.

Some of the elvers obtained at Karapiro Dam in 1996 had a wider size to age variability than Jellyman (1977) suggested. Numerous false rings were evident in many of the otoliths examined. Interpretation of these otoliths would be assisted by batch-marking glass-eels with tetracycline and releasing them in confined waterways where natural eel access is not possible. The release sites should include a small stream behind a water reservoir or dam, a farm pond, and an artificial channel, such as the NIWA facility at Ruakura.

The presence of elvers below Arapuni, Waipapa, Maraetai, and Whakamaru Dams indicates that elvers continue to migrate through the hydro lakes after their release. Many elvers congregated on the face of Maraetai I 27 days after releases were first made in Lake Waipapa. The observations at Whakamaru Dam were made 18 days after the first releases to Lake Maraetai, and at Waipapa Dam elvers were found only 8 days after being first released into Lake Arapuni. As releases in Lake Arapuni were made at Bulmers Landing, 20 km below Waipapa Dam, elvers had to cover at least 2.5 km each night to reach Waipapa Dam. This migration rate is similar to the 1.5–2.0 km. day^{-1} in the lower Waikato River by Jellyman (1977), but lower than the 4.8 km per night estimates of Mitchell & Saxton (1983).

Handfuls of dead elvers were found on the access platform and dam face below the penstock tunnels of Maraetai I. Those remaining in the water probably fall easy prey to trout and other fish. The reservoirs and upstream structures should be monitored to determine the proportion of each release that continues to migrate upstream. Batch-marked elvers (tetracycline or with temperature shock) may be useful for such work. One option to prevent stranding at dam faces would be to release elvers into tributaries, but it is not known whether they would continue up the tributaries or return to the lake. Growth rate is much slower in tributaries than in hydro lakes.

Other North Island elver transfers

Lakes Matahina and Aniwhenua

The Rangitaiki River in the Bay of Plenty has two major obstructions to elver migration, Matahina Dam (completed in 1967) and the upstream Aniwhenua Barrage (completed in 1981). After concerns were expressed by locals in 1983, the Wildlife Service (now DoC) began a programme of manual transfers into Lake Matahina and to the upper catchment, including Lake Aniwhenua, of elvers collected at the base of Matahina Dam. Transfers have occurred since 1983–84 and have involved a number of groups and government departments on a largely *ad hoc* basis. Some transfers by power station staff and local Maori were also made, but no records were kept of numbers or timing. The numbers of elvers manually transferred each year into Lakes Matahina and Aniwhenua are given in Table 1, and timing of transfers into Lake Aniwhenua in Figure 4. As numbers were often not available and had to be estimated, the data provide only the minimum numbers of elvers transferred. The data indicate that substantial quantities of elvers have been transferred since 1983, and clearly show that the elver migration is both regular and large enough for annual transfers to be worthwhile.

Because manual transfers depend on personnel, ECNZ installed a gravel-lined fish pass at Matahina Dam in 1991 and an electronic counter and data logger to monitor elver passage during the summers of 1991–92, 1992–93, and 1993–94 (Boubée & Mitchell 1994). The migration began in early to mid January each year, but ended in early March in 1992, mid March in 1993, and at the end of April in 1994. In the first year of monitoring, 15 000 elvers were counted (*see* Table 1), 27 000 in the second, and over 38 000 in 1993–94. These are the minimum numbers that would have used the pass, as during peak migrations the counter could not record individual elver passage. Because of its limits, and as it caused a bottleneck, the counter was removed in 1994. No monitoring has been done since, but station staff report that elver usage of the pass continued to increase each year. However, there were recurring problems with water supply for the pass and when inspected in early 1996, no water was flowing down it. (Lake Matahina was subsequently emptied for repairs and temporary catching facilities were to be installed.) Daily numbers and diel patterns of elvers moving over the pass in 1992, 1993, and 1994 are given in Figures 5 and 6. Peak daily numbers recorded varied by year but were generally highest between late December and late March. Diel movement was equally variable between years: in 1992 and 1993 movement was more common during darkness than daylight, but in 1994 the results were equivocal.

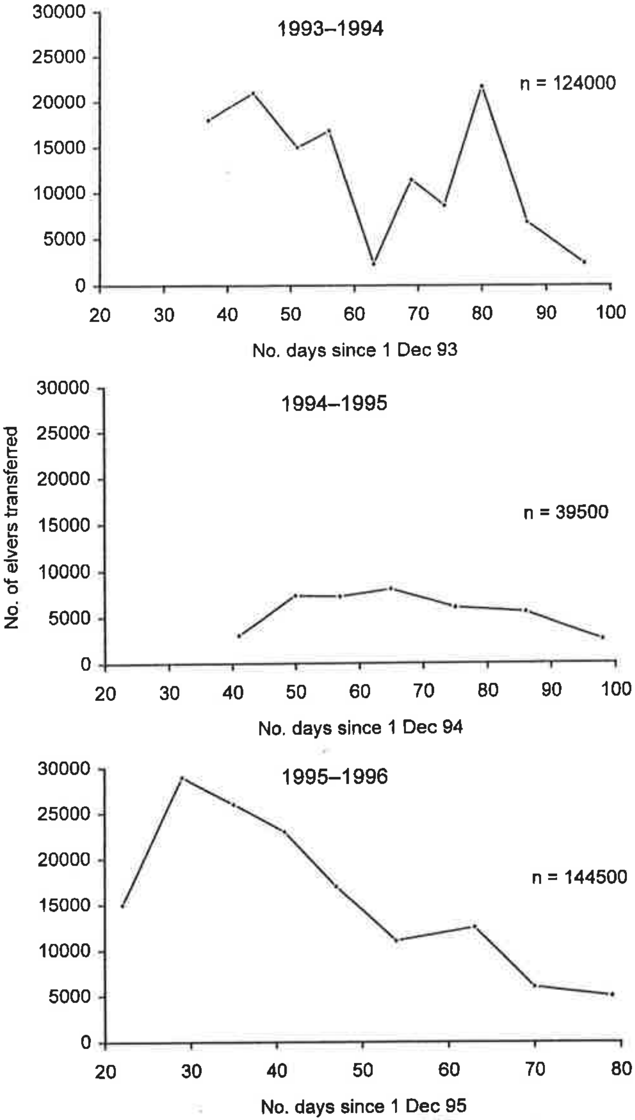

Figure 4: Numbers of elvers manually transferred into Lake Aniwhenua in 1993–94, 1994–95, and 1995–96.

Table 1: Numbers and/or numbers per hour of elvers recorded using elvers passes or that were manually transferred for New Zealand hydro lakes between 1983–84 and 1995–96. Dates of elver pass constructions are indicated by the word installed. * First record of manual transfer; -, no records available

								Waikato River hydro lakes					
	Rotorangi elver pass	Matahina elver pass	Matahina manual	Aniwhenua manual	Wairua manual	Waitaki elver pass	Aviemore elver pass	Karapiro manual	Arapuni manual	Waikare manual	Waipapa manual	Maraetai manual
1983–84	installed			*21 000								
1984–85	150/h			23 000								
1985–86	-			6 000								
1986–87	-			18 500								
1987–88	-			0								
1988–89	-		*18 000	-								
1989–90	-		6 000	40 000								
1990–91	-	installed	-	-								
1991–92	-	15 000	9000	-								
1992–93	-	27 000	4 500	-		installed	installed	*110 000				
1993–94	80 000	38 000	28 000	124 000		6	6	320 000	*300 000	*150 000		
1994–95	-	-	-	39 500	1000	2	0	316 000	10 000	120 000	*5 000	*7 000
1995–96	18 000	-	-	144 500	0	-	-	564 000	442 000	0	132 000	79 000

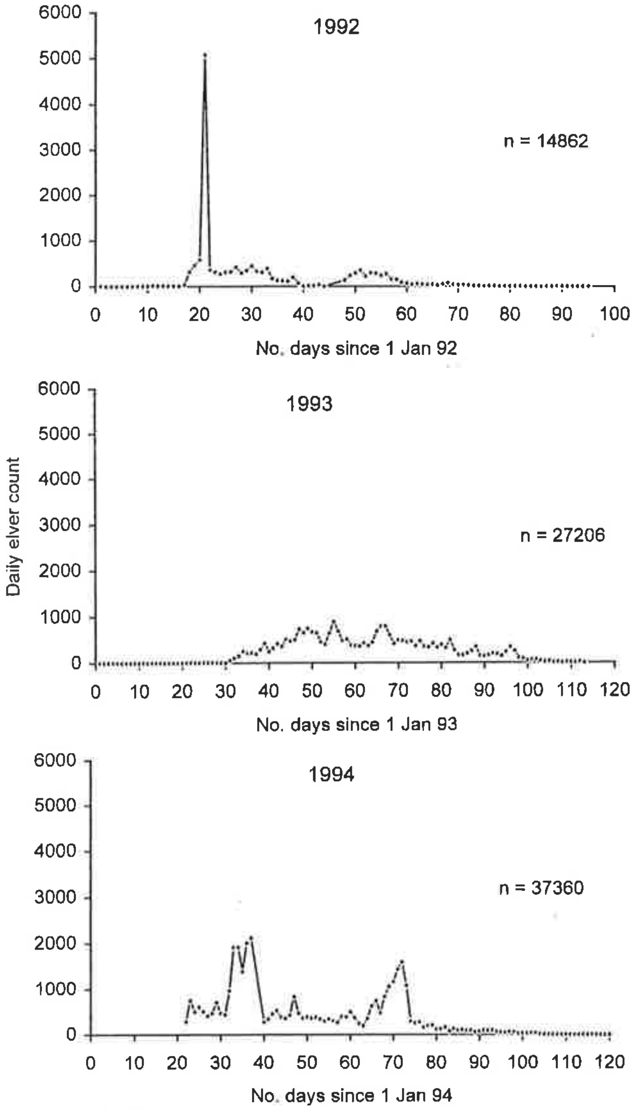

Figure 5: **Numbers of elvers passing over the elver pass at Matahina Dam in 1992, 1993, and 1994. Counts recorded from electronic counter and data logger.**

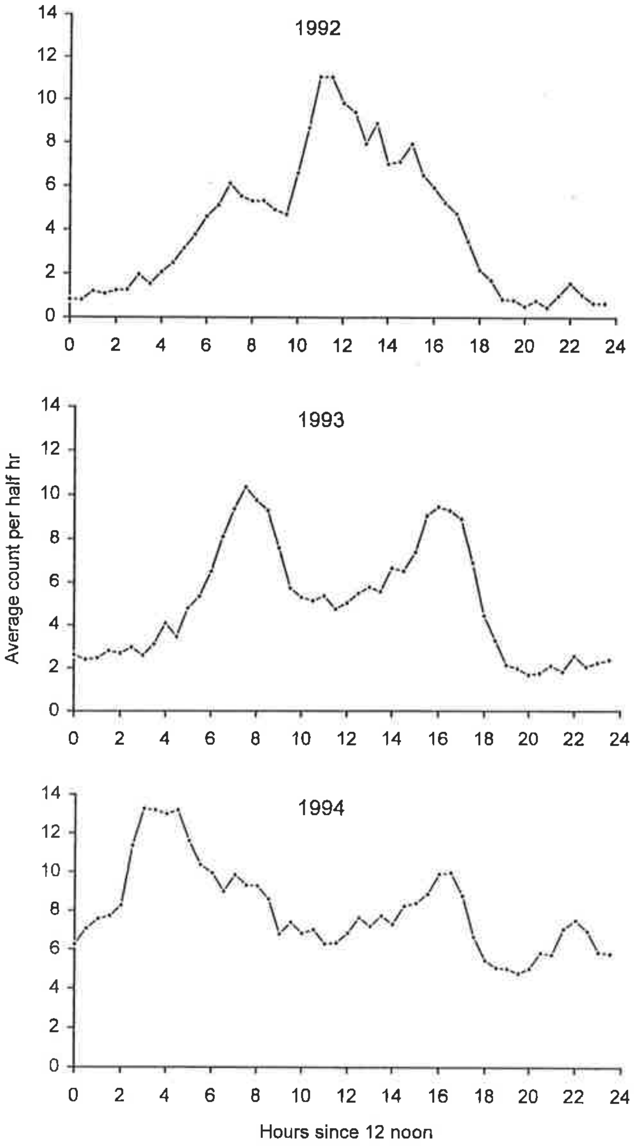

Figure 6: **Diel movement patterns of elvers passing over the elver pass at Matahina Dam in 1992, 1993, and 1994. Counts are half hour averages recorded from electronic counter and data logger.**

Lake Rotorangi

Lake Rotorangi is a hydro lake formed by the construction of Patea Dam on the Patea River in Taranaki. An elver pass was installed on Patea Dam in 1984 and became operational from 10 January 1985. The pass is over 300 m long and climbs 75 m. It starts at the turbine cooling water outlet, goes up the penstock slope and then, in a zigzag, climbs the rest of the dam. At the top of the dam it ends in a near vertical drop into the reservoir. The pass was initially of the bottle brush and PVC pipe design but because the brushes deteriorated they were removed in 1992, and glue and gravel were poured down the line to provide a climbing medium. The brushes were retained in some vertical sections of the pass. The pass was extended in late 1993 to link it to the turbine stop-log area, where elvers congregated in large numbers. The pass was monitored by C. Mitchell in 1985 and some 150 elvers per hour were reported entering the lake on 17 January 1985 (*see* Table 1). Elvers were estimated to take 2 days to complete the climb. A comparison of the species composition at the bottom and top of the pass indicated that passage of longfinned elvers was restricted (23.5% at bottom, 4.6% at top). Some elver deaths were also reported, and this was attributed to high temperatures within the pass from solar heating. The pass was subsequently partly shaded and the flow down the pass increased.

An elver counter was installed at the top of the pass in early January 1993. Although the data logger failed, manual readings were made at regular intervals. Many elvers used the pass during the season, but recorded counts were unrealistic because of a problem with the fish pass water supply. Both the counter and data logger were re-installed in early 1994. Trials indicated that vertical sections of the pass required the bottle brush inserts to allow passage of elvers. Again, problems with the water supply meant that no data were recorded for much of the season. Obvious errors were therefore removed from the data set. Over the

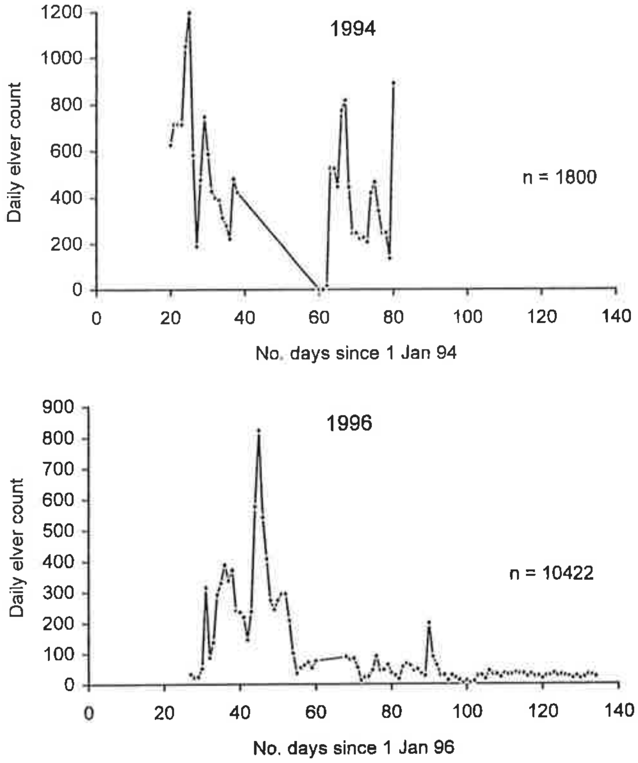

Figure 7: **Daily numbers of elvers passing over the elver pass at Patea Dam in 1994 and 1996. Counts recorded from electronic counter and data logger.**

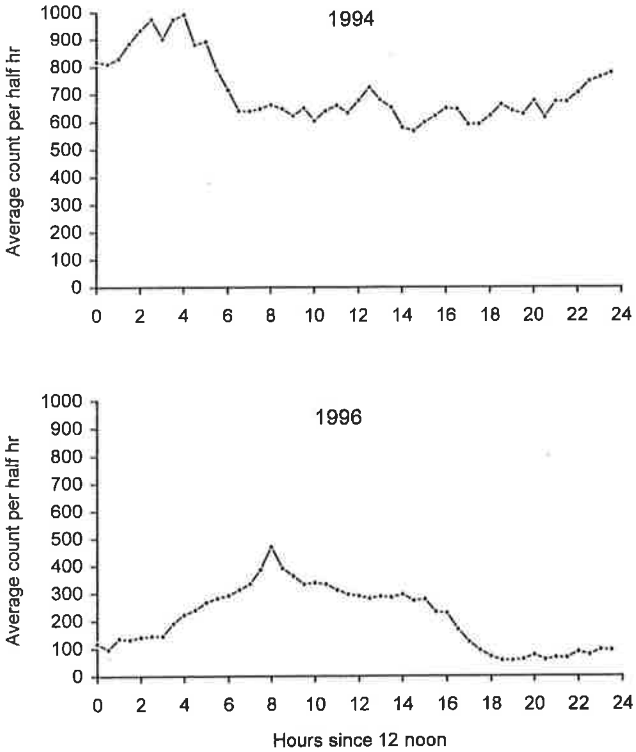

Figure 8: **Diel movement patterns of elvers passing over the elver pass at Patea Dam in 1994 and 1996. Counts are half hour averages recorded from electronic counter and data logger.**

41 days for which reliable daily records remain, an estimated 80 000 elvers entered the dam through the pass. The counter was reinstalled between 27 September 1994 and 5 July 1995, but only manual counts were taken. The records indicate that elvers used the pass between early January and late March. No estimate of total usage could be made, and without a logger it was not possible to separate false triggers caused by water supply problems from true counts of elvers.

