Enhancement of New Zealand eel fisheries by elver transfers, 1996–97

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Abstract

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***NIWA Technical Report 37.* 55 p.**

Elver transfers were monitored and eel populations in three stocked hydro lakes were evaluated over the 1996–97 summer.

Surveys of three Waikato River hydro lakes indicated thriving eel populations in each lake. Eels from Lakes Karapiro and Arapuni were still growing fast (averaging 220 g at 5 years and 2 years of age for each lake respectively), but these rates were overshadowed by the growth of shortfinned eels in Lake Maraetai (220 g in about 1 year). Such fast growth may be typically associated with the colonisation of virgin waters, but it is unlikely to continue with additional stocking. The upper Waikato hydro lakes are unlikely to sustain similar fast growth as prey abundance there is lower. Conversely, the growth rates, abundance indices, and size frequency distributions reported for Lakes Karapiro and Arapuni provide an indication of how existing populations affect eel production, and what to expect in the future from newly stocked waters. Future sampling of stocks in Lake Maraetai may allow a more accurate assessment of eel production because each year class stocked is easily recognised as there is no existing population.

Stocking rates into the two lowermost Waikato hydro lakes have been slightly higher than advocated for European fisheries in controllable waters. However, persistent low abundance indices of eels in these lakes, and the lower numbers of small eels caught in Lake Arapuni than last year, casts doubt on the survival of transferred elvers, or at least on their colonisation of the lakes themselves rather than their upper catchments. Predation and competition for resources by existing stocks may be strongly influencing population shape and ultimate success of transferred elvers in the hydro lakes. Successful colonisation by elvers is likely to be associated with the amount of suitable habitat for juveniles, stock densities, and food availability.

There was a general lack of correlation between estimated elver age (from narrow central growth bands in otoliths) and incremental growth of adults, indicating that there is no predisposition to poor growth due to retention of elvers below obstructions. This finding is encouraging for the transfer of juveniles from areas of poor growth to other water bodies, such as at the Roxburgh Dam (South Island) where longfinned elvers caught below the dam were surprisingly old (3–22 years, mean 12 years), indicating that most were repeat migrators having sustained very poor growth.

Introduction

Overview

This report presents the results of a research programme undertaken by NIWA for the Ministry of Fisheries (MFish) to monitor and evaluate elver transfers in several catchments. Success is assessed by monitoring the quantity and composition of the transfers and evaluating the survival, growth, and abundance of the new eel stocks. The species diversity and relative abundance of prey organisms is also assessed for three water bodies to establish links between food availability and eel production and gauge effects of the newly introduced eel stock on other species. Continued monitoring of elver transfer and resulting stocks provides an indication of survival and a means of determining the relationship between eel density, growth, and food availability. The data will be used to estimate potential yields, and will provide guidelines for future stockings. An elver is defined as a juvenile eel between 60 and 140 mm long (Jellyman 1977).

There have been several attempts to enhance eel populations in stock–depleted waterways by the construction of fishways or by manual transfer of elvers. In 1995–96, MFish contracted NIWA to monitor and assess the effectiveness and value of these enhancements (Beentjes *et al.* 1997): this monitoring was continued in 1996–97 (present report).

Manual stocking of the North Island hydro lakes has been highly effective in re-establishing eel stocks where passage was affected by dam construction, or in establishing new populations where previous natural barriers prevented or hindered recruitment (Beentjes *et al.* 1997). Although elver passes over low barriers have been shown to be as effective as manual transfers, numbers of elvers negotiating passes over high dams have been lower.

The most effective and coordinated programme of manual transfer enhancement has been based on the Waikato River, where manual transfers have been taking place since 1992–93. Since then, over 4 t (more than 4 million elvers: 1000 elvers to the kilogram) have been collected and transferred to several hydro lakes above Karapiro Dam and at least 270 kg have been transferred into Lake Waikare, the largest waterbody in the lower Waikato system.

High growth rates were recorded for both eel species in the North Island hydro lakes (e.g., 2 years to reach the current minimum legal size of 220 g in Lake Arapuni (Beentjes *et al.* 1997). This was attributed to a combination of low eel densities and good food availability. Variation in eel growth between the lakes appeared to be linked to the quantity and quality of littoral habitats available as well as to the diversity and abundance of prey species.

In the South Island, lakes that have potential for enhancement tend to be high altitude, cool, and oligotrophic — more suitable for longfinned eels. Growth rates are slower than in the North Island, with longfinned eels taking on average 20–25 years to reach 220 g.

The 1995–96 monitoring highlighted the need to regulate stocking to accomplish densities that suited each lake and to monitor eel prey species to ensure that food supply was not becoming depleted. Monitoring should include the accurate recording of the number, weight, and species composition of elvers transferred, as well as periodic assessment of eel stocks and associated prey species in the enhanced waterway.

In 1996–97, the objectives were to continue to monitor several key elver transfer programmes in both the North and South Islands, and further evaluate eel stocks in three Waikato River hydro lakes, Lakes Karapiro, Arapuni, and Maraetai.

North Island

Waikato River

The Waikato River basin supports New Zealand's single most productive eel fishery (over 25% of the national total). Since the 1960s, most of the lower basin has been fished intensively, in conjunction with an ever-shrinking aquatic habitat caused by agricultural development, which has decreased substantially the marketable component of the eel stock.

Eels have been recorded as far upstream as Ohakuri (Coulter 1977), presumably arriving there by natural means before construction of the hydro dams or by human transfer. However, because of natural barriers, few elvers reached habitats upstream of Horahora rapids (flooded by the construction of the Horahora Power Station in 1913 and now under Lake Karapiro). During construction of Arapuni Dam, Hobbs (1940) reported that substantial numbers of elvers did gain access to the upstream habitat. Subsequently, the completion of Arapuni Dam and the construction of Karapiro Dam all but prevented elvers from reaching Lake Arapuni and the habitat upstream. Before stocking, eel populations in the two lowermost impoundments were characterised by distinctively truncated size distributions with few eels smaller than 500 mm.

The three lakes being evaluated for this programme, Lakes Karapiro (lowermost dam), Arapuni (second dam), and Maraetai (fourth dam), were formed behind hydroelectric dams constructed on the Waikato River in 1947, 1929, and 1952 respectively. The two lowermost lakes are surrounded by extensive tracts of pastoral land, and forestry is the dominant land use upstream of Arapuni. Associated landforms are mostly gentle rolling hills, but aquatic margins are often steeply incised. Extensive beds of aquatic macrophytes dominated by *Egeria densa* and *Ceratophyllum demersum* are present throughout the littorals. The three lakes are considered to be eutrophic (Livingston *et al.* 1986).

Karapiro Dam

Recruitment. There are no elver passes on Karapiro Dam, but in wet weather elvers can successfully ascend the spillway and adjacent siphon tubes (electric fields were originally installed on the siphon and spillway to prevent elvers reaching the reservoirs where a trout fishery was being developed).

In 1993, the Ministry of Agriculture and Fisheries issued the first Special Permit authorising the North Island Eel Industry Association, in cooperation with Tainui (these groups work together as Tainui Tuna (Eel) Working Group), and the Electricity Corporation of New Zealand (ECNZ), to relocate elvers from the base of Karapiro Dam to enhance poorly stocked reaches of the Waikato River. Between the consecutive summers of 1993–94 and 1995–96, at least 1.8 t of elvers were manually transferred into Lakes Karapiro, Arapuni, Waipapa, and Maraetai, as well as into Lake Waikare in the lower basin (Table 1). NIWA and Department of Conservation staff assisted with all these transfers. In the 1995–96 season, ECNZ collaborated with NIWA and the Tainui Tuna (Eel) Working Group to test trial a collection and transfer facility at Karapiro Dam. About 1.2 million elvers were transferred into the four upper hydro lakes during the season (*see* Table 1).

The 1995–96 operation began in late December and catches were highest at the start of the season. This is in marked contrast with previous years' observations which suggested that elver migration began in mid January and peaked in February (Beentjes *et al.* 1997). Slight increases in catches were noted during the new and full moon, and during heavy rainfall. Early in the season, nearly 50% of the catch were longfinned elvers, but by mid February over 95% of the catch were shortfinned elvers. Most of the elvers transferred were between 0 and 4 years old (70–120 mm) but much older eels were also present in the catches.

Stock appraisal. There have been few attempts to document eel populations in any of the upper hydro lakes. Through a process of natural attrition (including migration of adults) and commercial exploitation, lakes upstream of Karapiro have remained virtually void of eels from about the mid 1970s. As part of an ECNZ study of the catchment, commercial eelers were contracted to sample Lakes Karapiro, Arapuni, and Waipapa in 1992 (Bioresearches 1992, *in* Chisnall 1993). The information obtained and commercial catch records, confirmed that there were few eels remaining above Arapuni Dam. Surveys of Lakes Whakamaru, Maraetai, Waipapa, and Arapuni in 1995 (Boubée *et al.* 1995) also indicated that few eels were present above Lake Arapuni.

Eel populations in Lakes Karapiro and Arapuni were evaluated in summer 1995–96 (Beentjes *et al.* 1997). Eels in both lakes were relatively low in abundance but growing 4–8 times faster than eels in the lower Waikato River basin (Chisnall *et al.* unpublished results). Eel growth in Lake Arapuni was twice as fast as in Lake Karapiro. Other differences between the two stocks, such as greater eel abundance and a lower number of longfinned eels in Lake Karapiro, reflected the more established but commercially exploited nature of the eel population in Lake Karapiro. Beentjes *et al.* (1997) concluded that as the population in Lake Arapuni was only about 15% of that in Lake Karapiro, stocking could safely continue at the same rate for several years without adversely affecting growth of the population.

Lake Waikare

Recruitment. The outlet of Lake Waikare is controlled by flood gates which are a barrier to fish migration from the lower Waikato River. An elver pass (PVC pipe with a bottle brush insert) was constructed on the outlet control gates of Lake Waikare in 1982 (Mitchell *et al.* 1984) and a second access for fish was provided in 1987 by re-opening the control gates on the Te Onetea Stream, the old lake outlet.

Because of deterioration of the brushes, the elver pass was upgraded in 1994 and replaced with a gravel-lined ramp and pipe structure. Problems with water supply continued to limit the effectiveness of the pass until Environment Waikato remedied the problem in January 1997.

After the 1994 upgrade, many elvers were observed using the pass but attempts to use an electronic counter to monitor the pass failed and no data were obtained (P. Empson, Environment Waikato, pers. comm.). A total of 150 kg of elvers were transferred to the lake from Karapiro Dam in 1993–94 and 120 kg in early February 1994–95. The species composition of the 1993–94 transfer was not determined, but in 1994–95 about 35% were longfinned elvers. On average, longfinned elvers were 1.5 g and shortfinned elvers were 1.1 g (NIWA unpublished data). No manual transfers were made in 1995–96.

Stock appraisal. Historical data on the eel stock size, distribution, density, and species composition in Lake Waikare are mostly anecdotal. This lake was commercially significant before it became a flood control area (McLea 1986). Eelers and commercial processers state that the lake was highly productive and dominated by longfinned eels. After the flood control structures were built and the outlet canal through the Whangamarino Swamp was completed in 1965, there was an initial boom in the fishery. Heavy fishing pressure combined with poor recruitment were such that by 1988 only a small population, 95% shortfinned eels, remained (Chisnall & Hayes 1991). However, since the improvement of the elver pass, the re-opening of the old lake outlet, and the release of elvers captured at Karapiro Dam (and possibly the transfer to the lake of undersized eels by the eel industry), the population appears to have increased markedly: for example, by 1992, the size distribution and relative abundance of the population were similar to those of other lowland Waikato lakes (Chisnall *et al.* unpublished results). Fast growth was a feature of the population in 1992, but the influx of new recruits through enhancement may change this.

The main food base for the lake's eel population, the mysid *Tenagomysis chiltoni*, was prolific (Hayes & Rutledge 1991), and appeared to compensate for the low availability of other prey species including low numbers of diadromous species (fish and *Paratya*).

Rangitaiki River (Bay of Plenty)

Recruitment. The two impoundments on the Rangitaiki River, Matahina Dam (completed in 1967) and Aniwhenua Barrage (completed in 1981), pose formidable upstream barriers to migrating fish. In 1983, the then Department of Internal Affairs began a programme of manual transfer of elvers from Matahina Dam to the upper catchment, including Lake Aniwhenua. Some transfers were also made by station staff and local residents, but no records were kept of the number of juvenile eels transferred or the timing of transfers.

A gravel-lined fish pass was installed on the Matahina Dam in 1991 by ECNZ, and an electronic counter and data logger were used to monitor elver movement during the three following summers (Boubée & Mitchell 1994). Elver numbers ascending the pass increased from 15 000 in 1991–92 to over 38 000 in 1993–94. These numbers are minima as during peak migrations the counter could not record individual elvers. The counter was removed in 1994 because of its sensitivity limits and the tendency of elvers to accumulate behind it, especially at the peak of the migration. No monitoring has been done since, but station staff report that elver usage of the pass has continued to increase each year.

DoC and ECNZ staff and local residents have continued manual transfers to Lakes Matahina and Aniwhenua with some assistance from Bay of Plenty Electricity. Major elver losses were reported at the collection site in 1995. Although no records were kept by local residents, the DoC data (Table 2) indicated that a manual transfer programme could be successful. In 1994, about 149 000 elvers were transferred manually to Aniwhenua. In 1995, transfers were 39 000, but this is likely to have been supplemented by unrecorded transfers made by local residents.

Timing of the migration in 1994–95, between mid January and early March, was similar to previous years (*see* Table 2). In contrast, the migration in 1995–96 was much earlier, with the largest transfer for the season occurring in late December (an early season was also recorded at Karapiro that year). Unfortunately, information collected on the species composition of elvers transferred has been sporadic (*see* Table 2) and it is not possible to determine if any changes have occurred over time.

Stock appraisal. Before dam construction, fishing for eels in the Rangitaiki River was mostly for customary use. Only a remnant population remained in the late 1970s. The sporadic manual transfer of elvers from the headrace of Matahina Dam since the early 1980s resulted in a sparse mixed species population in Lakes Matahina and Aniwhenua. When Lake Matahina was dewatered for repairs to the dam in 1988, surveys revealed a low abundance of eels of which 40% were longfins (Stancliff *et al.* 1989); the size distribution of the eels was substantially skewed towards large sizes. Since the pass was installed, manual stocking has continued. The net result of these passive and active transfers has been a significant increase of the eel stocks, particularly in Lake Matahina.

Sampling in 1996 indicated a more established eel population of a wide size range, but with a smaller proportion of longfinned eels (under 7%). The CPUE from Lake Matahina was still less than 20% of that in Lake Karapiro that year (Beentjes *et al.* 1997). Fish prey species were described as "low" in terms of diversity and abundance in both lakes. However, as both lakes are renowned for their trout fisheries, it is likely that invertebrates which support these fisheries will also be an important component of eel diet. Low eel density may have resulted in the relatively fast growth rates observed.

Patea River (Taranaki)

Recruitment. The Patea River is part of the Taranaki commercial eel fishery. 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 and Regional Water Board 1984). An earth-core hydroelectric dam was completed in the lower reaches of the river in 1984: Lake Rotorangi, formed behind the dam, is narrow and deep. A bottlebrush-lined, PVC pipe elver pass was installed on the dam face in January 1985. This was upgraded in 1991 to gravel-lined piping (Taranaki Regional Council 1992). Despite the pass, all diadromous fish (other than eels) and shrimp appear to have been excluded from the lake by the dam, but three exotic species (rainbow and brown trout and perch) are present in good numbers (Taranaki Catchment Board and Regional Water Board 1988).

Elvers have climbed the pass since its installation, peak migrations being recorded consistently in mid January with most elvers migrating over a 20 day period. The pass allows only a portion of migrant elvers access to the dam, and is selective for the smaller shortfinned elvers; larger longfinned elvers are less able to climb (Taranaki Catchment Commission and Regional Water Board 1984). There are plans to continue upgrading the pass and to instigate a programme of manual transfers (Williams 1997).

Stock appraisal. Despite poor recruitment, Lake Rotorangi and its catchment still contribute at least 26 t annually to the local eel fishery (P. Mischefski, eel processor, pers. comm.). Eel numbers are lowest in the upper catchment. Sampling in 1996 revealed catch rates similar to those in Lake Karapiro on the Waikato River. However, longfinned eels were far more abundant, making up 50% of the catch by number and 60% by weight, largely reflecting the remnant riverine stocks. Eels from Lake Rotorangi had the slowest growth of all the North Island hydro lakes sampled in 1996 (220 g in 7–10 years), but this was still at least twice as fast as in intensively fished areas, such as the lower Waikato.

Although there is a reasonably abundant eel population in the lake, little food seems to be available for eels. Steeply incised lake margins provide poor littoral zones and the young indigenous forest that covers most of the middle catchment probably provides little in terms of terrestrial food compared with pasture. Sizeable pockets of aquatic macrophytes no doubt contribute to macroinvertebrate production, but eels must also compete with what is now a substantial population of perch. This perch population appears to have expanded once the large carnivorous eels were removed by commercial fishing and out-migration of adults (Taranaki Regional Council 1995). Since perch prey on other fish species, it is likely that they were in part the cause of the drastic decline of other fish species, such as common bully, which now persist only in tributaries.

Other North Island elver transfers

Waikaretaheke River (Waikaremoana Scheme, Piripaua)

Piripaua power station was constructed on the Waikaretaheke River (Bay of Plenty) in 1943. Each summer elvers aggregate in the Piripaua tailrace. During turbine maintenance at Piripaua, "buckets of elvers" were removed from the draft tubes and transferred to upstream habitats. Numerous elvers have also been seen climbing the damp walls of the venturi well each summer. There is anecdotal evidence of elvers congregating below some weirs and control gates of the power complex, with some suggestions of fewer numbers in recent years.

Mokau River

Trial elver transfer facilities were installed by Waitomo Energy at one of their power plants on the Mokau River but no monitoring was undertaken. There is no evidence of any stocking before 1996–97.

South Island

Before 1995–96, elver transfer in the South Island was limited to passive transfer through elver passes on the Waitaki River and there were no authorised programmes for manual transfer of elvers within or between catchments. In 1995–96 and 1996–97, the South Island Eel Industry Association, with support from iwi and NIWA, tried to catch elvers below Roxburgh Dam. The 1995–96 elver transfer was reported by Beentjes *et al.* (1997).

Clutha River (Central Otago)

Roxburgh Dam (completed in 1956) and Clyde Dam (completed in 1992) on the Clutha River impede elver upstream migration. Four lakes on the Clutha River system are suitable for elver enhancement: Lakes Dunstan, Wakatipu, Wanaka, and Hawea, all of which are upstream of the Clyde Dam. Discharge from Lake Hawea is restricted by control gates, a further barrier to elver migration.

Eel populations in these lakes were sampled in 1995–96 to provide an assessment of relative abundance, age, and growth before stocking with elvers (Beentjes *et al.* 1997). All eels were females. Recruitment is extremely limited since the construction of Roxburgh Dam in 1958, and the ageing population is declining annually as eels migrate or are commercially fished. Without recruitment the eel population will be drastically reduced.

