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Taihoro Nukurangi

A review of evidence for a decline in the abundance of longfinned eels (*Anguilla dieffenbachii*) in New Zealand

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Report Title	A review of evidence for a decline in the abundance of longfinned eels (*Anguilla dieffenbachii*) in New Zealand
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7. Executive Summary

The report reviews available data to see whether there is evidence of a decline in the recruitment of longfinned eels (*Anguilla dieffenbachii*) in New Zealand waters. Data reviewed were glass eel and elver catches and species proportions, age composition of both juvenile and adult eels, changes in abundance and size distributions of longfins; computer models were then developed to simulate the influence of changes in recruitment on age and size composition of populations.

The data on glass eels and elver transfers were reviewed but were found to be too few and too variable to provide any clear evidence about trends in longfin recruitment. In addition, in the absence of measures of effort, it was not possible to determine whether differences in catches and species proportions reflected changes in absolute abundance

From the year class composition of adult eels, there was no evidence of the same strong year classes being present at the various sites. However, from an examination of the age structure and survival rates of juvenile eels, there is strong evidence that glass eel recruitment has declined in two North Island and 3 South Island waters. Annual recruitment is highly variable both between years and between waters and it is most unlikely that recruitment has declined at a steady rate. The rate of decline averages about 7% per annum since 1980; on this basis, glass eel runs now are estimated to be a quarter of the size of runs prior to commencement of commercial fishing in the early 1970's.

Low recruitment of longfinned (= longfin) glass eels has led to an unbalanced population structure dominated by old eels. Today, commercial fishers generally catch relatively small (<600 mm) longfins, whereas large (>700 mm) females are largely restricted to lightly fished areas. There has also been a major decline in the size of longfins caught over the past 20 years. Computer models indicate crop rates might be as high as 20% y^{-1} in some waters and show that this level of harvesting will lead to a rapid decline in stocks. Models also indicate that few females survive to spawn at comparatively low fishing rates of 5–10% per annum and that the upper size limit (4 kg) for female eels is virtually ineffective. In addition to harvest, eel numbers will have been reduced by dams preventing access to many upland waters, migrating females being killed by turbines, and reduction/loss of lowland streams and wetlands through channelisation and drainage.

The net result of these observations on age composition and the implications from population modeling, is that longfins are being overfished and this has significantly affected recruitment. Prediction from the models is that the rate of decline in stocks will accelerate in future. This report has important implications for the management and conservation of the longfin stocks. If the fishery and stock of New Zealand longfins is to be maintained, then further conservation measures need to be considered, such as complete closures of particular rivers or fisheries to maintain the breeding stock. Reduced minimum legal size and catch limits are unlikely to be effective because of the slow growth rate, low mortality rates and great age at maturity of female longfins. Because of the slow growth rates and correspondingly long response time of longfins to reduced recruitment, it is important that additional protective measures be implemented in the immediate future. While most available data for modeling are from the South Island, protection of the species must be carried out on a national basis.

It is recommended that

a) The results of this report and supporting studies are publicised and discussed with fisheries managers, commercial fishers, Maori, Ministry of the Environment and the Department of Conservation.

b) Immediate action is taken to reduce the commercial harvest of longfins and to establish additional reserves.

c) Further studies are undertaken to assess the current status of the longfin stock. Glass eel recruitment should be monitored during the peak months, and better information collected on the abundance of elvers at hydro dams. Surveys are needed to determine the populations of eels in fished and unfished habitats and to monitor the effectiveness of new reserves and restrictions on harvest.

8. Objectives

1. To utilise existing data sources, including glass eel information, age frequency data of elvers and adult eels and special permit data, to report on the past recruitment of longfins into specific catchments.

2. To determine feasibility of monitoring trends in longfin recruitment.

9. General Introduction

9.1 Distribution

Of the three species of freshwater eel present in New Zealand rivers, the longfin *Anguilla dieffenbachii*, is the most common and widely distributed. It occurs from estuaries to high country lakes and although it is considered a fish of flowing water, it also occurs in slow-flowing waterways, with swamps being the only habitat that it appears to avoid (Taylor and Main 1987). Historically, longfins have been New Zealand's most common native freshwater fish (Minns 1990), providing up to 90% of total fish biomass in small streams (e.g. Hopkins 1970).

9.2 Fisheries

Both shortfins and longfins form very important traditional and commercial fisheries. The considerable importance of freshwater eel (tuna) fisheries to Maori is recognised by the Crown and has resulted in the implementing of the six South Island Eel Management Committees which have equal Maori and fishing industry representation. These committees are charged with producing an eel management plan for their area, making recommendations on management practices and providing input into the setting of Total Allowable Catches once South Island eels enter the Quota Management System in October 2000. Similar committees are envisaged for the North Island.

The commercial eel fishery generates an estimated annual revenue of $36M (Te Waka and Maui me ona Toka Mahi Tuna 1996). Longfins constitute 35–40% of the total New Zealand catch (Jellyman 1993, Annala & Sullivan 1997) but dominate South Island catches. Over time there is evidence that the proportion of longfins in the catch of both islands has declined (Beentjes & Chisnall 1997), although this will be partly due to changing market requirements. In a review of the current status of stocks, Annala *et al.* (1999) stated "For most areas it is not known if recent catch levels are sustainable or are at levels that will allow the stock to move towards a size that will support the MSY" (maximum sustainable yield). The same authors noted that there were concerns about the "possible intermittent recruitment of longfins in some areas". South Island eels are scheduled to enter the Quota Management System on 1 October 2000, but there will not be separate quota for each species.

9.3 Growth and vulnerability of adults to overexploitation

The growth of longfins is highly variable and generally slow (e.g. Jellyman 1997; Beentjes 1999) with the species being the slowest growing of any of the 15 species of *Anguilla*, averaging 24 mm y^{-1} (Jellyman 1995, 1997). While longfins in captivity are capable of growing to 40 cm within a year (Jellyman & Coates 1976), the average growth rate in Lake Rotoiti, Nelson Lakes was 9 mm y^{-1} (Jellyman 1995) meaning that the average time for females to achieve maturity from this lake would be 93 years. Likewise Mitchell & Davis Te-Mairie (1994, 1995) recorded old (> 70 years) and slow-growing eels from the Waiau (Southland) and Coleridge catchments. On average mature males migrate at 23 years old, 62 cm and 600 g while females migrate at 34 years old, 115 cm and 4000 g (Jellyman & Todd 1987). Given such slow growth and large size at maturity, longfins would seem vulnerable to over-exploitation, with the potential for consequent recruitment failure.

Eel fisheries can maintain high fishing yields while spawner numbers are greatly diminished, so that reduced recruitment becomes evident in the adult fishery only after a long period. Longfins recruit to the commercial fishery at about 10–15 years old in the North Island (derived from data in Beentjes & Chisnall 1998) and at 16 to 26 years old in the South Island (Beentjes 1999).

9.4 Declines in recruitment of *Anguilla* species

Glass eels of northern hemisphere species of *Anguilla* (*A. anguilla* the European eel, *A. rostrata* the American eel, and *A. japonica* the Japanese eel) have all shown substantial reductions in abundance over the past decade (e.g. Moriarty 1994; Castonguay *et al.* 1994). A variety of possible causes have been suggested as reasons for the decline in recruitment, including loss of utilisable habitat, physical barriers, acute and chronic effects of pollutants, parasites, overfishing and changes in ocean currents (Moriarty 1996). However, a recent summary stated "there appears to be no single proven cause for declining recruitment" (Moriarty & Dekker 1997). In New Zealand there is hearsay evidence only of declines in the strength of glass eel migrations (Jellyman 1994); unlike Europe where glass eels catches at some sites have been recorded for 35 years, there are no comparable long-term datasets for New Zealand glass eels.

Over recent years, concern has been expressed about the apparent poor recruitment of glass eels to particular parts of New Zealand; for example, Te Waka and Maui me ona Toka Mahi Tuna (1996) suggested that an investigation of the poor recruitment on the east coast of the South Island should be a high research priority. Anecdotal evidence of decreased numbers of elvers congregating below the Waitaki Dam (Kelly Davis, pers. comm.) reinforce this perception as do data on the age distribution of juvenile eels from NIWA's Public Good Science Fund (PGSF) funded programme on Sustainability of Eel Fisheries (NIWA unpublished data).

These concerns have lead to the present research that examines the hypothesis that recruitment of New Zealand longfins has declined over recent years, primarily as a result of commercial fishing which has lead to a reduction in the number and size of adult longfins migrating to spawn.

9.5 Objectives

This programme objective was: To assess and monitor the recruitment of longfins (*Anguilla dieffenbachii*).

The project objectives were:

1. To utilise existing data sources, including glass eel information, age frequency data of elvers and adult eels and special permit data, to report on the past recruitment of longfins into specific catchments.

2. To determine feasibility of monitoring trends in longfin recruitment.

Although the focus was to be on utilising existing data on glass eels and elvers, the study objectives went beyond that and required that any appropriate data sources be canvassed.

The first objective involved collating and evaluating data from a range of sources to see whether there were definite indicators of a reduction in recruitment of longfins – data included glass eel species composition and density, species composition and age frequency data of elvers and adult eels. As considerable inter-annual variation in recruitment was expected (e.g. Jellyman 1979), the real issue was whether there were discernible trends towards reduced recruitment of longfins over time. The most important data sources were those which provided information on age-class strengths over the last 20 or more years. The data reviewed for this objective are presented by life-history stage, with each stage containing a description of the data sources used, methods and results. Factors that may have affected longfin recruitment are discussed together with the potential impacts of declining recruitment on the eel stocks, fishery and ecosystem. Finally actions which could be taken to increase recruitment are briefly discussed.

The second objective was to determine the feasibility of monitoring trends in longfin recruitment, i.e. is it possible to establish a monitoring programme for some life-history stage that could be used to measure subsequent trends and changes in recruitment? This objective is discussed in Section 6.0 "Methods for monitoring trends in longfin recruitment".

10. Glass eel recruitment

10.1 Introduction

There have been periodic records of the occurrence and migration patterns of glass eels in New Zealand throughout this century. Most of these records are anecdotal, or "one-off" observations of limited use for the present purposes. Specific studies on glass eels have been those of Jellyman (1974, 1977a, 1979), Jellyman & Ryan (1983), Jones *et al.* (1983), and Jellyman *et al.* (1999b).

10.2 Materials and methods

Evaluating information on glass eels required:

- an understanding of the seasonal differences in recruitment of both species
- a comparison of historic and present day data on species composition
- compilation of anecdotal information on glass eels recruitment

All known sources of quantified data on glass eels were reviewed. The usefulness of information varied considerably. Documenting the proportions of both eel species over a long timeframe is of some value as this may have changed over time. However, the proportions of both species at a given locality can vary during the season (Jellyman 1977a, Jellyman *et al.* 1999b), meaning that capture date must be known for the data to be of use. Of course, a high proportion of either species might be due to a better-than-average recruitment of that species, or it could result from low recruitment of the other species. Therefore, to measure actual changes in the abundance of longfins, samples need to be relative to a constant sampling unit (catch-per-unit-effort, or density).

The only quantitative database on glass eel abundance in New Zealand is that generated as part of NIWA's PGSF programme on the Sustainability of Eel Fisheries (FRST

Contract 1605). This programme includes the estimation of abundance of glass eels in five North Island and six South Island rivers/streams (both west coast and east coast rivers/streams for each island) at fortnightly intervals throughout the season (July-December). Samples are collected by electrofishing selected sites in the lower reaches of these waterways. Five consecutive seasons of data have now been collected. The study investigates both spatial and temporal variability in glass eel recruitment by asking :

(a) Is the strength of glass eel recruitment a local or national phenomenon? For example,

(b) What are the differences in the periods for peak recruitment between North and South Island and east and west coasts?

(c) How do species proportions vary seasonally at each sampling site?

While all 3 questions are relevant to the present proposal, the main benefit of these data is as a baseline of information against which future changes in abundance of longfins can be measured.

To investigate the actual abundance of glass eels, these catch data have been expressed as densities since the area sampled (m^2) often varied between visits. To reduce the likelihood of resampling glass eels that were present on a previous visit, "newly arrived" glass eels were defined by Jellyman *et al.* (1999b) as being those that showed little pigmentation (i.e. pigmentation stages 5B-6A23 of Strubberg 1913), and that definition has been adopted in the present report.

10.3 Results

10.3.1 Extent of glass eels migrations

Waikato River. During the 1970s, there was interest in establishing eel farming in New Zealand. As a result, considerable effort went into catching glass eels in the lower Waikato River, both for farming stock, but also as a potential export commodity to Japan. Catches varied substantially from year-to-year (Jellyman 1979), although some of this variation would have been due to differences in fishing effort. Total catches were recorded, and the species proportions derived from subsamples of glass eels examined. The resulting estimates of the total quantity of longfin glass eels among each year's catch (Table 1) show that although longfin comprised only 12% of the catch on average, the annual catch was less variable than was that for shortfins.

Table 1: Estimated catch of longfin and shortfin glass-eels from the lower Waikato River, 1970–1974 (data from Jellyman 1979)

Year	Longfin glass-eels (kg)	Shortfin glass-eels (kg)	Proportion of longfin (%)
1970	252	1622	13
1972	290	1776	14
1973	625	5738	10
1974	110	598	16
Mean (CV)	319 (0.68)	2433 (0.93)	12

There are a number of anecdotal accounts of the size of the annual glass eel migration in the Waikato River; the most comprehensive of these is by Cairns (1941) who noted that although most migrations occur at night, glass eels would migrate during floods and freshes "The writer observed one "run" of elvers (= glass eels) ascending the Waikato River, in daylight during a slight fresh, passing a point in the river for over eight hours; this shoal was over 15 ft wide and 8 ft to 10 ft in depth. The elvers were packed closely within this shoal". No migrations this extensive were observed during the 1970–74 period of glass eel fishing.