Manual readings of the elver counter were made early in 1996, and a data logger was installed on 26 January 1996. Again, water supply problems plagued the pass and a new pump and filter were installed on 10 January 1996. Records indicated that some of the counts were unrealistic (possibly because of recurring water supply problem and/or blockage of the counting head) and these were omitted from the data set. The total count from 27 January to 13 May 1996 was about 10 500. With the 7800 recorded before the data logger was installed, the total transfer to the lake for the 1996 season was at least 18 000 elvers.

Daily numbers and diel patterns of elvers recorded moving over the elver pass at Patea Dam are given in Figures 7 and 8 for times when the automated equipment was functioning. Peak daily numbers varied by year, but were generally highest between late December and late March. Similarly, diel movement was equally variable between years with movement being more common during daylight in 1994 and in darkness in 1996. Jellyman & Ryan (1983) found a similar pattern of diel elver movement to that of 1994 in Lake Pounui.

Conclusions

1. Elvers have used the Patea elver pass since its construction in 1985.
2. Accurate monitoring of the pass has not been possible, but up to 150 elvers per hour went through the pass on the evening of 17 January 1985. It appears that at least 80 000 elvers used the pass in 1994 and more than 18 000 in 1996.
3. Elver passes favour the smaller shortfinned elvers or elvers (under 120 mm).
4. Elver movement in the pass appears to start in early January and end in late April.
5. Diurnal movement of elvers has varied between 1994 and 1996.
6. Further monitoring of the pass with the elver counter is warranted only if water supply problems and regular maintenance of the counter can be guaranteed.
7. Although elver passes function well when properly maintained, a catch and manual transfer programme should be considered to supplement the fish pass. (Manual transfer would take place at the peak of the migration in mid January and the elver pass left to operate at other times.)

Other transfers

About 1 kg (1000 elvers) was transferred above the diversion weir on the Wairua River in 1994–95 by the eel industry.

A fish pass was installed on the outlet of the Taharoa lakes system in 1977. The pass was apparently monitored but no records have been made available.

A bottle brush and pipe elver pass was constructed over the flood control gates at Lake Waikare in 1982. This was modified to a gravel ramp structure in 1994. Monitoring has been restricted to occasional observations.

ECNZ is considering a catch and transfer programme at Piripau Power station on the Wairoa River (Waikaremoana hydro scheme).

A few manual transfers have taken place in the Mokau hydro scheme catchment, but no records have been kept. A fishway or catch and transfer programme is planned for the 1996–97 elver season.

Evaluation of North Island elver transfer programmes

Introduction

To evaluate the success of the elver transfer programmes in the North Island, the relative abundance and growth of eel populations were assessed for Lakes Karapiro and Arapuni on the Waikato River, Lakes Matahina and Aniwhenua on the Rangitaiki River, and Lake Rotorangi on the Patea River.

Waikato River

Lakes Karapiro and Arapuni were formed behind hydro-electric dams constructed on the Waikato River in 1947 and 1929, respectively.

The Waikato River basin supports New Zealand's most productive eel fishery (over 20% of the national total). Although small eels (under 500 mm) are abundant, larger eels are scarce (e.g., Hayes *et al.* 1992). This population structure has constrained eel growth, especially where food is limited (Chisnall 1989). Several eel population studies have been undertaken throughout the lower Waikato River basin but little is known about populations in the hydro lakes of the upper river (Chisnall & Hicks 1993). As part of an ECNZ study, commercial eel fishers were contracted to sample Lakes Karapiro, Arapuni, and Waipapa, the three lowermost impoundments on the Waikato River, in 1992 (Chisnall 1993). Based on this information and commercial catch records, it appeared that few eels remained above Arapuni Dam by 1992. Since then, there has been an annual summer transfer of elvers from the base of Karapiro Dam to several upper impoundments.

Rangitaiki River

Two hydro-electric lakes have been formed on the river, Lakes Matahina and Aniwhenua (earth-core dams completed 1967 and 1981, respectively).

Transfer of elvers into Lakes Aniwhenua and Matahina began in 1983 and 1988–89, respectively (*see* Table1). The eel population in Lake Matahina was sampled in 1988 (Stancliff *et al.* 1989): the population was 40% longfinned and 60% shortfinned eels, but abundance was low. The size distribution was strongly skewed towards larger sizes.

Patea River

In 1982, extensive sampling of Taranaki rivers revealed that eel densities, distributions, and species compositions in headwater tributaries of the Patea River and the mainstem of the river itself, were similar to those in other parts of New Zealand (Taranaki Catchment Commission 1984). A hydro-electric earth-core dam was completed in the lower reaches of the river in 1984, creating the narrow and deep Lake Rotorangi. Transfer of elvers into Lake Rotorangi began in 1984–85 (*see* Table 1).

Sampling

The five hydro lakes were sampled using large fine-meshed fyke nets (D-opening, winged-hoods, 0.75 mm square mesh (Chisnall & West 1996)) in conjunction with standard fyke nets (D-opening, double funnelled, 20 mm stretched mesh) deployed by a local commercial eel fisher. Large fyke nets were set primarily to fish aquatic margins, thereby targeting juvenile habitats (*see*, e.g., Chisnall 1996). Standard fyke nets were set throughout the area fished. Effort was applied consistently by limiting net numbers and area fished per location (Figures 9–13).

Net sites were chosen to represent the range of lake margin and open water habitat available in each location. Nets set on the margins were mostly positioned perpendicularly or obliquely to the shoreline, codends outermost, and were left to fish overnight. Some were deployed in beds of aquatic macrophytes and some were hung codend uppermost on submerged vertical cliffs. Deep water was mostly fished using single standard fyke nets, but the deep water of the Waikato River hydro lakes was fished using trains of paired standard fyke nets (leader to leader) strung together end to end and anchored at each end of the train.

All large fine-meshed fyke nets were fished unbaited. Standard fyke nets used in the Waikato River hydro lakes were also unbaited, but in the Rangitaiki River and Patea River lakes, standard fyke nets were baited with sheep heart and frozen greenlipped mussels (*Perna canaliculus*). Baited nets were deployed well away (300–500 m) from unbaited nets to limit any influence on catches, except in sampling the top reach of Lake Aniwhenua where the habitat was confined (*see* Figure 12): here, both net types were fished within 50 m of each other.

As time and weather permitted, tributaries of Lakes Rotorangi and Aniwhenua were electrofished to provide eel abundance information to complement data obtained for tributaries of Lakes Karapiro, Arapuni, and Matahina (Chisnall 1993, Chisnall & Hicks 1993). The sites fished may be used in long-term monitoring of stock densities. Where possible, sites were chosen to correspond to sites fished before dam construction (e.g., Patea River, Taranaki Catchment Commission 1984).

As nets were lifted, eel numbers and species composition per net were recorded. Catches were accumulated in 40 l plastic bins for subsequent length and weight measurement. A length stratified subsample (10–20 eels measured where available per 100 mm size interval) was kept for sagittal otolith abstraction for ageing. All bycatch species were counted, or estimated when there were more than 500 individuals, for each net and the size range of each species was recorded.

Analyses

Age structure and growth

Otoliths were prepared using the crack-and-burn method (Hu & Todd 1981). Otolith halves were mounted in silicone rubber sealant on microscope slides and observed under X10–50 magnification under a stereo-microscope using transmitted light. Hyaline zones or winter rings were counted and age expressed as years spent in fresh water, ignoring the central area of larval growth (Jellyman 1979). Narrow central growth bands previously observed in most eels taken from hydro lakes (Chisnall 1993, Chisnall & Hicks 1993) were thought to correspond to time spent below dams before relocation (natural or enhanced). Therefore, where appropriate, eels were given three counts: 1, narrow central growth bands counted as the "elver age"; 2, subsequent uniform wide growth bands along the caudal radius counted as the "lake age"; and 3, all growth bands making up the "total age'. A few individuals had zones of intermediate growth bands.

Growth was described by Model I least-squares linear regression of length-at-age and weight-at-age for samples from each location calculated using SYSTAT (Wilkinson 1990). Only lake-ages were used in modeling growth, and length was defined as *length* (mm) minus 95 mm (approximate size of elvers of both species at Karapiro Dam (Jellyman 1977).
Equations took the form

length = *a* + *b*lake-age and *weight* = *a* + *b*lake-age.

Because some of the datasets had limited size distributions which results in exaggerated *y*-intercepts (*a*, Tables 2 and 3), mean annual length and weight increments were also derived for all aged eels (length minus 95 mm or weight divided by lake-age). Where applicable, growth models were compared between locations using multivariate techniques. Where growth models were inaccurate ($P > 0.05$), annual increments were used to compare locations.

Historical data

Historical samples were reassessed for comparison with samples obtained in the present study. Otoliths from eels obtained from Lake Karapiro in 1989 and Lake Matahina in 1988 (Chisnall & Hicks 1993) were re-read and assigned "elver", "lake", and "total" ages as described above. Eel populations in these lakes at that time were characterised by distinctively truncated size distributions with few eels smaller than 500 mm, probably due to a combination of poor recruitment and cannibalism by large eels (Chisnall & Hicks 1993).

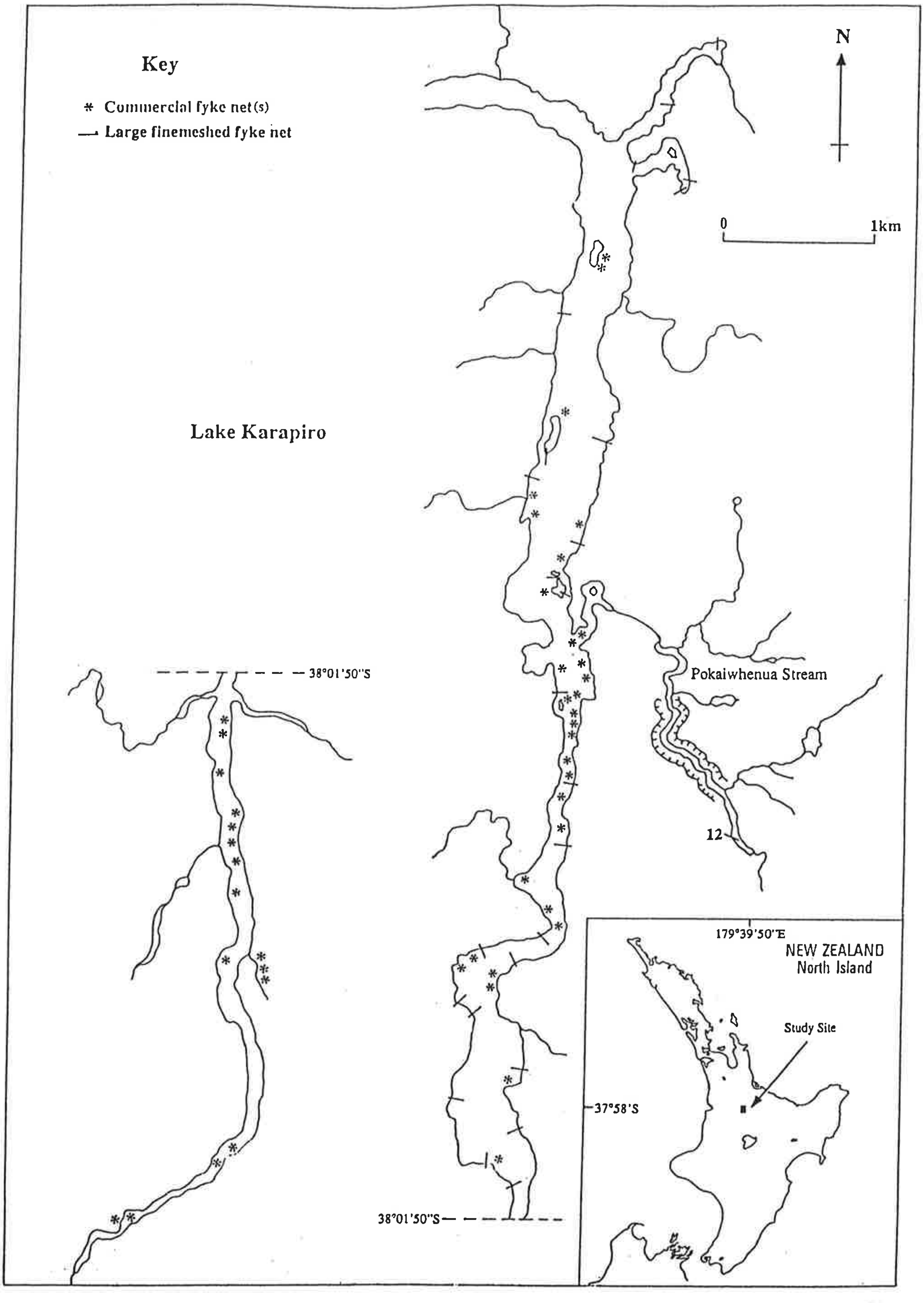

Figure 9: Map of Lake Karapiro (North Island) showing net positions used during sampling, January–February 1996.

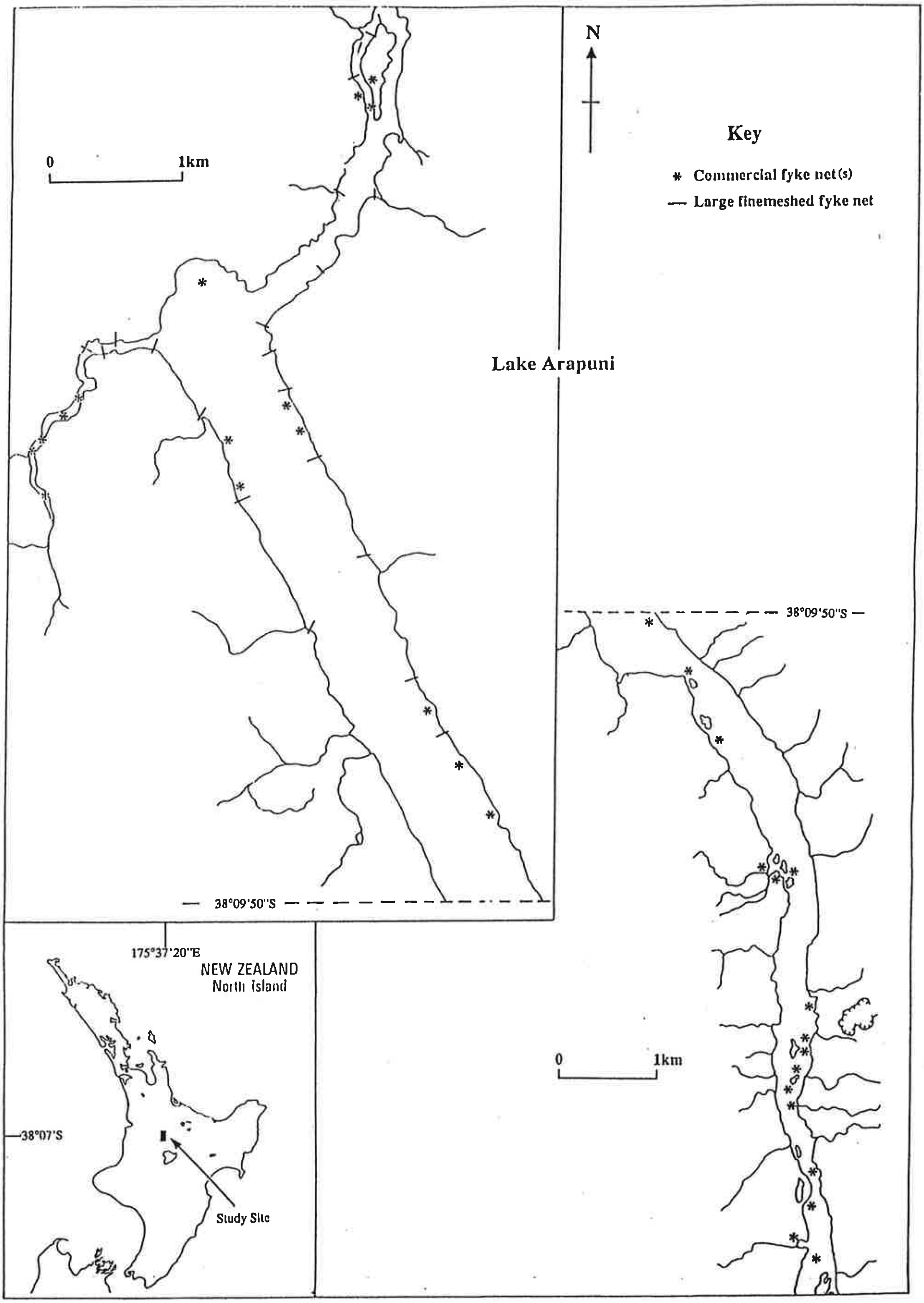

Figure 10: Map of Lake Arapuni (North Island) showing net positions used during sampling, January–February 1996.