In February 1996, acting under an MFish special permit, the South Island Eel Industry Association and NIWA (contracted by MFish to monitor the elver transfer) attempted to trap elvers below Roxburgh Dam with the intention of transferring them to Lake Wanaka (*see* Beentjes *et al.* 1997). A floating trap collected about 40 elvers. The low catch did not warrant transfer and a subsample only was retained for analysis (Table 3). Reasons for the low catch were discussed by Beentjes *et al.* (1997).

Waiau River (Southland)

The Waiau River was assessed in 1995–96 for elver migration and its potential for elver collection. Samples of elvers were taken for analysis (Table 3).

Methods

Manual transfers

Karapiro Dam

Four traps were used at Karapiro Dam during the 1996–97 season. These consisted of two floating traps with attached ramps on a pontoon set near the transformer cooling water outflow in the south west corner of the station; a ramp attached to the spillway wall which directed elvers towards a holding container positioned in the station's carpark; and a ramp in the stop-log stairwell with a collection tank on the middle landing.

Catches were monitored from early November 1996 to the middle of March 1997. A water flow was instigated down the first siphon tube and video monitoring was used at the top of the siphon crest to determine the number of elvers reaching the lake.

Early in the season, ECNZ made transfers to Lake Karapiro: all other transfers were by members of the Tainui Tuna Working Group who used three tanks aerated by a petrol-driven compressor to transport the elvers. Each could transfer about 33 kg of elvers. The elvers were removed from the tanks by a flushing valve and hose system.

All catches were weighed and a subsample retained at regular intervals throughout the season for species and size analysis.

Matahina Dam

In mid 1996, ECNZ lowered the level of Lake Matahina for strengthening works which are expected to take years to complete. While the lake remains lowered, the existing elver pass is inoperable. In December 1996, ECNZ commissioned NIWA to initiate, implement, and manage an elver capture and transfer programme during the repairs.

An elver trap was installed near the transformer cooling water outfall at the base of the dam on 23 December 1996, but, because of electrical problems, it did not become fully operational until 16 January 1997. Night observations indicated that elvers were attracted to the dewatering tunnel outlet, so two traps were installed on the left bank, becoming fully operational on 30 January 1997. One of these traps was set behind the diversion tunnel energy dissipater and the other in front of it.

Waikaretaheke River

A trial elver catch and transfer programme was instigated by NIWA for ECNZ at Piripaua power station in the 1996–97 summer to mitigate effects of the Waikaremoana power complex on eel migration. Two elver traps were installed in January: a ramp and trap set along the right bank of the power station tailrace, and a floating trap in a venturi well within the station. From 30 January 1997 to 15 April 1997, the traps were visited regularly, catches recorded, and the elvers transferred to the upper Waikaretaheke River catchment.

Roxburgh Dam

In 1996–97 permanent catching facilities (elver ramps) were installed at Roxburgh Dam by the South Island Eel Industry Association, NIWA, and the Araiteura Eel Management Area Committee. The entrance to the ramp faces upstream and enters the water just below the auxiliary generator outlet weir (Figure 1). Contact Energy reduced the flow on 26 January so that the lower section could be attached with the deepest part of the ramp about 2 m below the normal operating water level, which can fluctuate several metres in a day. Road chips were glued to the surface to provide traction for the elvers. Cooling water (about 20 °C) diverted from the auxiliary generator aerated the holding tank and kept the ramp moist. On 1 March 1997, a second ramp and holding tank were installed with the entrance facing downstream and a downstream entrance was attached to the lower section of the first ramp. A synthetic carpet was used as the substrate on the latter ramps.

Elvers that climbed t-he ramp and fell into the tanks were able to seek cover in short lengths of black alkathene pipe which minimised stress. Elvers were transferred in iced water in polystyrene containers to Lake Dunstan, and released just upstream of the Clyde Dam, a journey of about 40 min. Elver catches were monitored from 27 January to 12 March 1997. Elvers were sampled for length, weight, and age. The quantities and locations of any transfers were recorded.

Passive transfers (fish pass monitoring)

Lake Waikare

Before installing a counter and datalogger at the end of the fishway, it was decided to manually determine the number, size, and species composition of the elvers using the pass. Analysis of the catch confirmed that the pass was used not only by very small elvers but also juvenile eels. Because of miscounting of elvers with a large aperture counter and the risk of blockage with a smaller aperture, monitoring was continued with the trap (for future monitoring, a counter and datalogger with a grading system has been developed). From 21 January 1997, the trap was emptied every 2 days by a local farmer who also weighed and recorded the catch. Weekly visits were made to obtain a sample of elvers to assess size distributions and species compositions. By 21 March, only a trickle of elvers was entering the lake so the trap was removed and monitoring stopped.

Patea Dam

Records from the data logger were obviously erroneous and no reliable counts were obtained. Elvers used the pass to gain access to the lake during 1996–97, but the quantity is unknown.

Waitaki Dam

Waitaki Dam was visited on 16 November 1996 to assess the suitability of the elver pass for installation of an electronic elver counter and data logger.

Stock assessment

Information on eel population size and age distribution, species composition, abundance, and prey diversity and availability was collected from Lakes Karapiro, Arapuni, and Maraetai. Each was sampled following the methodology of Beentjes *et al.* (1997). Two days effort was applied to the first two lakes, but Lake Maraetai was fished for only 1 day because catches were negligible.

Sampling

The three impoundments were sampled randomly using large fine-meshed fykes (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), often fished in trains by a local commercial eeler. The large fine-meshed fykes were set to fish the lake margins, thereby targeting juveniles (Chisnall 1996). Standard fykes were set primarily in open waters. Effort was applied consistently by distributing the nets throughout a comparable predetermined area at each location (Figures 2–4).

Nets set on the margins were mostly positioned perpendicularly or obliquely to the shoreline with codends outermost and left to fish overnight. Deep water was mostly fished using trains of standard fykes strung together in pairs (leader to leader) and anchored at each end of the train. Some single fykes were also used. All nets were fished unbaited.

To complement the use of standard fykes in deep water, several transects of g-minnow traps (3 mm) were deployed in Lakes Karapiro and Arapuni to fish a range of deep waters (*see* Figures 2–4). Transects comprised 5–20 traps which were set and retrieved at the same time as the other nets.

Catch processing

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

Analyses

Age structure and growth

Otolith pairs were prepared using the crack and burn method (Hu & Todd 1981). Narrow central growth bands have been observed in most eels taken from hydro lakes (Chisnall 1993, Chisnall & Hicks 1993) and are thought to correspond to time spent below dams before relocation. Therefore, all eel otoliths were given three counts; 1, narrow central growth bands counted and referred to as the "elver age"; 2, subsequent uniform wide growth bands along the caudal radius counted and referred to as the "lake-age"; and 3, all growth bands, giving the "total age".

Growth was described by Model I least-squares linear regression of length-at-age and weight-at-age for samples from each location with n over 6 (SYSTAT, Wilkinson 1990). Only lake-ages were used in modelling growth and length was defined as *length* (mm) minus 95 mm (size of elvers of both eel species at Karapiro Dam (Jellyman 1977)) because most of the larger eels caught would have been recruited to the populations before recent stocking. In future, the size at stocking obtained from recent transfers should be used in these equations. Equations took the form:

length (mm) = $a + b$lake-age(yr)

weight (g) = $a + b$lake-age(yr)

Mean annual length and weight increments were calculated for all aged eels (length minus 95 mm [or weight] divided by lake-age) to allow comparison between data sets without regression models for growth (small sample size) or where the data sets had limited size distributions which result in exaggerated y intercepts (size at age) in growth models.

To determine if there was any evidence for predisposition to slow growth (i.e., if an elver has remained below the dam face for considerable lengths of time with negligible growth, did it continue to grow slowly when transplanted into new productive waters?), the frequencies of the narrow central growth-bands (i.e., assumed to represent growth as elvers) were plotted against growth rate (growth as adults).

Data from Lakes Karapiro and Arapuni from previous studies were combined with data obtained from last year's programme (Beentjes *et al.* 1997) to provide more robust growth models for the two lakes.

Natural log of weight vs length models were derived for each species and location using $\ln weight$ (g) $= \ln a + b \ln length$ (mm). Where only subsamples of eels had been weighed, lengths were used in the models to provide estimates of weights. Approximate catch weights from each location were obtained from these data.

Relative abundance

Accurate relative abundance indices for eel populations are difficult to determine because of large variations attributed to 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 the water bodies fished and was undertaken over a short time interval, avoiding new moons and freshes. Relative abundance for each lake was expressed as number and weight (kg) of the two eel species captured per net per night for the two net types.

Results

Manual transfers

Karapiro Dam

During the 1996–97 season 1857 kg of elvers were trapped and transferred to upstream lakes (*see* Table 1). Few elvers were trapped in November but numbers rose during December, peaking at the end of December and early January with the highest recorded catch of 66.28 kg being obtained on 11 January (*see* Figure 4a). Catches remained in the 20 to 60 kg per night range through January and early February, decreasing to 10 kg per night in late February and remaining at that level until the collections ended on 14 March 1997 (*see* Figure 4a). More elvers were collected on dark and stormy nights than on clear moonlit nights.

An estimated 1.2 million elvers were transferred (Table 4). The percentage of longfinned elvers in the transfers ranged from 15% at Ohakuri to 30% at Atiamuri (dependent on transfer date). Transfers to Lakes Arapuni, Waipapa, and Atiamuri were close to allocated quotas, but were lower than permitted in all other lakes.

The pontoon was by far the greatest collection point this season, and about 1.5 t of elvers were captured there (1490.24 kg). A total of 392.56 kg of elvers was collected from the stop-log trap over the entire season. The spillway trap collected only 19.53 kg. This low catch may have been caused by damage to the lower section of the ramp which prevented elvers from entering the structure. Repairs were completed only late in the season when elver numbers were declining, by which time it was too late to determine how effective this trap may have been.

As in 1995–96, shortfinned elvers predominated throughout the season (Figure 5b). Longfinned elvers became more prevalent towards the end of December, peaking at 50% of the samples at the end of January. As catches of elvers decreased, so did the proportion of longfinned elvers.

The mean length and weight of shortfinned elvers from all traps (excluding the spillway) was 101 mm and 1.37 g respectively. Longfinned elvers were larger with mean length and weight of 117 mm and 2.32 g respectively. Most shortfinned elvers were between 85 and 125 mm (Figure 5c, Table 5). Longfinned elvers tended to have a smaller size range, with most being between 100 and 135 mm. Elvers under 80 mm arrived at the end of February (Table 5). From last year's ageing study, these elvers would have been less than a year old. As sampling ended at the end of February, these smaller elvers were not caught in large quantities.

Video monitoring

Monitoring of the elvers on the pontoon showed that smaller elvers climbed along the edges of the ramp whereas larger elvers climbed in the middle of the ramp where there was greater water flow. Elvers tended to climb more slowly when climbing alone than in a group. Larger elvers were not as good at climbing as the smaller elvers.

Elvers always began climbing after 9 p.m. and their numbers remained constant through the night, with catches decreasing on day break.

Although video monitoring of the siphon crest proved that elvers were using this route to reach Lake Karapiro, on many occasions high lake levels which allowed water to spill over the siphon crest prevented elvers climbing. Towards the end of the season, as recommended after 1995–96 monitoring, a ramp was installed at the top of the siphon to stop elvers from re-entering the siphon chamber. No elvers were seen using the siphon tube once this ramp had been installed.

Trials in the stop-log area showed that no distinct differences in species composition, size distribution, or usage could be attributed to the type of aggregate used on the ramps.

Matahina Dam

Observations

Night and/or day inspections at regular intervals from 23 December 1996 to 11 April 1997 were timed to coincide with expected migrations of larger numbers of elvers (i.e., during new moons or storm events).

Very few elvers were attracted to the seepage in the diversion tunnel. The high mineral content of this water was obviously not favoured by elvers, which confirms previous observations that ground water does not attract elvers.

No elvers tried to climb the spillway, including the area within the splash zone of the dewatering tunnel. This is surprising, as large numbers were seen in the tailrace along the wall of the spillway. Although it would have been desirable to install a trap here, difficulty of access and safety issues prevented this.

Trap operations

The transformer trap became fully operational on 16 January. Two other traps were installed once observations had shown that elvers were congregating in the diversion tunnel area. Unfortunately, most elvers were seen in an area where access and flow conditions were difficult. Two prototype traps were installed in mid January and proved to be effective.

Most elvers collected in the traps were active, but on 20 January 10 elvers were found dead in the diversion tunnel trap. We believe that poor water quality from the pond which supplied the trap and restricted flows to the trap were responsible. On 30 January a number of elvers in the subsample had badly damaged fins: we do not know if this damage occurred before or after the elvers entered the trap.

Transfers

The mean weight of elvers caught during the season was 2.4 g for the transformer and floating traps and 9.86 g for the diversion trap. Using these weights, it is estimated that 13 870 elvers and juvenile eels weighing a total of 59.4 kg were released into Lake Aniwhenua and tributaries (*see* Table 2). When released, all elvers moved rapidly into deeper water.

Catches increased from about 1 kg of elvers when the traps first became operational in late January to about 2 kg in early February (Figure 6a). After this, they declined to about 0.5 kg transferred per visit. Catches declined rapidly from mid March and transfers were halted on 11 April.

Most elvers were released into Lake Aniwhenua near Rabbit Road bridge (NZMS 260 V16 401 107). Three additional releases were made at the boat ramp near the barrage (NZMS 260 V16 417 145), and one into Kopuriki Stream (NZMS 260 V16 419 132). A few elvers were transferred into the Whirinaki River (NZMS 260 V17 360 960).

Migration timing

From the estimated daily catch data (*see* Figure 6a) and night time observations it was evident that the elver migration had begun well before the traps became fully operational at the end of January. Daily catches increased to a peak around the new moon in early February, declined for a brief period, and rose to a second peak around the full moon at the end of February. Catches then declined gradually until the season ended in mid March.

Species composition and size distribution

It is estimated that 56% (about 9000) of the eels transferred to Lake Aniwhenua were shortfinned elvers or juveniles. The proportion of longfinned elvers in the catch peaked in late January (45%), but by mid February almost all eels were shortfinned (Figure 6b). No other fish species were captured during the transfer operations.

On average, the longfinned elvers were smaller than shortfinned elvers (Figure 6c, Table 6). This difference was due to the large proportion of juvenile shortfinned eels (135–300 mm) that were captured in the trap, and the addition of a significant quantity of juvenile eels captured with a dip net from around the trap.

Piripaua

Trap catches

Six elvers were found in the tailrace trap and three in the venturi well trap on 23 January. The traps were next emptied on 30 January and 0.2 kg of elvers recovered. All this catch came from the tailrace trap, which continued to catch significantly more elvers than the trap floating in the venturi well. The highest catch was on 13 February, with 0.5 kg taken and released to the upper Waikaretaheke. Consistent catches of about 0.3 kg were made from the end of February to early March (Table 7). A cyclone on 14 March increased flows and discoloured all the streams in the catchment and virtually ended the run. Estimated daily catch shows that the run began before 23 January, peaked in late February, and ended in mid March (Table 7). Spot measurements in the tailrace trap indicated that water temperatures varied between 15 and 17 °C.

An occasional freshwater crayfish and at least one juvenile koaro were also captured in the traps.

Transfers

About 2.1 kg of shortfinned elvers (about 2000 elvers based on a mean weight of 1 g) were collected and transferred to the upper catchment of the Waikaretaheke River: about 0.9 kg to the Kahutangaroa Stream, 0.7 kg to the Waikaretaheke River, and 0.5 kg to the Mangaone Stream. These transfers were within the limits set in the transfer permit issued by MFish. When released, all elvers moved rapidly out into deeper cover, with most heading upstream.

Night-time observations

Night-time observations indicated no congregation of elvers and careful inspection of the Piripaua tailrace at the end of the season indicated that few elvers remained there. From these observations and the overall low catch from the Piripaua tailrace, it appears that there was very low recruitment during the 1996–97 season.

Roxburgh

A total of 1.3 kg of longfinned elvers (317 elvers based on a mean weight of 4 g) was released into Lake Dunstan in February–March 1997. The bulk of the elver catch climbed the first ramp between 27 January and 13 February, before the installation of the water supply on 20 February. A sample of 458 g of elvers was frozen and analysed in the laboratory for determination of length, weight, species, and age (Figures 7 a, b, Table 3). All elvers were longfinned and the length frequency distribution was unimodal with the mode at 150 mm (Figure 7a). The largest elver to climb the ramp was 192 mm (9.2 g) (Table 3).

Passive transfers

Lake Waikare

Catches of elvers in the trap below the elver pass were recorded every 1–2 days from 21 January to 28 February 1997 (Figure 8a): about 581 kg (576 128 elvers) moved through the pass and into Lake Waikare during this period. Daily catches peaked at 56 kg on 25 January, then declined gradually to reach about 10 kg per 24 h in early February. Limited recruitment would have occurred before and after monitoring ended.

Except for the 24 January sample when 31% of the elvers measured were longfinned, all of the elvers examined were shortfinned (Figure 8b).

Shortfinned elvers in the first samples were the smallest at 80–90 mm, but later samples contained a larger proportion of 100–120 mm elvers (Table 8). The few longfinned elvers were from early in the sampling and were in the same size range as the shortfinned elvers caught at that time (80–90 mm) (Figure 8c).

Waitaki Dam

From the inspection visit to Waitaki Dam on 16 November 1996, it was concluded that the entrance to the elver pass is wrongly placed and in its present position is unlikely to result in many elvers locating and climbing the pass. An elver counter and data logger were therefore not installed. The entrance to the pass should be at the point where the turbine cooling water is discharged, an area where elvers are sometimes observed. ECNZ have proposed modifications to this effect, but these did not take place in 1996–97, and they do the pass may not function as intended.

Stock assessment

Overview

The locations of nets set in Lakes Karapiro, Arapuni, and Maraetai are given in Figures 2–4. In all, 187 longfinned and 387 shortfinned eels were captured during the sampling (Table 9). One longfinned eel caught in Lake Arapuni was identified morphologically as *Anguilla reinhardtii* (this was subsequently confirmed by vertebral count). Excluding elvers, eels ranged from 110 to 1420 mm (4–6600 g) and 0–30 years old (Tables 10–12, Figures 9–11).

Population size distributions and species compositions

Eel size distributions varied between lakes in accordance with recruitment history. Size ranges were similar for the lower two lakes, but small eels dominated catches in Lake Maraetai (Figure 9). More small eels, but fewer large eels, were captured in Lake Arapuni compared with Lake Karapiro. Catches from Lake Maraetai were mostly of eels smaller than 500 mm.

Most of the eels captured in the lakes were shortfinned (*see* Table 9). Only two longfinned eels were captured in Lake Karapiro, which was under 1% of the catch by number and weight. In contrast, longfinned eels made up 45% of the catch by number and 38% by weight in Lake Arapuni. Catches from Lake Maraetai were comparably small with only 1 longfinned and 20 shortfinned eels captured (Figure 9, *see* Table 9).