Before the 1970 glass eel fishing, Chapman (1970) discussed glass eel migrations with local Waikato eel and whitebait fishers, and noted that "at certain times of the year glass eels run in a continuous stream along the edge of the river day and night. A leading processor quoted a catch of 300 lbs in an hour, although this was subsequently altered to 300 lb in a day. The general picture was that of a column of eels roughly a foot wide and a foot deep, running continuously for 2 or 3 days". More recently, Annala and Sullivan (1999) reported that "Industry reports that runs of glass-eel up the Waikato River have been large over the past three seasons, and fishers report large numbers of under-sized eels in most areas". Of course, the majority of these "runs" would be expected to be comprised of shortfin glass eels.

On the 13–14 August and again in early September 1999, "reasonable" runs of glass eels were reported from the Waikato (Dave West Department of Conservation pers. comm.). However, experienced whitebaiters on the Waikato River are adamant that glass eel migrations are smaller today than they were historically e.g. 50 years ago, shoals of glass eels (approximately 0.75 m wide and 0.5 m deep) were observed to run for 4 days continuously (Chris Annadale, Department of Conservation, pers. comm.).

Bay of Plenty. During the late 1970s, considerable effort went into capture of glass eels from local rivers to stock the Te Kaha eel farm, Bay of Plenty. Catches (Jones *et al.* 1983) were 120 kg in 1978, 70 kg in 1979, and 256 kg in 1980. Most eels came from the Whangaparoa River, with a peak catch of 174 kg on 14 August 1980. Total annual catch by river is not available for these data, but most of the variation in catch was due to increased catches of shortfin glass eels and catches of longfin were more stable. Even so the authors remarked on the variability in the proportion of longfins between years (percentages from the main river, the Whangaparoa, were 35, 11 and 8% in 3 successive years).

Recent migrations. Reports of extensive glass eel migrations are infrequent today, although an exception was that recorded in the Buller River, South Island, when a whitebaiter at the mouth of the river saw "miles of small eels .... making their way up the Buller River. One shoal going up the river was unbroken for hours and hours" (Westport News 7 November 1996). A Department of Conservation spokesman assumed that they were shortfinned glass eels. Given that arrival of longfins tends to precede that of shortfins, and that high numbers of shortfin may arrive late in season in West Coast rivers like the Arahura (Appendix 2), then this is a reasonable assumption, However, it should also be noted that longfins dominate eels stocks of the Buller River (Jellyman *et al.* 1983), so that resolution of the species-composition of such runs requires examination of samples.

An additional record of a large recruitment into the Buller River took place during 1999 – a whitebait fisher recorded a run of glass eels on Sunday 10th of October, "on the true right of the Buller (near where the high tension lines cross the river). The glass eels were passing continuously for one and a half hours nonstop and still going when he left to go home. The shoal was about 50 fish wide and 20 fish deep. The glass eels were about 2" long and on the top of the tide" (Philippe Gerbeaux, Department of Conservation, Hokitika, pers. comm.).

10.3.2 Seasonal patterns in recruitment

Jellyman (1977a) found that in the Makara Stream, Wellington, glass eels of both species arrived from July to December – peak months for longfins were August to October, while shortfins arrived over the same season, with peak months being August to November. In a more extensive review, Jellyman *et al.* (1999b) confirmed these results i.e. although there were some differences between North and South Islands, and east and west coasts, the arrival of longfin glass eels preceded that of shortfins, and longfins appear to arrive in the North Island before the South Island. Ideally then, when comparisons are made of species composition or abundance over time, data for the same months should be used to avoid seasonal changes in species composition.

10.3.3 Species proportions

Summaries of available data on species proportions of glass eels catches (excluding NIWA's PGSF programme) are given in Appendix 1, while results from the latter programme are in Appendices 2 and 3. The data are summarised by island (North or South) and coast (east or west) in Figure 1. Unfortunately the data are too few to stratify by time (date of capture), so any conclusions drawn must be tentative. Months when samples were collected range from July – January, with peak months being September and October, a very similar result to the seasons determined by Jellyman (1977a) and Jellyman *et al.* (1999b). Thus there is no evidence for any shorter season of arrival.

Overall there are insufficient historic data to provide adequate comparisons with the present day information (Figure 1). Although the data for the South Island, especially the east coast, might indicate a decline in the proportion of longfin glass eels, the overall lack of data and the "scatter" preclude any firm conclusions being drawn.

From the historic data on species proportions of glass eels (Appendix 1), it is apparent that there are regional differences in the proportions of both species. High proportions of longfin glass eels are apparent from the Taranaki area (Warea – Opunake Rivers), Poverty Bay-East Cape (Waioeka – Whangaparaoa Rivers), West Coast, South Island (Hokitika and Waiatoto Rivers), and Southland (Mataura and "Southland" Rivers). Reference to Jellyman (1993) shows that the commercial catches in these regions are also dominated by longfins i.e., Taranaki 91% longfin, Poverty Bay 69%, Westland 58%, and Southland 87%.

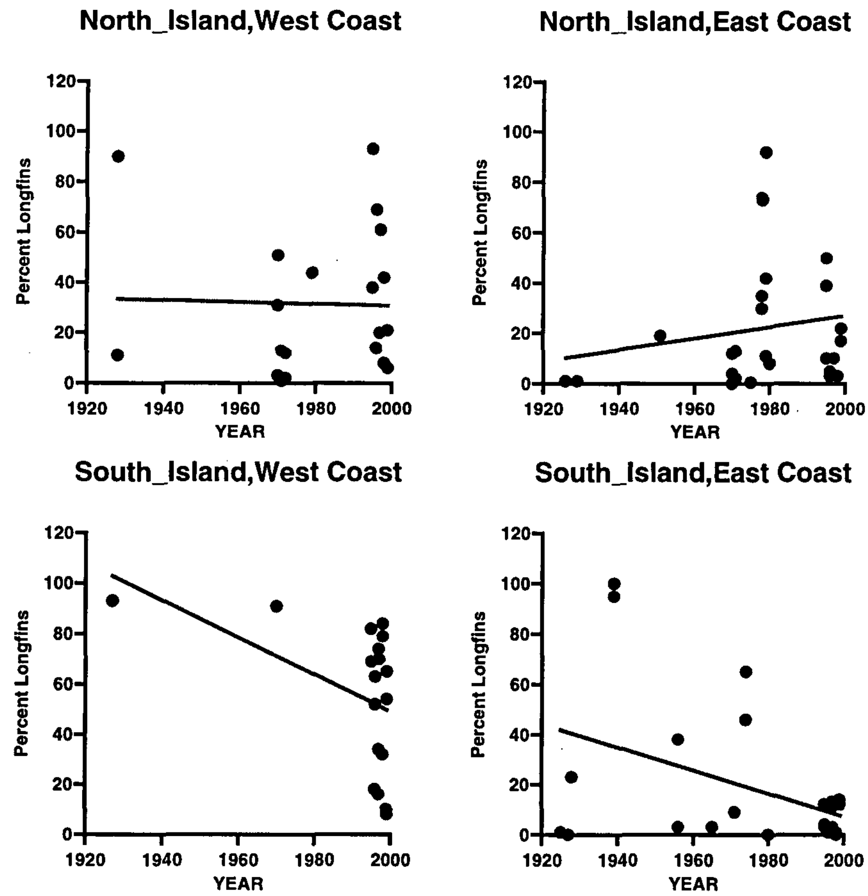


Figure 1: Trends in the proportion of longfin glass eels by region of New Zealand from 1920 to 2000. The lines show the best fit for the data but are not statistically significant.

Results from NIWA's PGSF study, (Appendix 2), show that the species proportions were found to vary considerably between sites even when those sites are in close proximity. For instance, Purau and Charteris Bay Streams are only 4 km apart in a direct line, but Purau averages 7.6% longfins, with Charteris Bay Stream averaging 2.9%; the most extreme example is Kerikeri Stream and Waitetuna Stream, 10 km apart, where the longfin compositions average 15.2% and 50.6% respectively. Jellyman *et al.* (1999b) discussed the likelihood of glass eels making specific offshore choices about the water-type they would enter - longfin may have a preference for water from stony streams with low organic content, while shortfins may prefer water from muddy streams. These differences in species proportions between nearby streams highlight the importance of having consistent data from the same streams rather than pooled samples from several streams.

For those sites where >100 glass eels have been collected over the 3–4 year period, longfins comprise >30% of the total sample (pooled by years) in the following waterways (% composition in brackets): Arahura (72%), Flowery Creek (64%), Waitetuna River (51%), Mill Stream (44%), Serpentine Stream (30%), Temata Stream (30%). However, for these streams, there is often large variability between years – for example, the Waitetuna Stream ranges from 21–93% longfin, and the Temata Stream from 2–39%.

Of interest is a comparison of the Ashley River and Purau Stream (South Island east coast) samples from the present PGSF programme, (Appendix 2) with pre-1981 samples (Appendix 1). The comparisons (Table 2) show that while there is some indication of a reduction in the percentage of longfin glass eels in the Ashley River, there is no indication of this for the Purau Stream. However, some caution must be used interpretation of these data as the 1956 Ashley River data were from a single sample and this can be misleading. For example, although the overall proportion of longfins was low from 1996–99, there were 3 successive samples during late August – mid September 1997 when the proportion of longfin glass eels was uncharacteristically high

i.e.,	22/08/97	N = 23	longfin = 44%;
	04/09/97	N = 49	longfin = 41%;
	17/09/97	N = 97	longfin = 13%.

Table 2: Comparison of historic (pre 1981) and recent percentage of longfin glass eels from 2 sites. N = total number of glass eels of both species

	Sample date	% longfin	N
Ashley River	**October 1956**	**38**	**39**
	October 1980	**0**	**306**
	1996–1999	**4**	**2748**
Purau Stream	**September-October 1965**	**3**	**494**
	1995–199	**8**	**879**

10.3.4 Densities

Densities of newly arrived glass eels (Appendix 3) provide a better basis for studying trends than do the species composition data alone. For some sites, sampling in 1995 did not commence until September and may have resulted in a lower overall density being recorded than in years when sampling started earlier eg. longfin arrival in the Kerikeri River peaks during August, so the most comparable data are for 1996 onwards. For rivers where the sum of the total of newly arrived longfin glass eels caught over the 4–5 years exceeded 100, the mean density per year is summarised in Figure 2.

There are no consistent trends within these data. The data for the Kerikeri and Arahura Rivers for 1996–99 show small annual variations in densities (coefficient of variation, CV = 0.41 and 0.16 respectively) whereas Waitetuna and Serpentine Creek (1995–99) show high inter-annual variability (CV = 0.97 and 0.90 respectively). For North Island west coast sites (Kerirkeri and Waitetuna Rivers), 1997 appears to have been a better than average year, while for South Island west coast waterways (Arahura River, Flowery Creek, Serpentine Creek), densities are reasonably consistent during the 4–5 years (low densities in the Serpentine 1995 and in 1996 may reflect partial mouth closure during these seasons).

10.4 Conclusions

The conclusion from reviewing available glass eel data is that there is no robust evidence of a reduction in the proportion of longfins, but this conclusion is qualified by the very limited time series available. High inter-annual variability in densities mean that extensive time series would be needed to determine longterm trends – historic data are too few and sample numbers too small to provide meaningful comparisons with present-day catches. From the limited data available, there is no evidence that the arrival season of glass eels has changed over time. There is some anecdotal evidence that the overall magnitude of glass eel migrations in the Waikato River has reduced, but without some species breakdown it is not known to what extent this reduction affects both species. To provide useful baseline data for future comparisons, glass eels catches should be carried out during the peak months of recruitment, and some measure of abundance recorded (density or CPUE).

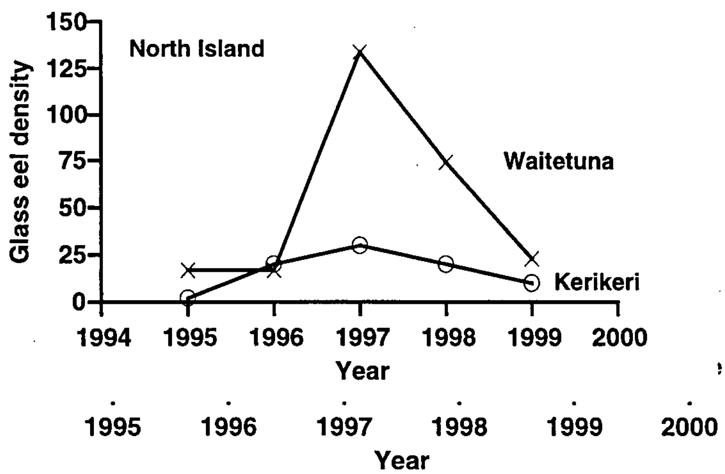


Figure 2: Mean annual density (n. 100 m^{-2}) of newly arrived longfin glass eels. Kerikeri was possibly affected by lack of sampling in August 1995.

11. Elver migrations

11.1 Introduction

The term "elver" is generally used to refer to juvenile eels during their summer upstream migration. Some confusion arises from reference to the literature where the term has often been used to describe "glass eels", although the latter is now in more common usage to describe the life-stage at the time of entry to fresh water from the sea. Elver migrations are most evident when they accumulate below an obstacle like a hydro dam or waterfall. The largest of such migrations is at Karapiro Dam, the most downstream dam on the Waikato River –during summer, tens of thousands of elvers try and climb the dam wall (30 m).

Some historic observations of the Waikato elver migrations have been made (Woods 1964, Jellyman 1977b), and manual transfers to waters above the dam have been carried out since at least 1992 (Chisnall *et al.* 1998). Elsewhere, elvers have been captured and transferred at hydro dams intermittently since 1984 (Beentjes *et al.* 1997), and this process continues at present.

11.2 Materials and methods

Evaluating the elver data available involved:

- collating all available historic data
- collating recent data collected under the Special Permits issued to agencies involved with transfer of elvers at hydro dams and weirs
- collation of available data on elver ages to look for any evidence of dominant age classes and cohorts

The main shortcomings of these data were:

- lack of a measure of effort (to provide indices of abundance)
- lack of historic data for comparison with present-day
- the inability to project backwards beyond the few age classes represented

Unfortunately as fishing effort, timing and method of capture has changed over time, it is not possible to obtain accurate trends on the size, timing and species composition of the elver run at each site. In the absence of a consistent measure of effort, greater catches in any particular year might reflect increased fishing effort rather than increased abundance of elvers. Similarly, the species proportions can also be misleading as, for example, a decline in the percentage of longfin elvers in any one year may represent an actual decline in abundance, but might also reflect an increased abundance of shortfin elvers. Despite these shortcoming the data were reviewed for evidence of a change in the numbers of longfin caught at the various sites, and the proportion of longfins in the catches.