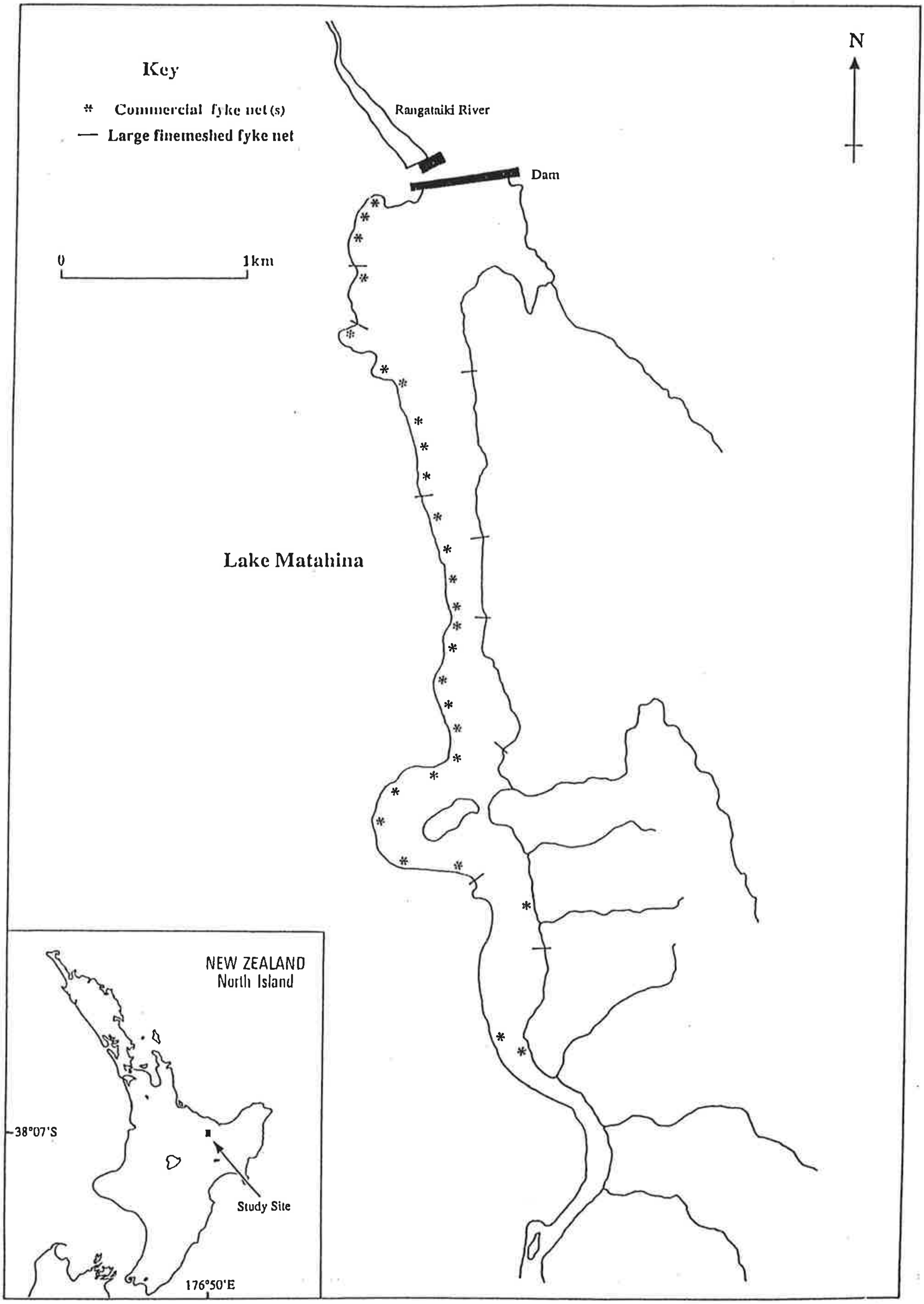

Figure 11: Map of Lake Matahina (North Island) showing net positions used during sampling, January–February 1996.

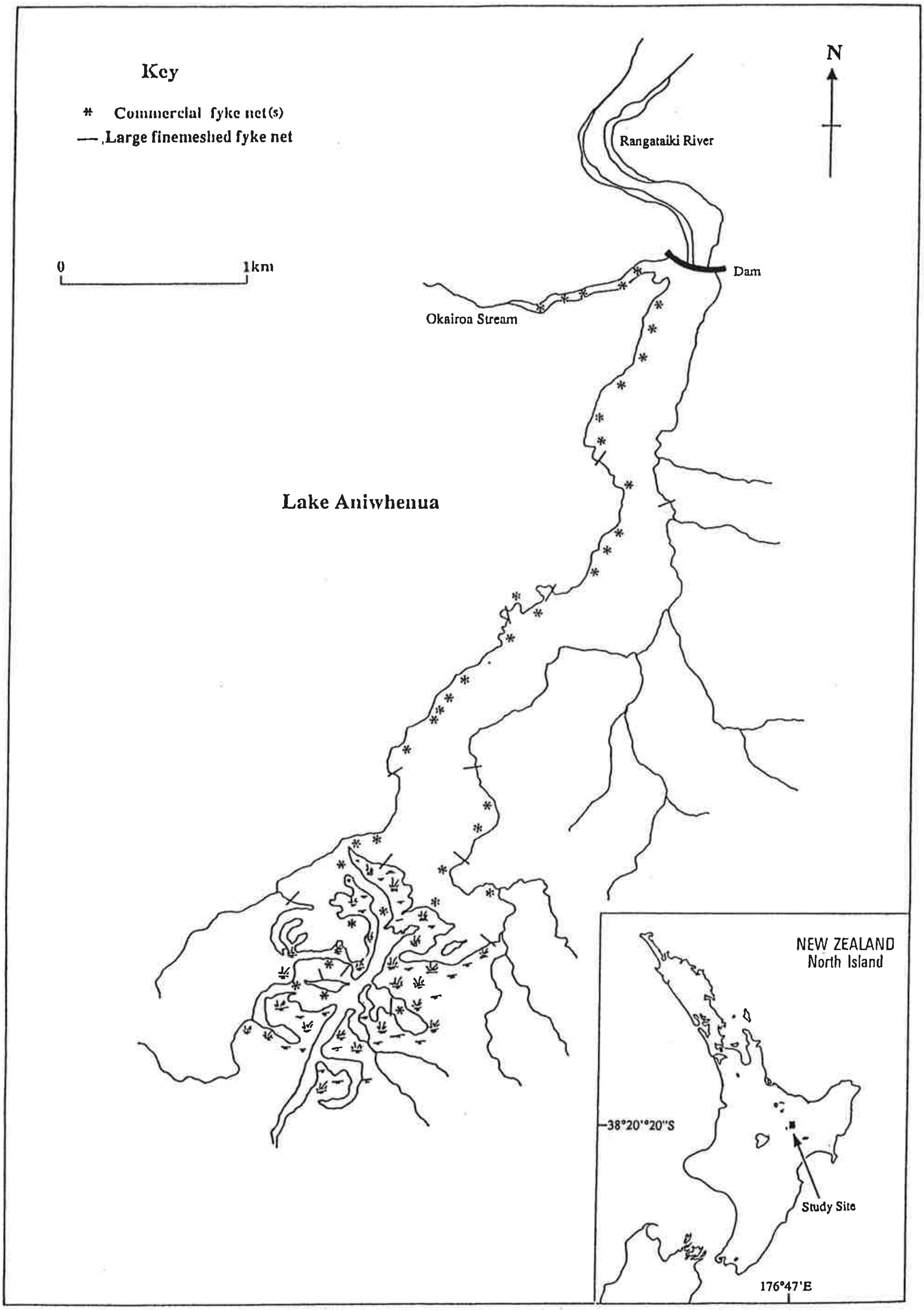

Figure 12: Map of Lake Aniwhenua (North Island) showing net positions used during sampling, January–February 1996.

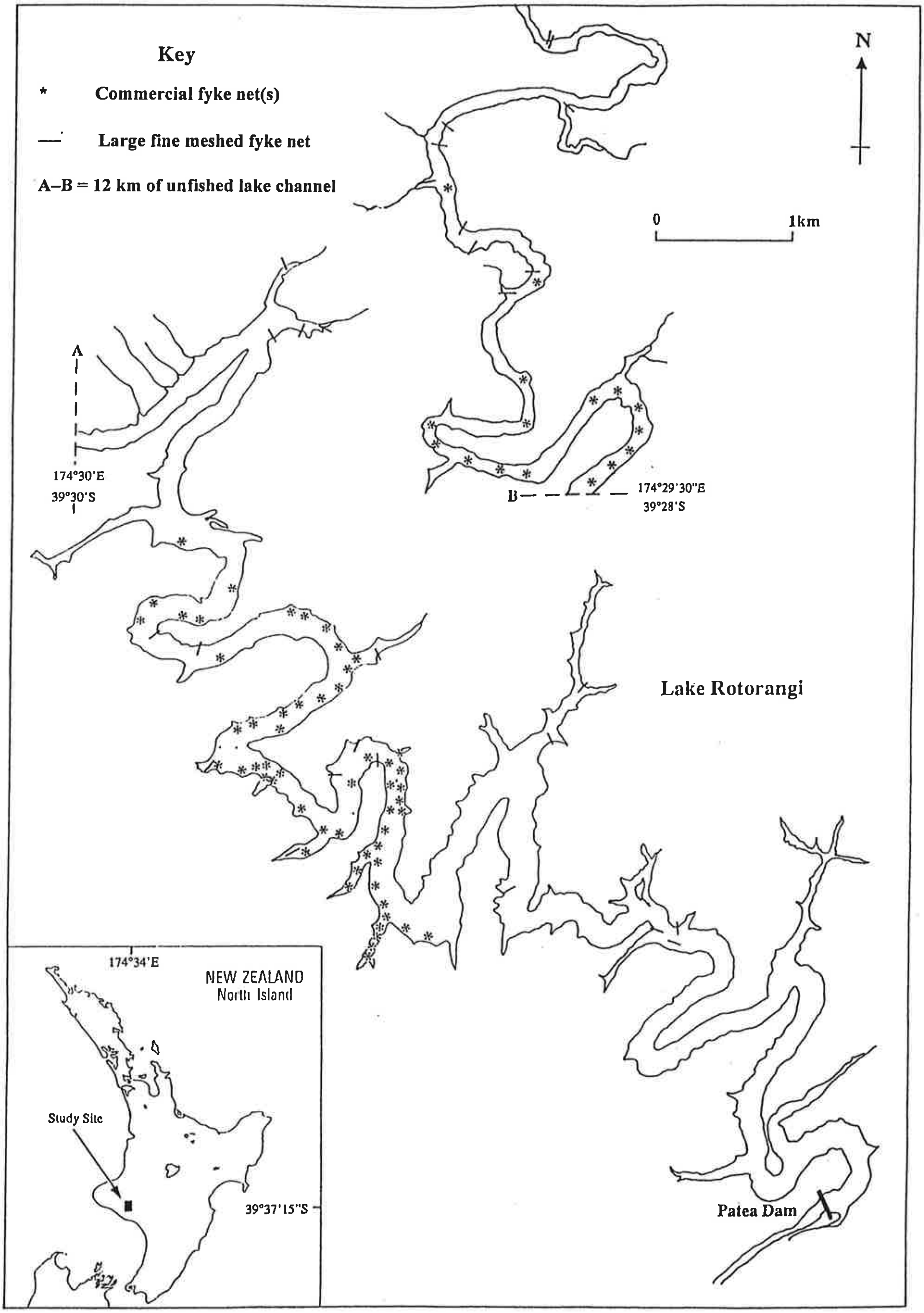

Figure 13: Map of Lake Rotorangi (North Island) showing net positions used during sampling, January–February 1996.

Table 2: Length-at-age coefficients (*a*, *b*) for shortfinned (S) and longfinned (L) eels sampled from North Island hydro lakes between February and March 1996. r^2, regression coefficient; *N*, number of eels aged; s.e., standard error; -, P > 0.05

	Species	*N*	Length range (mm)	Age range (y)	*a*	*b* ± s.e.	r^2	Mean annual length increment ± s.e. (mm)
Waikato River								
Karapiro	S	106	155–1 030	1–19	249.40	43.57 ± 3.53	0.60	92.7 ± 2.7
	L	5	380–535	3–8	-	-	-	75.0 ± 9.8
Arapuni	S	73	214–1 280	1–14	260.80	79.90 ± 4.02	0.85	222.3 ± 11.4
	L	39	228–1 420	1–26	332.46	46.29 ± 2.48	0.90	210.4 ± 17.3
Rangitaiki River								
Matahina	S	28	350–1 015	3–24	312.90	31.86 ± 4.13	0.70	75.4 ± 3.2
	L	3	375–520	5–9	-	-	-	56.9 ± 5.9
Aniwhenua	S	22	435–900	5–14	213.82	52.95 ± 9.87	0.63	74.0 ± 2.81
	L	5	818–1 430	9–26	-	-	-	54.5 ± 7.8
Patea River								
All	S	46	372–815	8–41	-	-	-	71.8 ± 2.4
	L	26	364–875	10–36	421.15	8.15 ± 3.14	0.22	32.8 ± 2.0
Rotorangi ≤ 16 y	S	32	372–815	8–14	295.64	24.39 ± 11.53	0.13	51.0 ± 1.7
	L	9	364–805	10–14	789.10	110.65 ± 16.62	0.86	42.9 ± 2.9

Table 3: Weight-at-age coefficients (*a*, *b*) for shortfinned (S) and longfinned (L) eels sampled from North Island hydro lakes between February and March 1996. r^2, regression coefficient; *N*, number of eels aged; s.e., standard error; -, P > 0.05

	Species	*N*	Weight range (g)	Age range (y)	*a*	*b* ± s.e.	r^2	Mean annual weight increment ± s.e. (g)
Waikato River								
Karapiro	S	70	32–2 500	2–10	3.50	0.31 ± 0.04	0.51	50.19 ± 5.85
	L	3	125–269	3–8	4.34	0.16 ± 0.01	0.99	36.67 ± 2.60
Arapuni	S	53	15–575	1–5	3.56	0.54 ± 0.12	0.27	77.91 ± 8.18
	L	24	22–4 200	1–12	4.25	0.38 ± 0.06	0.63	120.32 ± 15.43
Rangitaiki River								
Matahina	S	28	68–3 320	3–24	4.49	0.17 ± 0.03	0.59	52.79 ± 5.80
	L	2	147–378	5–9	-	-	-	35.7 ± 6.30
Aniwhenua	S	22	145–1 430	5–14	4.35	0.23 ± 0.06	0.47	71.39 ± 7.57
	L	5	1 500–10 000	9–26	6.51	0.09 ± 0.03	0.78	251.20 ± 43.67
Patea River								
All	S	46	91–1 148	8–41	-	-	-	30.34 ± 2.96
	L	26	114–1 428	10–36	5.41	0.04 ± 0.02	0.15	28.99 ± 4.35
Rotorangi ≤ 16 y	S	32	91–1 148	8–14	4.30	0.14 ± 0.07	0.13	36.42 ± 3.40
	L	9	114–1 428	10–14	1.56	0.62 ± 0.09	0.88	36.87 ± 1.95

Migrant eels of both species were caught on intake screens of Aniwhenua Dam in the autumn of 1992 (Mitchell & Chisnall 1992). The ages of most shortfinned eels (8–11 years) indicated that they were survivors of the first manual stockings. Longfinned eels were also considerably larger and older (1050–1590 mm, 25–60 y). Otoliths of these eels were also re-examined and were found to have three different growth band widths, probably corresponding to growth in three different habitats. These habitats are likely to be lake, riverine with indigenous forest, or riverine with pastoral catchments (Chisnall & Hicks 1993). In contrast, shortfinned eel otoliths had consistently wide growth bands. Neither species showed any narrow central growth bands.

Length/weight relationships and catch weight

Natural log of weight vs length models were derived for each species and location in the form of

$$\ln weight = \ln a + b * \ln length.$$

Where only subsamples of eels had been weighed, lengths were used in the models to provide estimates of weights, and from this approximate catch weight from each location.

Relative abundance indices

Accurate relative abundance indices for eel populations are difficult to determine because of variations in eel behaviour in response to environmental factors, such as moon phase, water temperature, and water level. The present study sought to apply standard efforts over a short time span, avoiding new moons, freshes, etc., to limit the effects of such factors on catches. To compare catches from the different locations the habitats fished and methods used were standardised. Relative abundance was expressed as catch per unit effort (CPUE) (number of eels caught / no. nets) for species, net type, and habitat type (soak time was generally overnight).

Table 4: Number and weight of shortfinned (S) and longfinned (L) eels sampled from North Island hydro lakes between February and March 1996

	Number of eels caught		Total weight eels caught (kg)	
	S	L	S	L
Waikato River				
Karapiro	326	18	806.4	26.8
Arapuni	375	89	87.6	113.2
elvers	130	18	-	-
Rangitaiki River				
Matahina	110	20	62.8	9.8
Aniwhenua	106	5	69.6	2.0
Patea River				
Rotorangi	214	223	94.4	123.3
Total	1 261	373	1 120.8	275.1

Table 5: Length weight coefficients (*a*, *b*) for shortfinned (S) and longfinned (L) eels sampled from North Island hydro lakes between February and March 1996. r^2, regression coefficient; s.e., standard error

	Species	*N*	Length range (mm)	Weight range (g)	*a*	*b* ± s.e.	r^2
Waikato River							
Karapiro	S	73	290–1 030	32–2 500	–14.74	3.25 ± 0.05	0.98
	L	3	380–446	125–269	-	-	-
Arapuni	S	54	214–670	15–575	–13.99	3.12 ± 0.06	0.98
	L	27	228–990	22–4 200	–15.71	3.45 ± 0.07	0.99
Rangitaiki River							
Matahina	S	72	350–1 015	68–3 320	–14.49	3.22 ± 0.06	0.98
	L	5	375–1 020	147–3 300	–13.47	3.11 ± 0.05	0.99
Aniwhenua	S	55	435–906	145–1 470	–13.63	3.08 ± 0.06	0.98
	L	5	818–1 430	1 500–10 000	–15.99	3.48 ± 0.18	0.99
Patea River							
All	S	158	372–815	91–1 148	–13.36	3.04 ± 0.05	0.92
	L	214	360–895	114–2 282	–13.30	3.07 ± 0.06	0.96
Rotorangi ≤ 16 y	S	32	372–815	91–1 448	–14.25	3.18 ± 0.06	0.99
	L	9	364–805	114–1 428	–14.32	3.19 ± 0.16	0.99

Results

General overview

A total of 373 longfinned eels (including 18 elvers) and 1261 shortfinned eels (including 130 elvers) were captured during the sampling (Table 4). Lengths of all the eels collected were measured and weights were obtained from the 272 eels retained for otolith abstraction plus another 338 eels. Eel species composition varied distinctly amongst the five lakes. Longfinned eels made up only 3–5% of the stocks in Lake Karapiro in number and biomass. In contrast, Lake Arapuni had 22% longfinned eels by number, but 56% in biomass as a result of the remnant large eels caught here. The Rangitaiki River lakes had few longfinned eels (less than 7%). Lake Rotorangi produced almost equal numbers and biomass of both species.

Excluding elvers, eels ranged from 155 to 1430 mm (15 g to 10 kg), and 1–41 years old (*see* Tables 2 and 3). About 4% of otolith pairs were rejected (poor retrieval, broken during processing, poor mounting, unreadable). Otoliths from many large longfinned eels were particularly difficult to interpret, with extensive portions of their lives represented as numerous narrow growth bands.