Far fewer longfinned eels were captured in the standard fykes than in the fine-meshed fykes which were set along the shore, particularly in Lake Arapuni where fine-meshed fykes caught five times that of standard fykes in both number and biomass (Table 9) (Figure 12).

Age structure and growth

Eel lake-age ranged between 1 and 24 years in Lake Karapiro, 1 and 8 years in Lake Arapuni, and 0 and 10 years in Lake Maraetai (*see* Tables 11, 12, Figures 10, 11). Age structures revealed that most of the eels sampled this year were derived from the recent stocking efforts, particularly in Lakes Arapuni and Maraetai. Two distinct year class strengths were observed in the sample from Lake Maraetai corresponding to two previous years stockings (Figure 11c).

Length and weight-at-age growth models calculated from this year's catches were poor in relation to previous records. The *y*-intercepts ('*a*' in Tables 11, 12) were large, the result of a skewed size distribution, and thereby unduly influenced each model except for shortfinned eels from Lake Karapiro. Mean annual size increments from the three lakes ranged from 73 to 254 mm per year (44–140 g per year), and from 96 to 225 mm per year (52 to 121 g per year) for shortfinned and longfinned eels respectively (Tables 11, 12).

Differences in growth between the two eel species' catch were difficult to assess as there were few data for longfinned eels. In Lake Arapuni (24 longfinned eels aged) the two species had similar length increments (127–161 mm per year) but longfinned eels were twice as heavy as shortfinned eels of the same age (*see* Tables 10–12).

Using all historical data for Lakes Karapiro and Arapuni (excluding this year's samples), and assuming little change had taken place with the onset of stocking (insufficient data to test), clear differences in growth between the two lakes and the two eels are evident (Figure 13, *see* Tables 11, 12). Both species grow more rapidly in Arapuni than in Karapiro, with little difference in growth between the two species over a wide size and age range; however, if recent species differences in the size of elver stocked were taken into account in calculating growth, longfinned eels would be growing distinctly faster than shortfinned eels.

Estimated elver ages

Distributions of central narrow growth-bands on eel otoliths (estimated elver-age) were comparable

between the three lakes (*see* Figures 10, 11). Estimated ages before elvers reached the lakes indicated that they had spent considerable time below the dam from 0 to 13 years, with peaks at 3 and 5 years (Figures 10, 11).

Potential predisposition to poor growth as a result of long periods as an elver below the dam was tested by regressing the number of central narrow bands (estimated elver age) against the incremental growth as adults for the three lakes (Figure 14). Incremental growth for most eels of both species was generally not affected by elver age, though the data for longfinned eels showed a marginally positive relationship between elver age and increment as an adult ($P < 0.05$). The particularly large increments from Lake Maraetai probably provided a positive bias to these models, despite which they remained statistically insignificant.

Relative abundance

Catch rates by both fyke net types were about the same for Lake Karapiro, but were greater for fine-meshed fykes in Lake Arapuni because of the many small eels caught there. Catch rates in Lakes Karapiro and Arapuni for both net types ranged from 2–5 and 0–6 eels per net per night for shortfinned and longfinned eels respectively. This corresponds to 1.3 kg per net from Karapiro (both net types), 3.1 kg per fine-meshed net, and 1.7 kg per net for standard fykes in Arapuni (*see* Table 9).

Catch rates in Lake Maraetai were low at 0.2–1.8 eels per net per night, and under 0.2 kg per net (most were caught in the fine meshed nets), with a combined total from the lake of less than 7 kg.

Catches from g-minnow traps in Lakes Karapiro and Arapuni were low (only five eels were captured, Table 13), but showed that juvenile eels were capable of inhabiting the deep water in each lake.

Bycatch

Other species captured in the fine-meshed fykes varied greatly in terms of both diversity and abundance (Table 14). In Lakes Karapiro, Arapuni, and Maraetai, seven other species were captured, six of which are known eel prey. The abundance of each species varied between the lakes, but common bullies (*Gobiomorphus cotidianus*), smelt (*Retropnina retropina*), rudd (*Scardinius erythrophalmus*), and goldfish (*Carassius auratus)* were numerically dominant (Table 14).

The standard commercial fykes often caught large numbers of catfish (*Ictalurus nebulosus*) (up to 20 kg per day in Lake Karapiro), and occasional rudd and goldfish in shallow water sets. Koura (*Paranephrops planifrons*) were also caught frequently in Lake Maraetai by standard fykes.

Discussion

Manual transfers

Karapiro Dam

The traps installed at Karapiro Dam, particularly the floating traps, continued to prove highly effective. The numbers of elvers caught and species compositions over the season were similar to those of the 1995–96 season. As last year, the peak migration occurred about a month earlier than reported historically (Jellyman 1977). Increased water temperatures may be providing earlier cues triggering migratory behaviour (e.g., White & Knights 1994), and the persistently warmer temperatures in December may have caused such a shift.

This year's elvers appeared to be larger than last season's. The mean shortfinned elver length last year was 92 mm compared to this year's 101 mm and the corresponding mean longfinned elver lengths were 103 mm and 117 mm. However, this apparent increase in mean length may be due to sampling ending before the smaller elvers arrived.

Later peak arrival coupled with larger size may indicate that age class 0 elvers are arriving at Karapiro later than in the early 1970s (Jellyman 1977) and therefore ascending the dam the following season (i.e., earlier). Further monitoring is required to resolve this.

Shortfinned elvers were the predominant species in most samples, and by mid February catches were almost exclusively this species. Most longfinned elvers were captured between December and January, and numbers appear to have been lower than in previous years. As occurred last year, catches of longfinned elvers had virtually ceased by mid February. Species composition should continue to be recorded to more accurately determine the timing of the migration of the two species and determine if the proportion of longfinned elvers in the catches is declining.

Last year large numbers of elvers transferred upstream continued to migrate to the next dam and ECNZ staff observed the same this year. 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 temperature shock treatment) may be useful for such work. Also, trials should be undertaken to attempt to modify this behaviour. We suggest that temporary retention of the stocks in holding pens within the destination lake may allow elvers to acclimate and stop migrating. Temperature shock treatment may also prove useful.

Alternatively, preventing elvers accumulating at dam faces may be achieved by release of elvers into tributaries. However, information would be needed on elver behaviour once released into tributaries to determine whether they continue migrating upstream or return to the lake. If elvers continued up tributaries then it would be important to determine if they remained there and for how long, since growth rate is much slower in tributaries than in lakes (e.g., Chisnall & Hicks 1993).

Video monitoring showed that elvers were climbing into the lake via the siphon and highlighted areas for improvement of the facilities. For example, video observations in the stop-log area established that elver species or size distributions were unaffected by the type of aggregate used on the ramps. Elvers climbed the ramps throughout the night, so it should be possible to construct fishways to cater for a wide range of elver size. Furthermore, since elvers are able to continue migrating all night, high dams are not necessarily insurmountable barriers. However, manual transfer still provides major advantages over passes (no size or species selectivity, no restriction on number/volume, and low mortality).

Observations at Karapiro and elsewhere indicate that other native species can benefit from fish passes and manual elver transfer programmes. In particular, the capture of galaxiids and bullies in the elver traps shows that given appropriate adjustment to suit the different migration timing of the various species, enhancement of upstream populations by manual transfer is possible and potentially efficient for these species.

Matahina Dam

Although migration was well underway before the installation of the traps at Matahina, a considerable number of elvers were captured and transferred into the upper hydro lakes during the remainder of the 1996–97 season. As catches peaked in the Waikato in December-January, it is likely that the peak migration was missed at Matahina. Because longfinned elvers tend to be more prevalent early in the season, it is important that any catch and transfer programme be in place by early December at the latest.

This year's manual transfer would have provided better transfer of longfinned elvers than the pass could have achieved because of the poorer climbing ability of larger longfinned elvers.

Piripaua

During the summer of 1996–97, Piripaua power station operated more consistently than during past years, with generation occurring for about 79% of the time in February and 60% in March. Strickland (1996) suggested that, during shutdown, reduced flows over Mangapapa Falls, about 10 km downstream of the station, could ease the upstream passage of elvers over this 5 m barrier. If this contention is correct, it is possible that the apparently poor catch at Piripaua was a result of the more consistent flows down the tailrace during the spring and early summer of 1996–97. However, there are no historical data for comparison, and since annual elver runs are highly variable, it is not possible to test this suggestion. Further monitoring of the runs should continue.

From observations by Strickland (1996), we expected to find at least a few elvers below the man-made barriers of the power complex. None were seen. This, together with anecdotal evidence suggesting that large numbers of elvers were present in the past, seems to indicate that there was a poor run of elvers in the Wairoa River last season. There is anecdotal evidence of a substantial catch and release operation at Te Reinga Falls in the past. Whether this operation ended through lack of interest or because of poor return should be determined, if only to put the present operation at Piripaua in context.

A few elvers were identified to species level: all were shortfinned elvers. However, the transfer programme started late in the season, perhaps after the migration of longfinned elvers had ended, and this may account for the absence of longfinned elvers. Since the habitat available in the Waikaretaheke catchment is considered more suitable for longfinned eels, this species composition is disturbing. Concerns have been expressed about the long-term survival of longfinned eel throughout New Zealand (Beasley *et al.* 1996). The species may require protection should present trends continue.

Roxburgh Dam and Mararoa Weir

The trapping of elvers at Roxburgh Dam and transfer into Lake Dunstan was the first official manual transfer of elvers in the South Island. Historically, elver presence at Roxburgh Dam appears to have been intermittent, with no elver run observed in 1960 (Boud & Cunningham 1960) or in 1983 and 1984 (Pack & Jellyman 1988): elvers were seen at Roxburgh Dam in 1971 (Jellyman 1977). This conclusion is not surprising based on our observations over the last 2 years, including more than six night-time visits during the elver migration season. We observed elvers in any numbers on only a few occasions and this tended to be over a short period of a few consecutive nights, concentrated at the site where the ramps were installed. The permanent ramps should provide a better picture of elver relative abundance each year and this can be correlated with such factors as rainfall, air temperature, time of year, and moon phase. The greatest catch of elvers at Roxburgh Dam coincided with a new moon and a period of rainfall, both conditions known to favour elver migration (Beentjes *et al.* 1997). A significantly greater elver catch is anticipated this season as the ramp will be in place and operating over the entire (1997–98) migration season.

The mean length, weight, and age of longfinned elvers from Roxburgh Dam are considerably greater than those from Karapiro Dam. For example a longfinned elver caught at Karapiro Dam may be 1–3 years old compared with 3–22 years at Roxburgh (Beentjes *et al.* 1997; c.f. Table 3 this report). This suggests that most of Roxburgh elvers are repeat migrators but those from Karapiro are not since elver transfer has been occurring there since 1992–93. The ages of Roxburgh Dam elvers are similar to those of commercial sized eels (mean age at 220 g = 17 years, Beentjes and Chisnall, unpublished results) indicating that growth of elvers below the dam is very slow.

Jellyman (1997) gave maximum size for vertical climbing by elvers of 120 mm, but elvers as large as 192 mm were able to climb the ramps at Roxburgh Dam. Nearly all elvers caught were larger than 120 mm and the 45° angle of the ramp is not a barrier to large elvers.

No mass elver strandings were reported below Mararoa Weir in 1996–97, indicating that the minimum flow regime of 19 cumecs is having the desired effect. No elvers were trapped from below the weir and transferred, although the Waiau Mahinga Kai Trust did monitor elver presence at the weir. As a condition of their water right renewal, ECNZ is required to build a Borland Fish Lift at Mararoa Weir specifically to facilitate upstream passage of brown trout. This fish pass will, however, be of little or no value in assisting elvers passage over the weir as it is in the wrong place. ECNZ is also required to construct elver passes at Mararoa Weir and at the control gates at Lake Te Anau: this work is unlikely to be completed for the 1997–98 elver migration season.

Passive transfers

Lake Waikare

Elver passes are effective only if they are regularly maintained. At all the sites, water supply problems, poor positioning, and even failure of the pass entrances have resulted in poor performance to various degrees. At Lake Waikare, simply ensuring that water flows were maintained resulted in the passage of over 500 kg of elver into the lake. Had the water supply problem been recognised and fixed earlier in the season, considerably more elvers would have no doubt entered the lake. More importantly, perhaps, it would have allowed the passage of longfinned elvers in significantly larger numbers.

Patea Dam

Although the data logger failed during the 1996–97 migratory season, elvers were observed to climb the pass effectively and diel activity and seasonal timing were similar to those of previous years, according to eel fishers and dam site staff. In previous years the electronic counter and data logger showed that most elvers used the pass between late December and late March.

The number of elvers using the pass appears to be increasing each year. Unfortunately, the pass accommodates only a portion of the migration available at the dam and is species selective, favouring shortfinned elvers. Upgrading, as outlined by Williams (1997), would improve the pass efficiency but manual transfer is needed to increase the volume of elvers transferred.

Waitaki Dam

Based solely on elver numbers climbing the passes on Waitaki and Aviemore Dams over the last few years, elver migration on the Waitaki River is poor. In 1996–97 only three longfinned elvers were recorded. This brings the total to have climbed Waitaki Dam elver pass over the last 4 years to 13: clearly the pass is not functioning as intended. Elvers were observed massing near the turbine cooling water outlet from early January through to early February 1997 (based on five observations between early January and mid March). This suggests that time and energy could be profitably spent identifying the best locations for elver trapping and/or for the entrance to the elver pass. It also indicates that the elver pass entrance is incorrectly positioned. An elver counter and data logger should be installed at Waitaki Dam only after the pass has been repositioned.

Stock assessment

Overview

Size distributions, species compositions, age structures, and growth rates of the eel populations sampled in the three North Island hydro lakes studied in 1997 reflected the different levels of recruitment, exploitation, and productivity of habitats. Lake Karapiro has an abundant eel population (although not as abundant as in 1996) with fast growth (market size 220 g in 5–6 years), unchanged from last year's evaluation (Beentjes *et al.* 1997). Fast growth in Lake Karapiro is likely to be a result of high productivity, extensive littoral zones, and abundant and diverse prey. Stocked eels in Lake Arapuni, the next lake up the Waikato River, are exploiting a virtually virgin waterway. High food availability (high species diversity and abundance), high quality littoral habitat, and low eel densities have resulted in very fast growth for most of the eel population there (220 g in 1–2 years). Considerably fewer large eels were caught in Lakes Karapiro and Arapuni this year, probably as a result of considerable commercial fishing effort during the last season.

Growth was fast in Lake Karapiro compared to other sites within the Waikato commercial fishery (three times as fast as lower Waikato waters (e.g., Chisnall & Hayes 1991), but yields per unit of stock transferred are likely to be considerably less in this lake than in Lake Arapuni because existing eel densities are higher and food availability lower. Thus, stocking Arapuni and other hydro lakes needs to carefully balance the food resource and eel population density to avoid depressing eel production.

Eel stocks are currently low in Lake Maraetai and eels there are growing faster than in Lake Arapuni, attaining market size in about 1 year. Lake Maraetai has a high abundance of suitable prey species, including koura, and gives an indication of what could be achieved in the other hydro lakes currently devoid of eels but with abundant prey species. This is the only lake where distinct year classes resulting from stocking could be clearly seen and therefore tracked in future assessments.

Population size distributions and species compositions

Data from each lake reflected the stocking efforts over the last 3 years. Lake Karapiro had fewer small eels than Lake Arapuni, reflecting the natural recruitment that has taken place there over many years and the resulting established eel population compared to the recent enhancement in Arapuni.

Eel size distributions in Lakes Karapiro and Arapuni have changed since last year. Stocks in Karapiro retained two modes similar to those present in 1996 (550 and 750 mm), but the larger size mode was much less distinct this year (*see* Figure 9). In Lake Arapuni, the smaller size mode had increased in length to be more comparable to that of Lake Karapiro, and reflects the maturing population. The second larger mode was no longer present. Both lakes therefore appear to have been affected by the developing fishery, the larger eels being removed.

The length distribution of eels from Lake Maraetai was dominated by two modes reflecting the two most effective stocking years (1995 and 1996). This year's releases of elvers were not present in the catch, and no large eels were caught, indicating a lake without eels before enhancement.

The decline in longfinned eel numbers and biomass in Lake Karapiro appears to be a direct effect of intensive fishing as this species appears to be selectively removed by the commercial fishery. The territorial and aggressive behaviour of longfinned eels, along with their greater body size/girth to length ratio (i.e., more vulnerable to netting at smaller length), are thought to contribute to this effect

(Chisnall 1994). The increase in the number of longfinned eels in Arapuni is thought to be due to both the removal of remnant large eels through fishing and the species composition of elver transfers which have tended to occur early in the season when a greater proportion of longfinned elvers are present.

The relatively greater catches of longfinned eels in the shorebased fine-meshed fykes compared with the deepset standard fykes in Lake Arapuni may reflect a lake margin and/or cover preference of this species (*see* Figure 12). Prey species trapped in fine-meshed fykes may encourage longfinned eels to enter nets, thus resulting in sampling bias.

Age structure and growth

The slopes of this year's regression models of length and weight for shortfinned eels from Lake Karapiro were slightly lower than in previous years (Tables 11, 12, *see* Figure 13). This may be the first evidence of a decline in production with increasing stock density and associated impact on food availability. The poor size distribution of this year's age samples from Lakes Arapuni and Maraetai resulted in non-significant regression models ($P > 0.05$). However, incremental growth in both length and weight for this year's samples from Lakes Karapiro and Arapuni was about twice as fast as recorded previously (*see* Tables 11, 12), suggesting that the regressions would have been biased by the truncated size distributions recorded (i.e., fewer "remnant" large eels captured).

In previous sampling, larger eels were mostly obtained in the upper riverine sections of the lake, which are probably areas of poorer growth. Similarly with the sample from Lake Arapuni, few large eels were caught this year even in the upper reaches of the lake. Thus, most of the eels aged this year are likely to have been recently stocked (most eels sampled had spent less than 6 years in the lakes, or at least in fast growth mode).

Incremental growth of eels from Lake Maraetai was very rapid at 254 mm and 140 g per year for shortfinned eels, almost twice as fast as in eels from Lake Arapuni (*see* Tables 11, 12). Such growth rates may be approaching the maximum expected in the wild and are similar to rates achieved in trial culture (*see* Jones *et al.* 1983). Conversely, fast growth of eels in Lake Maraetai, along with the distinct differences between the two lowermost lakes, provides a warning that with uncontrolled stocking rates, production will decline. The two principal age classes correspond to two previous stockings and may allow more accurate assessment of eel production in future years.

Estimated elver ages

Narrow central growth-bands and single large growth-bands on otoliths in small eels (120 mm) from Lake Maraetai support, but do not prove, the contention that these bands are laid before the transfer of the elvers and that large growth-bands are formed in the lake. Without validation, there is no other evidence that narrow central growth-bands are formed each winter while the juvenile eels or elvers remained below the dam. There are two other hypotheses that may account for these otolith characteristics: that these bands are growth checks (not annuli) formed as elvers ascend waterways, or that narrow annual growth-bands are formed as a result of poor growth while living in tributaries.