Methods used in capture of elvers vary between sites, and also between years at the same site. Both manual (traps, hand netting) and passive (fish pass) transfers are involved; the various methods are extensively reviewed in Beentjes *et al.* (1997), and Chisnall *et al.* (1998). For the present review, considerable effort was expended in collating the elver transfer data. Although a few recent fishing permits require that regular samples of elvers be measured (length and weight) and analysed for species composition, in most cases only the total weight of elvers and the transfers locations have been stipulated. In some instances, transfers are known to have been made without permits.

Because there were many gaps in the data and some of the information supplied was of dubious quality, a "best guess" approach had to be taken to determine the number of elvers transferred at various sites. For instance, often only the total weight of transferred elvers was given – to translate this to numbers of each species, a species mean weight had to be assumed, together with the likely species proportion at that time (often available from samples of elvers retained to determine species proportions). In several instances, the species composition of several samples was listed as "50:50", which seemed unlikely but had to be adopted. Additional problems were that for the Patea samples, there were no weight data of subsamples from which to estimate mean eel weight, while the data for Piripaua gave total weight of transferred elvers only. Where such specific information was lacking, the best available estimates were included (e.g. mean weights from other locations, species composition anticipated from previous samples).

Our best estimate of the number and species composition of the elvers transferred is presented in Appendices 5 and 6. Although very limited use could ultimately be made of these data, they are presented in some detail (i.e. number of longfin elvers and total number of both species caught per month per season) as some consolidation of the information is considered important for future reference. Some figures differ from the information presented by Beentjes *et al.* (1997) and Chisnall *et al.* (1998), and also from the summary information provided to the Ministry of Fisheries by permit holders usually because slightly different mean weights of elvers have been used.

11.3 Results

11.3.1 Timing of migrations

As with glass eels, some understanding of the peak months of migration of each species is of importance to enable valid comparisons to be made. In a review of upstream migrations of elvers, Jellyman (1977b) found that samples from 11 sites throughout New Zealand (including 8 hydro dams) were all collected during January and February. Previously, Cairns (1941) also noted that these months were the main ones for elver migrations; both Hardy (1950) and Hopkins (1970) observed elvers migrating during February. Woods (1964) recorded climbing elvers at Karapiro Dam during February and March, and Boud & Cunningham (1960) stated that elvers arrived at Roxburgh Dam on the Clutha River during the first four months of the year. From such records, there is a consistency of January-February being the main periods of elver movement.

Although most migrations are encountered at the lowermost hydro dam on any river, usually 20 – 100 km inland, migrations commence further downstream, probably at the upstream tidal limits where glass eels normally take up residence after their spring arrival in freshwater. Thus Schicker *et al.* (1989), monitoring the elver migration at Huntly, 70 km below Karapiro Dam on the Waikato River, found movements commenced during November, peaked during December – February, and continued until April. Fifteen kilometers upstream of Huntly, at Ngaruawahia, Schicker *et al.* (1990) recorded elvers migrating over a shorter period, from early November to late February.

Historically, the arrival times of elvers at Karapiro Dam have shown some seasonal consistency. Thus Cairns (1941) recorded arrival time at the (then) lowest hydro station on the Waikato River between 14–18 January during 4 consecutive years, 1936–39. Likewise, Jellyman (1977b) found that mid-January was the arrival time at Karapiro Dam for 4 years (1970–71, 1973–74). More recent data have shown earlier arrival times – thus Beentjes *et al.* (1997) recorded highest elver catches at the commencement of their 1995–96 sampling in late December 1995; during more prolonged sampling the following season, catches commenced in early December, peaked in mid-January, and continued through into mid March. Beentjes *et al.*.(1997) and Chisnall *et al.* (1998) suggested that the earlier arrival during the 1995–96 and 1996–97 seasons may have been due to unseasonably warm temperatures in December. Part of this apparent advance in arrival is because observations on arrival at the spillway only indicate the peak periods of elver activity (J. Boubee, NIWA pers. comm.). Despite this caution, there appears to have been an advance in the commencement of migration over recent years.

For Karapiro, the average catches of both species per month for the five recent seasons for which monthly data are available (Table 3) show that although some elvers have been caught as early as August and as late as June, the longfins season is essentially

December to February (98.0% of total catch) while that for shortfins is December to March (99.5% total catch). Also shown in Table 3 is the species composition per month – these data show that for the important months (December – March), the proportion of shortfins always exceeds that of longfins, but highest proportions of longfins are caught during December and January. These data enable comparisons to be made with historic species proportions, although substantial variability between years means that basing conclusions on a single years data would be unwise. For example, the percentage of longfins caught at Karapiro during January (1995/96 – 1998/99) were: 10, 27, 61, 39 %, and equivalent data from February (1994/95 – 1998/99) were 31, 6, 19, 39, 16 % (full seasonal data for Karapiro and other sites are given in Appendix Tables A5 –1–6).

11.3.2 Species composition and abundance

North Island. Elver transfer is carried out Karapiro Dam and Lake Waikare (Waikato River), Matahina Dam and Aniwhenua Barrage (Rangitaiki River), Patea Dam (Patea River), and Piripaua (Waikaretaheke River, Lake Waikaremoana). Although the longest-running transfers are those from Matahina Dam and Aniwhenua Barrage (1983/84 to present), the largest catches are recorded from Karapiro Dam.

The number of elvers caught at Karapiro Dam varies considerably from year-to-year (Appendix Table A5–2). This will reflect both changes in capture technique and efficiency, as well as the absolute number of elvers arriving. Changes in capture methods over the years from nets to floating traps (Holmes 1996; Beentjes *et al.* 1997) have resulted in both greater efficiency of capture and also, a greater size range of elvers being caught. All that can be reported on therefore are seasonal trends and to some extent, species composition, although even the latter may vary because changes in capture efficiency have often resulted in capture of larger longfin elvers (J. Boubee, NIWA pers. comm.).

Table 3: Seasonal catch of elvers and monthly proportion of each species, by month of capture at Karapiro Dam; pooled data for 1994/95 – 1998/99. <, = <0.05 %

	(A) Seasonal distribution (%) of each species		(B) Monthly proportion (%) of both species	
	Longfin	**Shortfin**	**Longfin**	**Shortfin**
August	0.2	0.1	49.2	50.8
September	0	0	–	–
October	0.1	0.1	50	50
November	<	0.1	13.5	86.5
December	23.8	18.1	36.9	63.1
January	52.3	41.3	36.1	63.9
February	21.9	31	23.9	76.1
March	1.5	9.1	6.8	93.2
April	0	0	–	–
May	0.1	0.1	25.2	74.8
June	0.1	0.1	31.4	68.6
July	0	0	–	–
	100	100		
Total elvers	1,630,459	3,661,576	1,630,459	3,661,576

The annual catches of longfin elvers from Karapiro Dam, and Matahina Dam, are shown in Figure 3. Both sites are dominated by shortfins (Karapiro 69% shortfin; Matahina 24% shortfin). The largest catches of longfin elvers at both sites occurred in the same season, 1997/98 when Karapiro recorded 894 531 (52% of the total catch) and Matahina recorded 176 164 (27% of the total catch). The number of longfins caught at each site between 1992/93 and 1998/99 were significantly correlated (linear regression, $p<0.01$). Elvers from both locations are dominated by age class 1 (Jellyman 1977b; Beentjes *et al.* 1997). Thus the correlation in catches between the two sites *may* reflect similar trends in year class recruitment, although how catches are affected by changes in effort is unknown. However, caution is again required as the decreased catch for 1998/99 at Karapiro was largely caused by a change in trapping method when a lift was installed (J. Boubee, NIWA pers. comm.).

Despite the shortcomings of "snapshot" samples, some comparisons can be made of historic and present-day elver catches for the equivalent sampling periods, to see whether there are any apparent changes in the percentage of longfins over time (Tables 4 & 5).

From Table 4, there is a suggestion of a reduction in the species composition at Karapiro Dam, but the proportion of longfin elvers at the other two sites is greater over recent years than recorded previously. Because of the differences in peak arrival times of both species, Table 5 compares monthly catch data from Karapiro Dam – assuming that the limited "historic" adequately represent the actual situation, then it is possible that the arrival season for longfin elvers has become somewhat protracted over time. However, without abundance data to go with the species composition, this cannot be confirmed.

South Island. There are currently five locations where elver transfer has taken place or is still occurring in the South Island: Clutha River, Waiau River, Waitaki River, Mataura River, and Taieri River. At the time of writing, the Roxburgh Dam elver pass (Clutha River) is not operating, apparently because of unresolved issues of management responsibility, while the Waitaki River pass has never operated satisfactorily – three traps have recently been built at the Waitaki Dam to replace the elver pass (J. Boubee, NIWA pers. comm.).

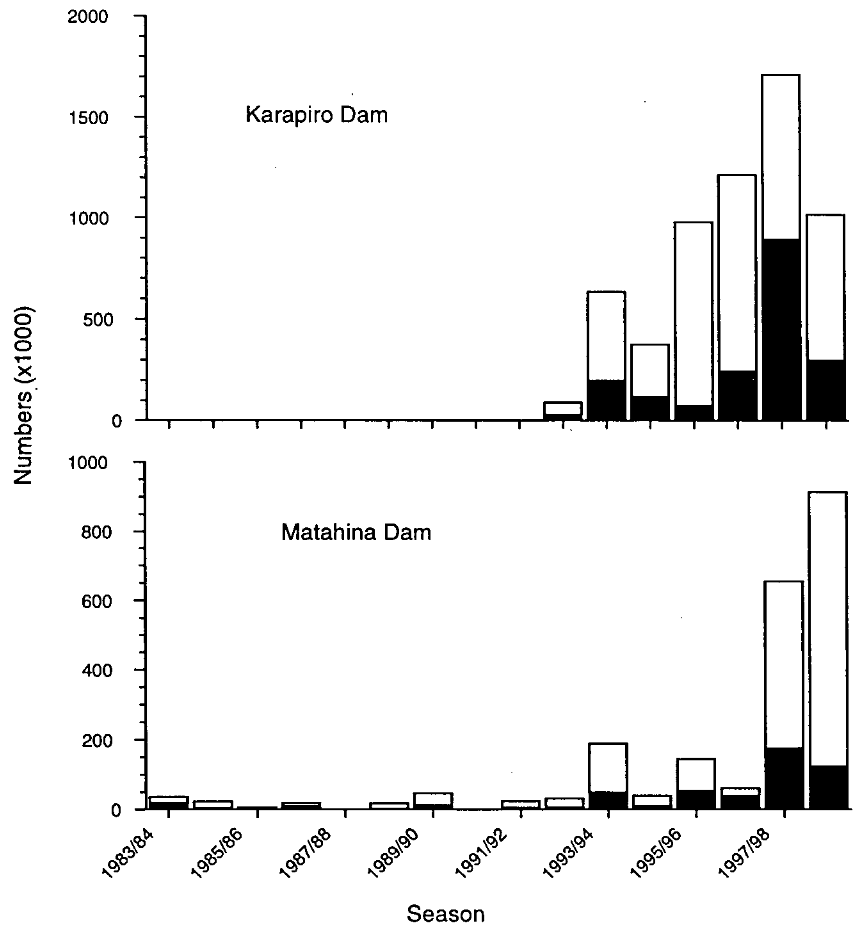


Figure 3: **Numbers of shortfin (open bar) and longfin elvers (black bar) estimated to have been captured at Karapiro and Matahina Dams.**

Table 4: Comparison of historic (1970–74) * and recent species composition of elvers from North Island sites. N = number of both species combined in sample. % = percentage of longfins in sample

	1970–74		1994/95 – 1998/99	
	N	%	N	
Lake Waikare	743	0	584,647	15
Karapiro Dam	3646	38	5,292,035	31
Matahina Dam	168	21	2,207,245	24

* Data from Jellyman 1977b

Table 5: Historic (1962–74)* and recent (1994/95 – 1998/99) species composition of elvers from Karapiro Dam. N = no. of longfins, % = percentage of longfins in total monthly samples

	Historic		Recent	
Month	**N**	**%**	**N**	**%**
January	655	37	853, 467	36
February	638	39	356, 737	24
March	75	24	26, 384	7
Seasonal total	1368	37	1,630, 459	31

* data from Jellyman 1977b

Quantities of elvers caught and transferred in the South Island are small compared to those in the North Island and there is little quantitative data to meaningfully compare longfin elver catches between years. Catches are summarised in Appendix 6. Like the North Island, for the data to be used as an index of longfin abundance, we would need to know accurately the timing, quantities caught and the effort expended to catch these elvers.

11.3.3 Age composition of migrating elvers

The contract required analysis of age frequency of elvers (and larger eels) " to see whether there are any gaps in the age frequency of longfins that could suggest an absence of recruitment". Obviously this is more relevant to larger, and hence older, eels than elvers; however, if elvers were to be used as an index of longfin recruitment, then some understanding of the age composition is important. Further, age composition of elvers could be compared with abundance of glass eels of the appropriate cohort, to see whether there was evidence of, say, strong glass eels recruitment translating into equivalent strong recruitment of elvers in subsequent years.

Unfortunately, relatively few elvers have been aged. The only North Island elvers aged are all from the Waikato catchment (Table 6). Not surprisingly, elvers from Lake Waikare are younger on average than those from further upstream at Karapiro Dam (130 km upstream). The age frequencies show that age classes 1 and 2 dominate at Karapiro, although the relative proportions vary between the two years data available.