Species compositions, size distributions, and growth rates for each of the lakes reflected a complex combination of productivity, recruitment/stocking levels, and the present and historical legacy of habitat characteristics. Eel species composition and relative effectiveness of the two net types used varied considerably between sites. These differences may have been real, but could also have been caused by baiting of the net, net placement, and size distribution of the population.

Length/weight relationships

Eel condition varied slightly between locations (ANCOVA $P < 0.001$) (Table 5). Eel condition in the Waikato and Rangitaiki River lakes was similar and greater than in Lake Rotorangi. However, if only lake-grown eels (16 y and over, i.e., eels resident in the lake after dam construction) were compared, differences became insignificant (ANCOVA $P > 0.05$). The condition of longfinned eels was substantially greater than that of shortfinned eels in Lakes Arapuni and Aniwhenua (ANCOVA $P < 0.001$).

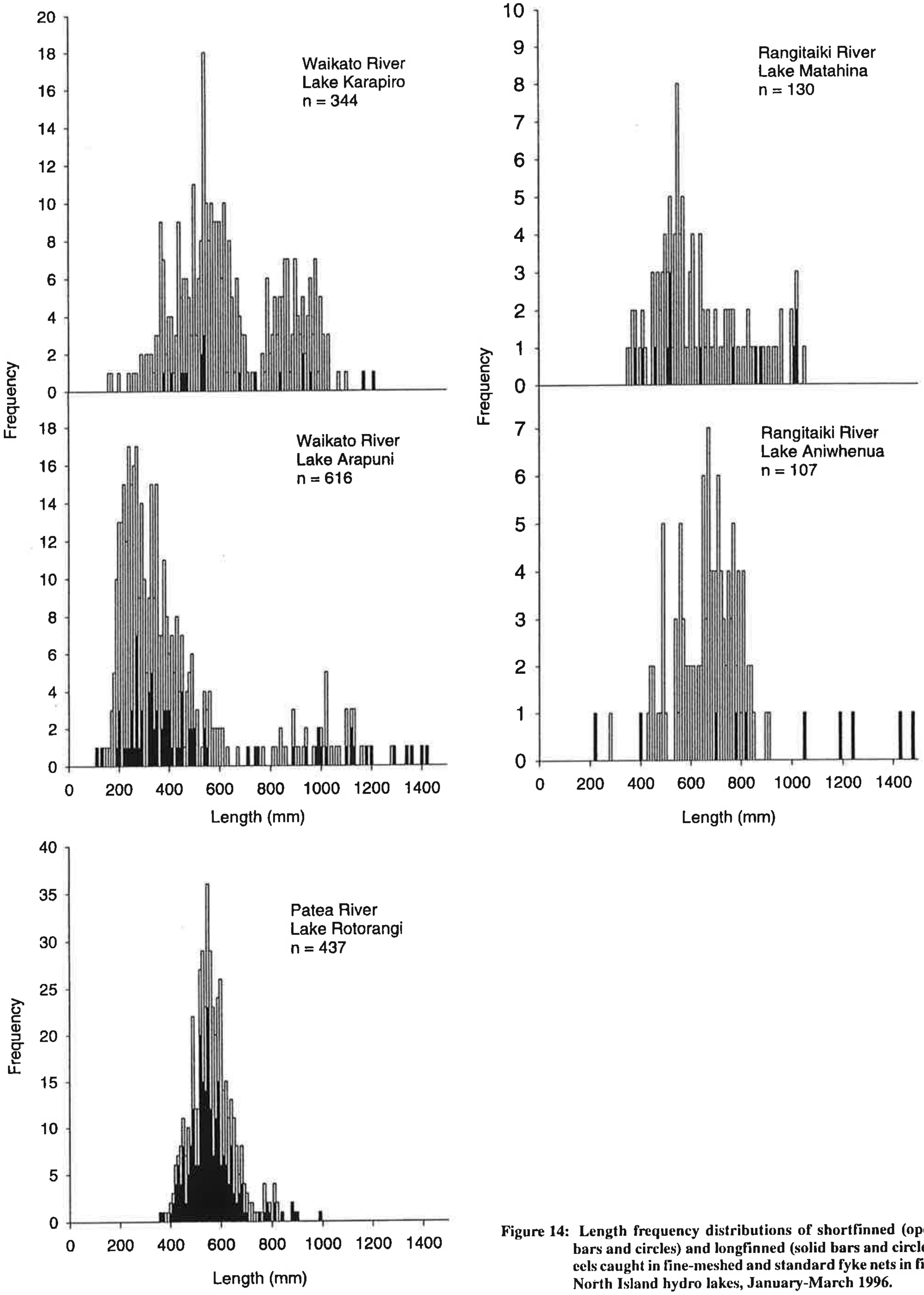

Figure 14: Length frequency distributions of shortfinned (open bars and circles) and longfinned (solid bars and circles) eels caught in fine-meshed and standard fyke nets in five North Island hydro lakes, January-March 1996.

Population size distributions

Eel size distributions varied between lakes and catchments, but were similar for both species (Figure 14). Lakes Karapiro, Matahina, and Rotorangi, all had modes at about 550 mm (350 g). The modes for Lake Aniwhenua were at about 700 mm (600 g), and for Lake Arapuni at 250 mm (40 g). Secondary modes at about 950 mm (1400 g) were also apparent in Lakes Karapiro and Arapuni. Although numbers were low, Lakes Matahina and Rotorangi also had secondary modes at 1000 mm (1300 g) and 800 mm (1100 g), respectively. The distributions of eels smaller than 500 mm varied and reflected recruitment success and/or stocking level.

Waikato River lakes, which have been stocked over the last 3 years, had good numbers of small young eels (Figure 15). In contrast, lakes on the Rangitaiki and Patea Rivers, with predominantly passive enhancement, had few eels smaller than 500 mm or less than 5 years old (Figures 16 and 17). However, stocks in Lake Matahina appear to be of much wider size distribution and greater abundance than in 1988, evidence of successful elver transfer facilitated by the fish pass installed in 1992.

Age structure and growth

Age frequencies of all lake eel populations generally reflected known levels of stocking and/or passive enhancement. The age structures from the Rangitaiki River lakes reflect sporadic efforts to enhance the two lakes over the last 10 years, and consistent passive enhancement via the elver pass on the Matahina Dam since 1992.

Estimated elver ages

Distributions of central narrow growth bands on eel otoliths were consistent within catchments, but variable between locations. Estimated ages for elvers before they reached the lakes indicated that they spent considerable time below the dam faces. For eels from the Waikato, this period ranged from 0 to 13 y, with a mode at 1 and another at 4 y (Figure 15 A). The estimated age of elvers reaching the Rangitaiki River lakes ranged between 0 and 8 y, and most seem to have entered the lake in their first year (Figure 16 A). Estimated age of elvers reaching Lake Rotorangi on the Patea River ranged between 0 and 9 y, but most eels entered the lake during their first year (age class 0). A minor secondary mode was also present at 2 y (Figure 17 A).

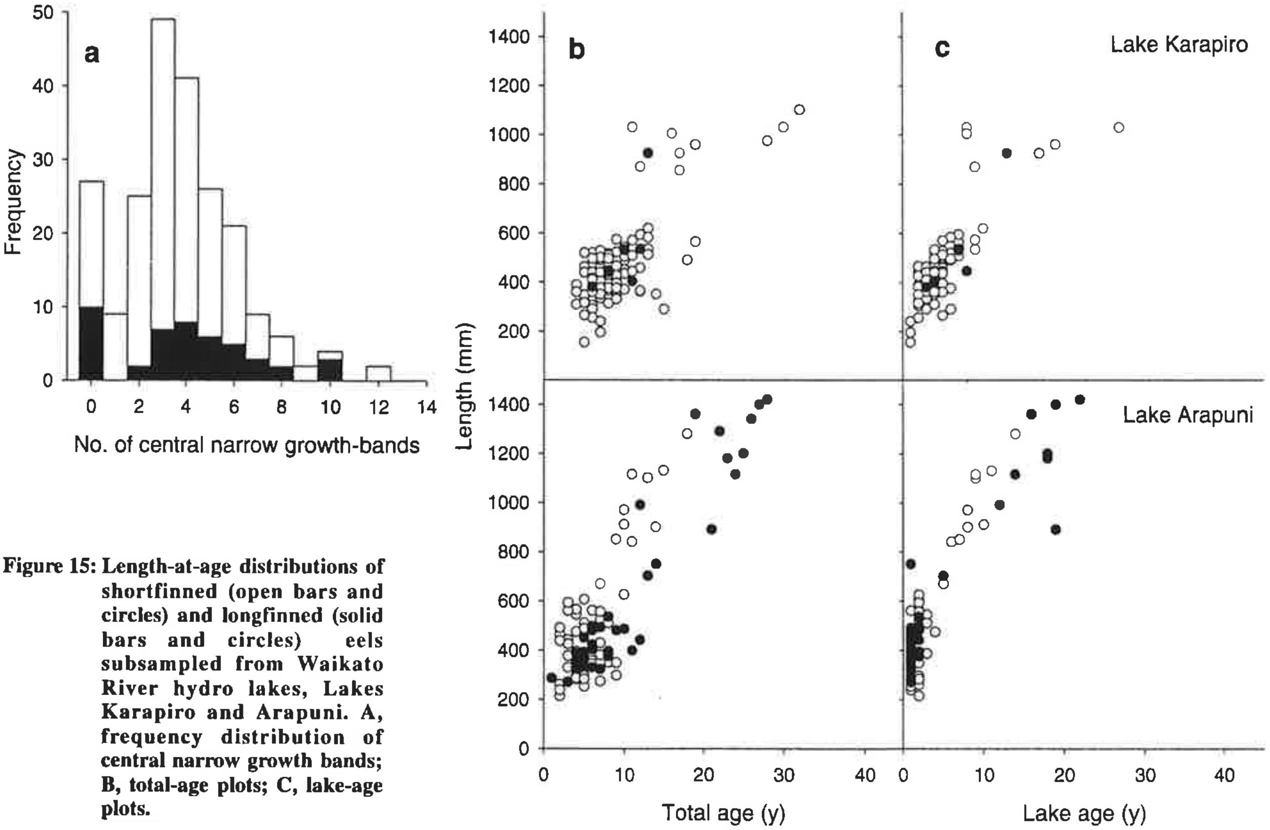

Figure 15: Length-at-age distributions of shortfinned (open bars and circles) and longfinned (solid bars and circles) eels subsampled from Waikato River hydro lakes, Lakes Karapiro and Arapuni. A, frequency distribution of central narrow growth bands; B, total-age plots; C, lake-age plots.

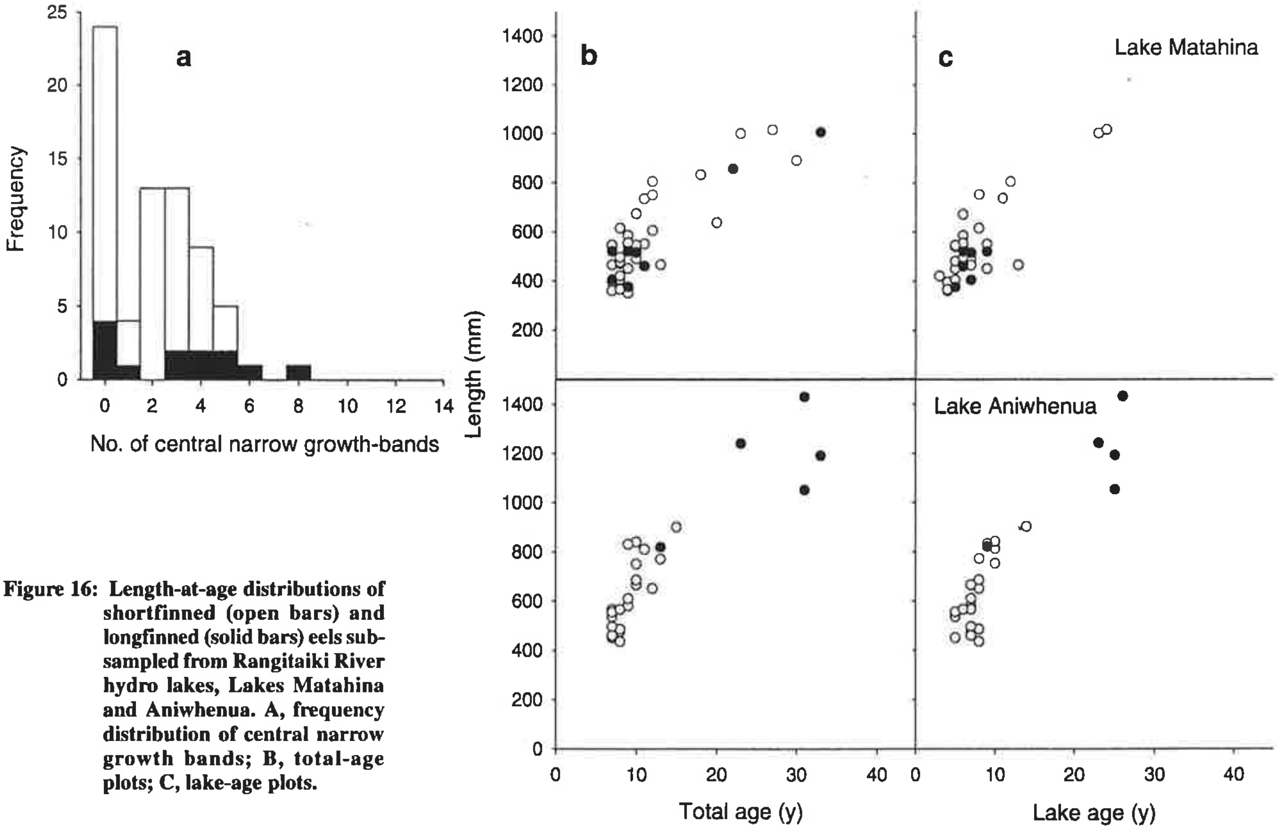

Figure 16: Length-at-age distributions of shortfinned (open bars) and longfinned (solid bars) eels subsampled from Rangitaiki River hydro lakes, Lakes Matahina and Aniwhenua. A, frequency distribution of central narrow growth bands; B, total-age plots; C, lake-age plots.

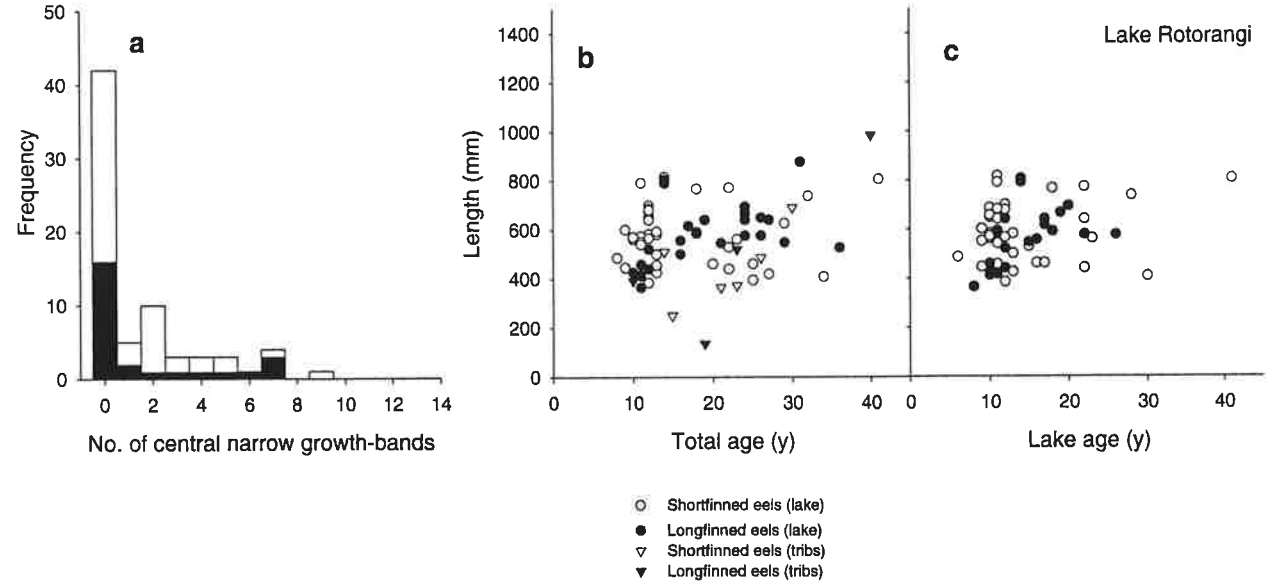

Figure 17: Length-at-age distributions of shortfinned (open bars) and longfinned (solid bars) eels subsampled from the Patea River hydro lake, Lake Rotorangi, and several tributary streams (*see* Table 2). A, frequency distribution of central narrow growth bands; B, total-age plots; C, lake-age plots.

Estimated ages at lake entry obtained in previous studies of Lakes Karapiro and Matahina were comparable to the present data but showed greater extremes (0–21 y). Growth rates were also similar for lake-age data from these lakes.

Comparative growth

Length and weight-at-age growth models were generally all isometric (consistent growth throughout eel size distribution). All *y*-intercepts (*a*, Tables 2 and 3) were larger than expected, the result of a skewed size distribution. Slopes of the lines indicate that growth was greatest in the Waikato River. Mean annual increments for these lakes ranged from 75 to 222 mm and 37 to 120 g.

Growth models for eels from Lake Rotorangi showed poor fits (*see* Tables 2 and 3). By removing eels older than 16 y (i.e., before dam construction when a riverine habitat would have existed), a better correlation of size-at-age was obtained. Mean annual increments for this data set were 43–51 mm and 37 g.