The general lack of correlation between estimated elver age and incremental growth of adults indicates that there is no predisposition to poor growth due to retention of elvers below obstructions. There are thus good grounds for the transfer of juveniles from areas of poor growth to other water bodies.

The proportion of eels with no to three narrow growth-bands is smaller this year than last (*see* Figures 10, 11). The fewer small eels in samples from Lake Arapuni may account for this, and may indicate that as the stocks become established, available habitat diminishes and mortality through competition and cannibalism by larger eels play considerable roles in governing population size distribution. If this is correct, it has serious implications for the success of transferred elvers.

Good catches of small eels from Lake Maraetai show that new stocks are dominated by juvenile eels. A progressive shift in size distribution should follow here as it has done in Lake Arapuni. Available littoral habitat may contribute to the success of transferred elvers, but existing stocks of larger eels may be ultimately governing the rate of successful colonisation.

Relative abundance

In Lake Karapiro, catch rates for both net types were about a third lower this year than last year (Table 9, Beentjes *et al.* 1997). Longfinned eels were considerably less abundant this year (1996, Karapiro by number 5%, by biomass 3%; 1997 by number 1%, by biomass 0.5%). Considerably more commercial fishing effort has been applied over the last fishing season than before (according to several eelers and factory processors), and this has considerably reduced the large sizes in the standing stocks.

In Lake Arapuni, catches by standard fykes were similar to those of 1996, but biomass was lower this year. Catches from the fine-meshed fykes were similar in total numbers, but the species composition changed markedly. This year's catches had fewer shortfinned eels and more longfinned eels (longfins in 1996, number 19%, biomass 56%; 1997, number 45%, biomass 38%). The removal of remnant large eels through fishing is also likely to have played a significant role in this change. With better information on the number of each species being transferred, more informed decisions on the size/quantity of transfers will be possible in future.

Bycatch

The lower catches of juvenile rudd this year in both lowermost lakes may be a reflection of the poor condition of the macrophyte beds. The 50% reduction in bully numbers in Lake Karapiro is difficult to interpret (*see* Table 14). Fewer large eels in both lakes should have allowed bullies to flourish. However, there were considerably fewer juvenile bullies in Lakes Karapiro and Arapuni than last year, so spawning failure may account for the lower numbers. Other fish species were caught in similar proportions and numbers as last year.

It appears from the large numbers of koura captured in Lake Maraetai that this may be the first species to be severely predated by eels (there are very few koura in the two lowermost lakes). Fewer smelt were caught in this lake than in Karapiro or Arapuni and mosquitofish were absent, indicating that the availability of fish prey species for eels may be lower in the upper hydro lakes.

Yields and management strategies

There is little information on the ecology of stocked eels on which to base New Zealand stocking. Unanswered questions remain the same; which habitats do introduced elvers occupy in hydro lakes? What food do they require? How does continued migratory behaviour of stocked elvers affect their survival? What percentage of elvers survive where existing eel stocks exist? These questions can be answered only by long-term monitoring of relative eel abundance, growth, species composition, size distribution, diversity and abundance of prey species and, especially, stocking and harvest rates. The records obtained from the 2 years studies now completed should provide a valuable benchmark for such monitoring.

Beentjes *et al.* (1997) reviewed production rates from controllable waters in European fisheries, and proposed a target stocking rate of 444 elvers per hectare annually (about 0.4 kg/ha) as appropriate for a high yielding lake (producing around 22 kg/ha per annum). Moriarty (1990) considered that a well managed fishery in a mesotrophic lake should be capable of yielding a minimum of 16 kg/ha per annum. The Waikato hydro lakes are all eutrophic, so these waters may well yield higher returns. Unfortunately, no harvest records have been maintained and without such data it is impossible to assess the success of the programme. Average stocking rates over the last 3 years have been about 0.6 kg/ha for Karapiro (area 5.37 km^2), 0.7 kg/ha for Arapuni (area 4.95 km^2), and 0.2 kg/ha for Maraetai (area 4.21 km^2) (areas from Livingston *et al.* 1986). So if we speculate on the densities arising within the lakes exclusive of existing stocks, it is surprising that abundance indices have not indicated a massive establishment resulting from the huge numbers being stocked (the biomass from CPUE is considerably less than 16 kg/ha). These data suggest that there is a substantial post-stocking mortality of elvers (possibly linked to the size of established eel stocks) or that the elvers are ascending the tributaries and not remaining in the lakes.

It may be more appropriate to base stocking rates on the area of shallow bathymetry where there is plenty of cover (the most preferred habitat of colonising elvers) rather than the basic lake area.

Different fishing strategies may aid eel production from these controllable waters. A balance between sufficient food, suitable habitat, and eel population densities needs to be maintained. Thus, as the size distribution of the eel population enlarges, there will be an increasing top-down effect on the smaller eels and competition between the larger eels. Conversely, when the larger eels are removed through fishing, competition will increase amongst the smaller size classes.

At current eel densities, we advocate intensive removal of the commercial component of the stock as has occurred recently in Lake Karapiro. As the population is thinned, the improved food availability should improve conditions for new recruits. This should be carefully monitored because it may become necessary to reduce entry of new recruits to ensure that the lake is not overstocked.

Additional hydro lakes have been stocked this year and, although these are virgin waters, they may be less productive for eels as our surveys indicate that there are fewer prey species available.

Heavy metal contamination

The upper Waikato River hydro lakes receive natural geothermal waters which contain contaminants such as arsenic and mercury (Vant 1987). In addition, Lake Maraetai has been the recipient of wastes from the Kinleith Pulp and Paper Mill (e.g., Brooks *et al.* 1976). Some bioassay studies on contamination in fish flesh have found sporadic individuals with high levels of mercury (e.g., Jolly 1994, Mills 1995a, 1995b, Jones 1996). Point source discharges are likely to be the main problem, and as eels have small home ranges and are at the top of the food chain, they accumulate contaminants. A recent study undertaken in the Waitangi River, Northland, which receives geothermal waters with high levels of mercury, found that most eels from a mainstem river site several kilometres below the geothermal input had more than 0.7 ppm mercury (N.Z. maximum 0.5 ppm): in addition, the concentrations were not associated with eel size (Chisnall & Rowe 1997). Thus, simply introducing an upper size limit for the fisheries in the Waikato hydro lakes may not restrict the levels of mercury in fish offered for sale.

General Discussion

There are indications from this study that there is no predisposition to poor growth after transfer of elvers that have exhibited poor growth caused by retention below obstructions. This indicates that transfer of small eels from areas with poor growth to more productive waterways should benefit the fishery.

North Island enhancement programmes are likely to continue to produce rapid benefits. Elvers grow to a commercial sized eel in Lake Arapuni in as little as 2 years, while in Lake Maraetai the recorded average annual growth of 225 mm per annum for shortfinned eels is the fastest known for any wild eel fishery (c.f. Berg 1990). Overall growth rates in the North Island hydro lakes are 4–10 times faster than observed in wild eel fisheries elsewhere within New Zealand (e.g., Chisnall 1989, Chisnall & Hayes 1991, Jellyman *et al.* 1995). In contrast, last year's sampling of South Island hydro lakes Wanaka, Wakatipu, Dunstan, and Hawea indicated that growth rates were slow, requiring 20–25 years for longfinned eels to reach the current commercial size of 220 g: enhancement of these waters can therefore only be regarded as a medium to long term investment (Beentjes *et al.* 1997).

Elver passes allow unattended passage of elvers over the migration season. However, they have not been particularly effective for passing the larger longfinned elvers. Poor original design and lack of maintenance are largely to blame for this, although the poorer climbing ability of larger individuals of both species remains an ultimate limitation.

In contrast, manual stocking has been highly successful, particularly in replenishing eel stocks in North Island hydro lakes. It has distinct advantages over passive transfers in allowing the transfer of large numbers of elvers in a short time, and the quantity and species composition of elvers transferred can be accurately assessed. It also permits the transfer of a greater size range than passes. Careful monitoring of transfers will allow a better understanding of the relationship between stocking density and yield, detect changes in species compositions, and monitor elver migratory periodicity enabling more focused transfers of migrations. Manual transfers have been enthusiastically adopted at Matahina Dam and Lake Waikaremoana hydro scheme during 1996–97, and are now proposed for Patea Dam.

The first successful manual elver transfer in the South Island occurred at Roxburgh Dam on the Clutha River in 1996–97. The permanent elver trapping installation at Roxburgh Dam should see a substantial increase in the quantities transferred in future years. Elvers sampled from Roxburgh Dam were considerably larger and older than those from Karapiro Dam, an indication that most Roxburgh Dam elvers were repeat migrators. If manual transfers continue at Roxburgh Dam and significant quantities are transferred, the size and age of elvers should decline over time as the proportion of repeat migrators is reduced.

The timing of elver migrations on both North Island east (Rangitaiki River) and west (Waikato River) coasts over the last 2 years appears to have occurred a month earlier than historically recorded. The average size of elvers has also increased. As water temperature is important in the onset of elver migration (Jellyman & Ryan 1983), a possible explanation is that warmer water may be providing earlier triggers for migration. In conjunction with the increased occurrence of the Australian longfinned eel (*Anguilla reinhardtii*) in North Island waters during the last decade (Jellyman *et al.* 1996, Chisnall 1997), these observations may also be evidence of a biological response to oceanic warming.

Macrophytes and littoral habitats provide habitat and refuge for eel prey species and appear to be nursery habitats for juvenile eels in hydro lakes. Although juvenile eels have been found throughout the waters investigated, they were most concentrated in shallow marginal areas with cover. The amount of this type of habitat within a lake must affect rates of successful colonisation by transferred elvers. However, the top-down effects of existing stocks may be even more influential in governing the successful colonisation of these lakes.

The direct relationship between fish-food organisms and fish biomass is integral in the management of eel production (Barthelmes 1988). Maintenance of existing aquatic fauna is crucial to the continued well being of the eel populations in enhanced waterways. Improvement in invertebrate and fish production and delivery to aquatic ecosystems may include allowing macrophytes to flourish without compromising other water values; increasing land-water interfaces by manipulation of water levels to improve the terrestrial component of food supply as proposed by Duncan & Kubecka (1995); introduction of fish prey where appropriate; and improvement of elver passes to allow diadromous fish and invertebrates entry into water bodies affected by obstructions. The impact of intensive fishing on eel stocks in Lake Karapiro cannot be evaluated yet, but the reduced abundance of larger eels observed this year is likely to allow prey species to flourish and juvenile eel stocks to grow faster, provided the population is not overstocked.

Fishing effort should be managed to structure populations of resident eels to allow the most benefit to be gained from lower densities and high food availability. Intensive harvest of smaller commercial sized eels may be appropriate for areas where there is a high production of food suitable for small eels. Intensive harvest of large eels will avoid excessive downstream passage wastage through hydroelectric turbines.

Eel growth in these stocked hydro lakes should be carefully monitored and annual harvests estimated to enable better understanding of yields and, therefore, appropriate stocking levels. Stocking rates appear to be more appropriately linked to the most preferred habitat available in the hydro lakes (shallow margins rather than simply lake area). Eel prey abundance and diversity should continue to be monitored to avoid depletion of the prey populations. The relatively closed waters of hydro lakes may be particularly vulnerable to removal of prey species if eel stocking is unregulated. Adequate monitoring may be accomplished through the annual fishing and reporting by commercial fishers (using small-meshed nets in addition to their own standard fykes), along with periodic sampling of the eel populations and prey species using the standardised methods established by Beentjes *et al.* (1997). We suggest that a three yearly evaluation be undertaken.

Recommendations

- The narrow central growth-bands found in otoliths from elvers below dams and in adult eels from within the hydro lakes should be validated.

- During the next transfer, attempts should be made to modify the behaviour of elvers which tend to continue migrating after being transferred to the lakes. Temporary retention of the stocks in holding pens in the destination lake may allow elvers to acclimate and stop migration. Temperature shock treatment may also be tested.

- Accurate records of transfer must be kept, including species composition, size, and quantities moved, to establish a better understanding of the relationship between stocking density and yield. It will also allow the monitoring of the migratory period, enable the detection of changes to species composition, and allow more focused transfer in future. Where elver passes are installed, samples should be taken throughout the migratory season to provide similar information.

- Eel growth and harvest in lakes that are enhanced should be monitored to enable better understanding and more accurate prediction of yields and therefore appropriate stocking levels and other associated management strategies. Catch and effort records need to be kept by fishers eeling enhanced waters, particularly the three Waikato hydro lakes investigated, to better understand the link with stocking density.

- Eel prey abundance and diversity should continue to be monitored to avoid depletion of the prey populations.

- The two previous recommendations may be accomplished through the annual fishing and reporting by commercial fishers (using small-meshed nets in addition to their own standard fykes), along with sampling of the eel populations and prey species using standardised methods at three year intervals.

- Contamination of sediments in upper Waikato hydro lakes by geothermal activity and effluent discharges may have resulted in mercury contamination of eel flesh. High mercury contamination in eels can occur throughout the size range. Immediate monitoring of mercury contamination in eels in the upper Waikato lakes should be undertaken to avoid the potential product rejection in the marketplace.

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References

Barthelmes D. 1988: Fish predation and resource reaction: Biomanipulation of background data from fisheries management. *Limnologica 19*: 51–59.

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

Berg, R. 1990: The growth of eels: a critical assessment of data from open waters. *Internationale Revue der gesamten Hydrobiologie 75*: 775–762.

Beasley, I., Charteris, M., McKinlay, S., Moore, S., & Whiting, M. 1996: A review of the harvest and ecology of New Zealand freshwater eels, with recommendations for research and management. *University of Otago Wildlife Management Report 86*. 59 p.

Boubée, J., West, D., Kane, D., Barrier, R., & Richardson J. 1995: Fish population survey of the Waikato River upstream and downstream of the Kinleith Mill discharge. NIWA Consultancy Report PPL301/2.1. 84 p.

Boubée, J., Lee, D., Dean, T., & Kusabs, I. 1997: Matahina Power Station elver catch and transfer programme 1996–97. NIWA Consultancy Report: ELE702.21. 30 p.

Boubée, J. & Mitchell, C. 1994: The eels that climb over a dam. *Water and Waste in New Zealand 82*: 23–24.

Boubée, J. & Winitana, B. W. 1997: Piripaua power station elver catch and transfer programme 1996–97. NIWA Client Report, ELE702/12/1. 16 p.

Boud, R. & Cunningham, B. T. 1960: An investigation of the upstream eel migration at Roxburgh Dam, on the Clutha River. Marine Department Investigational Report, Job No. 23 (Unpublished report held in NIWA library, Wellington.)

Brooks, R. R., Lewis, J. R., & Reeves, R. D. 1976: Mercury and other heavy metals in trout of the central North Island. *New Zealand Journal of Marine and Freshwater Research 10*: 233–244.

Chisnall, B.L. 1989: Age, growth, and condition of freshwater eels (*Anguilla* sp.) in backwaters of the lower Waikato River, New Zealand. *New Zealand journal of Marine and Freshwater Research, 23*: 459–465.

Chisnall, B. L. 1993: Age and growth of freshwater eels in the Waikato River. Report to electricity corporation of New Zealand Ltd. NIWA Consultancy Report No. ELE113/1 22 p.

Chisnall, B. L. 1994: An unexploited mixed species eel stock (*Anguilla australis* and *A. dieffenbachii*) in a Waikato pastoral stream, and its modification by fishing pressure. *Conservation Advisory Science Notes No. 69*.

Chisnall, B. L. 1996: Habitat associations of juvenile shortfinned eels (*Anguilla australis*) in a shallow New Zealand lake. *New Zealand Journal of Marine and Freshwater Research 30*: 233–237.

Chisnall, B. L. 1997: interim report: Review of known biology/ecology of *Anguilla reinhardtii*, its distribution and likely impact on New Zealand fauna. NIWA Consultancy Report DOC70213. 9 p.

Chisnall, B. L. & Hayes, J. W. 1991: Age and growth of shortfinned eels (*Anguilla australis*) in the lower Waikato basin, North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 25*: 71–80.

Chisnall, B. L. & Hicks, B. J. 1993: Age and growth of longfinned eels (*Anguilla dieffenbachii*) in streams in pasture and under indigenous forest in the Waikato River basin, and in two hydro - electric lakes in the North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 27*: 317–332.

Chisnall, B. L. & Rowe, D. K. 1997: Heavy metals in muscle tissue of eels at sites near the Ngawha geothermal field. NIWA Consultancy Report TSA70201. 24 p.

Chisnall, B. L. & West, D. 1996: Design and trials of a fine meshed fyke net for eel capture, and factors affecting size distribution of catches. *New Zealand Journal of Marine and Freshwater Research 30*: 355–364.

Coulter, G. W. 1977: Ecological impact on the Waikato River of untreated effluent for proposed Broadland Geothermal Power Station. *Freshwater Section, DSIR Ecology Division, Taupo Report No. 26.* 33 p.
Duncan, A. & Kubecka, J. 1995: Land/water ecotone effects in reservoirs on the fish fauna. *Hydrobiologia 303:* 11–30.
Hayes, J. W. & Rutledge, M. J. 1991: Relationship between turbidity and fish diets in Lakes Waahi and Whangape, New Zealand. *New Zealand Journal of Marine and Freshwater Research 35*: 149–169.
Hobbs, D. F. 1940: Natural reproduction of trout in New Zealand and its relation to density of populations. *Fisheries Bulletin 8.* 104 p.
Hu, L. C. and Todd, P. R. 1981: An improved technique for preparing eel otoliths for ageing. *New Zealand Journal of Marine and Freshwater Research 15*: 445–446.
Jellyman, D. J. 1977: Summer upstream migration of juvenile freshwater eels in New Zealand. *New Zealand Journal of Marine and Freshwater Research 11*: 61–71.
Jellyman D. J. & Ryan C. M. 1983: Seasonal migration of elvers (*Anguilla* spp) into Lake Pounui, New Zealand, 1974–1978. *New Zealand Journal of Marine and Freshwater Research 17*: 1–15.
Jellyman, D. J., Chisnall, B. L., & Todd, P. R. 1995: The status of the eel stocks of Lake Ellesmere. *NIWA Science and Technology Series 26.* 62 p.
Jellyman, D. J., Chisnall, B. L., Dijkstra, L. H., & Boubée, J. A. T. 1996: The first record of the Australian longfinned eel, *Anguilla reinhardtii,* in New Zealand. *Marine and Freshwater Research 47*: 1037–1040.
Jolly, B. 1994: Test report for heavy metal analyses of eels from the upper Waikato River. Unpublished Ministry of Agriculture and Fisheries consultancy report. 6 p.
Jones, J. B., Astill, M., & Kerei, E. 1983: The pond culture of *Anguilla australis* in New Zealand - with special reference to techniques and management of the experimental farm at Te Kaha, Bay of Plenty. *Estratto dalla Rivista Italiana di Piscicoltura e Ittiopatologia Anno 18*: 85–117, 138–166.
Jones, P. D. 1996: Biommarker and contaminant studies of caged and feral fish in the Waikato River. Report to Environment Waikato Hamilton, ESR Environment, Lower Hutt. 75 p.
Livingston, M. E., Biggs, B. J., & Gifford, J. S. 1986: Inventory of New Zealand lakes. Part I. North Island. Ministry of Works and Development, Wellington. *Water and Soil Miscellaneous Publication 80.* 200 p.
McLea, M. C. 1986: Ohinewai regional resource study biology and water quality. *Waikato Valley Authority Technical Publication 37.* 199 p.
Mills, G. N. 1995a: Mercury and arsenic in Waikato River fish. NIWA Consultancy Report SCJ129/06. 47 p.
Mills, G.N. 1995b: The upper Waikato River study. An overview and summary. NIWA Consultancy Report SCJ129/05. Prepared for Environment Waikato. 28 p.
Mitchell, C. P., Huggard, G., & Davenport, M. 1984: Homegrown fish pass helps eels get by. *Freshwater Catch 24*: 21-22.
Mitchell, C. P. & Davis-Te-Maire, K. T. A. 1993: Mahinga kai survey of the upper Waitaki. Report to Ngai Tahu and Electricity Corporation of New Zealand. 25 p.
Moriarty, C. 1990: Eel management practice in three lake systems in Ireland. I*n* Proceedings of a symposium organised by the European Inland Fisheries Advisory Commission, Goteborg, Sweden, 31 May–3 June 1988, pp 262–269. Pudoc, Wageningen.
Pack, Y. M. & Jellyman, D. J. 1988: Fish stocks and fisheries of the lower Clutha River. *New Zealand Freshwater Fisheries Report 98.* 117 p.
Stancliff, A. G., Boubée, J. A. T., & Schicker, K. P. 1989: Matahina Fish Survey No.4. Report to Electricorp by Waikato Fisheries consultants 18 p.
Strickland, R. 1996. Fish of the Waikaretaheke and Wairoa Rivers, Hawkes Bay. Report to the Fuel Resource Group, ECNZ, Hamilton, by Lake, River & Sea, Rotorua. 57 p.