Table 6: Age frequency of North Island longfin elvers

	Karapiro Dam		Lake Waikare
Age	January 1971	1995–96	January1971
0	1	1	7
1	15	5	6
2	10	11	2
3		6	
N	26	23	15
Mean (SE)	1.4 (0.1)	2.0 (0.2)	0.7 (0.2)

Samples of South Island elvers have been aged from the Clutha River (Roxburgh Dam) in 1971 (Pack and Jellyman 1988), 1997 and 1998, the Mataura River (Mataura Falls) in 1998, and from the Waiau River (Mararoa Weir) in 1996. Age frequencies (Table 7) show a wide range of age classes are present at Roxburgh Dam and the Mararoa Weir, probably because both sites are well inland (approximately 100 km and 70 km respectively) whereas the Mataura Falls are 45 km inland, and some larger elvers may be "repeat migrators" if they were unsuccessful in negotiating the dam in previous years.

Table 7: Age frequency of South Island longfin elvers

	Roxburgh Dam			Mataura Falls	Waiau
Age	Feb 1971	Feb 1997	Feb 1998	Feb 1998	Feb 1996
2		1	8	9	4
3		1	11	12	1
4	5	1	23	2	8
5	8	1	7	1	10
6	6	3	1	–	–
7	3	5	–	–	5
8	4	4	1	–	3
9	1	5	–	–	–
10	2	7	–	–	1
11		4	–	–	1
12		2	–	–	–
13		8	–	–	–
14		4	–	–	–
15		2	–	–	–
16 – 21		7	–	–	–
N	29	55	51	24	33
Mean (SE)	6.1 (2.8)	11.9 (0.6)	3.7 (0.2)	2.8 (0.2)	5.2 (0.4)

From the South Island data, it is clear that elver migrations are comprised of multiple cohorts; the Roxburgh dam data show that the age composition of migrating elvers varies considerably from year-to-year. No single age class stands out as consistently strong.

Assuming that the number of elvers caught at Karapiro Dam are indicative of abundance (and not just varying sampling effort), then the magnitude of annual catches can be compared with glass eel abundance data from sampling sites on the North Island west coast (Waitetuna and Kerikeri Rivers Appendix 2). Therefore is there any evidence that higher-than-average densities of glass eels at the latter sites correspond with large catches of elvers at Karapiro Dam? (this assumes that glass eel recruitment into these two streams is indicative of recruitment into the Waikato River).

The highest average annual densities of glass eels in the Kerikeri River (Appendix 2) occurred in 1997, followed by 1996 and 1998; for the Waitetuna River, 1997 was also clearly the "best" year, followed by 1998. Given that the age composition of elvers at Karapiro Dam is dominated by classes 1 and 2 (Table 7), then strong recruitment of glass eels during 1997 would be expected to show as large catches of longfin elvers during 1998/99 (age class 1) and 1999/00 (age class 2). The 1999/00 data are unavailable at the time of writing, but the 1998/99 catch of 300 000 longfins (Appendix 2) was only about a third of that of the preceding season. Thus there was no clear evidence that glass eels catches from elsewhere could be used as an index of abundance of elvers in the Waikato River, although as previously stated, the reduced catch during 1998/99 was largely due to changed capture methods..

Further evidence of the variable contribution of glass eels to recruitment into waterways comes from Lake Pounui, Wairarapa, where the annual influx of glass eels and elvers (< 20 cm) was trapped over 4 seasons (Jellyman & Ryan 1983). Because of large fluctuations in the numbers of shortfin glass eels and elvers recruiting into Lake Pounui (Table 8), the variation in the percentage of longfin recruits is misleading – the absolute number of longfin vary between seasons by factors of 12.4 and 3.8 for glass eels and elvers respectively. The CV for longfin glass eels and elvers were 0.73 and 0.75, compared with 1.41 and 0.73 for shortfin glass eels and elvers. The overall extent of longfin recruitment did not appear to be related to shortfin recruitment as peak seasons were longfin glass eels 1977–78, longfin elvers 1975–76, shortfin glass eels 1977–78, shortfin elvers 1977–78.

Table 8: Total and percentage of longfin glass eels and elvers entering Lake Pounui, 1974–78. The percentage figures are for the combined catch of both species

	Total longfins		% longfins	
	Glass eels	Elvers	Glass eels	Elvers
1974–75	5	289	25.0	4.3
1975–76	25	1100	0.2	2.2
1976–77	42	287	0.05	0.3
1977–78	62	408	0.4	0.4

11.4 Conclusions

Potentially, the annual migration of elvers and their interception by fishers, offer important opportunities for monitoring recruitment – migrations occur during summer when flows are usually lower making sampling easier, and as several age classes are involved, it is theoretically possible to obtain simultaneous information on the relative abundance of several cohorts .

Information available from elver transfer operations at various sites throughout the country have been collated and analysed. Unfortunately, the quality of the data do not allow for any robust conclusions to be drawn. The most significant omission from the data is the lack of measures of effort – without this, it is not possible to know whether differences in catches and species proportions are a reflection of changes in absolute abundance.

The data have been reviewed to establish peak arrival periods, compare historic with recent catch data (species proportions, age frequency), and produce a consolidated database of catches by capture site. In the absence of effort data, any conclusions are tentative – for instance, there is a suggestion in the data that the arrival season of longfins at Karapiro Dam has become compressed, which could indicate decreased abundance of the species.

In future, for elver data to be of use as an index of recruitment of either species, it is imperative that catch data be recorded consistently between years. Because methods and capture sites are subject to change from year-to-year, this will necessitate establishing a specific sampling programme using a permanent trapping facility. Again, accurate documentation of catches is essential, including regular measures of species proportions – without such data, the information currently collected by industry is of little benefit for long-term monitoring of longfin abundance.

12. Age composition and abundance of juvenile and adult eels

12.1 Introduction

This report and previous studies (Jellyman 1979; Jellyman & Ryan 1983) have shown that annual glass eel and elver recruitment varies considerably. Mitchell & Davis Te-Mairie (1994, 1995) also concluded there was evidence of years of "better than average recruitment" from analyses of adult eel year-class frequencies and that strong cohorts were common to separate populations. If this is correct it would imply that there are periodic very strong years of recruitment for longfins, and that these strong years occur nationally. Conversely, if substantial periods of low or intermittent recruitment occurred, especially prior to extensive commercial fishing, i.e. pre-1970 (Jellyman 1993), then any recent declines in recruitment may be less significant than originally thought.

We therefore examined data on the age composition of juvenile and adult longfins to assess the extent of annual variations in year class abundance and to determine whether recruitment has declined in recent years. Historical changes in size composition, especially of large eels, and the influence of commercial harvesting are described later in this report.

12.2 Materials and methods

This involved:

- determining the age composition of juvenile eels collected from three coastal streams and the Arahura River

- determining variations in year class abundance of adult eels caught in fyke nets
- reviewing the literature and databases to determine historical trends in length and hence age composition
- developing computer models to determine the influence of changes in recruitment on age and size composition

12.2.1 Age composition of juvenile eels

The best information on changes in age composition and hence recruitment comes from the NIWA PGSF-funded programme on "Sustainability of Eel Fisheries". The sampling protocol and data analyses are complex; a full description will be published separately and only an outline of techniques, together with some of the assumptions made, are given here.

Juvenile eels were quantitatively sampled in three small coastal streams (Pigeon Bay, Canterbury; Horokiwi Stream, Wellington; Te Maari Stream, Raglan) over three years using electric fishing equipment (Glova *et al.* 1998). The abundance of all size/age groups within the entire catchment were estimated and used to determine age composition and mortality rates. It was assumed that all populations showed linear growth in length from entry into fresh water as glass eels and that the standard deviation in length increased with increasing age (Graynoth 1998, Francis & Jellyman 1999). As growth in these streams was slow (10.0 to 17.9 mm y^{-1}), up to 35 age classes were represented in eels <400 mm. Mortality rates, estimated for different size classes of eels using a maximum likelihood model, were used to calculate the relative strength of different year classes of juvenile eels (<15 years of age) and hence historical trends in glass eel recruitment over the period 1984 to 1998.

The second dataset came from the Arahura River (West Coast, South Island) where NIWA undertook an electricfishing survey of juvenile eels during early 1998 for the Department of Conservation (Jellyman *et al.* 1999a). These data represent a different geographic location and a larger catchment. Longfins ranged from 60 to 1000 mm in length and 66 juveniles (<400mm) were aged. Growth rates were very slow (9.5 mm y^{-1}) and it was estimated that males probably mature and migrate to sea at about 50 years of age and 550 mm (Todd 1980 and NIWA unpubl. data) while females are even older (~100 years, ~1100 mm). Trends in recruitment were determined using simulation models to fit the length frequency of eels found in the lower reaches of the Arahura River (see below).

12.2.2 Age composition of adult eels

Only four sets of data on the age composition of adult eels caught in experimental and commercial fyke nets were used (Table 9). Data from three other locations (Clutha River, Lake Coleridge, Waiau River) could not be used because there was excessive variation in age distribution between sites. A large sample from Lake Pounui was also rejected because it was derived from several fishing methods with markedly different selectivities. Other samples were rejected because the sample sizes were too low. Three of the four samples came from the recent catch-sampling programme (Beentjes & Chisnall 1997, 1998; Chisnall and Kemp 1998). Age-length keys derived from aged fish were applied to length frequency data scaled to landing weight of subsampled landings. Because of limited sample sizes, broad length classes were used in these keys (5 cm wide in the middle of the range and broader classes at the extremes). Sampling errors were estimated by generating 95% confidence intervals for each bar of each histogram. First, for each location, 1000 bootstrap samples were generated by resampling (with replacement) the original data (for the catch-sampling data, only the aged subsample was resampled). Then ageing error was added to each bootstrap sample using an ageing-error model and an age-frequency histogram was created (via a new age-length key, in the case of the catch-sampling data). The confidence interval on each bar of the original histograms represents the range within which 95% of the bootstrap-generated histograms lay.

Table 9: Details of samples analysed to investigate longfin recruitment

Location	No. of otoliths	No. of lengths	Year sampled	Age range
Waikato River	325	325	1984	4–26
Oreti River	86	1 603	1995–96	14–61
Mataura River	206	3 612	1995–96	12–43
Waitaki River	198	1 359	1995–96	9–38

12.2.3 Changes in abundance of juvenile eels

The New Zealand Freshwater Fish database (NZFFDB) contains records from 4264 locations where longfins where caught using electric fishing equipment and is a potentially valuable source of information on historical trends in juvenile eel abundance and hence recruitment. However, length and density data are not stored on computer requiring the original data cards to be examined. We found that sample sizes were often small (<50 fish), and that many observers measured only large eels, and we therefore abandoned this work after extracting and processing records from 12 South Island rivers.

We also reviewed all known scientific literature, and published reports issued by MAF and other organisations. However, published data were sometimes unsuitable for use, raw data were either unavailable or confidential and there were further limitations on the remaining data. It was difficult to determine historical trends in eel size and abundance because no locations were repeatedly sampled in a consistent manner over the past 20 to 30 years. Additionally the sample sizes were often small and it was difficult to compensate for annual and seasonal changes in abundance and catchability. Also, current electric fishing methods are only effective in shallow water (<75 cm) and may underestimate the stocks of medium and large eels in deep water. Although several comprehensive electric fishing surveys have been undertaken (e.g. Hanchet & Hayes 1989, Jowett & Richardson 1995,1996, Richardson & Jowett 1998; Jowett *et al.* 1996, 1998) sampling was confined to shallow riffles and runs and as a consequence, few medium and large eels were caught (NZFFDB records).

Eels were divided into three size groups for data tabulation and comparison. The groups were: Small eels <450 mm (i.e., <220 g and commercially undersized), Medium 450–700 mm (i.e., 0.5 to 2 lbs), Large >700 mm (i.e., >2 lbs or 908 g i.e., all females). Large eel numbers were also expressed as a percentage of medium and large eels combined to determine size changes in commercial catches. For length frequency analysis, fish were grouped into 25 to 50 mm size classes. The percentage frequency was plotted on a logarithmic scale for electric fishing data and on a linear scale for fyke net and trap data. Lengths (L mm) were converted to weight (Wg) using the equation $W = 0.00000118L^{3.18}$ (Francis & Jellyman 1999).

12.2.4 Modelling

Deterministic computer models were used to assess the effects of changes in recruitment on eel populations and the fishery. They were programmed in Microsoft Excel and SYSTAT (Wilkinson 1999) using techniques described in Francis & Jellyman (1999) and Hoyle & Jellyman (in press). Survival rates for eels (>350 mm) in the three streams were determined by modifying parameters and fitting model outputs to field data on length frequencies and on the percentage and mean length of migrant eels.

A model was also written to demonstrate the theoretical effects of declining recruitment and the effect of harvesting on the length frequency and other features of the stock (in SYSTAT basic). The annual cycle of the model is described in Francis & Jellyman (1999) and additional features were added to test the effects of historical trends in recruitment, survival and growth rates. The base model produced stock abundance, harvest, and migrant estimates by 5 cm size classes for 10 year intervals from 1970 to 2040.

Simulations were run using our best estimates of growth, recruitment, migration and survival rates. These were largely derived from PGSF studies on the three coastal streams (Table 10). Where site specific information was unavailable we used standard estimates for parameters controlling the outmigration of mature eels (Hoyle & Jellyman in press) and for growth rates (24.2 mm y^{-1}). Equal sex ratios for small eels were used (Francis & Jellyman 1999) although recent studies (Beentjes 1999) indicate that males are more abundant than females in commercial catches. However, if most immature eels develop into females, then equal sex ratios could occur.

Table 10: Parameter values used to model recruitment rates (See Francis & Jellyman (1999) for more details). Note – The standard deviation (SE) varied with age according to the equation SE =0.1+0.17*b1*age (Francis & Jellyman 1999)

Parameter	General model	Arahura River
Growth rates		
Calculated length (mm) at age 0 (a1)	83	96
Standard deviation at age 0 (a2)	10	10
Growth rate mm.y^{-1} (b1)	24	9.5
Survival rates y^{-1} by length class		
<150 mm	0.80	0.80
150–299 mm	0.93	0.93
300–399 mm	0.77	0.77
400–699 mm	0.93	0.93
>700 mm	0.96	0.96
Maturity rates – Females (^{F}) – Males (^{M})		
Gamma (no units)	0.24^F 0.61^M	0.24^F 0.61^M
Lambda (mm)	108^F 57^M	108^F 57^M
Nu (mm)	5.1^F 2.3^M	5.1^F 2.3^M

12.3 Results

12.3.1 Age composition of juvenile eels

Three coastal streams. Small juvenile eels (<250 mm) were relatively scarce in the Horokiwi and Pigeon Bay Streams from 1996 to 1998 (Figure 4) but were more abundant in Te Maari stream.