Table 6: Catch per unit effort (CPUE) using large fine-meshed and standard fyke nets for North Island hydro lakes between February and March 1996. CPUE expressed per location, by species, net type and habitat (LFM fykes only). *28 nets set but two nets stolen and analysis restricted to 26 nets. ¯catch from 2 standard fykes alone. CPUE = no. eels/no. nets; S, shortfinned eel; L, longfinned eel; LFM, large fine meshed; std, standard fyke net; s.e., standard error

	Nets (N)		Eels (N)				CPUE ± s.e.(all habitats)				CPUE (habitat type - LFM fyke)								
	LFM fyke	Std fyke	LFM fyke		Std fyke		LFM fyke		Std fyke		Margins with cover			Open margins			Open water (> 3 m deep)		
			S	L	S	L	S	L	S	L	Nets	S	L	Nets	S	L	Nets	S	L
Waikato River																			
Karapiro	26	62	113	7	213	11	4.3	0.3	3.4	0.2	21	2.2	0.9	2	0.2	0.1	3	0.3	0.1
Arapuni	21	114	220	61	155	28	11.0	3.0	1.3	0.2	12	6.2	1.7	5	2.6	0.7	4	2.1	0.6
Elvers	21		130	18			6.2	0.9			12	3.7	0.5	5	1.5	0.2	4	1.2	0.2
Rangitaiki River																			
Matahina	9	27	17	0	93	20	1.9 ± 0.3	0	3.4 ± 0.4	0.6 ± 0.1	5	1.0	0	3	0.6	0	1	0.2	0
Aniwhenua	10	34	0	1	¯106	4	0	0.1 ± 0.1	3.4 ± 2.9	0.1 ± 0.06	10	0	0.1	-	-	-	-	-	-
Patea River																			
Rotorangi	*28	76	35	24	179	199	1.2 ± 0.4	0.8 ± 0.2	2.4	2.6	17	1.0	0.7	5	0.04	0.04	6	0.2	0.1

Differences in growth between the two eel species were difficult to assess as there was little data for longfinned eels. In Lake Arapuni (24 longfinned eels aged) the two species had similar length increments (210–222 mm), but longfinned eels were about 30% heavier than shortfinned eels of the same age (*see* Tables 2 and 3).

Relative abundance

In all North Island locations, for both species, CPUE obtained with fine-meshed fyke nets was greatest in habitat where cover was available compared with uncovered margins or deep water (Table 6). In locations where standard fyke nets were baited, catches were considerably greater than for the unbaited fine-meshed fyke nets. (Thus South Island catches in baited standard fyke nets can be compared directly only with baited standard fyke net catches from the Rangitaiki and Patea Rivers in the North Island.) CPUE for both fyke net types was about the same in Lake Karapiro, but greater for fine meshed fyke nets in Lake Arapuni because of the many small eels caught there.

CPUE for both net types ranged between 0 and 11.0 and 0 and 3.0 for shortfinned and longfinned eels, respectively (Table 6), corresponding to 0–9 kg per net. Estimated catch weight ranged between 62 and 806 kg for shortfinned eels and 2 and 123 kg for longfinned eels (*see* Table 4). Total catch weight was greatest in Lake Karapiro at 833 kg, Lake Arapuni and Rotorangi produced about 200 kg, and Lakes Matahina and Aniwhenua about 70 kg.

Fishing of tributaries

Five tributaries each of Lakes Aniwhenua and Rotorangi were electrofished (Table 7). At all sites, eel numbers were very low (0–4 per 60 m fished). Eels were aged only for the Patea River catchment (Figure 17 B). Generally, eel growth for both species was slower in the streams than in the lakes.

Size and age at migration

Few migrants were identified during sampling; 24 females and 61 males (Table 8). As the study progressed, a greater proportion of migrants was caught. Lake Rotorangi was sampled last (March) and migrant eels made up 17% of catches in this lake. Size and age distribution of each species and sex varied between the lakes, reflecting the growth rates in each system. Considerable overlap in size distribution occurred between the sexes. Longfinned females ranged from 610 to 1430 mm and 572 to 10 000 g, and from 22 to 28 y old. Longfinned males ranged from 484 to 693 mm and 252 to 708 g, and from 11 to 26 y old (ages from Lake Rotorangi only). Shortfinned females ranged from 585 to 1000 mm and 438 to 1920 g, and from 6 to 28 y old. Shortfinned males ranged from 394 to 803 mm and 101 to 1030 g, and from 15 to 30 y old (ages from Lake Rotorangi only). Longfinned females were particularly large in Lake Aniwhenua.

Table 7: Fish and crayfish catches (koura) from electrofishing of locations within tributaries of two North Island hydro lakes between January and February 1996. S, shortfinned eel; L, longfinned eel; R, rainbow trout; B, brown trout; Bully, common bully (galaxid) *Galaxias divergens*; A, abundant; C, common

				Eels		Trout				
	NZMS 1:50 000	Distance fished (m)	Area fished (m²)	S	L	R	B	Bully	Galaxid	Koura
Rangitaiki River										
Kopuriki Stream	V16 419 132	60	150	-	-	3	1	-	-	-
Hikurangi Stream	V17 435 092	60	120	-	1	3	2	-	C	1
Mangahouhi Stream	V17 405 098	60	120	2	-	-	-	A	-	A
Horomanga River	V17 391 079	60	120	-	4	77	-	-	-	A
Ruarepuae Stream	V17 402 012	60	90	2	-	-	-	-	A	-
Patea River										
Mainstream	Q20 206 062	25	61	-	2	-	-	-	-	3
Pastoral Tributary	Q20 364 945	350	525	1	3	-	25	4	-	1
Manganui Stream	Q20 191 132	50	100	-	-	-	-	-	-	1
Kahouri Stream	Q20 069 252	30	60	-	-	-	-	-	-	2
Trib. to Toko Stream	Q20 252 089	80	80	4	-	-	-	-	-	-

Bycatch species

Bycatch species in the fine-meshed fyke nets varied greatly in both diversity and abundance (Table 9). In Lakes Karapiro and Arapuni, seven other species were captured in abundance, six of which are known eel prey. In contrast, the Rangitaiki and Patea River hydro lakes had low diversities and generally low abundance of other species, except was Lake Matahina where many juvenile common bullies (*Gobiomorphus cotidianus*) under 15 mm were captured, reflecting recent spawning success of this species.

Discussion

Unstocked New Zealand hydro lakes are generally characterised by remnant eel populations dominated by large longfinned eels, some of great age (*see*, e.g., Chisnall & Hicks 1993). Eel population size distributions, species compositions, age structures and growth rates in North Island hydro lakes were variable, reflecting levels of recruitment and stocking and quality of habitat in terms of food availability, which generally in turn reflected the quality of littoral zones. Without exception, growth was considerably faster than in South Island lakes (e.g., South Island, Tables 10, 11, and 12 compared to North Island, Tables 2 and 3). The two lowermost hydro lakes on the Waikato and Rangitaiki Rivers have been stocked naturally and artificially over a number of years. Commercial and non-commercial exploitation in these lakes is low. Lake Karapiro has an abundant eel population compared with Lake Matahina, but both lakes have fast growth, with eels reaching the minimum legal size (220 g) in 5–6 years. Fast growth in Lake Karapiro is likely to be a result of extensive littoral zones and abundant and diverse prey, whereas in Lake Matahina it is likely to arise from low eel densities and high bully numbers. Stocked eels in Lake Arapuni, the next lake up on the Waikato River, are exploiting a virtually virgin waterway. High food availability (high species diversity and abundance), reflecting high quality littoral habitat and low eel densities, has resulted in very fast growth for most of the eel population there (220 g in 1–2 y).

Eel density is low in Lake Aniwhenua, and growth, while fast (220 g in 2–4 y), is lower than in the Waikato, probably because of poorer littoral zones and much lower food availability.

Growth in Lake Rotorangi the slowest in all the North Island locations sampled (220 g in 7–10 y). Although there is a low density eel population in the lake maintained by passive stocking via an elver pass on the dam, little food is available for the eels — steeply incised landforms provide poor littoral zones and indigenous forest in most of the mid catchment probably means there is little terrestrial food available. Sizeable pockets of aquatic macrophytes no doubt contribute to macroinvertebrate production, but eels must also compete with substantial populations of perch in the lake. No other prey fish species appears to have survived the formation of the lake. Previously, perch were probably kept in check by large eels, but now that these eels have been mostly removed by commercial fishing and out-migration of adults (towards the sea for spawning) perch numbers appear to have increased. This abundant perch population is probably partly responsible for the drastic decline of other fish species previously known from the lake (e.g., common bully).

Age structure and growth

Eel growth rates in North Island hydro lakes are the fastest recorded for wild New Zealand eels: they are up to eight times faster than anywhere in the two most productive lowland fisheries of the Waikato basin (North Island) and Lake Ellesmere (South Island). Previous growth studies of wild populations have described wide variations that were mostly associated with habitat productivity and levels of exploitation or stock densities (e.g., Burnet 1969, Chisnall & Hayes 1991, Chisnall & Hicks 1993, Jellyman 1995, Jellyman *et al.* 1995). Average age at minimum

Table 8: Migrant eels identified and their biological parameters (where available) from sampling of North Island hydro lakes between January and March 1996. S, shortfinned eel; L, longfin eel, F, female; M, male; N, total number migrants caught, *numbers weighed and aged if less than N, in brackets. s.e., standard error

	Species	Sex	N	Length range (mm)	Mean length ± s.e.(mm)	Weight range* (g)	Mean weight ± s.e.(g)	Total-age range* (y)	Lake-age range* (y)	Mean lake-age ± s.e.(y)
Waikato River										
Karapiro	S	F	4	840–980	911 ± 30.7	-	-	-	-	-
		M	2	475–500	488 ± 12.5	-	-	-	-	-
Rangitaiki River										
Aniwhenua	L	F	4	1 050–1 430	1 228 ± 78.6	3 800–10 000	6 750 ± 1284.9	23–33	23–26	25 ± 0.7
Matahina	S	F	5	585–1 000	746 ± 75.5	477–1 920	963 ± 275.0	9–23	6–23	13 ± 3.6
Patea River										
Rotorangi	L	F	7	610–880	691 ± 39.5	572–1 428 (6)	823 ± 132.0	-	-	-
		M	41	484–693	579 ± 7.3	252–708	467 ± 26.8	17–36 (13)	11–26 (9)	18 ± 1.5
	S	F	9	610–810	687 ± 23.0	438–875 (6)	602 ± 66.1	22–32 (4)	22–28 (3)	24 ± 2.0
		M	17	394–803	516 ± 28.2	101–1 030 (10)	336 ± 110.9	18–41 (10)	15–30 (7)	20 ± 2.0

legal size for the lower Waikato and Lake Ellesmere has been about 13–18 y for both species. Overseas, there are very few reports of eel growth exceeding 60 mm p.a., and anything greater is viewed sceptically (e.g., Berg 1990). Exceptional growth reported for migrants of both eel species from Lake Aniwhenua (Mitchell & Chisnall 1992) was corroborated by the findings of this report. Varied growth of longfinned eel migrants was attributable to growth in different parts of the catchment.

Elver age estimation

Age frequency histograms of narrow central growth bands on otoliths of aged eels from Lakes Karapiro and Arapuni correlate well with similar data obtained from elvers collected at the Karapiro Dam in January 1996. This tends to support the hypothesis that narrow central growth bands represent age before entry into the lake. If elvers were removed more frequently from the Karapiro Dam face, the mean age of elvers used for stocking would be expected to decrease. Alternatively, the two main modes of estimated elver ages from the Waikato system could reflect the natural behaviour of elvers: the first arrivals of glass-eels in coastal waters penetrating the catchment immediately forming the first mode, and later arrivals spending longer in the system before migrating up the catchment to form the second mode.

Size/age distributions and catch

The generally large size of eels caught in Lake Aniwhenua reflected the lack of fishing pressure on the eel population combined with limited manual transfer of elvers into the lake. For Lakes Karapiro, Matahina, and Rotorangi, size and age distributions were characteristic of lightly fished eel populations. In contrast with all other eel populations, size and age distribution for Lake Arapuni indicated a very small remnant stock of large eels (depleted by commercial fishing in the 1970s and out-migration of mature adults) outnumbered by substantial numbers of small eels resulting from stocking over the last 3 years.

Large longfinned eels are thought to be significant predators in New Zealand eel populations (e.g., Chisnall 1994). Eel stocks in North Island hydro lakes were dominated by considerable numbers of large specimens of both species, but their impact on new recruits is unknown.

Age frequencies in North Island hydro lakes generally reflected known stocking dates and levels.

Relative abundance

The CPUE data must be interpreted with caution as standard fyke nets were mainly used to fish open or deep waters, whereas fine-meshed fyke nets were predominantly used to fish lake margins. In addition, CPUEs for unbaited fine-meshed fyke nets are probably not comparable with CPUEs derived from baited standard fyke nets. However, CPUEs from baited standard fyke nets in the Rangitaiki and Patea Rivers should be comparable with South Island catches (cf, South Island, Table 13 and North Island, Table 6).

The habitat characteristics, together with eel size composition and abundance in Lake Karapiro, appear to be conducive to rapid growth rates. The total weight of eels caught in Lake Arapuni was only 24% of that caught in Lake Karapiro (effort in both lakes was similar) (*see* Table 4) and therefore stocking can probably safely continue in Lake Arapuni for several years without adversely affecting the growth of the population. In contrast, total weights of eels caught in Lakes Matahina and Aniwhenua were 9% and 8% respectively, of that caught in Lake Karapiro, although stocks are increasing through passive and manual elver transfer (evidenced by comparison with historic data). The lower growth rates in Lake Matahina (and in Lake Rotorangi on the Patea River) indicate that this lake is unlikely to continue to produce at the same rate if stocks are increased without additional food supplies (e.g., introduction of lacustrine fish species). However, eels from Lake Aniwhenua had faster growth rates, suggesting that the lake may sustain a larger eel population than Lake Matahina.

There is only limited understanding of the ecology of eels in lakes. To make specific recommendations on the optimal stocking rates would require answers to such questions as: do habitat preferences of both species change with size, and what proportion of elvers choose to reside in a lake as opposed to those that continue to migrate? In the absence of such data, growth rate, condition, and yield from the fishery should be closely monitored to find whether stocking levels are starting to negatively affect any of them.

Table 9: CPUE of bycatch species caught in large, fine-meshed fyke nets during sampling of North Island hydro lakes between February and March 1996. *28 nets set but 2 nets stolen and analysis restricted to 26 nets. CPUE, no. of fish caught/no. of nets; s.e., standard error

			Species CPUE ± s.e.								
	Nets (*N*)	Life stage	Bully	Smelt	Goldfish	Mosquitofish	Rudd	Koura	Catfish	Trout	Perch
Waikato River											
Karapiro	26	Juvenile	-	-	1.15 ± 0.9	-	1.9 ± 1.1	-	0.03 ± 0.7	-	-
		Post-juvenile	1 066 ± 351	22.1 ± 11.8	0.15 ± 0.1	8.3 ± 4.2	21.7 ± 1.1	0.07 ± 0.4	0.12 ± 0.8	-	-
		Adult	-	-	-	-	1.7 ± 1.2	-		-	-
Arapuni	21	Juvenile	-	-	9.5 ± 0.7	-	78.6 ± 11.7	1.9 ± 1.1	7.9 ± 3.1	-	-
		Post-juvenile	8.07 ± 34.6	62.4 ± 19.8	0.1 ± 0.1	-	2.1 ± 1.0	1.4 ± 0.9	-	-	-
		Adult	-	-	-	-	1.0 ± 0.7	1.1 ± 0.5	-	-	-
Rangitaiki River											
Matahina	9	Juvenile	1 527 ± 486	-	1.1 ± 0.5	-	-	-	-	-	-
		Post-juvenile	-	-	0.1 ± 0.1	1.1 ± 1.0	-	-	-	-	-
		Adult	-	-	-	-	-	-	-	0.1 ± 0.1	-
Aniwhenua	10	Juvenile	50.0 ± 28.4	-	13.2 ± 4.7	-	-	-	-	-	-
		Post-juvenile	100.0 ± 20.0	-	1.0 ± 0.4	5.0 ± 4.8	-	-	-	-	-
		Adult	3.5 ± 2.9	-	0.4 ± 0.4	-	-	-	-	-	-
Patea River											
Rotorangi	28*	Juvenile	-	-	-	-	-	-	-	-	0.54 ± 0.12
		Post-juvenile	-	-	-	-	-	-	0.05 + 0.05	0.05 ± 0.05	0.05 ± 0.19
		Adult	-	-	-	-	-	-	-	-	-

Table 10: **Descriptive statistics and length weight parameters (*a, b*) for longfinned eels sampled from South Island lakes Dunstan, Wanaka, Wakatipu, and Hawea between November and December 1995. r^2, regression coefficient; s.e., standard error**

	N	Mean length (mm)	s.e.	Length range (mm)	Mean weight (g)	s.e.	Weight range (g)	*a*	*b* ± s.e.	r^2
Lake Dunstan	60	760	2.09	490–1 130	1 722	164.83	314–5 454	-15.705	3.46 ± 0.06	0.98
Lake Wanaka	355	695	0.65	440–1 130	1 118	43.87	234–5 376	-15.26	3.38 ± 0.04	0.96
Lake Wakatipu	70	795	1.61	490–1 070	1 812	126.34	322–4 602	-15.15	3.37 ± 0.08	0.97
Lake Hawea	3	1 120	6.64	1 010–1 240	5 189	1 290.98	3 260–7 640	-	-	-

Table 11: **Length-at-age parameters (*a, b*) for longfinned eels sampled from South Island lakes Dunstan, Wanaka, Wakatipu, and Hawea between November and December 1995. r^2, regression coefficient; s.e., standard error**

	N	Length range (mm)	Age range (y)	*a*	*b* ± s.e.	r^2	Mean annual length increment ± s.e. (mm)
Lake Dunstan	60	490–1 130	15–65	377.08	10.88 ± 1.07	0.64	20.96 ± 0.59
Lake Wanaka	83	440–1 130	18–60	205.40	16.20 ± 1.19	0.70	20.96 ± 0.40
Lake Wakatipu	68	490–1 070	19–66	339.17	11.61 ± 1.43	0.50	18. ± 0.36
Lake Hawea	2	1 010–1 120	58–60	-	-	-	-

Table 12: **Weight-at-age parameters (*a, b*) for longfinned eels sampled from South Island lakes Dunstan, Wanaka, Wakatipu, and Hawea between November and December 1995. r^2, regression coefficient; s.e., standard error**

	N	Weight range (g)	Age range (y)	*a*	*b* ± s.e.	r^2	Mean annual weight increment ± s.e. (g)
Lake Dunstan	60	314–5 454	15–65	5.36	0.05 ± 0.01	0.66	45.13 ± 3.2
Lake Wanaka	83	234–5 376	18–60	4.44	0.08 ± 0.01	0.70	43.45 ± 3.21
Lake Wakatipu	68	322–4 602	19–66	5.33	0.05 ± 0.01	0.49	44.57 ± 2.56
Lake Hawea	3	3 260–4 668	58–60	-	-	-	67.00 ± 10.80

Table 13: **CPUE and relative biomass of longfinned eels sampled from South Island lakes Dunstan, Wanaka, Wakatipu, and Hawea between November and December 1995. CPUE = number of eels/ number of nets; Relative biomass = total weight/ proportion of shore line fished**

	Eels (*N*)	Nets (*N*)	CPUE	Total weight (kg)	Proportion of shoreline fished	Relative biomass (kg)
Lake Dunstan	60	148	0.40	103.4	0.8	129.25
Lake Wanaka	355	378	0.94	396.9	1.0	396.9
Lake Wakatipu	70	347	0.20	126.9	0.5	253.8
Lake Hawea	3	77	0.04	15.6	0.3	52.0

South Island elver transfers

Clutha River (Otago)

There were no manual transfers of elvers in the South Island before the 1995–96 season although the South Island eel industry had for many years shown considerable interest in collecting elvers from below Roxburgh Dam on the Clutha River and transferring them to the upstream lakes. Two dams on the Clutha River impede elver upstream migration: Roxburgh Dam (completed in 1956) and Clyde Dam (completed in 1992). Four lakes on the Clutha River system upstream of the Clyde Dam are suitable for elver enhancement: Lakes Dunstan, Wakatipu, Wanaka, and Hawea. Discharge from Lake Hawea is restricted by control gates, a further barrier to elver migration.