Taranaki Catchment Commission and Regional Water Board 1984: The ecology of eels in Taranaki. Technical Report 84-5. 82 p.

Taranaki Catchment Board and Regional Water Board 1988: Lake Rotorangi monitoring a new hydro lake. Taranaki Catchment Board. Technical Report 88, 169p.

Taranaki Regional Council 1992: Egmont Electricity Lake Rotorangi 1991/92 monitoring annual report water quality and biological programmes. Technical Report. 30 p.

Taranaki Regional Council 1995: Egmont Electricity Lake Rotorangi 1994/95 monitoring: annual report water quality and biological programmes. Technical Report. 40 p.

White, B.; Knights, B. 1994: Elver and stock assessment in the Severn and Avon. R&D project record 256/13/ST. Bristol, England: National Rivers Authority. 141 pp.

Williams, G. 1997: Migratory fish capture and transfer proposal at Patea hydro dam. Discussion document, 20 p. (Unpublished report held in NIWA, Hamilton library.)

Wilkinson, L. 1990: SYSTAT: the system for statistics. SYSTAT Inc., Evanston, Illinois.

Zelco New Zealand Ltd. 1995: Native fish passes: Waitaki, Aviemore, Benmore. Report prepared for Electricity Corporation of New Zealand.

Table 1: **Manual elver transfers from the Karapiro Dam headrace (kg)**

Lake	1992–93	1993–94	1994–95	1995–96	1996–97
Waikare		150	120		
Karapiro	110	320	316	564*	208
Arapuni		300	10	442	550
Waipapa			5	132	100
Maraetai			7	79	149
Whakamaru					253
Atiamuri					136
Ohakuri					460
Total	110	770	458	1217	1856

*More elvers are known to have reached the lake via the spillway and siphon.

Table 2: **Recorded elver transfers from the Matahina dam headrace. MAF, Ministry of Agriculture and Fisheries; ECNZ, Electricity Corporation of New Zealand; DoC, Department of Conservation; NIWA, National Institute of Water and Atmospheric Research; Kokopu Trust (local organisation)**

Year	Numbers released (time, location, organisation)	Estimated weight* (kg)	% longfinned eels (time, collection point)
1983–84	6 000 (Dec, Aniwhenua)	16.3	60 (Dec)
	13 500 (Jan, Aniwhenua)	44.7	44 (Jan)
	1 500 (Mar, Aniwhenua)	4.1	48 (Mar)
1984–85	23 000 (Aniwhenua)	62.3	23
1985–86	6 000 (Aniwhenua)	16.3	24
1986–87	18 500 (Aniwhenua)	50.1	60
1987–88	0	-	-
1988–89	18 000 (Matahina)	48.8	10 (Jan, transformer)
1989–90	40 000 (Aniwhenua)	108.4	-
	6 000 (Jan, Matahina)	16.3	
1990–91	?	?	-
1991–92	9 000 (Matahina, MAF)	24.3	26 (Feb, in pass)
	? (ECNZ and DoC)	?	31 (Feb, transformer)
	Over 15 000 for elver pass	40.6	
1992–93	4 500 (Jan, Matahina, MAF)	12.2	22 (Jan, top of pass)
	Over 27 000 for elver pass	73.2	
1993–94	20 000 (Matahina, Jan, NIWA)	54.2	-
	8 000 (Matahina, Feb, NIWA)	21.7	
	149 000 (Aniwhenua, DoC)	403.8	
	Over 38 000 for elver pass	103	
1994–95	39 000 (Aniwhenua, DoC)	105.7	-
	Others ?	?	
	Unknown number for elver pass	?	
1995–96	144 000 (Aniwhenua , DoC)	312.5	
	Unknown number for elver pass	?	
1996–97	13 700 (Aniwhenua, NIWA)	59.4	44 (whole season)
	? (Kokopu Trust)	84.5	?
	Manual collection only, elver pass not operating		

***Table 3*: Length, weight, and age characteristics of longfinned elvers (LFE) sampled from Waiau River, Roxburgh Dam, and Karapiro Dam. *, data from Beentjes *et al.* (1997)**

		Length (mm)		Weight (g)			Age		
		mean	range	mean	range		mean	range	% LFE
Waiau River (1995–96)*	46	131.5	-	2.2	-	33	5.2	2–11	96
Roxburgh Dam (1995–96)*	10	191.9	125–220	-	-	10	9.1	5–12	100
Roxburgh Dam (1996–97)	101	151.4	112–192	4.0	1.5–9.2	55	11.9	3–22	100
Karapiro Dam (1995–96)	188	103.4	83–130	1.5	0.7–3.3	23	ca.2	0–3	0-44

***Table 4*: Estimated weight and numbers of elvers transferred from Karapiro Dam during the 1996–97 season**

Transfer site	Permitted (kg)	Achieved (kg)	Number (000s) Shortfinned	Longfinned
Karapiro	No limit	208	103	27
Arapuni	550	550	269	73
Waipapa	100	100	49	13
Maraetai	250	149	64	28
Whakamaru	450	253	145	28
Atiamuri	140	136	54	26
Ohakuri	750	460	279	48
Total Waikato		1 856	962	243

***Table 5*: Species composition, number, and size range of samples of elvers from elvers transferred from Karapiro Dam to other habitats**

Sample date	Shortfinned eels (mm)			Longfinned eels (mm)		
	n	Range	Mean ± SE	*n*	Range	Mean ± SE
11/11/96	32	85–152	100.6 ± 2.36	0	-	-
18/11/96	95	85–125	99.7 ± 0.85	1	120	120
22/11/96	62	83–140	101.5 ± 1.42	0	-	-
25/11/96	20	83–125	106.7 ± 3.02	3	108–142	120 ± 11.01
28/11/96	90	81–155	99.9 ± 1.18	0	-	-
2/12/96	12	87–106	93.3 ± 1.87	11	108–162	125 ± 5.6
4/12/96	50	84–147	105.7 ± 1.77	5	122–168	141 ± 7.82
9/12/96	50	83–137	100.4 ± 1.5	7	120–129	123.3 ± 1.19
16/12/96	50	88–134	106.2 ± 1.44	23	98–132	112.2 ± 1.58
18/12/96	50	94–160	110 ± 1.88	29	100–176	119.4 ± 3.31
24/12/96	50	88–207	105.8 ± 2.55	50	96–135	111.5 ± 1.27
30/12/96	50	91–123	106.2 ± 1.19	50	97–137	114.6 ± 1.44
6/1/97	50	85–125	101.3 ± 1.23	50	100–170	116.7 ± 1.88
9/1/97	101	80–120	99.4 ± 0.86	101	91–142	114.4 ± 0.79
12/1/97	152	83–138	101.2 ± 0.93	75	95–145	117.5 ± 1.05
21/1/97	50	83–138	97.1 ± 1.62	50	96–197	113.9 ± 2.0
28/1/97	50	85–118	97.1 ± 1.04	50	93–247	124.8 ± 1.01
5/2/97	50	85–220	101.7 ± 3.27	50	100–203	118.4 ± 2.43
12/2/97	50	78–119	95.1 ± 1.17	50	94–175	115.6 ± 2.04
20/2/97	50	70–109	95.8 ± 1.02	50	97–165	115.2 ± 1.69
26/2/97	50	70–117	95.2 ± 1.25	41	89–240	118.4 ± 3.89

***Table 6*: Species composition, number, and size range of samples of elvers from elvers transferred from Matahina Dam**

Sample date	Shortfinned eels (mm)			Longfinned eels (mm)		
	n	Range	Mean ± SE	*n*	Range	Mean ± SE
20/1/97	32	80–650	208.1 ± 21.0	8	92–265	131.1 ± 20.1
26/1/97	102	81–290	145.1 ± 5.10	50	86–163	119.6 ± 2.33
30/1/97	42	87–445	207.1 ± 14.4	51	82–179	112.9 ± 2.26
07/2/97	50	85–350	138.5 ± 9.50	50	84–142	108.8 ± 2.02
24/2/97	50	78–324	122.5 ± 8.05	33	79–151	104.9 ± 2.55
05/3/97	50	82–236	117.9 ± 5.00	50	87–135	109.8 ± 1.87
13/3/97	50	85–390	171.2 ± 12.90	17	86–145	110.5 ± 4.84

***Table 7*: Catches and transfers (kg) of elvers from the Piripaua Power Station tailrace during the 1996–97 season**

Date	Total	Tailrace trap	Venturi trap	Release site (grid ref.)
30/1/97	0.2	0.2		Mangaone (W18 666568)
13/2/97	0.5	0.4	0.1	Kahutangaroa (W18 707583)
17/2/97	0.04	0.03	0.007	Mangaone(W18 688560)
24/2/97	0.2	0.2	0	Waikaretaheke (W18 699573)
26/2/97	0.3	0.28	0.02	Mangaone(W18 688560)
28/2/97	0.3	0.3	0	Kahutangaroa (W18 666568)
06/3/97	0.3	0.3	0	Kahutangaroa (W18 707583)
11/3/97	0.3	0.3	0.01	Kahutangaroa (W18 707583)
14/3/97	0.001	0.001	0	Waikaretaheke (W18 716543)
18/3/97	0.01	0.007	0.003	Kahutangaroa (W18 666568)
20/3/97	0.003	0.003	0	Waikaretaheke trib. (W18 715543)
26/03/97	0.001	0.001	0	Tapiu Creek.
15/04/97	0.003	0.003	0	Waikaretaheke (W18 699773)
Total	2.16	2.02	0.14	

***Table 8*: Species composition, number, and size range of samples of elvers taken from Lake Waikare flood gates elver pass**

Sample date	Shortfinned elvers (mm)			Longfinned elvers (mm)		
	n	Range	Mean ± SE	*n*	Range	Mean ± SE
24/1/97	52	63–149	84.1 ± 2.08	24	69–205	89.7 ± 5.30
31/1/97	56	63–212	93.9 ± 3.90	3	71–90	79.0 ± 5.68
7/2/97	50	68–251	98.2 ± 5.30	3	74–115	90.0 ± 12.7
14/2/97	52	62–305	102.2 ± 5.12	0	-	
21/2/97	50	65–210	90.1 ± 4.14	0	-	
28/2/97	57	68–243	107.0 ± 5.90	0	-	
7/3/97	53	55–375	119.5 ± 8.60	0	-	
14/3/97	53	61–232	104.7 ± 4.90	0	-	

Table 9: **Catch rates (number and biomass) taken by large fine-meshed (LFM) and standard (Std) fykes in Lakes Karapiro, Arapuni, and Maraetai, 28–31 January 1997. [1, 2, 3] 1–3 nets omitted from analyses respectively because catches were stolen; *, derived using estimated weights from length-weight models where actual weights not recorded**

Lake	Nets			Eels		Total biomass *(kg)		Number per net ± SE		kg per net*	
	LFM	Std	Species	LFM	Std	LFM	Std	LFM	Std	LFM	Std
Karapiro	23[1]	60	S	55	93	22.892	79.290	2.88 ± 0.69	1.82 ± 0.18	1.270	1.322
			L	3	0	0.573	-	-	-	0.026	-
Arapuni	20[2]	66	S	108	114	34.013	66.272	4.83 ± 1.59	1.89 ± 0.26	1.889	1.004
			L	87	97	23.732	39.007	6.0 ± 0.72	1.24 ± 0.25	1.318	0.591
Maraetai	10[3]	36	S	15	4	6.460	0.400	1.8 ± 0.66	0.22 ± 0.07	0.646	0.01
			L	1	0	0.200	-	-	-	0.020	-

***Table 10*: Length weight coefficients (a, b) for shortfinned (S) and longfinned eels (L) sampled from Waikato River hydro lakes Karapiro, Arapuni, and Maraetai, 28–31 January 1997, and combined historic data from Lakes Karapiro and Arapuni ([1] Chisnall (1994) combined with Beentjes *et al.* 1997); r^2, variation coefficient**

Lake	Species	Eel N	Length range (mm)	Weight range (g)	a	b ± SE	r^2
Karapiro	S	127	203–1080	11–3000	14.77	3.26 ± 0.04	0.98
	S[1]	95	155–1100	32–2500	14.99	3.79 ± 0.04	0.98
	L	3	354–460	93–257	-	-	-
	L[1]	75	345–1205	80–3750	14.85	3.30 ± 0.07	0.97
Arapuni	S	153	240–1180	20–3700	14.25	3.17 ± 0.04	0.98
	S[1]	65	136–1280	15–4000	14.72	3.25 ± 0.04	0.99
	L	100	225–1250	21–6700	14.71	3.29 ± 0.04	0.96
	L[1]	38	225–1420	22–6600	15.22	3.37 ± 0.04	0.99
Maraetai	S	20	110–565	2–368	14.23	3.20 ± 0.05	0.99
	L	1	315	75	-	-	-

Table 11: **Length-at-age coefficients (a, b) for shortfinned (S) and longfinned eels (L) sampled from Lakes Karapiro, Arapuni, and Maraetai, 28-31 January 1997, and combined historic data from Lake Karapiro and Arapuni ([1] Chisnall (1994) combined with Beentjes *et al.* 1997). r^2, variation coefficient; *, not significant $P > 0.05$; [2], two outliers omitted from data**

Lake	Species	Eel N	Length range (mm)	Lake-age range (yr)	a	b ± SE	r^2	Mean annual length increment ± SE (mm)
Karapiro	S	57	200–1060	1–24	341.10	20.74 ± 2.46	0.57	73.5 ± 3.8
	S[1]	132	155–1100	1–23	309.80	28.95 ±	0.59	42.4 ± 2.6
	L	3	353–465	2–6	-	2.25	-	95.5 ± 20.0
	L[1]	77	345–1205	3–30	337.84	-	0.62	32.7 ± 0.9
						22.66 ± 1.97		
Arapuni	S	40	235–1000	1–7	-	-	*	126.7 ± 9.7
	S[1]	84	136–1280	1–14	268.29	77.87 ± 3.22	0.88	80.1 ± 4.5
	L	22	230–860	1–8	-	-	*	160.5 ± 17.5
	L[1]	53	110–1420	1–26	347.42	42.29 ± 2.14	0.89	67.3 ± 4.2
Maraetai	S	21	110–565	0–2[2]	-	-	*	253.8 ± 43.7
	L	1	315	1	-	-	*	225

Table 12: Weight-at-age coefficients (a, b) for shortfinned (S) and longfinned eels (L) sampled from Lakes Karapiro, Arapuni, and Maraetai, 28-31 January 1997, and combined historic data from Lake Karapiro and Arapuni ([1] Chisnall (1994) combined with Beentjes _et al._ 1997). r^2, regression coefficient; *, not significant $P > 0.05$; [2], two outliers omitted from data

Lake	Species	Eel	Weight range (g)	Lake-age range (yr)	a	b ± SE	r^2	Mean annual weight increment ± SE (g)
Karapiro	S	55	13–2700	1–24	5.872	0.038 ± 0.006	0.46	44.0 ± 3.2
	S[1]	95	32–2500	1–23	4.464	0.148 ± 0.016	0.52	31.0 ± 3.1
	L	3	97–279	2–6	-	-	*	52.4 ± 4.5
	L[1]	75	80–3750	3–30	4.757	0.0120 ± 0.011	0.69	47.6 ± 3.1
Arapuni	S	40	14–1864	1–7	-	-	-	69.8 ± 13.1
	S[1]	65	15–4000	1–14	3.773	0.426 ± 0.036	0.71	62.4 + 11.0
	L	22	21–2500	1–8	-	-	*	121.0 ± 32.6
	L[1]	38	22–6600	1–26	4.637	0.201 ± 0.018	0.80	89.0 ± 17.3
Maraetai	S	20	3.8–368	0–2[2]	-	-	*	139.5 ± 32.7
	L	1	75	1	-	-	*	73

Table 13**: Juvenile shortfinned eel catches from strings of g-minnow traps deployed in Lakes Karapiro and Arapuni, 28–30 January 1997. *, position in lake, refer to Figures 1, 2**

Lake	Position*	Depth (m)	Number of g-minnows	Number of eels
Karapiro	1	< 1	5	0
	2	3	5	1
	3	17	13	1
	5	7	10	0
	6	27	10	2
Arapuni	+	12	10	1

Table 14**: Mean number of bycatch species caught in large fine-meshed fykes during sampling of Lakes Karapiro, Arapuni, and Maraetai, 28–31 January 1997**

	No of nets	Mean number per net ± SE						
Lake	(n)	Bully	Smelt	Goldfish	Mosquitofish	Rudd	Koura	Catfish
Karapiro	23	517.7 ± 264.8	49.3 ± 31.8	1.0 ± 0.5	1.6 ± 1.1	5.3 ± 2.8	-	0.4 ± 0.4
Arapuni	20	74.3 ± 13.6	59.1 ± 19.6	10.9 ± 6.2	-	-	0.4 ± 0.2	0.9 ± 0.4
Maraetai	10	151.7 ± 55.6	17.1 ± 9.7	0.4 ± 0.3	-	4.9 ± 4.5	2.3 ± 1.3	1.6 ± 0.7