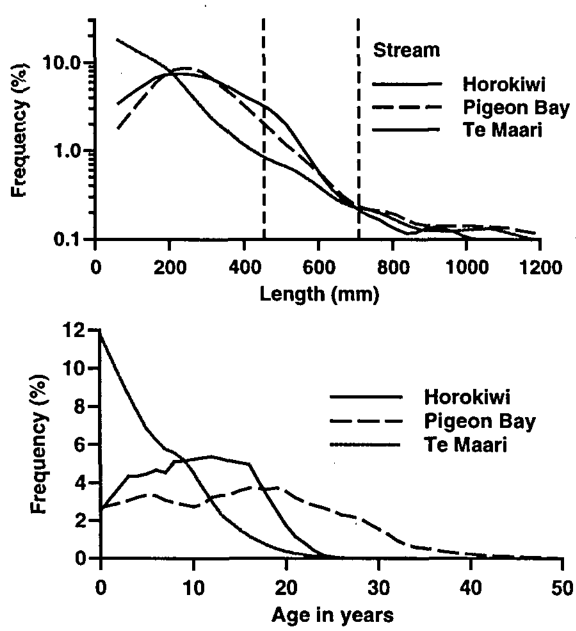


Figure 4: Length and age frequency composition of longfins caught using electric fishing in three coastal streams from 1996–1998. The vertical dashed lines delimit eels <450 mm and >700 mm.

Maximum likelihood analysis showed recruitment has declined in two of the three streams (Figure 5). In the Horokiwi Stream recruitment has declined sharply since the mid 1980's and very few glass eels have entered Pigeon Bay Stream since 1984. If we take, as a measure of this decline, the percentage reduction from the early (fixed) recruitments to the mean of the later recruitments, then we find substantial declines: 88% for the Horokiwi Stream and 67% for Pigeon Bay Stream. In Te Maari Stream the long term trend is not significant, mainly because the 1990 and 1991 year classes were particularly strong. However, there are indications that recruitment has declined since then.

Annual recruitment is highly variable both between years and between waters (Figure 5) and it is most unlikely that recruitment has declined at a steady rate. We also have insufficient information to be able to state with any precision when the glass eel runs started to decline. However, in order to describe and model historical trends we have calculated the average rate of decline since 1980. Average rates of decline since 1980 varied among streams from a high of 18% y^{-1} (standard error $\pm$3.1%) in the Horokiwi Stream to 8.3% y^{-1} ($\pm$4.6%) in Pigeon Bay Stream and to 4.8% y^{-1} ($\pm$2.7%) in Te Maari Stream. Although the average for all waters combined is about 10% y^{-1}, a more conservative figure of 7% y^{-1} has been used in Figure 6 and in computer models derived from this work (i.e., Recruitment = $100*e^{-0.0726*(year-1980)}$. Therefore in the year 2000, recruitment is estimated to have declined a total of 77% and hence averages only 23% of 1980 levels.

There was no significant relationship between streams in glass eel runs. The highest correlation was 0.37 between the Horokiwi and Te Maari Streams for the eleven years from 1986 to 1998 and this is not significant at the 0.05 level of probability.

Arahura River Small eels were also relatively scarce in the Arahura River in 1998 and were found mainly in the lower reaches (<10 km from the sea, Figure 7). Nevertheless the proportion of small fish (<350 mm) present in the lower reaches was only 14% of that predicted using the Excel and SYSTAT simulation models (Figure 8 Table 10) which were driven by field data on growth rates (Figure 9) and the length frequency distribution of larger eels (>350 mm) (Figure 8).

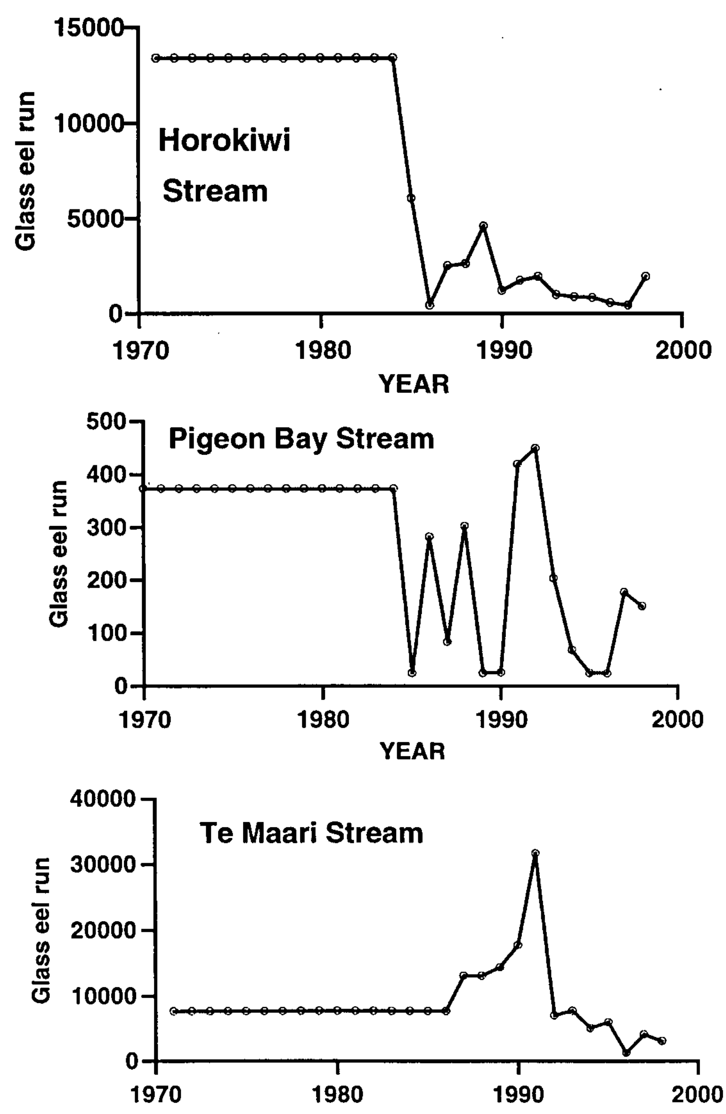


Figure 5: Estimated recruitment of longfinned glass eels into three coastal streams from maximum likelihood analysis model. Early trends in recruitment are averaged because the data are inadequate to determine the extent of annual variations.

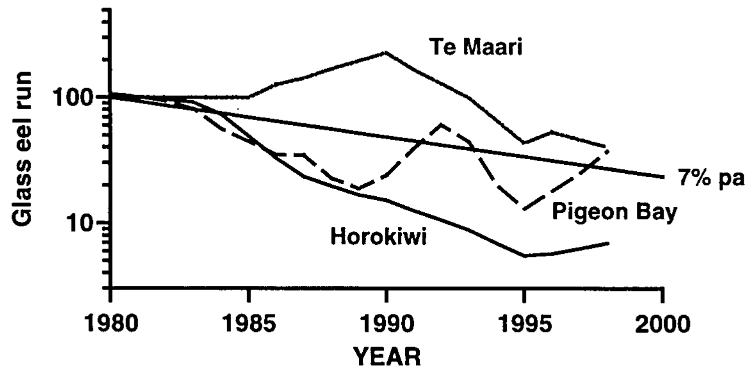


Figure 6: Decline in glass eel runs from 1980 in the three coastal streams. Indexed to 100 in 1980 and fitted with a lowess smoother and a tension of 0.4.

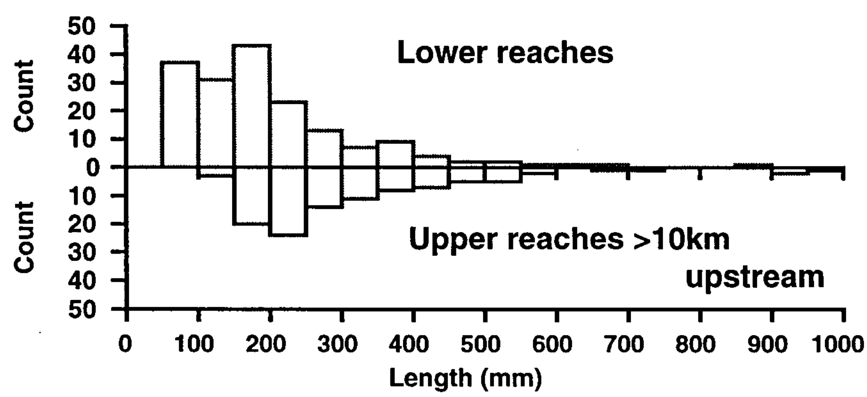


Figure 7: Length frequency of eels in the lower and upper reaches of the Arahura River in 1998.

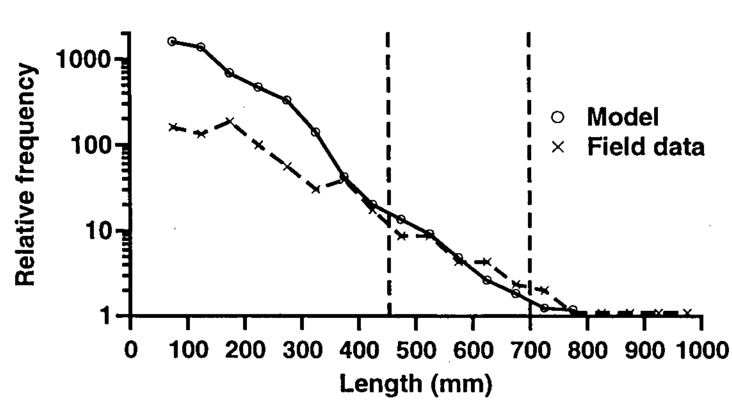


Figure 8: Comparisons between model estimates and observed field data on the length frequency of longfins in the Arahura River. Dashed vertical lines as Figure 4.

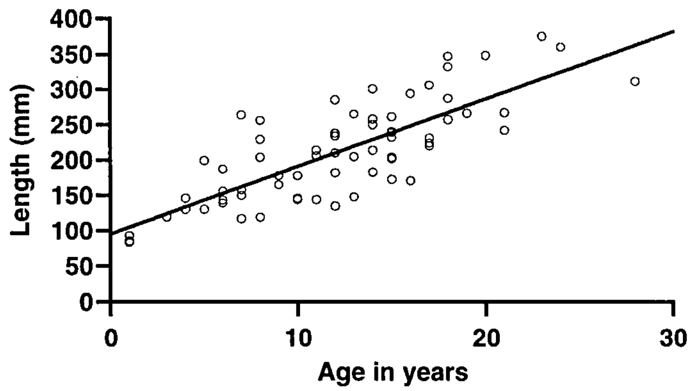


Figure 9: Length at age of longfins caught in the Arahura River and tributaries.

These models indicated that glass eel runs have declined by about 5% y^{-1} over several decades and that low recruitment is the reason for the lack of small eels in the Arahura River. This is because it seems unlikely that large numbers of small eels were present in deep fast flowing water which could not be electric fished (Glova *et al.* 1998, Jowett & Richardson 1995). Small longfins were confined to the edges of the runs and riffles because of high water velocities in deeper water (senior author pers obs.). However, no adjustments were made for changes in electric fishing efficiency with fish size and slightly more small eels might be present if this correction was made.

Small longfins were also scarce in electricfishing samples collected from the Ashley River in 1999 (Figure 10; NIWA unpubl. data). This is probably due to reduced recruitment levels because longfin glass eels only comprised a low proportion (1–11%) of the glass eel recruitment into the Ashley River in recent years (Appendix 2).

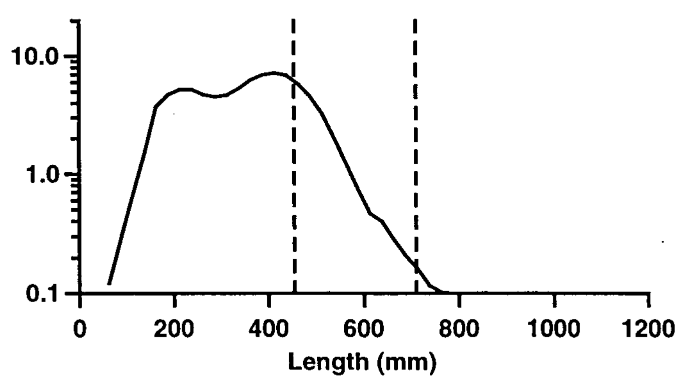


Figure 10 : Length frequency distribution of longfins in the Ashley River in 1999. Dashed vertical lines as Figure 4.

12.3.2 Age composition of adult eels

Age frequency histograms (Figure 11) often showed what appear to be substantial contrasts in the abundance of adjacent (or nearly adjacent) cohorts For example, In the Mataura River sample 18-year olds appeared to be substantially less abundant than adjacent cohorts. The question next addressed was whether this was an indication of year-to-year fluctuations in recruitment, or simply noise due to sampling error.

Confidence intervals showed that most of the structure in the histograms could be caused by sampling error. We could have no confidence in the existence of more than one mode for each histogram, and so it was not possible to extract any information about short-term fluctuations in recruitment from these data. Thus it is not possible to make any inferences about long-term trends in recruitment from these histograms. Although such trends affect the overall shape of the histograms, so do other factors such as natural and fishing mortality, emigration, gear selectivity, and sampling bias. The lack of information about these other factors means that we cannot distinguish their effect from that of recruitment.

12.3.3 Changes in abundance of juvenile eels

We found no useful information on historical trends in the density of small eels (<450 mm) either in the NZFFDB or in the published literature. However, there is some information available on trends in the length frequency and hence relative abundance of small eels (Table 11).