A pilot programme to trap and transfer elvers by the South Island Eel Industry Association at Roxburgh Dam was monitored, evaluated, and supported by NIWA. A floating trap was placed in a spillway at the base of Roxburgh Dam from 17 February to 10 March 1996. The spillway used was nearest the turbines and was chosen for the amount of water which continued to flow under the gate after closure. This water created a "splash" and a small current in the spillway channel considered to be of sufficient force to attract elvers. More water was directed near the trap from a hose supplied by river water. The current below the dam is very swift and it was not feasible to locate the trap in the main flow of the river below the turbines. The spillway trap was monitored until midnight for the first few nights to ensure that it was functioning as intended. The trap was checked each morning and elvers were removed with a dip net, immediately placed in 70% alcohol, and later examined for length, species, and age. All parts of the dam, as well as the river banks below it, were checked for signs of migrating elvers. Special attention was paid to any damp walls or areas where water was discharging from the dam structure, but very few elvers were found.

About 40 elvers were collected in the floating trap. The low catch did not warrant transferring them and a subsample only was retained for analysis. The mean length was 191.9 mm (s.e.,10.0; range, 125–220 mm, N = 10) and mean age was 9.1 y (s.e., 0.7; range, 5–12 y; N = 10).

Waiau River (Southland)

The Waiau River was visited on 21 February 1996 to determine whether elver migration was occurring and to assess its potential for elver collection. The visit was partly prompted by a report of masses of desiccated elvers on the gravel banks 50–100 m below the weir on 15 January. Mararoa Weir and Monowai Power station were checked during the afternoon, and during the same evening in darkness when elver migration is most intense. Elver numbers and behaviour were documented and samples of elvers were collected. A return visit was made in mid March 1996 for further observations.

The thousands of desiccated elvers seen in mid January were not evident on 21 February. Under normal operating conditions the weir is closed and the Waiau and Mararoa Rivers are diverted into Lake Manapouri and thence into West Arm Power Station. Between 1 December 1995 and 29 February 1996 the gates were opened and closed on six occasions (ECNZ source) to discharge flood waters with flow varying between 35 and 415 cumecs, the greatest flows being in mid January. This led to intermittent water coverage of the gravel banks below the weir and the elvers in this area becoming stranded. This probably caused the mass mortality in mid January and probably occurs repeatedly under this type of flow regime.

Elvers were easily found in the ponding area below Mararoa Weir during the daytime by lifting small rocks and disturbing shingle. During darkness, elvers emerged from their hiding places and began to mass and climb near sources of water discharge, at the concrete ramp below the gates, and along the vertical walls on either side of the gates. Many elvers were seen swimming into the trout pass, but it is unlikely that they were successful in negotiating this pass in which flow rates were very high. Trout, large longfinned eels, and rats were seen feeding on the elvers.

A sample of 46 elvers collected with a dip net showed that all but 2 were longfinned (96%), with a mean length of 131.5 mm (s.e. 2.9 mm) and an average weight of 2.2 g. This would approximate to 454 elvers per kg. A second sample of 33 elvers taken for ageing were also all longfinned with a mean length of 126.3 mm (s.e. = 3.79, range 91–167 mm) and mean age of 5.2 y (s.e. = 0.38, range 2–11 y).

At Monowai Power Station, elvers were found during the daytime at the base of the concrete wall at the turbine outlet. They had burrowed deeply into the shingle and could be collected only by digging and then using dip nets. During darkness, elvers were observed climbing the wet fan-shaped area of wall fed from a small trickle of water. Small elvers were the most successful at climbing vertical surfaces. Larger elvers massed near the edge of the turbine outflow and at the base of the walls.

On a return visit in mid March elvers were difficult to find and accumulation of elvers had ceased at both sites.

Waitaki River (North Otago)

The Waitaki River and upper catchment has been extensively dammed for hydroelectric power generation. The first two dams on this river are Waitaki and Aviemore (completed in 1935 and 1968, respectively). Elver passes were installed in the summer of 1992–93 on both dams, although only 10 and 8 elvers were recorded as successfully using the passes at Waitaki and Aviemore, respectively, over the combined 1993–94, 1994–95, and 1995–96 summers (*see* Table 1). Modifications to improve the effectiveness of these passes were documented in a report commissioned by ECNZ (Zelco New Zealand Ltd 1995). To date, these modifications have not been made, nor are they planned (Greg Carson, ECNZ, pers. comm.). No elver counters have ever been deployed at this dam although the passes are monitored by a Fish and Game officer during the migration period. Until these modifications are effected, there is little value in installing an elver counter on Waitaki Dam elver pass.

Discussion

Record flooding in the Clutha River when elvers were expected to arrive at Roxburgh Dam delayed the installation of the traps, which would otherwise have been in place by early January. There are three factors that could explain the lack of elvers seen and/or trapped at Roxburgh Dam.

1. High flow rates adversely affected the ability of elvers to negotiate the river and prevented large numbers of elvers from accumulating at the base of the dam

2. The timing of the attempt in mid February was too late: migration had ceased for the year.

3. 1995–96 was a poor season for elver migration in the Clutha River.

The lack of elvers at Roxburgh Dam in 1995–96 may be attributed to a combination of all three factors. Upstream progress is achieved by alternate bursts of swimming in the boundary layer or water column and by resting in the substrate (Barbin & Krueger 1994). Increased flow during the summer floods would have made arrival at Roxburgh Dam at this time energetically very expensive with few places to rest below the dam. Evidence of migration before the trapping attempts is supported by the presence of elvers in the water-cooling filters of the outermost turbines, and during routine maintenance in January, elvers were found in the turbine chambers (Roxburgh Dam operators, per comm.). This indicates that elvers travel close to the sides of the river, thereby avoiding higher midstream velocities by using the protection of rocks and river banks. Historically, elver presence at Roxburgh Dam has been intermittent, with no elver run observed in 1960 (Boud & Cunningham) and 1983 and 1984 (Pack & Jellyman 1988). Elvers were seen at Roxburgh dam in 1971, though this was not quantified (Jellyman 1977).

Elvers were clearly migrating on the Waiau River system during January and February 1996. The contrast between elver presence at Roxburgh Dam and on the Waiau River at the same time shows that elver migration frequency and intensity can vary between geographically close catchments. Elver migration on the Waitaki River over the last few years has also been poor. The Mararoa Weir is logistically more suitable for trapping elvers and also carries a greater likelihood of success than Roxburgh. The Mahinga Kai Trust (Waiau Working Party), using funding provided by ECNZ, planned to collect elvers from below Mararoa Weir in 1996–97 and manually transfer them to Lakes Te Anau and Manapouri: the long-term option of installing an elver pass is also being investigated. ECNZ has plans to build a Borland Fish Lift at Mararoa Weir to facilitate upstream passage of brown trout, but this will be of little or no value in assisting elvers over the weir. ECNZ has also agreed to a new flow regime for Mararoa Weir in which a minimum residual flow will be maintained (not less than 16 cumecs between November and March, 14 cumecs in April and October, and 12 cumecs during the winter months). This should reduce strandings provided discharge of floodwaters is not too severe and/or frequent during the summer migration.

An elver counter and data logger should be installed on the elver pass at Waitaki Dam, but only after the recommended modifications to the pass have been completed. Numbers using the pass have been insignificant and elver migration in the Waitaki River in recent years has been poor (Davis-Te Maire 1994, 1995), so the low counts may not be wholly due to a poorly functioning or designed elver pass. There were many elvers at Waitaki Dam in the 1980s (Waitaki Valley Acclimatisation Society 1986). In the Waitaki catchment, eel ages predate the years of dam construction (Mitchell & Davis-Te Maire 1993), indicating that no eels have managed to migrate upstream since the dams were built.

Age, growth, and relative abundance of eels in some South Island lakes

Introduction

Eel populations in Lakes Wanaka, Dunstan, Wakatipu, and Hawea were sampled to provide estimates of relative abundance, age, and growth before future stocking with elvers. Recruitment into these lakes is considered to be extremely limited since the construction of Roxburgh Dam in 1958. As there is likely to be little natural recruitment and eels are lost to the remnant population when they undergo spawning migration, the population can be described as aging. No elver transfers initiatives are known for any of these lakes.

Methods

Sampling

Each lake was divided into a number of geographical strata of similar size: strata boundaries were usually defined by points, bays, or some other geographical feature. A representative portion of each lake was selected for the budgeted fishing effort between 14 November and 22 December 1995 (Figures 18–20). Using a chartered vessel and nets, 20 standard commercial baited fyke nets were set per strata during the morning, after which nets set the previous day were retrieved. Escape tubes were blocked for samples taken near the outlet of the Clutha River from Lake Wanaka where it was known that the smallest eels in the lake are usually caught commercially. At all other sites, escape gaps would have been ineffective because of the large size of these eels. Soak time was standardised at 24 h unless weather prevented retrieval. Nets were set near the shoreline in depths ranging from 1 to 10 m in sites scattered evenly throughout the strata and selected on the basis of favoured eel habitat (macrophyte beds, log jams, undercut banks). Captured eels were taken ashore and subjected to a lethal dose of 2-phenoxyethanol before having species, length and weight recorded, gonads checked for sex and stage, and otoliths removed. Otolith pairs were prepared at a later date using the crack-and-burn method (Hu & Todd 1981). All otoliths taken were processed except those from Lake Wanaka, where a length stratified subsample was processed.

Age structure and growth

Length-weight models were derived for each location in the form of

$$\ln \mathit{weight}\ (\mathrm{g}) = \ln a + b \ln \mathit{length}\ (\mathrm{mm})$$

Growth was described by Model I least-squares linear regression of length-at-age and weight-at-age for samples from each location calculated using using SYSTAT (Wilkinson 1990). Equations took the form

$\mathrm{length} = a + b\,\mathrm{lake\text{-}age(y)}$ and $\mathit{weight} = a + b\,\mathrm{lake\text{-}age(y)}$.

Relative abundance

Accurate relative abundance indices for eel populations are difficult to determine because of large variations in eel behaviour in response to factors such as moon phase, water temperature, and water level. The present study sought to apply standard efforts over the water bodies fished and attempted the task in the shortest time possible, avoiding new moons, freshes etc., to limit effects of extraneous factors on catches. Catch per unit effort (CPUE) was derived by relating the total effort applied (total net n) to the numbers or weight of eels caught (number of eels or weights/number of nets). Soak time was generally overnight.

Results

A total of 488 longfinned eels (355 of them from Lake Wanaka) were caught and sampled: no shortfinned eels were caught. Eel length and weight ranges were similar for Lakes Wanaka, Dunstan, and Wakatipu and the largest eel was taken from Lake Hawea (1240 mm, 7640 g) (*see* Table 10). Regression coefficients for length-weight, length-age, and weight-age are given in Tables 10, 11, and 12, respectively.

The length frequency distribution for Lake Wanaka has a single mode around 600–700 mm and is skewed slightly to the right; no eels under 440 mm were caught (Figure 21). The smallest eels were caught near the Clutha River outlet of Lake Wanaka (outlet mean length, 587 mm; Lake Wanaka mean length, 695 mm). Small sample sizes for Lakes Dunstan and Wakatipu make it difficult to determine if modes are present, but length ranges are similar to that in Lake Wanaka. Length distribution has not been plotted for Lake Hawea because only three eels were caught. Mean lengths and weights were smallest for Lake Wanaka, followed by Lakes Dunstan, Wakatipu, and Hawea (*see* Table 10).

Age ranges of eels from all lakes were similar (15–66 y) (Figure 22, Table 11). Excluding Lake Hawea, where sample size was small, mean annual length and weight increments were also similar at about 20 $\mathrm{mm.y^{-1}}$ and 44 $\mathrm{g.y^{-1}}$ respectively (Tables 11 and 12). (Because eel weight increases as a cubic function of length, the annual weight increments of these large eels are much greater than for

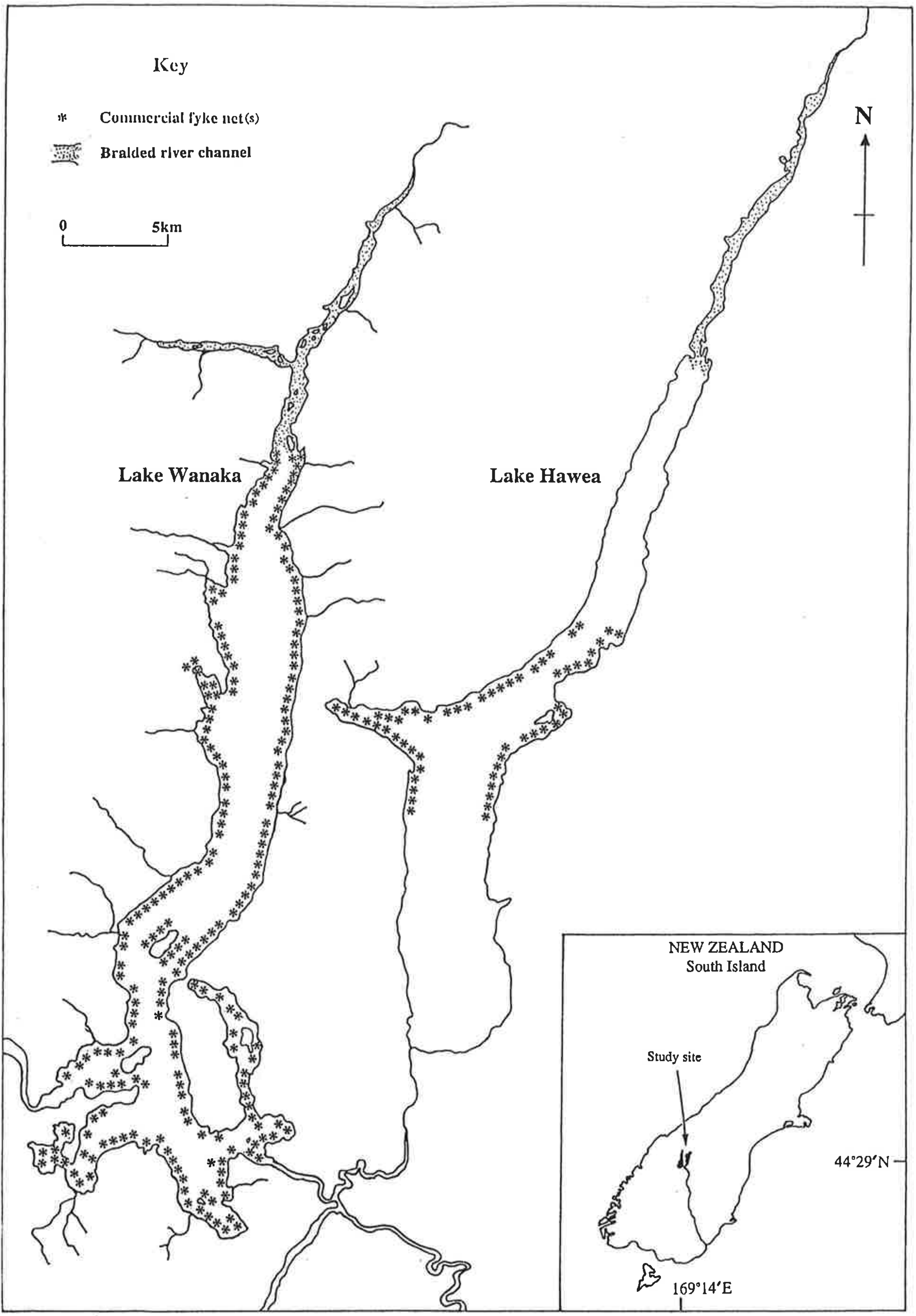

Figure 18: Map of Lakes Wanaka and Hawea (South Island) showing net positions used during sampling, November–December 1995.