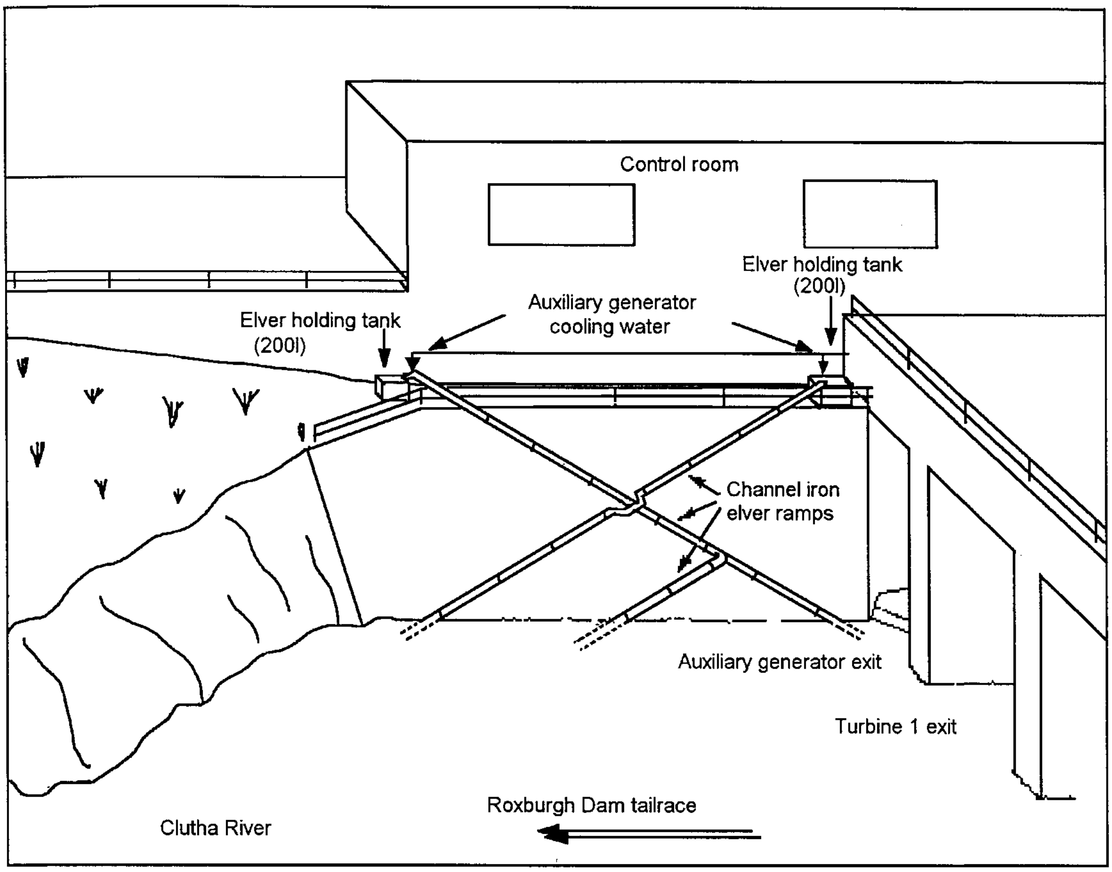

Figure 1: Diagram of the elver ramps installed at Roxburgh Dam in January 1997.

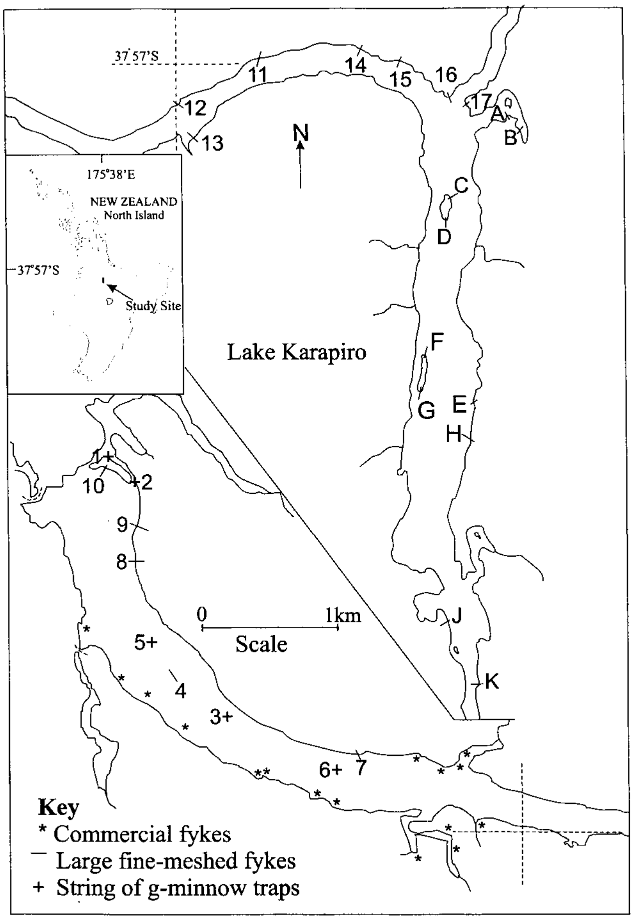

Figure 2: Map of Lake Karapiro showing net and trap positions, January 1997.

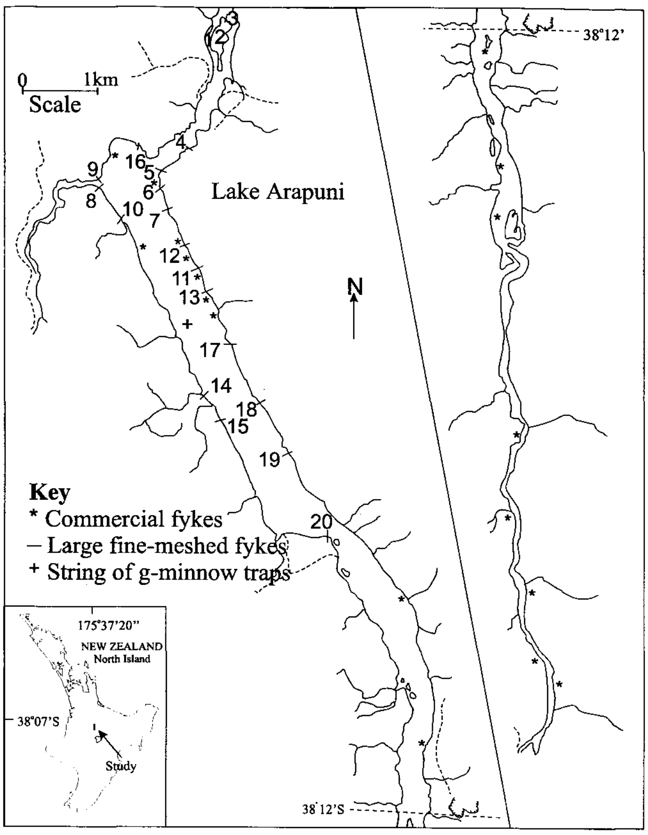

Figure 3: Map of Lake Arapuni showing net and trap positions, January 1997.

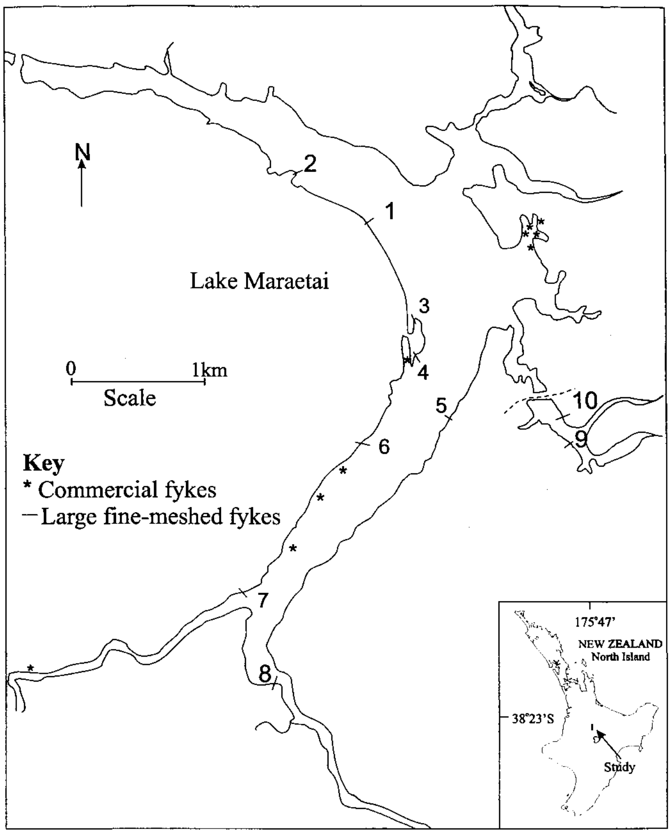

Figure 4: Map of Lake Maraetai showing net positions, January 1997.

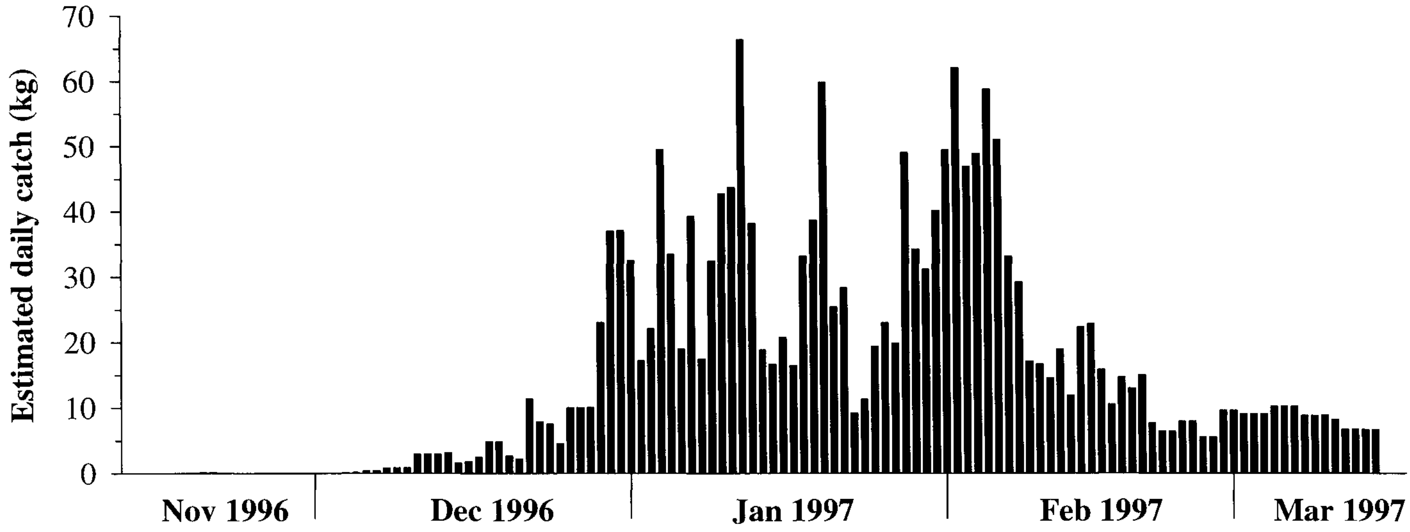

Figure 5a: Estimated daily catch of elvers from all traps at Karapiro, 1996-97.

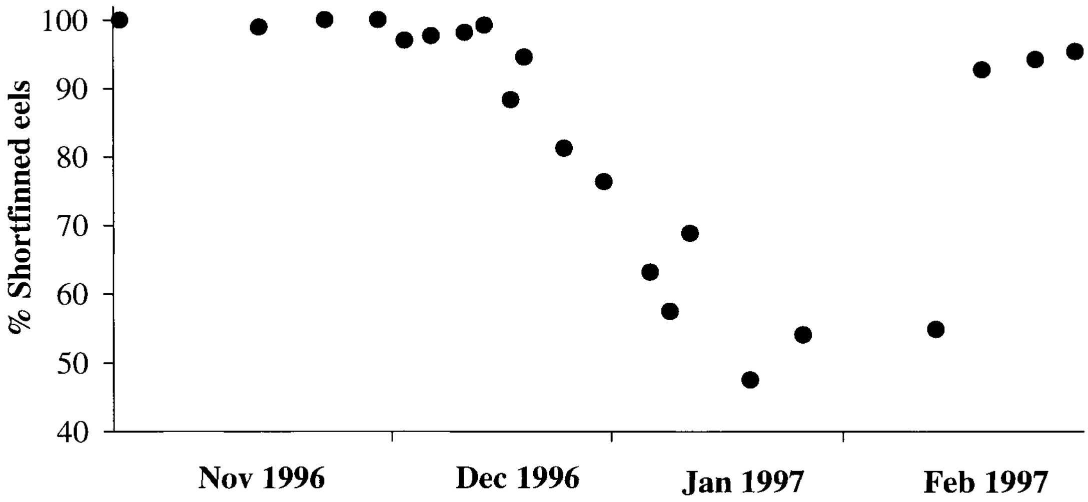

Figure 5b: Species composition of elvers collected from Karapiro Dam, 11 Nov 1996 to 14 March 1997.

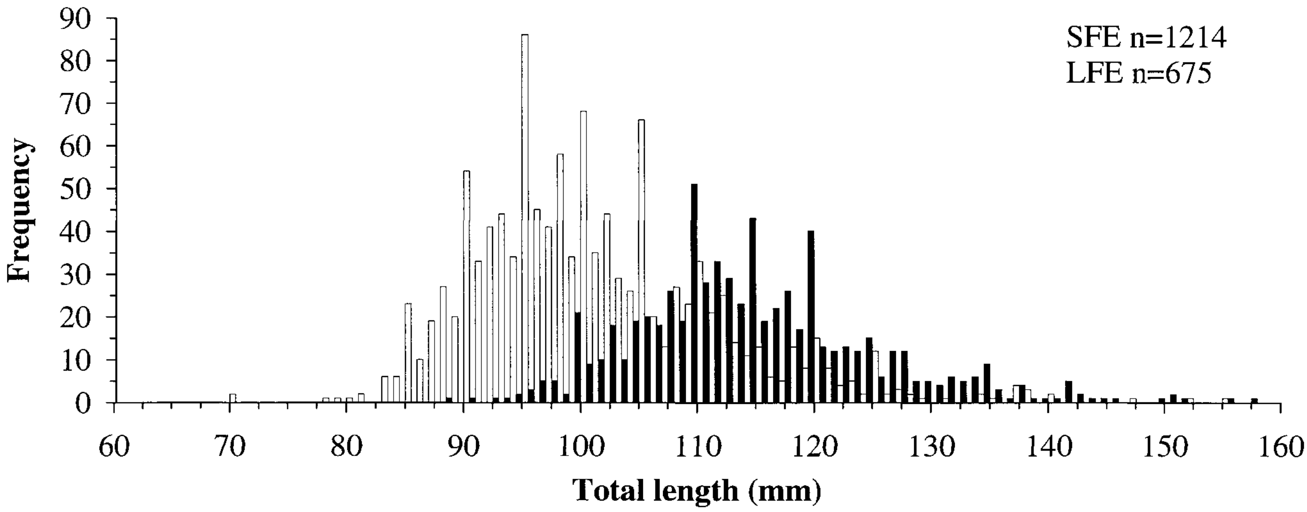

Figure 5c: Length frequency distribution of elvers (<160mm) collected from Karapiro Dam, 11 Nov 1996 to 14 March 1997. Shortfinned eels Longfinned eels

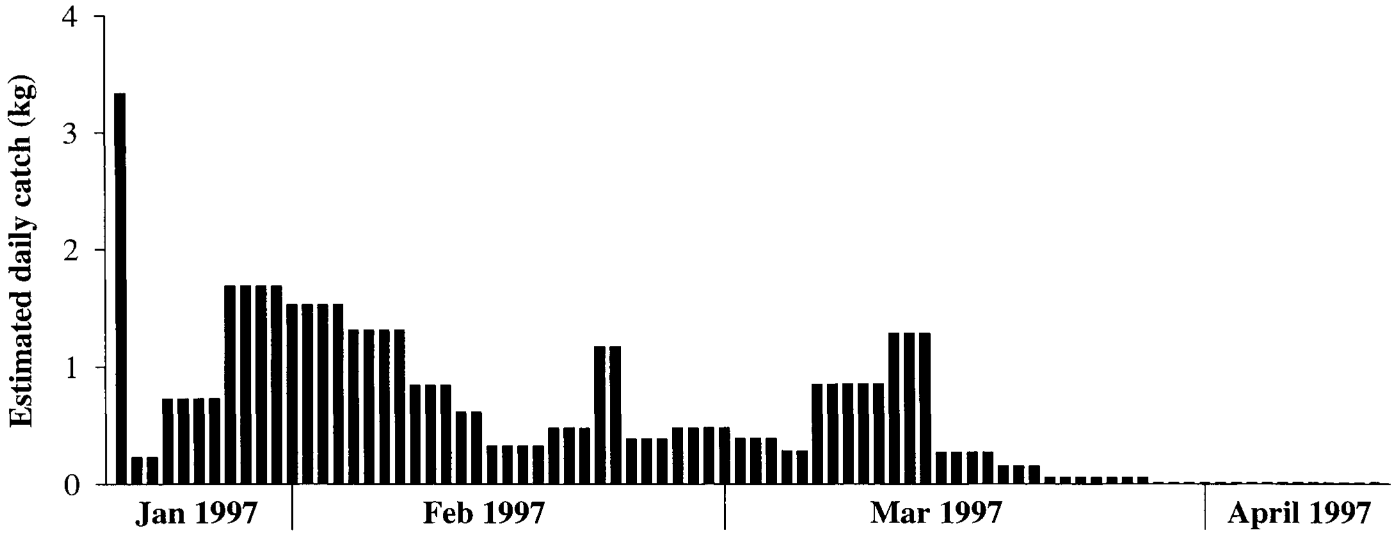

Figure 6a: Estimated daily catch of elvers from all traps at Matahina Dam 1997.

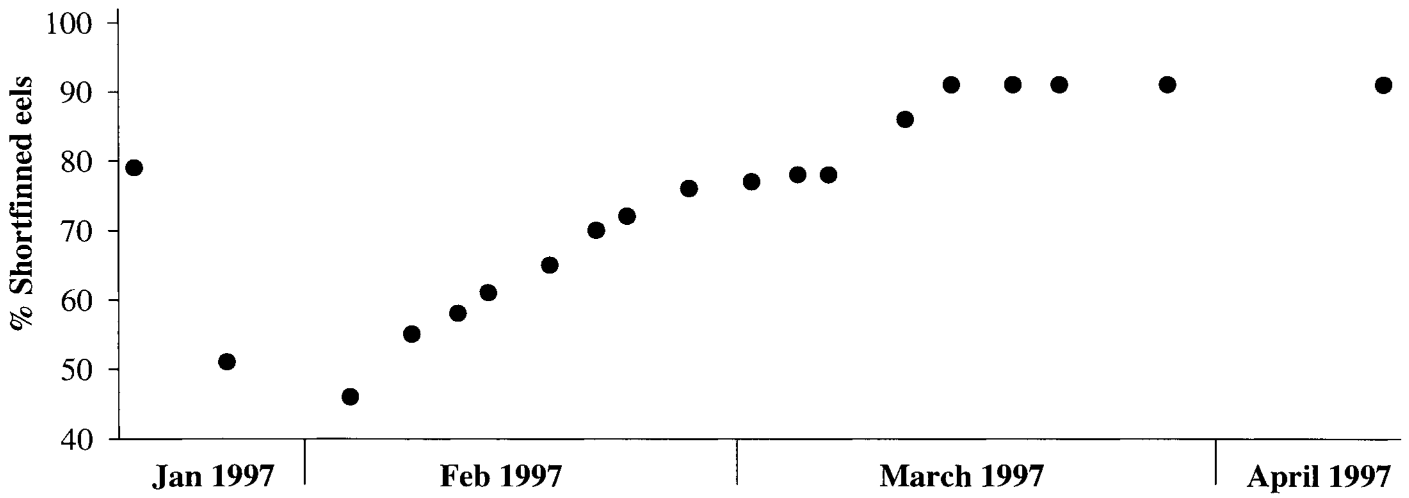

Figure 6b: Species composition of elvers collected from Matahina Dam, 20 January to 11 April 1997.