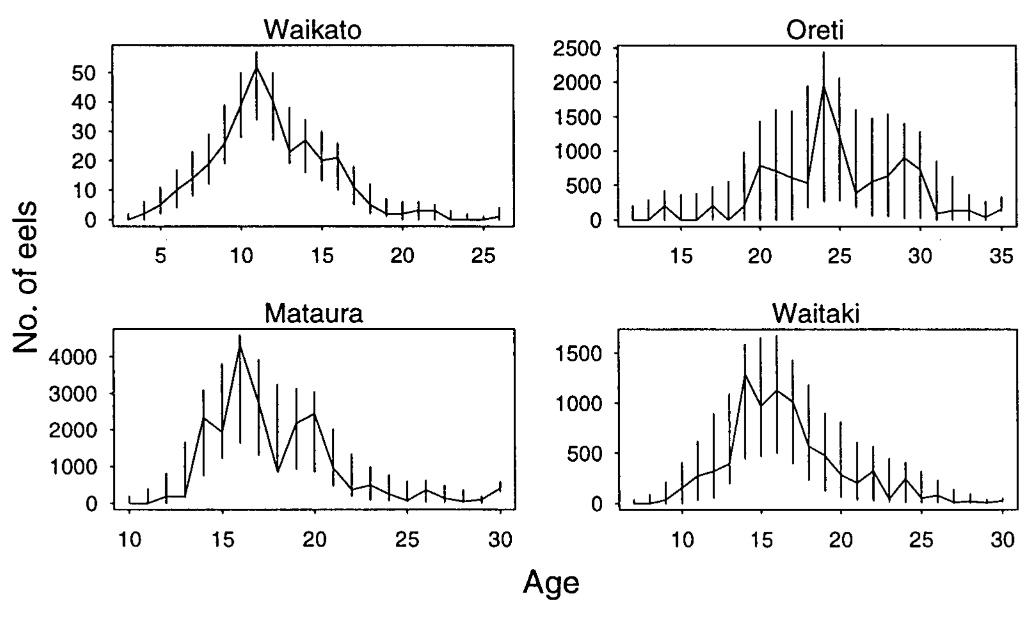


Figure 11: Age-frequency histograms, with 95% confidence intervals, for four rivers.

Table 11: Length frequency (%) of longfins caught using electric fishing techniques. Small <450mm, Medium 450–700 mm, Large >700mm, Large % = Large eels as a % of eels >450 mm

Water	Year	N	Small %	Medium %	Large %	Large % >450 mm	Reference
Horokiwi Stream	1952	645	68.1	29.9	2.0	6	Burnet 1952b
Wainuiomata River	1952	501	86.0	10.0	4.0	29	"
South Branch (Waimakariri River)	1960	2082	63.6	35.3	1.1	3	Burnet 1968, 1969a
Paraparaumu Stream	1964	272	91.2	7.7	1.1	13	Woods 1964
Waitaha River	1982	45	91.1	8.9	0.0	0.0	NZFFDB
Greenstone River	1985	140	97.9	2.1	0.0	0.0	NZFFDB
Various rivers in Nelson	1989	63	81.0	19.0	0.0	0.0	NZFFDB
Whanganui River	1989	73	98.6	1.4	0.0	0.0	NZFFDB
Styx River	1990	143	59.4	35.0	5.6	13.8	NZFFDB
Stillwater River	1992	47	95.7	4.3	0.0	0.0	NZFFDB
Horokiwi Stream	1996–98	1064	83.5	15.5	1.0	6.3	Glova *et al.* 1998
Pigeon Bay Stream	1996–98	1389	89.2	9.2	1.6	14.7	"
Te Maari Stream	1996–98	2412	92.5	6.0	1.5	19.9	"
Arahura River	1998	280	91.4	6.4	2.1	25	Jellyman *et al.* 1999a
Ashley River	1999	294	78.6	21.1	0.3	1.6	NIWA unpub. data

These streams and small rivers, which were sampled before commercial fishing started in the late 1960's and early 1970's, contained a high percentage of small eels and a low percentage of large eels (Table 11). However, few eels in the 50–150 mm size range were captured and peak numbers occurred at lengths of 200–300 mm with secondary peaks at 500–650 mm in three waters (Figure 12). The secondary peaks in the Horokiwi and Wainuiomata Rivers may have been caused by the selection of sites with relatively good eel cover (Burnet 1952b). In the South Branch, numbers declined rapidly from 550 mm onwards due to both the outmigration and exclusion of mature males from the measured sample (Burnet 1969a).

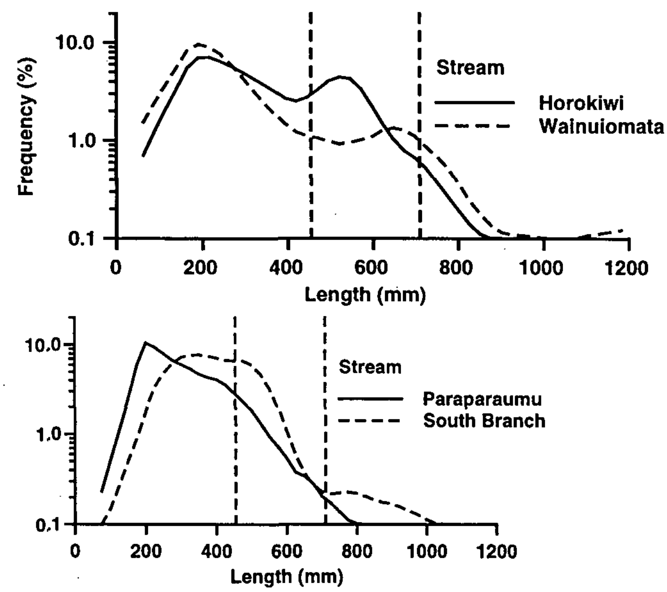


Figure 12: Length frequency of unfished populations of longfins. Smoothed line using lowess with a tension = 0.2 The vertical dashed lines delimit eels <450 mm and >700 mm.

The Horokiwi is the only one of these streams which has been intensively studied and repeatedly electric fished (Jellyman *et al.* 1999c). Comparisons between data collected in 1952 and 1996–99 (Table 11, Figure 13) show there were slightly **less** small eels (<200 mm) present in 1952 than in 1996–98. The reasons for this are not known. It is possibly a sampling error caused by differences in locations fished and techniques used.

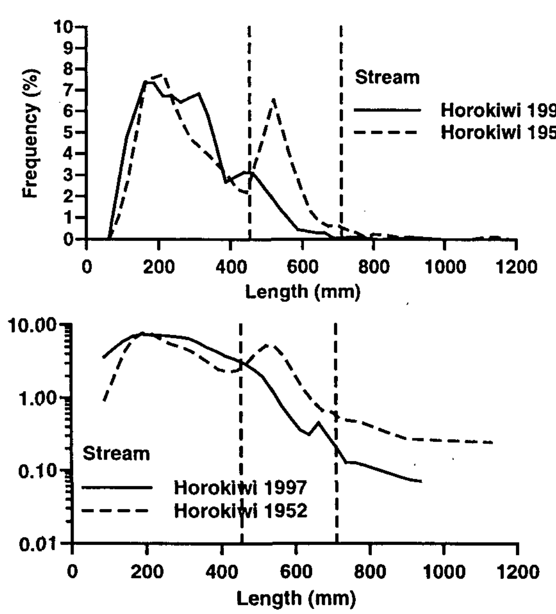


Figure 13: Changes in the length frequency distribution of longfins caught in the Horokiwi Stream in 1952 and 1996–1998 using a lowess smoother with tensions of 0.1 (normal frequency) and 0.2 (log frequency) respectively.

There was stronger evidence that there has been a decline in the total % of medium and large eels (>450 mm) present in the Horokiwi Stream. This could have been caused by either sampling error and bias due to differences in sampling techniques, or by historical changes in harvesting, survival and growth rates.

Possible reasons for these changes are listed below in order to demonstrate the difficulty of identifying causative factors. For example:

(a) Areas of relatively good cover were fished in 1952 (Burnet 1952b) and this may explain the exceptional catches of medium sized 450–700 mm eels.

(b) Increased commercial fishing pressure may account for the lack of medium and large eels in 1996–98. Modelling indicated natural survival rates were relatively low in 1952 (400–700mm = 0.891 and >700 mm = 0.917), assuming no eels were harvested and that growth rates were the same as in 1997 (15.4 mm y^{-1}). If eels in 1997 had similar survival rates then an additional 5% of the stock (>220g) (~40 fish) was harvested every year since 1970. (Although, some eels may have been harvested prior to 1952, for recreational and customary fishing, this had no effect on the relative increase in crop rate.)

(c) These changes could also be explained by a slight decrease in annual survival rates of medium sized eels, from 0.891 prior to 1952 to 0.870 in recent years.

Other explanations for these changes include either reductions in growth rates (~5%) between 1952 and 1997, or increases in the percentage of males eels present or in the proportion of male eels migrating to sea. Therefore the reasons for these changes remain unknown. Also it is debatable whether some of the changes, such as in growth and survival rates, could ever be detected using current scientific techniques and usual sample sizes.

There was no evidence of trends in the relative abundance of juvenile eels caught using electric fishing equipment over the period 1982–1992 (Table 11, Figure 14). Length frequency distributions varied between waters possibly because only a few locations were fished and sample sizes were inadequate (N = 45–140). The absence of large eels (>700 mm) from all waters, except the Styx, is possibly due to the lack of suitable habitat, although it might also be due to increased fishing pressure. Small longfins (<250 mm) were noticeably scarce in the Styx River, possibly because the deep, slow flowing, water and mud substrate was more suitable for larger long and shortfinned eels (Eldon & Taylor 1990).

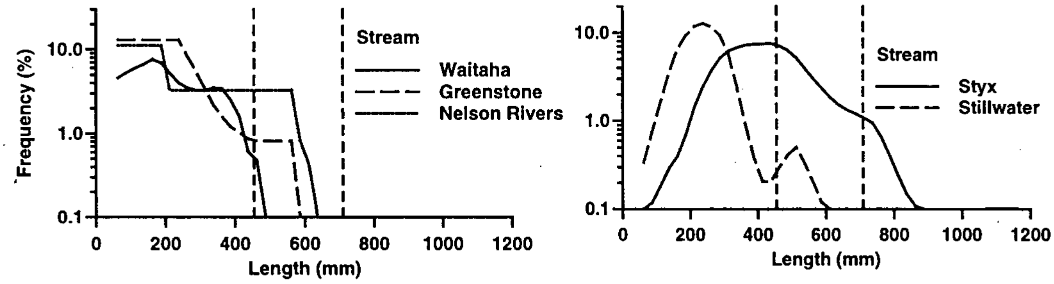


Figure 14: Length frequency of longfins caught in coastal streams (<20 km from sea) from 1982 to 1992 using electric fishing equipment. Smoothed line using lowess with a tension = 0.2 The vertical dashed lines delimit eels <450 mm and >700 mm

12.3.4 Changes in abundance of adult eels

Crop rates can be estimated by fitting computer simulation models to the actual length frequency of the catch if sufficient information is available on fyke net size selectivity, survival and growth rates and other features of the population. For example length frequency data, from eels netted in the lower reaches of the Aparima River in 1995/96 (Beentjes & Chisnall 1997), were modelled using a growth rate of 20 mm y^{-1} (derived from Beentjes 1999) and the survival and maturity rates shown in Table 10. The model (SYSTAT) predicted the length frequency distribution of eels both when fishing started (~1970) and in 1995/96. It was assumed recruitment has declined at 7% y^{-1} since 1980 and that fishers have harvested 20% of all eels (>220 g) annually since 1970. Figure 15 shows that this model gives an excellent fit to the data.

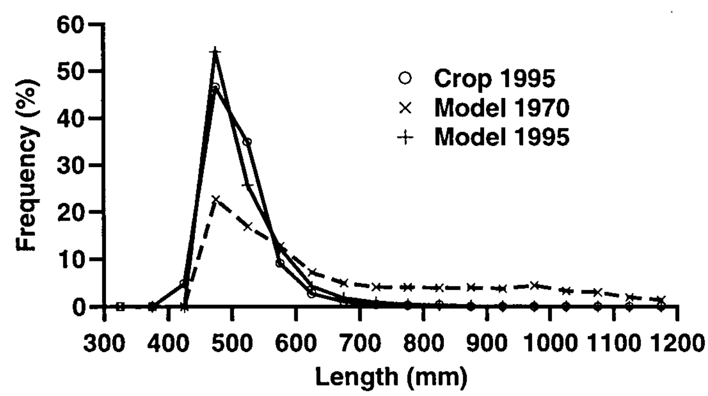


Figure 15: Comparison of the length frequency of eels harvested from the Aparima River (Beentjes & Chisnall 1997) with estimates from a simulation model.

Various historic and recent studies have recorded biomass of eels. A survey of these data (Table 12) shows that biomass of longfins ranged from 4 to 353 $g.m^{-2}$ in different waters and habitat types (Table 12). There was a small decrease (23%) in biomass in the Horokiwi Stream between 1952 and 1996/98, the only water where comparable data have been collected.