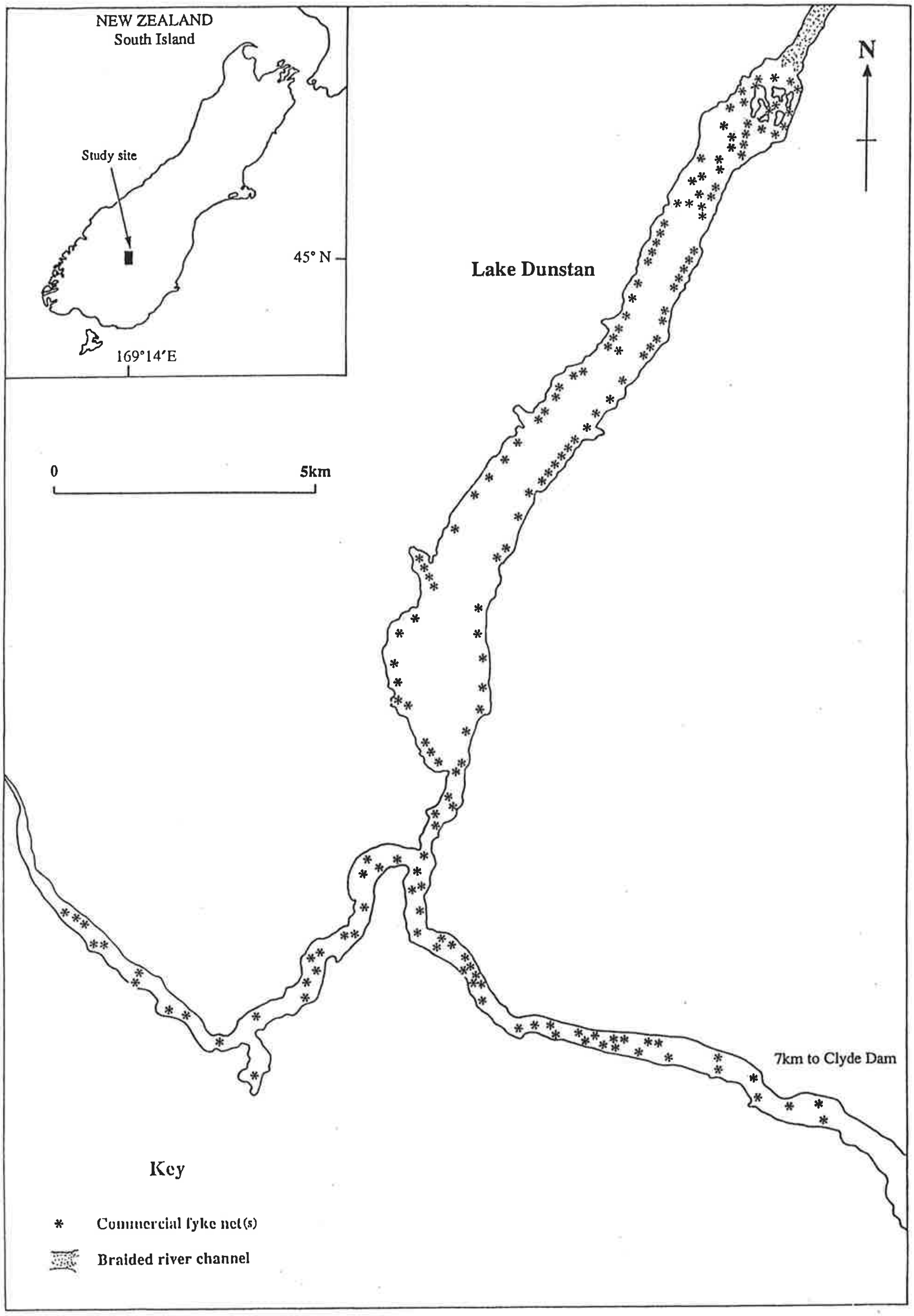

Figure 19: Map of Lake Dunstan (South Island) showing net positions used during sampling, November–December 1995.

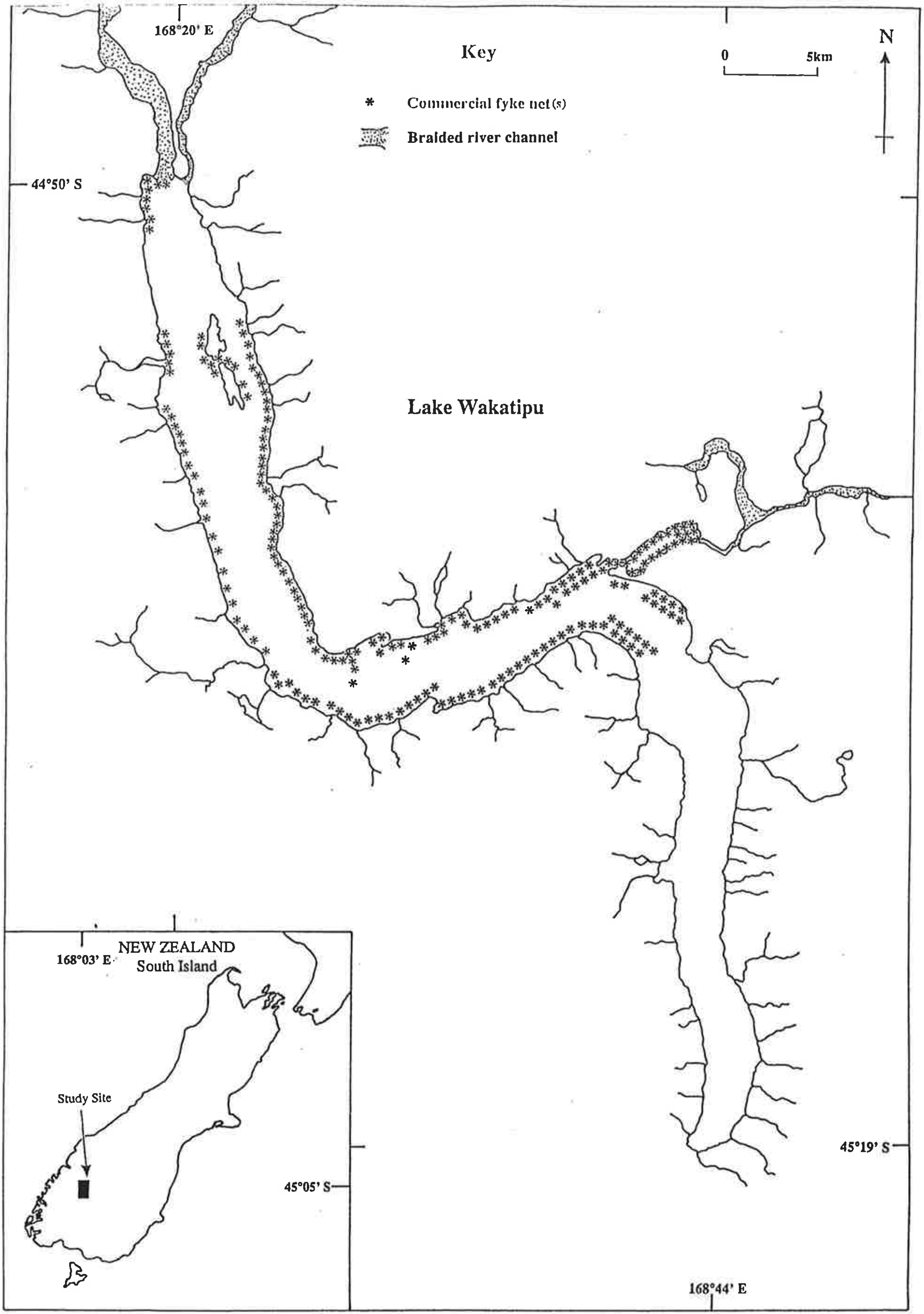

Figure 20: Map of Lake Wakatipu (South Island) showing net positions used during sampling, November–December 1995.

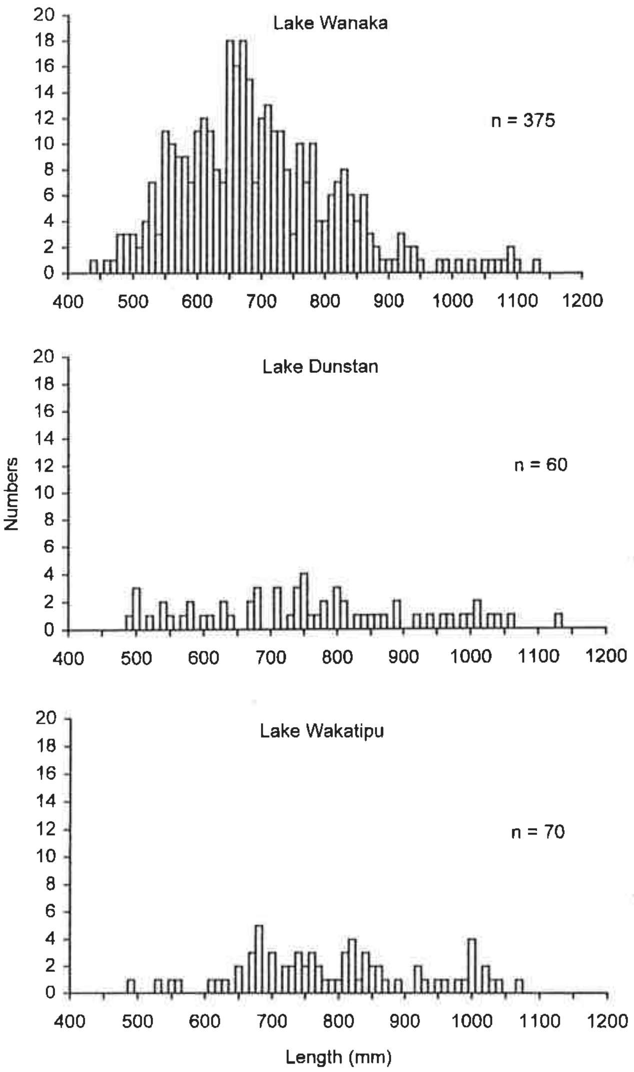

Figure 21: **Length frequency distributions of longfinned eels caught in Lakes Wanaka, Dunstan, and Wakatipu in November–December 1995.**

those under 220 g and should not be used to estimate the time to reach 220 g.) Most eels did not exhibit central narrow growth bands, although 12% and 23% of eels from Lakes Wanaka and Wakatipu, respectively, had 6–14 narrow central growth bands. The time spent below dams could therefore not be determined from otoliths.

CPUE (eels per net per night) was highest in Lake Wanaka (0.94), followed by Lake Dunstan (0.40), Lake Wakatipu, (0.20), and Lake Hawea (0.04) (Table 13).

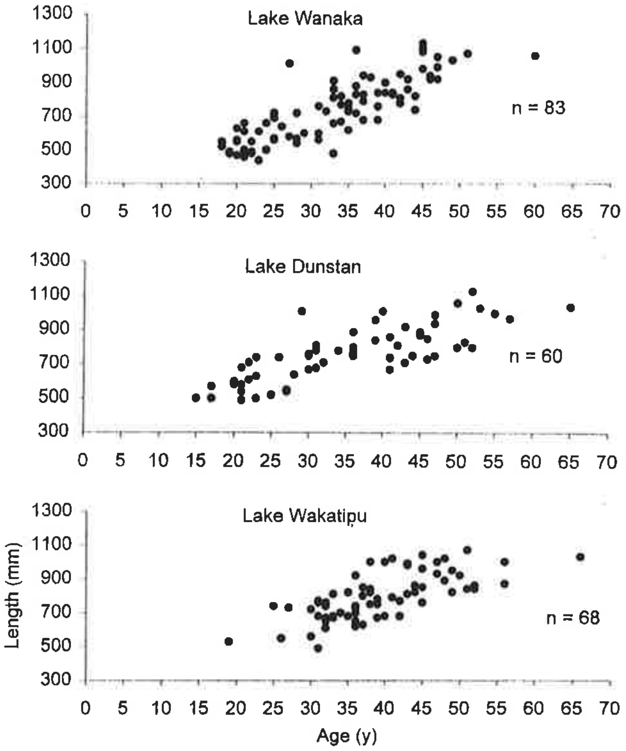

Figure 22: **Age of longfinned eels caught in Lakes Wanaka, Dunstan, and Wakatipu in November–December 1995.**

Discussion

Of the eels caught in Lakes Wanaka, Dunstan, and Wakatipu during this study, 57% were less than 38 y old and therefore must have recruited to these lakes after Roxburgh Dam was constructed, 37 years ago. A comparison of eel stocks below and above the dam showed that eels in Lake Roxburgh were considerably larger and older than eels from below the dam (Pack & Jellyman 1988) but limited recruitment had occurred as only 2 of 15 eels were older than 32 y, the period between dam completion and sampling. A 1996 study of eel populations in the Clutha River above Lake Dunstan (Charles Mitchell, pers. comm.), yielded similar minimum ages to this study and concluded that eels must have been gaining access above Roxburgh Dam until about 16 years ago. Discussions with power station staff revealed that in the 1980s one operator at Roxburgh Dam would facilitate elver passage by allowing a small trickle of water to pass down one of the spillways when elvers were observed attempting to migrate. Trapping confirmed that elvers were successfully negotiating the spillway (Dave Richardson, commercial eel fisher, pers. comm.). The retirement of the operator in the early 1980s saw an end to this practice and recruitment since then seems to have been nil.

Unstocked New Zealand lakes where hydro dams have impeded passage of elvers are generally characterised by remnant eel populations dominated by large longfinned eels, some of great age (e.g., Chisnall & Hicks 1993). As could be expected without stocking, eel populations in upper Clutha lakes were characteristic of remnant stocks, with skewed size frequency distributions towards large eels and low relative abundance. Despite low densities, growth rates here were slow, typical of high country oligotrophic lakes (20–25 y to attain the minimum legal size of 220 g). The relative abundance estimates for these lakes would vary depending on the conditions in the lakes at the time. For example, a greater catch would be expected later in the season when water temperature had increased. There are no relative abundance estimates for the eel fishery on these lakes and therefore the CPUE estimates should be regarded as a benchmark or reference abundance index. Any future estimates should be carried out using the same gear, in the same areas, and at the same time of year to be directly comparable.

Evaluation of South Island lakes for eel enhancement

Growth rates

Juvenile eels transplanted into waters already containing eels cannot be expected to grow any faster than the resident eels — if anything, growth rates would be slower, particularly if food and space were limiting. Hence, some assessment of known growth rates will give an indication of the growth that can be expected for transplanted eels. The results of several studies of growth rates of eels in South Island lakes are summarised in Table 14 as mean length for given ages.

For longfinned eels, lengths may be converted to weight from

$$\log W = 3.488(\log L) - 15.947$$

where W is weight (g), and L is length (mm).

It can be calculated that the minimum legal weight of 220 g equates to a length of 454 mm, and a 1 kg eel is about 700 mm long. In Lake Ellesmere, shortfinned eels will achieve commercial size within 15 y. The equivalent size for longfinned eels would take about 10 y in Lake Roxburgh, 13 y in the Lake Coleridge region, 17–18 y in lakes of the Waiau catchment, and 23 y in Lake Rotoiti. Growth in Lakes Benmore and Tekapo seems at least equivalent to that in Lake Roxburgh, and early growth in Lake Ohau is similar to Lake Rotoiti. Although sparse, these data serve to show that in cool, oligotrophic, high-altitude lakes, growth can be expected to be slow, with eels taking 10–20 y to achieve minimum legal. Unfortunately, most of the large South Island lakes affected by hydro development are of this type.

Assessment of potential

Estimates based on physical features of lakes

Most South Island lakes with intermittent (or nil) recruitment of elvers are large lakes modified for hydrogeneration. As such lakes are currently being targeted by industry for enhancement, the following assessment is done for South Island hydro lakes over of 5 km² surface area. Many smaller artificial ponds with considerable enhancement potential are outside the scope of this report.

Desktop assessments of the fisheries production of lake ecosytems invariably use such factors as surface area, temperature regime, trophic status, and extent of the littoral zone (e.g., Vostradovsky 1988). Physical features of 35 South Island lakes likely to influence production of eels are summarised in Table 15. The most important factors are the temperature range and the extent of the littoral zone, i.e., the zone where there is sufficient light to maintain growth of rooted plants, where most of the benthic food production occurs. Although eels in Lake Wakatipu have been caught to a depth of 120 m, and some chironomids and snails will occur deeper than this, most fishing will be within the littoral zone (Jellyman & Todd 1980).

For present purposes, the littoral zone was defined according to a series of ranked preference criteria. The first preference was to use the attenuation coefficient of downward irradiance (K_d), and then estimate the euphotic zone (1% surface light) i.e., depth of the euphotic zone = $4.6/K_d$. If K_d were unavailable but secchi disc depth was, then the latter was converted to K_d using $K_d = 1.44/\text{secchi}$

Table 14: Mean length (mm) at age for both species of eel from South Island lakes. *, best estimate as age/length relationship not significant ($p > 0.05$)

	Age										
	5	10	15	20	25	30	35	40	45	50	Reference
Shortfinned eels											
Lake Ellesmere	240	360	480	590	710						Jellyman 1997
Longfinned eels											
Lake Rotoiti	290	330	380	420	470	510	560	600	640	690	Jellyman 1995
Lake Roxburgh		480	560	630	710	790	860	940			Pack & Jellyman 1988
Waiau (various sites)			400	500	600	680	760	820	900	960	Mitchell & Davis-Te-Maire 1994
Lake Benmore*						980	1 120	1 240			Mitchell & Davis-Te-Maire 1993
Lake Tekapo*							800	940	1 060	1 180	Mitchell & Davis-Te-Maire 1993
Lake Ohau*								650	780	880	Mitchell & Davis-Te-Maire 1993
Lake Coleridge region		390	480	560	630	690	750	810	860	910	Mitchell & Davis-Te-Maire 1995

depth. If neither K_d nor secchi depth were available, then the maximum depth to which macrophytes grow was used (Anne-Maree Schwarz, NIWA, pers comm.). Failing all of the above, then a simple "average" euphotic zone depth was estimated from the status of the lake (with some allowance made for special features like lowered light penetration due to the presence of glacial flour, etc.).