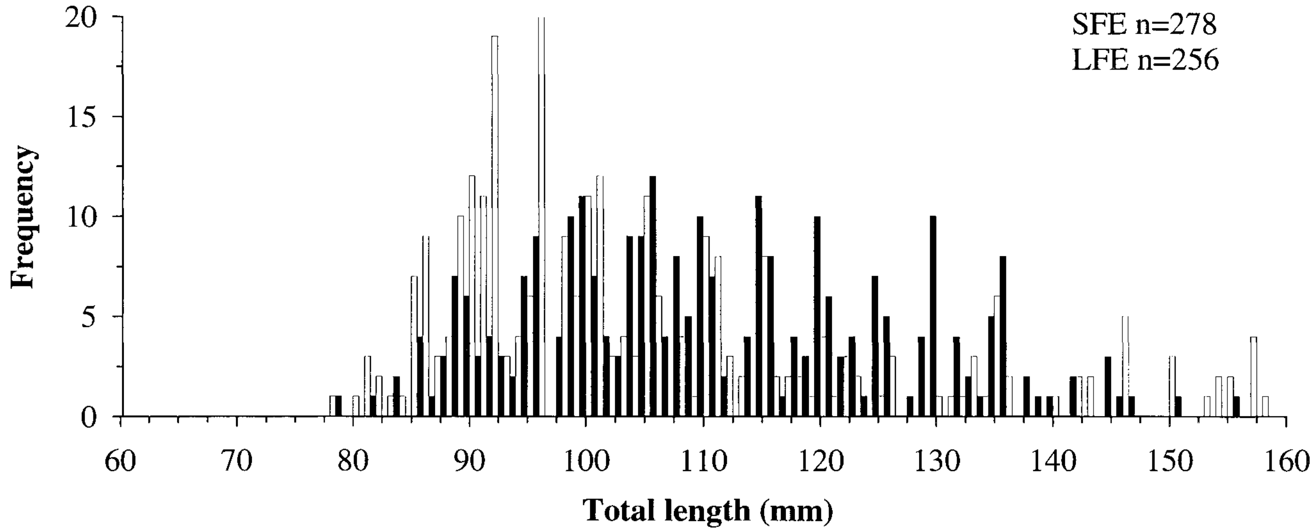

Figure 6c: Length frequency distribution of elvers (< 160 mm) collected from Matahina Dam, 20 January to 11 April 1997. Shortfinned eels Longfinned eels

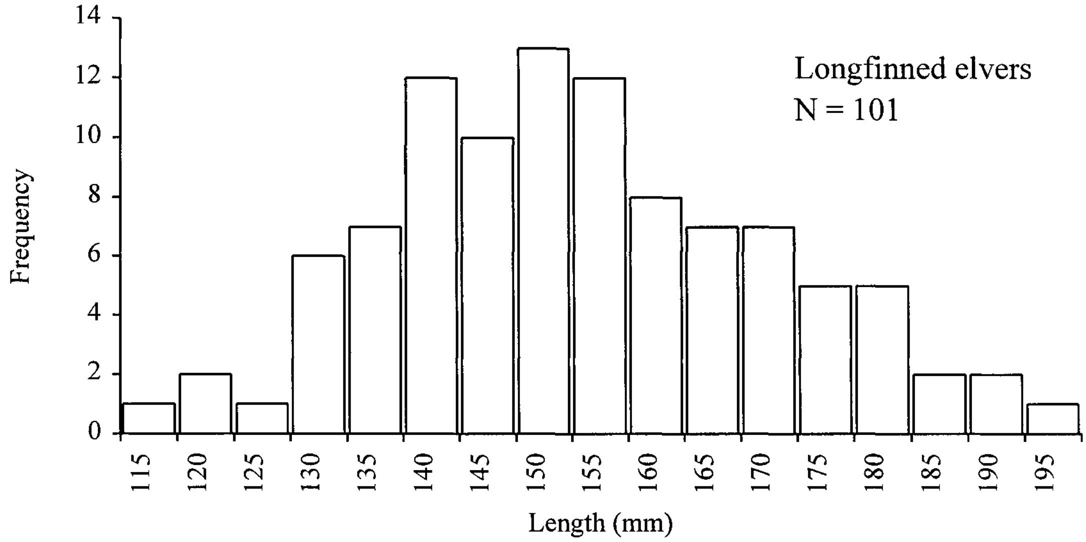

Figure 7a: Length frequency distribution of longfinned elvers from Roxburgh Dam, January–February 1997.

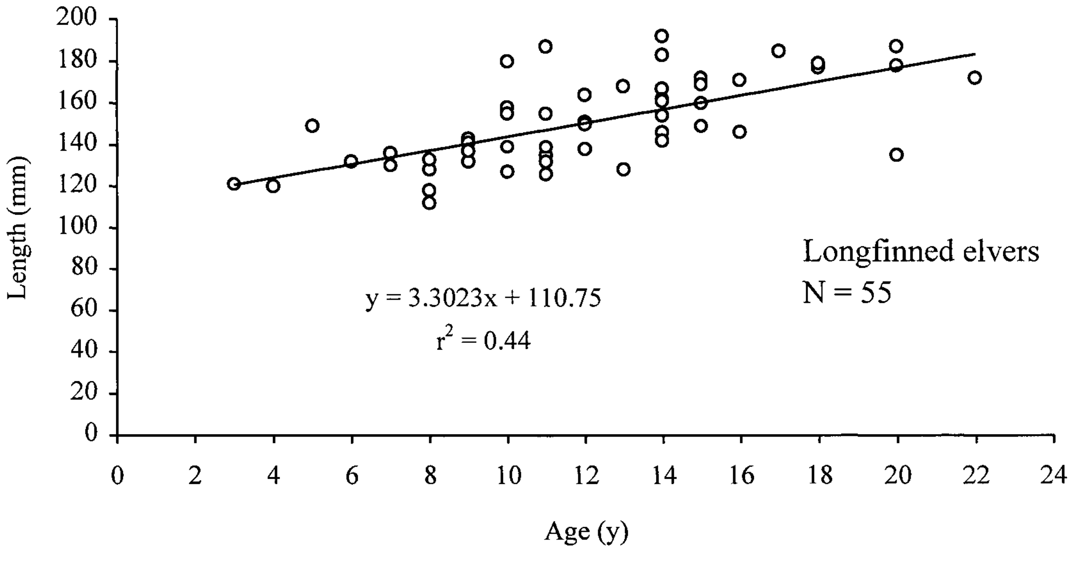

Figure 7b: Age length distribution of longfinned elvers from Roxburgh Dam, January–February 1997.

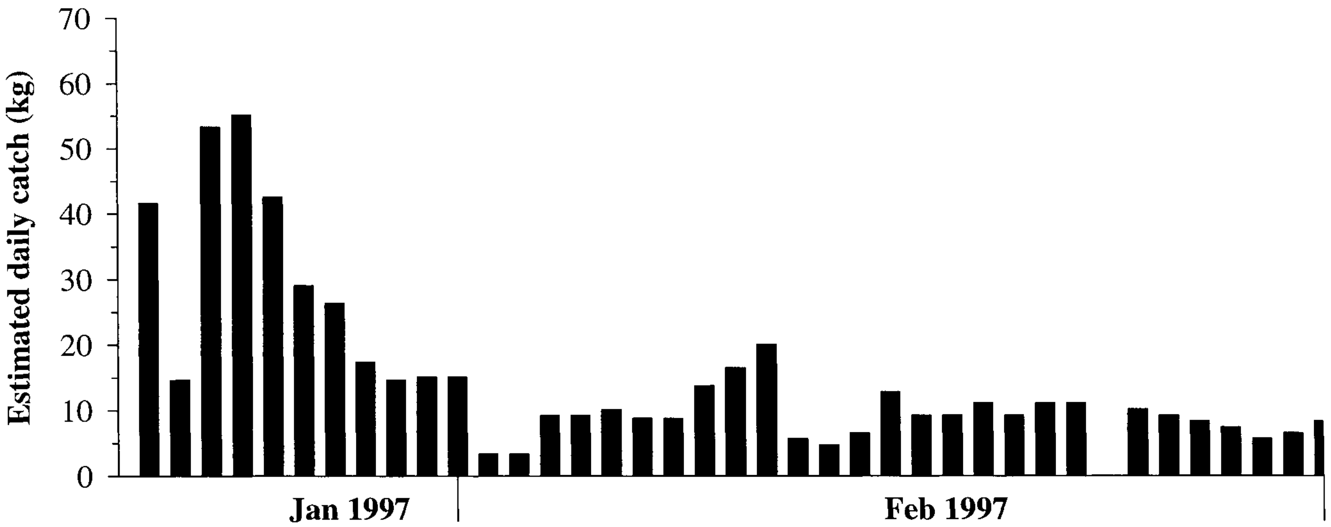

Figure 8a: Estimated daily catch of elvers from traps at elver pass over the Lake Waikare gates during 1997.

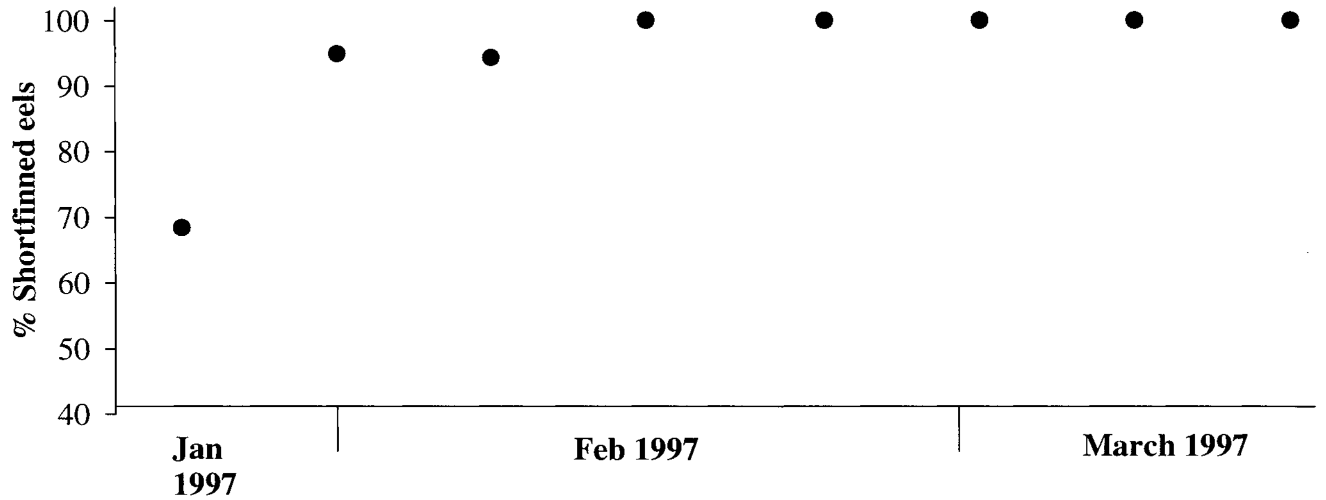

Figure 8b: Species composition of elvers collected from Lake Waikare flood gates elver pass, 24 January to 14 March 1997.

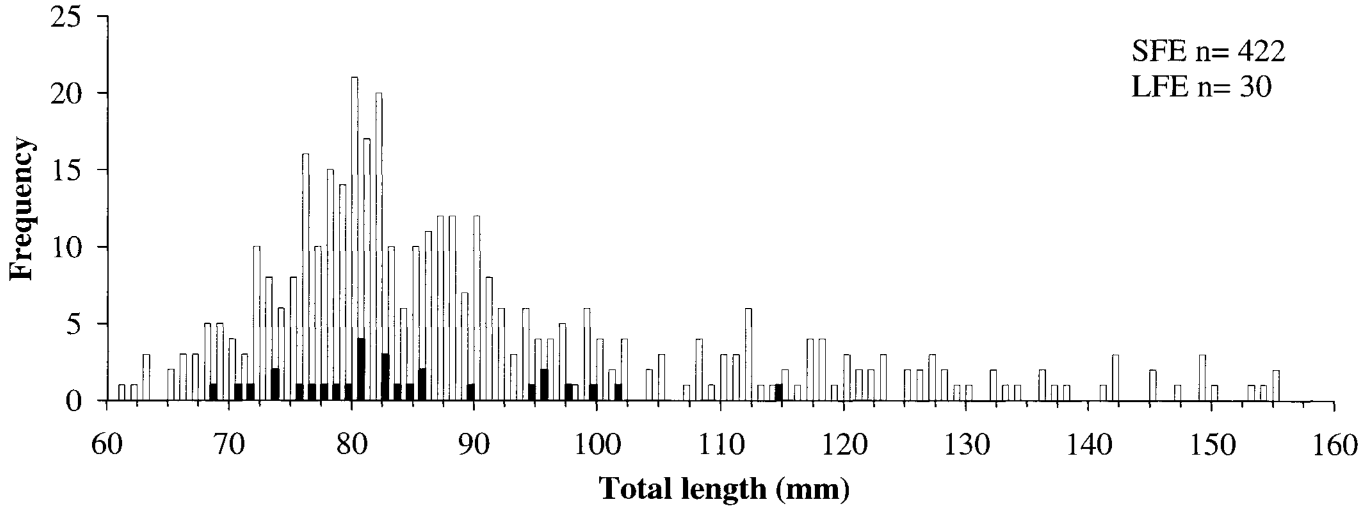

Figure 8c: Length frequency distribution of elvers (< 160 mm) collected from Lake Waikare gates, 24 January to 14 March 1997. Shortfinned eels Longfinned eels

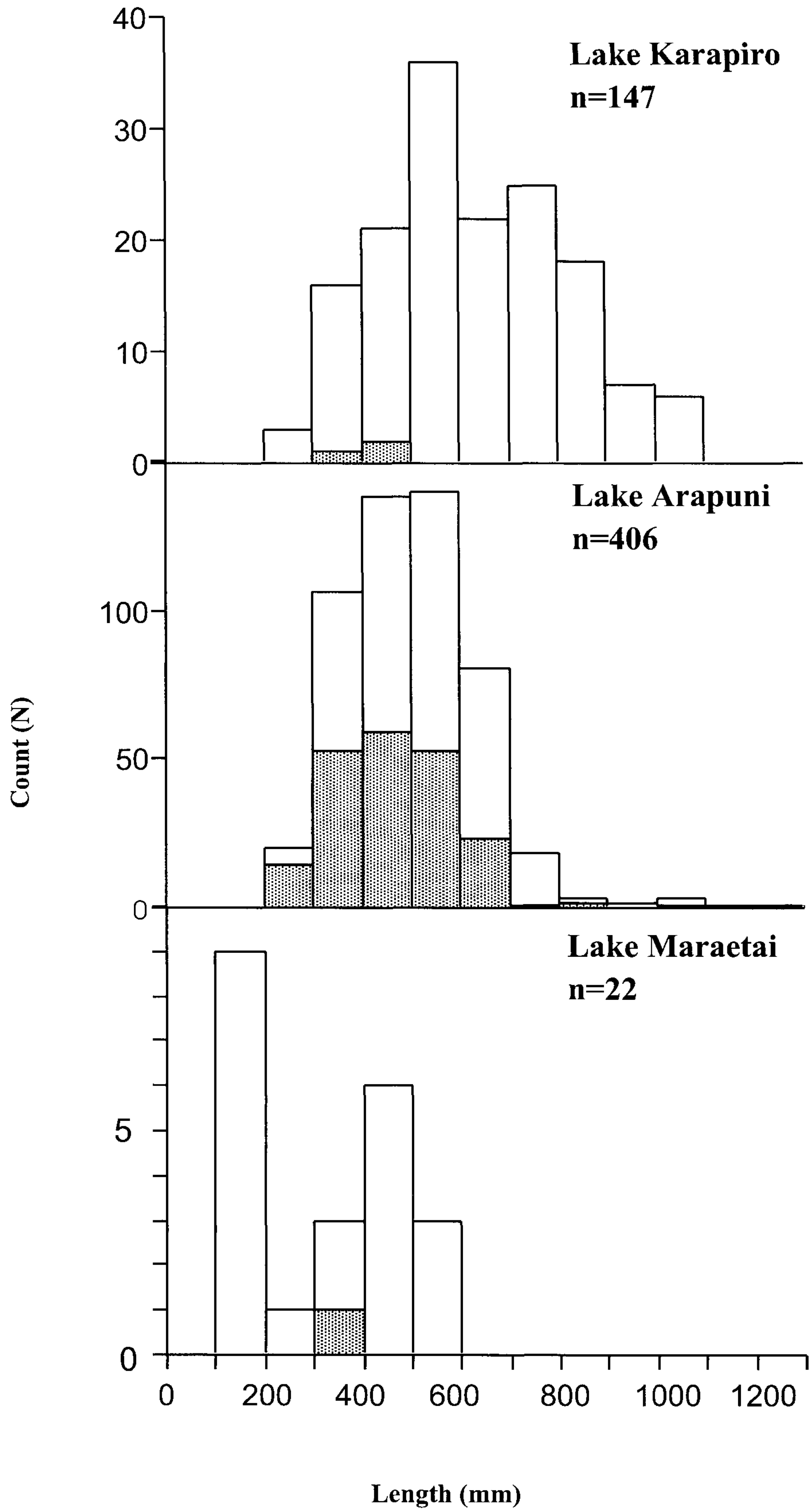

Figure 9: Length frequency distributions of shortfinned (open bars) and longfinned (solid bars) eels caught in fine-meshed and standard fykes in three Waikato River hydro-lakes during January 1997.