Table 12: Biomass (g.m^2) of longfins caught using electric fishing (EF) techniques and traps in different reaches of streams and rivers (Burnet 1952a,b, 1959, 1968, 1969a, unpubl. data). The biomass of eels caught in traps was multiplied by 2.4 to include the biomass of small eels (Burnet 1952b). *, includes some shortfinned eels which were probably <20% by weight of the total

Habitat type of water	Year	Method	Mean biomass	Min.	Max.
Stable streams with good cover	1947/48	Trap	233	73	353
Moderate stability with some good cover	1947/48	Trap	25	19	36
Open shingle beds with little cover	1947/48	Trap	9	4	12
Horokiwi Stream	1952	EF	45.4	12.7	101.6
Wainuiomata River	1952	EF	31.3	4.6	46.6
Doyleston Drain*	1954	EF	13.0	–	–
Cust Main Drain	1955	EF	13.5	–	–
Hanmer Road Drain*	1956	EF	6.6	–	–
South Branch	1959	EF	84.5	50.1	126.4
Horokiwi Stream	1996/8	EF	29.7	25.0	35.2
Te Maari Stream	1996/8	EF	35.1	31.4	38.1
Pigeon Bay Stream	1996/8	EF	56.0	52.7	59.4

Reduced recruitment and heavy fishing pressure will lead to reductions in eel abundance and biomass. Theoretical declines in eel abundance in a representative water, such as the Horokiwi Stream, are shown in Figures 16 & 17 using the parameter values listed in Table 10. We assumed recruitment was constant at 10,000 glass eels per year until 1980 and then declined at 7% y^{-1} (Figure 6) and that fishers removed a moderate crop of 10% y^{-1} of the stock of eels >220 g in weight from 1970 onwards. Note that the rate of decline in small eels (<450 mm) is not constant but declines rapidly from 1990 onwards. Similarly for medium and large eels the stock remains reasonably constant from 1980 to 2000 and then drops rapidly.

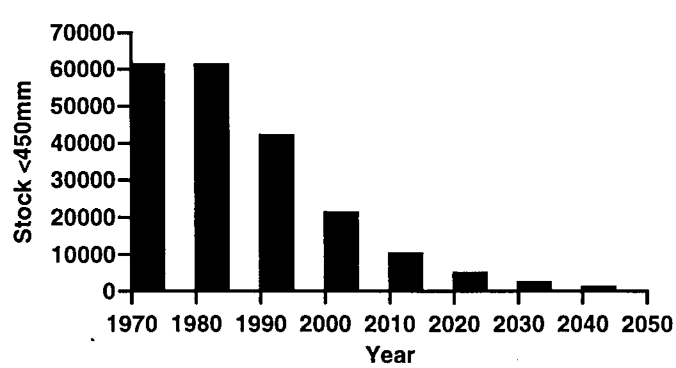


Figure 16: Theoretical decline in the abundance (N) of small eels (<450 mm) from 1970 to 2040

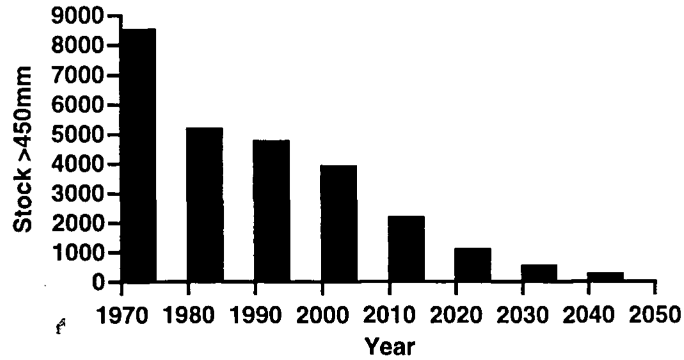


Figure17 : Theoretical decline in the abundance (N) of medium and large eels (>450 mm) from 1970 to 2040.

There is no information available on historical trends in the numbers of migratory eels leaving New Zealand waters. Computer models (Hoyle & Jellyman in press) show that large female longfins are very vulnerable to overfishing because they are exposed to the fishery for 18 to 50 or more years, depending upon growth rates. Males migrate at a smaller size and are exposed to exploitation for about 7 years. Relatively low crop rates of 5% and 10% per year are capable of reducing the spawner biomass of longfin females by 80% and 95.5% respectively (Figure 18). Even at a crop rate of 10%, the maximum size limit of 4 kg in the South Island has virtually no affect as almost all eels are caught before they reach this size.

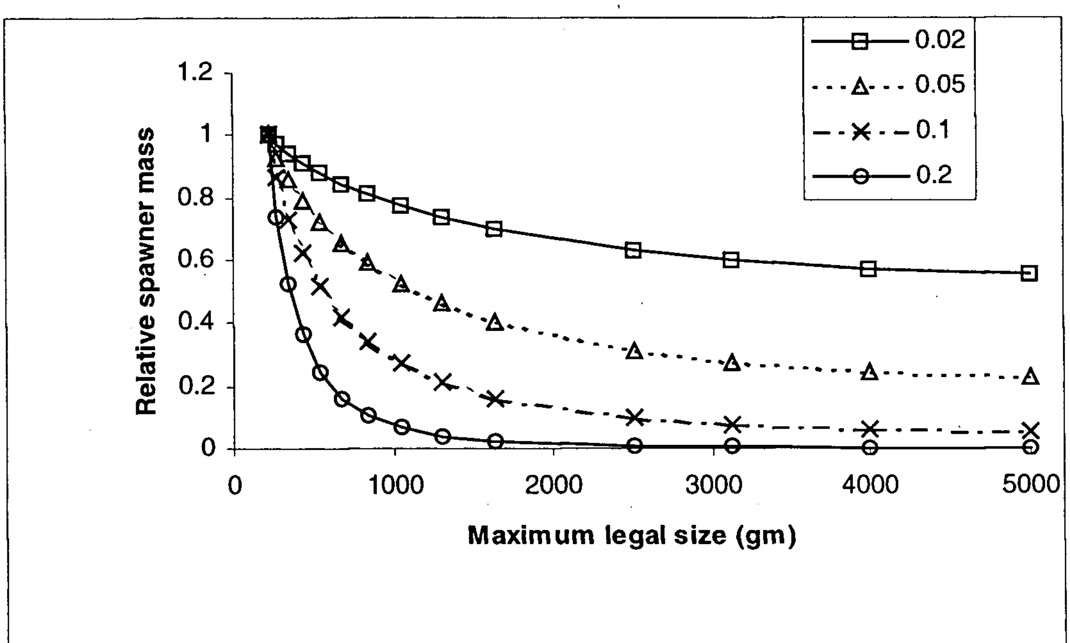


Figure 18: Model of the reduction in the biomass of mature longfins at different exploitation rates (0.02 to 0.2 proportion harvested each year) and with different maximum legal size limits (grams).

Modelling (SYSTAT) indicates that with a 10% crop rate, female migrants will have already been reduced to very low levels and that the number of male migrants will decline from 2010 onwards (Figure 19).

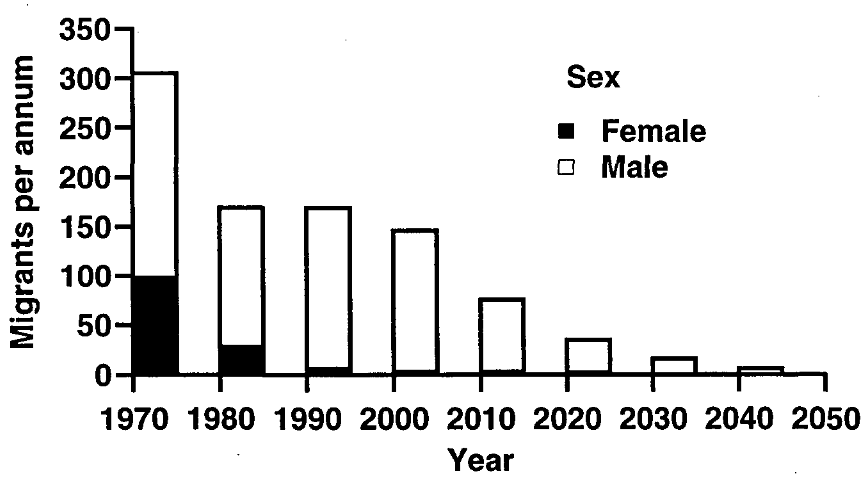


Figure 19: **Theoretical decline in migrants 1970–2040 based on a crop rate of 10% y^{-1} and declining recruitment.**

12.3.5 Changes in size of adult eels

A plot of the percentage of large longfins (> 70 cm) in the catches of historic and recent surveys (*Figure* 20) shows a general reduction in the availability of large eels.

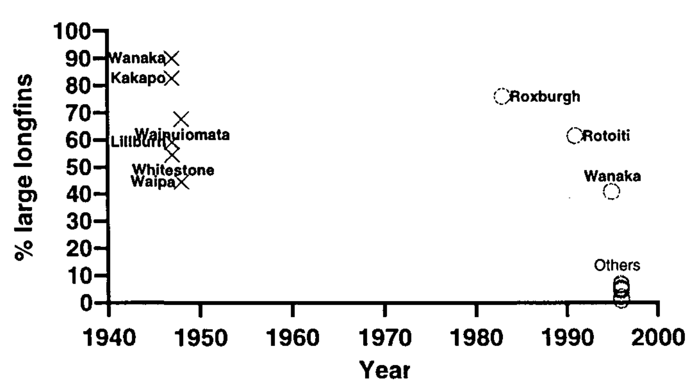


Figure 20: **Percentage of large eels caught in traps (<1960) and fyke nets. Data from Appendix 7.**

Further evidence of the decreased abundance of larger eels is available from Lake Wanaka where comparisons can be made between 1947 and 1995 (Figure 21).

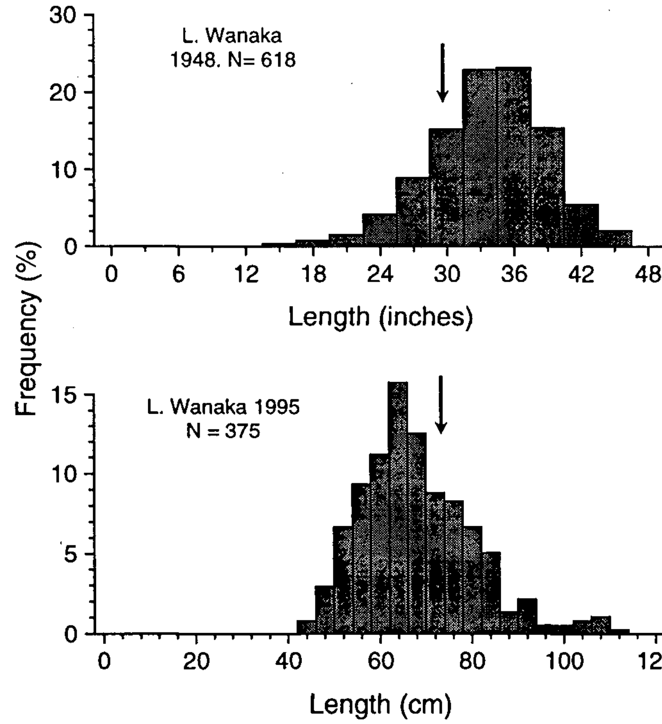
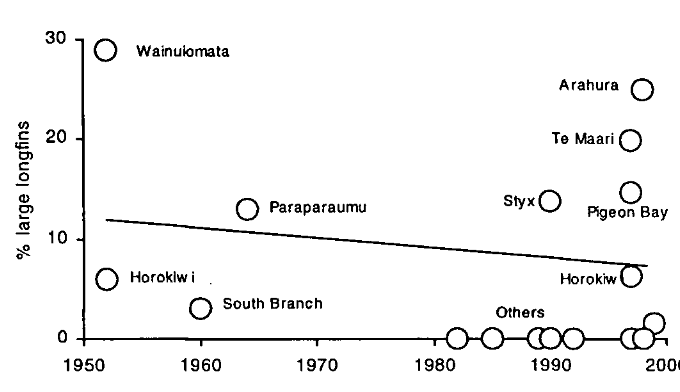


Figure 21: Length frequency of longfins caught in Lake Wanaka prior to commercial fishing in 1948 using baited traps and after commercial fishing in 1995 using baited fyke nets. The arrow marks 750mm, the minimum size for migrating longfin females.

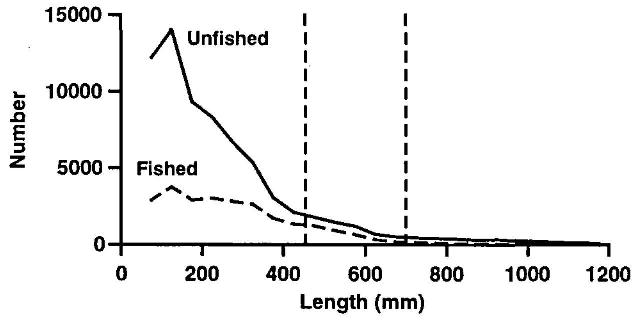
Although relatively few large eels are caught using electric fishing equipment compared with traps and fyke nets (Table 11, Figure 22), there is little evidence that the ratio of large to medium sized eels has declined over time even when differences in water type are taken into consideration. For example, although the relative lack of large eels in the Styx River in 1990, compared with earlier records from similar waters such as the Wainuiomata River (Table 11, Appendix 7, Burnet 1952 a & b)



might be due to commercial fishing, other explanations are possible.

Figure 22: Trends in the proportion of large (>700 mm) eels in the electric fishing catch (>450 mm) Data in Table 11.

Theoretical models demonstrate that the combined effects of low recruitment and increases in fishing pressure on the length frequency of longfins can be quite subtle. Although the differences in absolute numbers are quite large (Figure 23), the differences in percentage composition are much smaller and can only be detected with adequate and unbiased samples from all size classes.



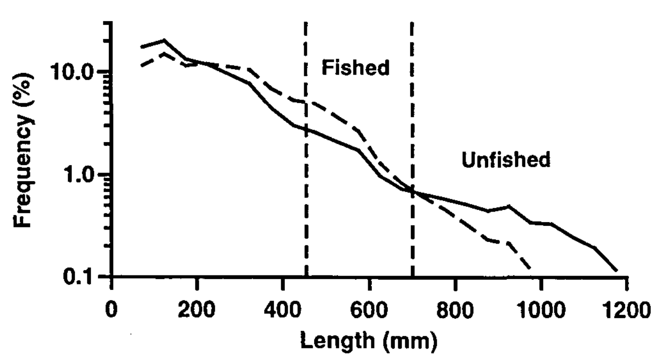


Figure 23: **Effects of increased fishing pressure and low recruitment on the number and length frequency of longfins present. Unfished (solid line) = 1970, Fished (dashed line) =2000. The vertical lines show the size at which fishing starts (450 mm) and when only females are present (>700 mm).**

12.3.6 Crop rates and harvest

The effects of a continued decline in recruitment of 7% y^{-1} and constant fishing pressure which removed 10% of the stock per annum (see earlier) were modelled for a small stream, such as the Horokiwi or Te Maari. The total yield (kg y^{-1}) declines steadily from 1980 onwards (Figure 24) while the total number of eels caught (crop) declines rapidly from 2000 onwards (Figure 25). If fishers increased their fishing effort to compensate for declining catch rates and catches, this will accelerate the reduction in stock abundance and yields. Given average catch rates of 5.7 to 6.8 kg/net/night during the 1980's (Annala & Sullivan 1997) the model yield of 215 kg in 1990 equates to 31 to 38 net nights fishing which seems about right for a small stream.