The area occupied by the littoral zone was then estimated from bathymetric maps (e.g., Irwin 1969) by measuring the distance occupied by the nearest isobath corresponding to the depth of the littoral zone along 6–10 equally spaced transects across the lake (the actual number varied according to the shape and bathymetric complexity of the lake); the resulting mean distance was converted to a percentage of the lake at that depth, and then to an equivalent area from the known surface area of the lake (*see* Table 15). Unfortunately there are no bathymetric maps for Lakes Green, Hakapoua, Onslow, Poteriteri, Roxburgh, and Dunstan (although approximate bathymetric data were known for this lake). The lakes with the largest littoral zones were (in decreasing order of size) Ellesmere, Wakatipu, Hawea, Benmore, Te Anau, Tekapo, Wanaka, Coleridge, Mahinerangi, and Dunstan. Except for Lakes Ellesmere, Dunstan, and possibly Benmore the others are all oligotrophic, low productivity lakes.

Many of the lakes listed in Table 15 have been developed for hydro power and are those most likely to benefit from elver enhancement. Assuming the extent of the littoral zone to be the major factor limiting eel production, the theoretical yields from these 21 lakes, under appropriate stocking regimes (Appendix 1), can be estimated (Table 16). Collectively these lakes cover 1627 km^2, and require an estimated 2.89 million juvenile eels per annum to produce an annual yield of 145 t. Greatest yields are from Lakes Wakatipu (27 t), Benmore (25 t), Hawea (23 t), Te Anau (9), Dunstan (9), Tekapo (8), Wanaka (8), and Brunner (7).

Yield estimates from yield equations

Leopold & Bninska (1984) reviewed 454 Polish lakes to determine the factors important in assessing potential yield of eels to the fishery. They concluded that eel catch was dependent upon stocking rate, an index of exploitation (expressed as the number of months per year in which fishing was possible), average depth of the lake, and the shoreline development (i.e., the length of shoreline/surface area is a measure of shoreline indentation). The relationship they developed was:

$$Y = -0.70 + 0.0077z + 0.381x + 0.0119u - 0.082v$$

where Y = yield of eels (kg.ha^{-1})
z = stocking rate (number.ha^{-1})
x = average number of months when fishing is possible
u = shoreline development (m.ha^{-1})
v = average depth

The average yield of eels from deep, large lakes with poorly developed shorelines was 1.09 kg.ha^{-1}, compared with 2.01 kg.ha^{-1} for smaller, shallower, more eutrophic lakes with well developed shorelines.

Yields for a range of New Zealand lakes were estimated from the data in Table 14. Unfortunately, the relationship does not fit deep lakes well as it is very sensitive to mean depth and gave negative results for all large glacial lakes. For other lakes it gave results ranging from 1 kg.ha^{-1} (Lake Benmore, assuming a mean depth of 30 m) to 3.9 kg.ha^{-1} (Lake Ellesmere). Thus, although results followed a predictable order with oligotrophic lakes producing a lower yield than eutrophic lakes, estimated yields were considerably lower than expected, and it was concluded that the model was not an appropriate one for New Zealand conditions.

Table 15: Physical criteria for South Island lakes over 5 km² in area. Type: g, glacial; r, riverine; b, barrier; d, man-made dam. Trophic status: o, oligotrophic; m, mesotrophic; e, eutrophic; d, dystrophic; *

Lake	Type	Trophic status	Area (km²)	Altitude (m)	Max depth (m)	Mean depth (m)	Shoreline length (km)	Shoreline development (m/ha)	Min. temp. (°C)	Max. temp. (°C)	Max weed depth (m)	Secchi (m)	Coeff. downward Irradiance K_d	Euphoti c zone (m)	Littoral area %	Littoral area (ha)
Alexandrina	g	m	5.8	747	30	13.4		30.2			17	6	0.4	11.5	53	307
Aviemore	r	o	24.8	271	62		46	18.5		13.3	3.5	1		3.2	8	192
Benmore	r	o	68.6	360	120		145	21.1				4		12.8	36	2 485
Brunner	g	m	36.1	86	109	51	42	11.6		17.8	7.8	4.5	0.57	8.0	20	728
Coleridge	g	o	32.9	507	200	99	47	14.1	10	15	35	13	0.14	32.9	41	1 341
Dunstan	g	m	25.2	180	54	14.5	104	41.1				5		10.0	34	857
Ellesmere	b	e	181.7	15	2.1		102	5.6			2.1	0.1		0.3	100	18 170
Forsyth	r/b	e	5.6	36	4.1		17	30.4				0.2		0.6	100	560
Green	g	o	5	838			11	22.6								0
Hakapoua	g	o	5	15			15	30.6								0
Hauroko	g	o	68.3	157	462	231	92	13.4			16	15.1	0.3	15.3	12	800
Hawea	g	o	137.6	347	384	192	124	9.0		14	31	18.8	0.14	32.8	34	4 654
Heron	r	o	6.3	694	37		23	35.7			9			10.0	79	499
Hochstetter	g	d	6.6	256	16.8		12	17.4		19	1.5	1.75	2.41	1.9	27	181
Kaniere	g	d	14.6	132	197		23	15.4	10.2	22.2	7	7.7	0.39	11.8	14	207
Mahinerangi	r	o	18.6	391	31.2	6.2	109	58.7				3.1		9.9	48	901
Manapouri	g	o	143.3	179	444	100	167	11.7	8	17.7	10	6.5	0.3	15.3	3	451
Mapourika	r	o/m	8.3	76	114		18	21.1				4		12.8	16	132
Mavora N	g	o	10.8	619	77.4		26	24.2			10.5	8.09	0.24	19.2	39	424
McKerrow	gb		18.3	3	121.3		36	19.7						15.0	20	372
Monowai	g	o	32.5	206	161	80	59	18.1		13	12.6	7.8	0.3	15.3	11	356
Ohau	g	o	53.8	517	129	74.5	48	9.0	7.1	12	20	9.6	0.22	20.9	14	749
Onslow	d		8.3	685			32	38.0								0
Poteriteri	g	o	42.5	23			65	15.2	7.5							0
Pukaki	g	o	98.9	494	70	47	88	8.8		11	0	0.6	1.56	2.9	4	351
Rotoiti	g	o	9.2	609	82	49.2	23	25.0	0	20	14.5	12.2	0.26	17.7	28	254
Rotoroa	g	o	21.4	444	152	96.5	34	15.7	7	21	21	13.9	0.28	16.4	22	462
Roxburgh	r	o	6	133	45	13.3	60	100.0	6	21.5	9	2.8		8.9		0
Sumner	g	o	11.8	521	134.5		26	21.6	10.9	13.5	15	4	0.33	13.9	19	224
Te Anau	g	o	347.5	203	417	132	312	9.0	8.8	16.8	13.1	10	0.28	16.4	5	1 817
Te Anau	g	o	347.5	203	417	132	312	9.0	8.8	16.8	13.1	10	0.28	16.4	5	1 817
Tekapo	g	o	86.8	708	120	69	152	17.5	12	13.1	0	4.1	0.634	7.3	18	1 535
Waihola	r		6.1	0	16		19	31.1						0.8	100	610
Waitaki	d	m	5.1	230	40		21	41.2						3.2	22	111
Wakatipu	g	o	289.7	310	380	210	199	6.9	8.7	16.7	30.6	12.6	0.1	46.0	19	5 464
Wanaka	g	o	180.1	277	311	155	176	9.8	8.5	16.9	23.6	17	0.18	25.6	8	1 507

* Lake areas, altitude, status, type, temperature and mean depth came from Livingston *et al.* (1986) and Viner (1987). Shoreline length was calculated from NZMS260 maps.

Table 16: Estimated annual yield of eels from those South Island lakes affected by hydro development. -, unknown

Lake	Stocking rate (no/ha)	Total eels stocked	Expected yield (kg.ha^{-1})	Estimated annual yield (t)
Alexandrina	200	61 352	10	3.1
Aviemore	100	19 245	5	1.0
Benmore	200	496 938	10	24.8
Brunner	200	145 555	10	7.3
Coleridge	100	134 068	5	6.7
Dunstan	200	171 400	10	8.6
Hawea	100	465 363	5	23.3
Kaniere	100	20 747	5	1.0
Mahinerangi	100	90 136	5	4.5
Manapouri	100	45 140	5	2.3
Mavora N	100	42 368	5	2.1
Monowai	100	35 588	5	1.8
Ohau	100	74 943	5	3.7
Pukaki	100	35 110	5	1.8
Te Anau	100	181 743	5	9.1
Tekapo	100	153 462	5	7.7
Waitaki	200	22 297	10	1.1
Wakatipu	100	546 374	5	27.3
Wanaka	100	150 744	5	7.5
Totals		2 892 572		144.6

Discussion

The main purpose of this overview has been to identify the larger South Island lakes with the greatest potential for eel enhancement. Of the 35 lakes over 5 km², 21 are affected by hydro development in some way, and probably have associated problems for recruitment of juvenile eels. Yield estimates (based on overseas data) suggest that these lakes could contribute an additional 145 t of eels annually. Lakes Manapouri, Monowai, and Te Anau are within Fiordland National Park where commercial fishing is prohibited so any enhancement of their populations would be for the long-term benefit of longfinned eels as a species, but would not benefit the commercial fishery.

Growth rates in these (generally) high altitude, cool, oligotrophic waters will be slow, and eels will take 10–20 years to achieve the present minimum legal size of 220 g. Thus, enhancement of these lakes should be regarded as a medium- to long-term investment in the industry, and not one that will produce immediate gains.

Eel growth rates are highly variable (Jellyman 1997), and more rapid growth occurs in lowland, warmer, eutrophic lakes and ponds, especially where eel numbers are low. For example, elvers transplanted into Lake Aniwhenua, Rangitaiki River, averaged 105 cm (about 3 kg) after 10 y (Chisnall 1993), but such rates remain the exception rather than the rule.

Wherever feasible, juvenile eel stock for transplants should be obtained from within the same catchment to stop transfer of diseases and undesirable aquatic weeds, and because there may be a number of separate stocks of eels within New Zealand. Although most diseases of eels are probably ubiquitous, one localised parasite is known (the copepod *Abergasilus amplexus*, which affects 80–100% eels in Lake Ellesmere (Hewitt 1978)) and others are possible. While separate stocks of eels within New Zealand seem unlikely, the possibility is currently being investigated by NIWA through establishing DNA profiles of both species from a wide range of locations. Until this has been resolved, it is prudent to minimise mixing of eels from different catchments.

General discussion

Dams and weirs often provide an impenetrable barrier to elver migration in many New Zealand rivers. Installation of elver passes and manual transfers have lessened the impact of hydro development on elver migration. There is no way of estimating to what extent these initiatives are mimicking natural recruitment, but it is clear that on rivers such as the Waitaki, Clutha, and Waikato recruitment would otherwise be virtually nil. Historically, advice from fishery managers was often that exclusion of eels from waters above hydro dams was advantageous as it promoted the development of trout fisheries, for example, Roxburgh Dam (Jellyman 1993) and Arnold Dam (Jowett 1987). This would explain why so many hydro structures were built without the requirement to mitigate the obstruction to eel passage. Attitudes have now changed and there is greater awareness of the desirability of maintaining and/or restoring elver and spawning eel migrations (e.g., Jellyman 1993, recommendation no. 6, p. 32). Enhancement can have the following positive results: it restores the intrinsic value and ecological balance to habitats; it provides a greater reservoir or reserve of spawning stock; commercial and customary eel fisheries are enhanced; it opens new areas to commercial fishing, which relieves pressure within existing fishing areas; and as elver growth and mortality are probably density dependent, by transplanting elvers from dense aggregations, growth is accelerated (results of this study) and mortality may be reduced.

Lakes Te Anau and Manapouri lie within Fiordland National Park and constitute about 73% of New Zealand longfinned eel lake habitat. However, the lack of access to these lakes by elvers as a result of the Mararoa Weir on the Waiau River means that eel populations are declining rapidly as spawning eels continue to migrate. Additionally, these spawning eels incur 100% mortality as they attempt to migrate through West Arm Power Station. Stocking is required to restore the eel populations; equally important is a solution to prevent mortality of migrating spawning eels.

Elver passes on the Waitaki, Patea, and Rangitaiki Rivers provide a means of passive elver transfer over the entire migration season, provided that they are well maintained and supplied with running water. Patea Dam elver pass, for example, provided passage for at least 80 000 elvers (80 kg) in 1993–94. Elver passes, however, are less favourable for the larger longfinned elvers which appear to be less successful in climbing the passes than shortfinned elvers. To provide accurate data on numbers and frequency of passage of elvers, passes should be equipped with electronic elver counters and data loggers which need to be properly maintained and checked regularly.

Manual stocking in North Island hydro lakes has been highly successful, particularly in the Waikato River, due to the coordinated efforts of ECNZ, government departments, the eel fishing industry, Maori, and NIWA. It has the advantage over passive transfer in that it can move large numbers of elvers in a short time to any chosen location, does not discriminate between species, and probably includes a greater size range. Properly monitored, it can provide exact and accurate data on species composition, age, length, weight, and quantities moved to specific areas. It is strongly recommended that these data be recorded so that the best possible relationship between stocking density and yield can be determined. Data from Karapiro Dam before 1995–96, recorded as a condition of an MFish special permit, provided only approximate estimates of quantities and spurious release data. In the South Island, manual elver transfers were attempted for the first time in 1995–96, but no transfer resulted because there were no elvers. Historical information on elver migration on the Clutha River indicates that the number of elvers trapped at Roxburgh Dam is likely to be highly variable between years as migration of elvers is sporadic. Elvers sampled below Roxburgh Dam and Mararoa Weir in 1995–96 were considerably larger and older than those from below Karapiro Dam and most were probably repeat migrators.

In the North Island, enhancement programmes in Lakes Karapiro and Arapuni are likely to see short term benefits as growth from elver to a commercial size is within 2 y. In contrast, growth rates in the oligotrophic South Island Lakes Wanaka, Wakatipu, Dunstan, and Hawea are slow, requiring 20–25 y for longfinned eels to reach the current minimum legal size of 220 g. It can, therefore, be regarded a medium- to long-term investment for the eel fishing industry.

Overseas enhancement programmes using glass-eels, elvers, or juvenile eels provide a basis on which to model a New Zealand programme. Stocking rates and associated yields are highly dependent on the water type or productivity. Annual stocking rates between 100 and 300 glass-eels per hectare and annual yields of 5–15 $\mathrm{kg.ha^{-1}}$ have been assumed appropriate for New Zealand lakes, with the highest stocking rates and yields in eutrophic and the lowest in oligotrophic lakes. By failing to ensure that waterways are negotiable to elvers during migration, the full potential of these areas as eel fisheries is not realised. The 21 South Island recruitment limited hydro lakes, for example, could yield an estimated additional 145 t of eels annually if appropriately stocked.

Acknowledgments

This research was carried out by NIWA under contract to the Ministry of Fisheries as a part of Eel Fisheries and Enhancement, MFish Project No. INEE01

NIWA thanks the following for their assistance in this research programme: Bill Gibson, Mike Holmes, Neil Gillespie (Contact Energy), Peter Gwynn (Egmont Electricity), Dr Ian Johnston (ECNZ), Karapiro Dam station staff (ECNZ), Lindsey Kerr, Charlie Mitchell, Mossburn Enterprises, Rra Muru, Shirley Nichols, North Island Eel Industry, Dave Richardson, Bosem Rota, Roxburgh Dam station staff (Contact Energy), South Island Eel Industry Association, Tainui, Victor Thompson, and Grant Williams.

The following NIWA staff contributed to this programme: Rhys Barrier, J. Cairney, Mark Lokman, David Speirs, Rob Wass, and Andrew Willsman. Larry Paul reviewed the manuscript and provided helpful suggestions on presentation.

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Appendix 1: Review of overseas stocking rates for elvers/juvenile eels and yields

Starting stock

Glass-eels, the most widely used starting stock for transplants, are used in Ireland, Austria, Finland, Poland, Sweden, and Russia. Italy appears to use elvers of 5–20 g (Rossi *et al.* 1988) plus some even larger eels (Minervini *et al.* 1990). Sweden mainly uses 10–100 g eels for stocking, although recent trends have been towards using glass-eels (Wickstrom 1984).

Stocking rates

Stocking rates for glass-eels vary by a factor of 4 depending on the water type, with mesotrophic-eutrophic lakes able to sustain a higher stocking rate than less productive oligotrophic lakes (Appendix Table 1). For potential yield estimates of New Zealand lakes, stocking rates of 100, 200, and 300 glass-eels per hectare were adopted for oligotrophic, mesotrophic, and eutrophic lakes, respectively.

Yields

Yields vary considerably (Appendix Table 2), reflecting factors like nutrient status, temperature range, bathymetry, and other species of fish present (Appendix Table 2). Production from Lough Neagh (396 ha) is exceptional (21.6 kg.ha^{-1}), whereas the overall range would be 3–5 kg.ha^{-1}. In comparison, Lake Ellesmere covers about 18 000 ha, with an annual allowable catch of 136.5 t (Jellyman *et al.* 1995) which equates to 7.6 kg. ha^{-1}. For the present report, potential yield estimates of 5, 10, and 15 kg. ha^{-1} were adopted for oligotrophic, mesotrophic, and eutrophic lakes, respectively.

Appendix Table 1: Summary of various stocking rates for juvenile eels used in Europe. *, glass-eels

	No./ha	kg.ha^{-1}	Reference
Ireland. Lough Neagh	444 *	0.13	Moriarty 1990
Ireland. Shannon lakes	357 *	0.105	Moriarty 1990
Poland "optimal rate"	127 *	0.081	Moriarty *et al.* 1990
Sweden	100 *	0.029	Wickstrom 1984
Russia	23–300		Kostyuchenko & Prishchepov 1972

Appendix Table 2: Summary of yields of eels from stocked waters in Europe

	kg.ha^{-1}	Reference
Ireland, Lough Neagh	21.6	Moriarty 1990
Ireland, Shannon Lakes	0.6–1.7	Moriarty 1990
Ireland, "mesotrophic lakes"	16	Moriarty 1990
Holland, Ijsselmeer 1947	15	Van Densen *et al.* 1990
Holland, Ijsselmeer 1988	2	Van Densen *et al.* 1990
Holland, Frisian Lakes	8.6	Steinmetz *et al.* 1990
Austria	7	Deelder 1984
Poland 1980	1.1–2.1	Leopold 1980
Poland 1990 (average)	3.3	Moriarty *et al.* 1990