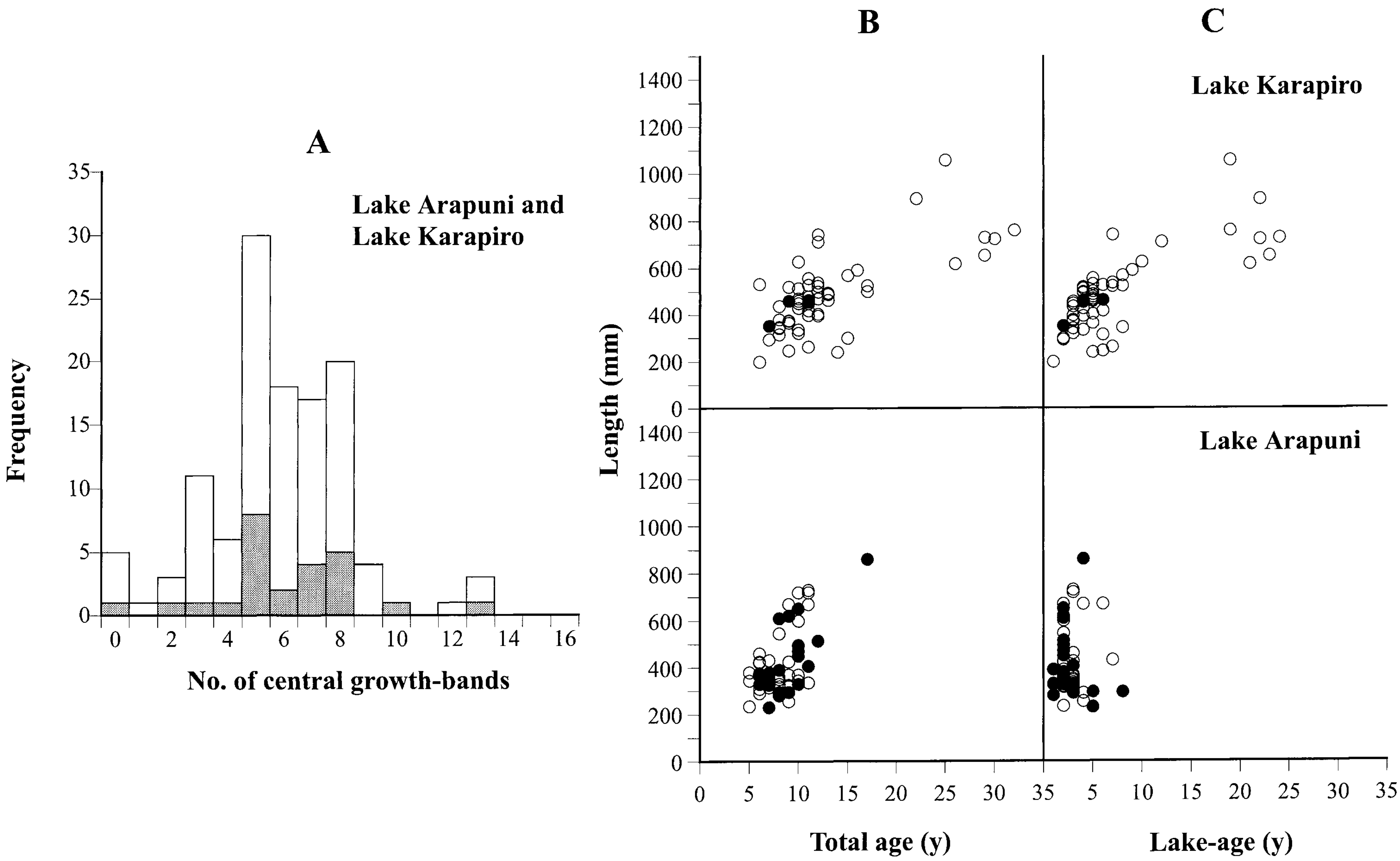

Figure 10: Length-at-age distributions of shortfinned (open bars) and longfinned (solid bars) eels sub-sampled from Lakes Karapiro and Arapuni. A - frequency distribution of central narrow growth-bands, B - total-age plots, C - lake-age plots.

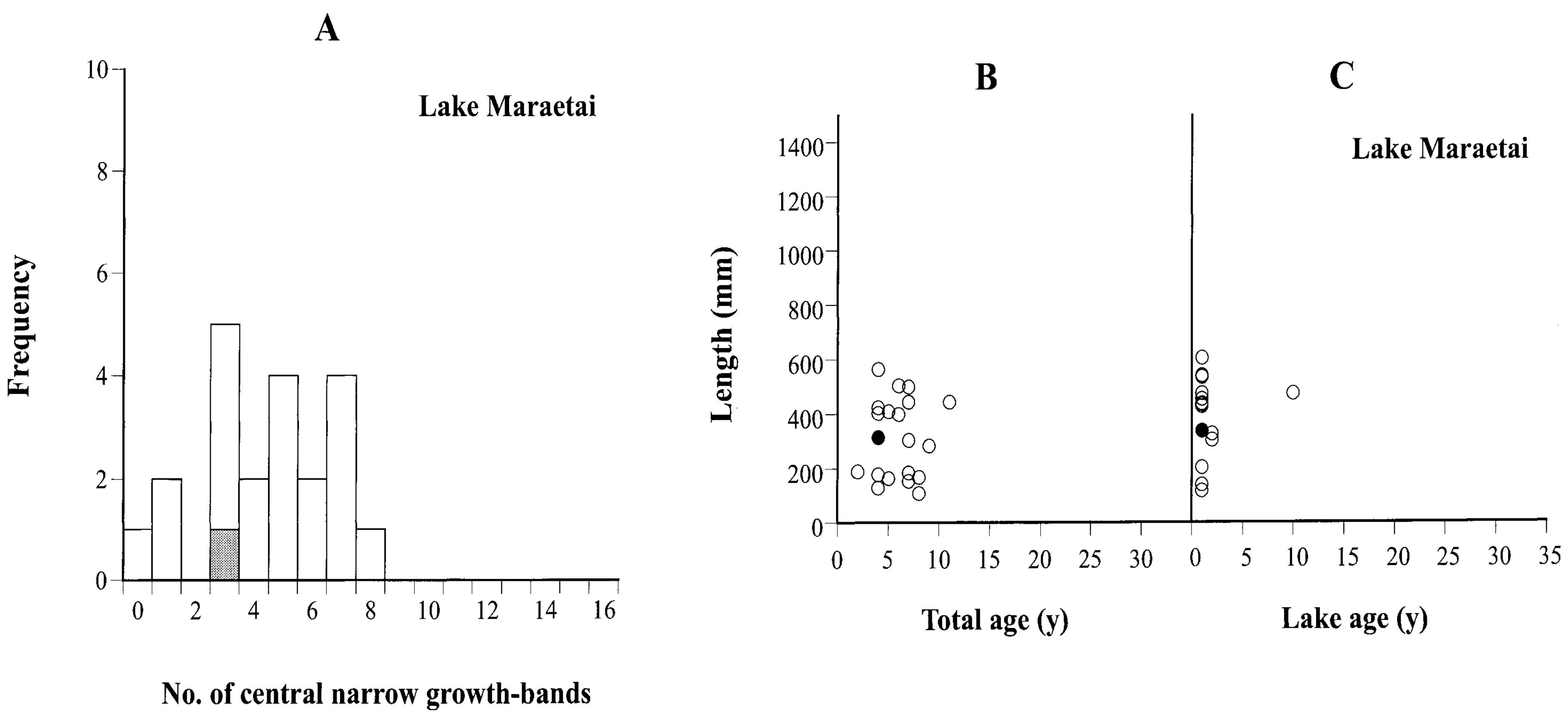

Figure 11: Length-at-age distributions of shortfinned (open bars) and longfinned (solid bars) eels sub-sampled from Lake Maraetai. A - frequency distribution of central narrow growth bands, B - total-age plot, C - lake-age plot.

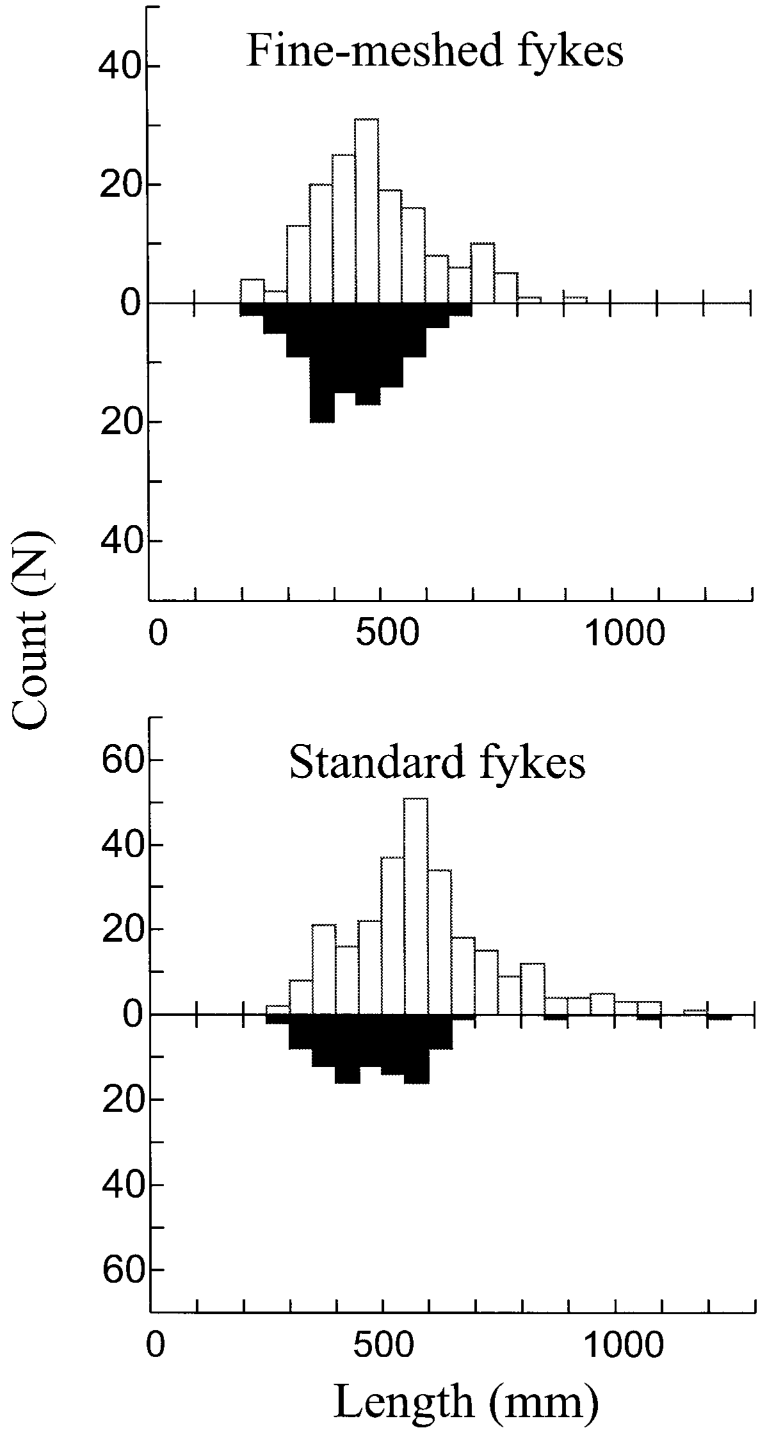

Figure 12: Length frequency distributions of shortfinned (open bars) and longfinned (solid bars) eels sampled from the Lakes Karapiro and Arapuni in fine meshed and standard fykes.

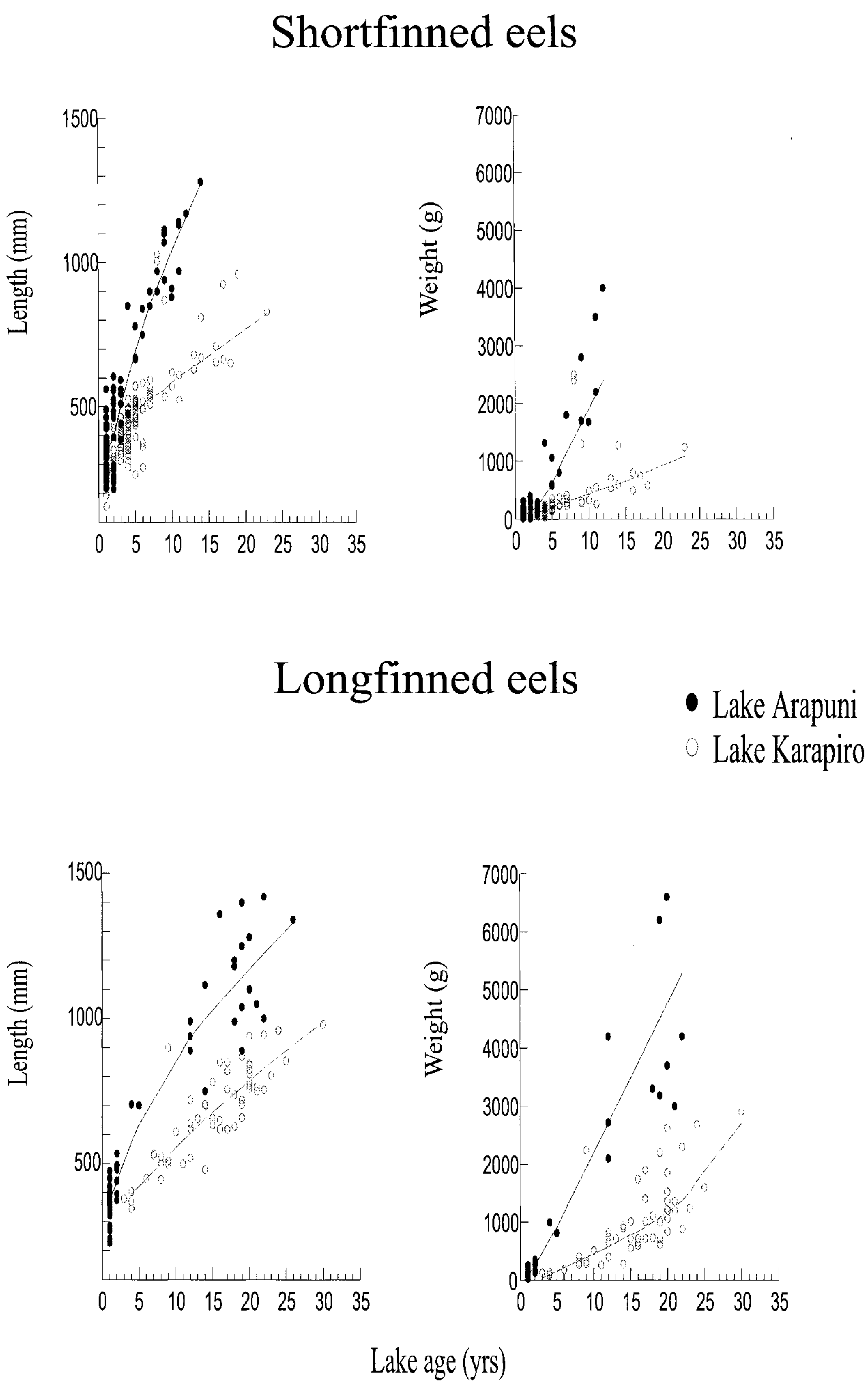

Figure 13: Length-at-age distributions of shortfinned and longfinned eels sub-sampled from Lakes Karapiro and Arapuni between 1988 and 1996 (Chisnall (1994) combined with Beentjes *et al.* (1997)).

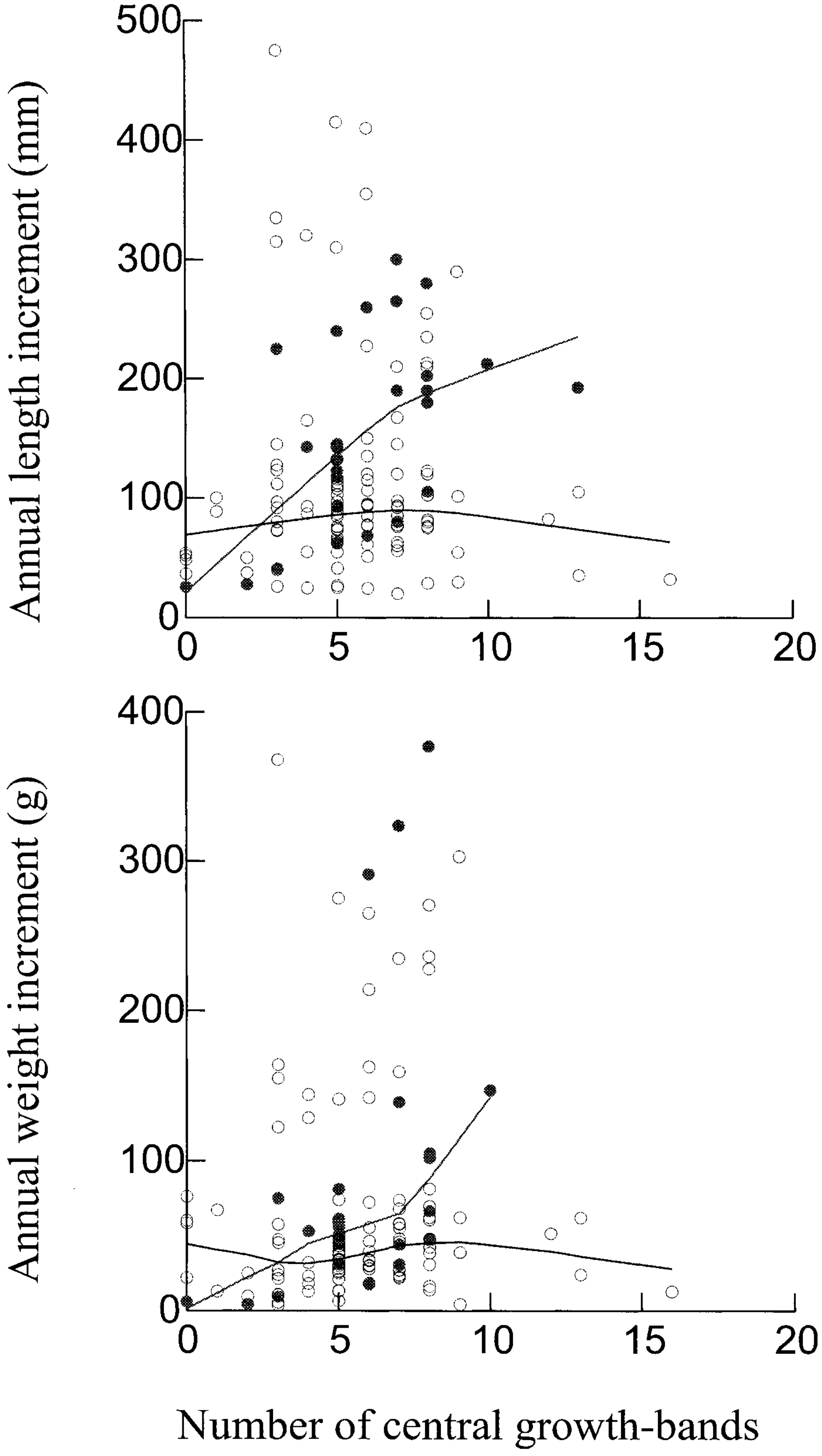

Figure 14: Incremental growth of adult shortfinned (open circles) and longfinned (solid circles) eels vs the number of central growth bands on otoliths (estimated elver age), from sub-sampled eels caught in Lakes Karapiro, Arapuni, and Maraetai, in January 1997. Lines represent Lowess smooth curves (least squares fits; P>0.05 for SFE and P< 0.05 for LFE).