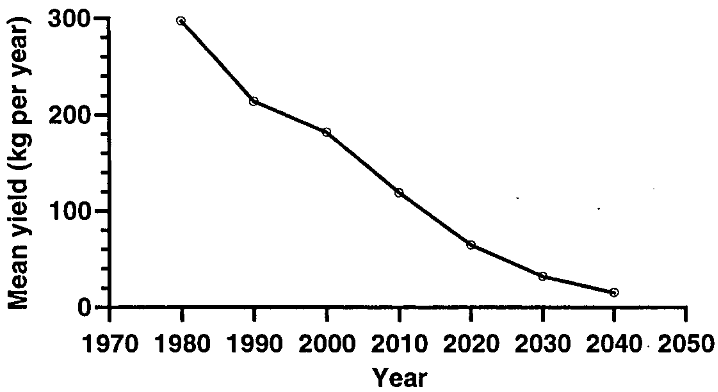


Figure 24 : **Theoretical changes in the mean annual yield of longfins from 1980 to 2040 in a small stream.**

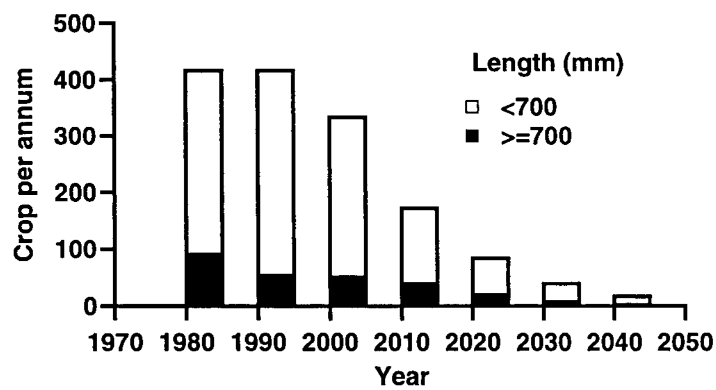


Figure 25: **Theoretical decline in the number of longfins harvested per year from 1980 to 2040 in a small stream.**

It is of interest to note that the model predicted the mean weight of eels increased over the next 20 years and then declined due to the passage of currently unfished, strong year classes through the fishery (Figure 26). This supports Francis & Jellyman's 1999 study which showed that trends in the size of eels caught in the fishery cannot be used to monitor short term changes in the status of eel stocks.

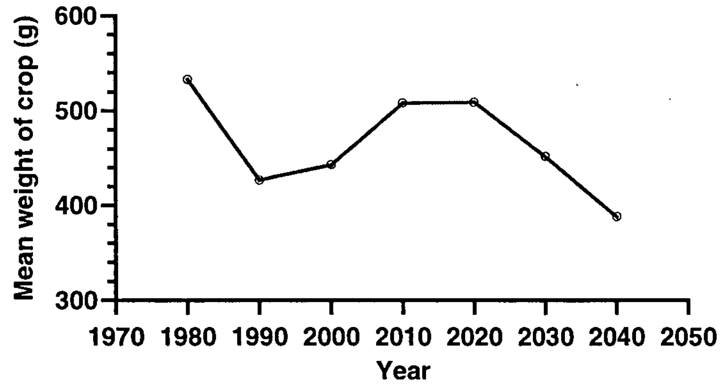


Figure 26: Theoretical changes in the mean weight of longfins caught by eel fishers from 1980 to 2040 in a small stream.

13. General discussion

13.1 Factors responsible for the decline in recruitment

Studies on the age structure of juvenile eels indicate that glass eel runs have declined in recent years. Several factors could be responsible for this decline including changes in the oceanic environment, habitat deterioration in fresh water, hydro-electric dam construction and commercial fishing.

13.1.1 Changes in oceanic environments

It could be speculated that oceanic currents may have altered in recent years, due to climate changes. For example, the comparatively recent arrival of the Australian longfin *Anguilla reinhardtii* in the North Island may be due to changes in oceanic currents (Jellyman *et al.* 1996). Such changes could conceivably have affected adult migrations and the spawning grounds, which are believed to be situated east of Tonga (Jellyman 1987), and the routes by which leptocephali reach New Zealand. Glass eel runs in the South Island, especially those closest to the southern range of the species, may be more sensitive to these changes. For example, although the recruitment of glass eels to Europe has shown a significant reduction over the past decade, recruitment to the Bay Of Biscay region (the region most strongly influenced by the Gulf Stream) has been less affected than areas at the extremes of the species range (senior author pers. comm.).

Alternatively oceanic mortality rates may have increased for some unknown reason. Each female longfin contains, on average, 8 million eggs and it seems quite likely that there is a huge mortality in the ocean of either the eggs or the leptocephali.

There is no evidence for or against these hypotheses and no information on their likely magnitude.

13.1.2 Habitat deterioration

Partial or complete loss of habitat can occur through such mechanisms as swamp drainage, stream and river channelisation. The drainage can be extensive; for instance it is estimated that 90% of the wetland of the lower Waikato catchment which was present at the time of European settlement, has since been drained. In addition, flood protection measures on the lower Waikato now mean that the periodic flooding of marginal wetlands seldom occurs (Chisnall, 1987): such seasonal flood events were important occasions for eels to forage for terrestrial food on the flooded margins. Likewise the removal of willows and channelisation of streams all result in loss of habitat quality and quantity for both species of eel. The extent of habitat loss has not been quantified throughout both North and South Islands and an assessment is needed.

Recent research by NIWA (Glova *et al.* 1998) has highlighted the importance of cover especially for large eels in streams and small rivers. In brief, the density of large eels is in proportion to the total amount of available daytime cover (Burnet 1952a, Glova *et al.* 1998) and thus loss of cover also has serious implications for the well being of eel stocks.

13.1.3 Hydro electric dam development

Upstream migration. The upstream access of juvenile eels has been curtailed throughout New Zealand by the installation of hydro-electric dams especially in the lower reaches of major rivers. For instance the four largest catchments in New Zealand, (Waiau River, Clutha River, Waitaki River and Waikato River) which collectively amount to 21% of the total catchment area of New Zealand, are all affected by hydro development. Being a species which penetrates further inland than do shortfins, the longfin is more affected by barriers to upstream passage at hydro-dams. Eels delayed at hydro-dams are subject to loss of condition, direct mortality by desiccation and increased predation by a variety of birds, rodents and other fish species (Jellyman 1977b).

An evaluation of the total areas of catchments that have been impacted by hydro-dam development is needed. Such a survey could also be extended to include areas affected by installation of various flood protection measures (e.g., storage dams and weirs), and other culverts and floodgates which also have the potential to impact both upstream and downstream migrating eels.

13.1.4 Downstream migration

The autumn seaward migration of maturing eels is also affected by passage through hydro-electric dams and all large female longfins are presumed to die after passing through turbines. NIWA currently has a PGSF funded programme looking at options for safe passage of downstream migrants. While there is some predictability about the seasonal events which trigger these downstream migrations, they often occur during floods when eel collection at areas upstream of the dams is difficult due to increased flows (Boubee *et al.* in press).

One alarming feature is the extent to which lakes within National Parks are affected by hydro development or natural dams. In the South Island, 80% of the National Parks lake area is within the Waiau River catchment (Fiordland National Park). Eel access into Lakes Monowai, Manapouri and Te Anau is affected by both the Mararoroa Weir and the Monowai hydro-dam and virtually all downstream migrants will be killed during passage through the turbines (Jellyman 1993). The Mahingakai Trust is currently investigating ways of capturing migratory eels during their downstream migration before they reach the Manapouri intake. All the North Island National Parks lakes area (59 km2) is within the Urewera National Park i.e., Lakes Waikaremoana and Waikareiti. However, elvers were unable to surmount the 80 m waterfall at the outlet of Lake Waikaremoana (J. Boubee, NIWA, pers. comm.) and the lakes are not stocked with eels.

13.1.5 Commercial fishing

There is evidence from the present study that heavy fishing pressure since 1970 has reduced the stocks of large female longfins and that this is responsible for the decline in glass eel recruitment. Fyke nets are highly effective, and easier to handle, transport and quicker to set than the hinaki's and wire mesh traps used in earlier years and can be adapted for use in virtually all habitats. In the late 1980's eel catches averaged 1362 tonnes per year of which about 35% were longfins (Jellyman 1993). Using this percentage, and assuming eels averaged about 620 g in weight (derived from Mossburn Enterprises data in Beentjes & Chisnall 1997) then at least 20 to 30 million longfins were harvested from New Zealand waters over the past 30 years. Unfortunately, with the inclusion of an "unidentified" species column in the fishers return form in 1989, there are no meaningful estimates of species proportions in the commercial catch since about 1992.

Exact figures on crop (exploitation) rates are not available from individual waters, because of the cost and difficulty of field work needed to estimate eel stocks and harvests. However, some waters are heavily fished and fishers find it necessary to rest them for several years before repeat harvesting. A model developed for the Aparima River (Figure 15) showed that a crop rate of 20% produced an excellent fit to the data. However, actual crop rates may be less than 20% because the model assumes that the main stem of the lower Aparima River contains a representative and full size range of eels, as was found in the three small coastal streams described earlier. There is evidence that large female eels are relatively more abundant in upstream tributaries and that the lower reaches of large rivers support large numbers of small male eels and relatively few large female eels (Cairns 1941, Beentjes 1999, V. Thompson pers. comm.). If this is the case then few large fish would have been present or caught in the Aparima River in 1970 and crop rates will be overestimated. Thus more quantitative information is needed, especially on the spatial distribution and movements of eels in large river systems, before simulation models can be used to estimate crop rates.

13.1.6 Lack of reserves

Eel fishing is undertaken throughout most of New Zealand and until recently, no reserves have specifically been set aside to protect eel stocks. However, under the present management structure in the South Island, the Eel Management Committees are able to set aside particular waterways for customary fishing only, or as reserve areas. Areas where commercial eel fishing is prohibited include National Parks and a range of recreational, Government purpose, and local purpose reserves. In a review of eel fishing, Jellyman (1993) identified a total of 53 government purpose reserves and 15 scenic reserves with waters likely to contain eels. The sum of assumed longfinned habitat within these reserves was 3 672 hectares, an area slightly larger than Lake

Rotoiti in the North Island. Also, the Department of Conservation controls access to a significant proportion of the Crown Estate and this is managed to either enable or discourage access by commercial eel fishers.

Surveys are needed to determine the status of eel stocks in these actual and nominal reserve areas, especially those which have been illegally fished. There also may be a few unfished waters such as small tributaries, inaccessible river gorges (e.g. West Coast) and large rivers which still contain abundant localised stocks of longfins.

13.2 Potential impacts of declining recruitment on eel stocks and the fishery

13.2.1 Recruitment

Although recruitment appears to be declining at about 7% per annum, there is no guarantee this decline will continue and it may accelerate. Much will depend upon how the eel fishery is managed in the future and upon habitat restoration and other conservation measures.

There is no information on the exact relationship between the stock of migrating mature eels and the recruitment of glass eels. A detailed review of stock-recruitment curves from angulliid, salmonid and marine fish stocks should be undertaken. This would indicate the probability of recruitment failure at different stock levels and show what type of curves should be included in models of eel population dynamics. This review may indicate what reductions in the yield of mature eels are likely to be sustainable. Information on the spawning process and the importance of density dependant and independent processes is also needed but is virtually impossible to collect. If survival rates are depensatory (Ricker 1975, Ward & Larkin 1964) with a constant number dying each year, then complete failure of recruitment at low stock levels could occur.

If management decisions are made to reduce commercial harvests, then information on stock-recruitment relationships become of vital importance in determining the rate at which stocks may recover and hence the value of different management actions.

13.2.2 Natural mortality rates

It is difficult to predict the exact affects of declining recruitment on mortality rates because of the lack of field and experimental research on this topic. Mortality rates of juvenile eels may be density dependant and small runs of glass eels may have better survival rates than larger runs. On the other hand depensatory mortality may result in reduced survival rates.

Recent studies in three coastal streams (NIWA unpubl. data) indicate juvenile eel survival rates decrease in the 300 to 400 mm size range (Table 10). These eels may be subject to increased predation and competition as they grow and move from instream gravels into bank cover and other habitats occupied by larger eels. In theory, bank cover and other habitats may act as a bottleneck limiting the abundance of medium and large eels in these streams. These density dependant processes would stabilise stocks and compensate for annual variations and declines in glass eel runs. However, longfins have high survival rates (Table 10) and there is little opportunity for increased survival. Indeed in some waters (Figure 4) there are **more** old eels present than young eels and therefore by definition numbers **must** decline in the future.

The mortality rates of juvenile eels in large rivers, lakes and wetlands have not been studied. Mortality rates may have decreased in recent years due to the reduction in density of large female longfins which predate on fish and smaller eels. Although "fishers report large numbers of under-sized eels in most areas" (Annala & Sullivan 1997), this does not necessarily mean recruitment is sufficient. For example in the Waikato, eels 450–500 mm in length are 10 to 20 years old (Beentjes & Chisnall 1998) and are derived from glass eel runs in the 1980's.

Medium and large longfins have very high survival rates (>90%) (Table 10). This means that commercial harvesting is the major mortality factor and that most eels now caught by fishers would have eventually migrated to spawn as silver eels.

13.2.3 Growth rates

In theory, reductions in recruitment and longfin densities decrease competition, increase food supplies and hence growth rates (Chisnall & Hayes 1991). Although there is evidence that growth is less than the maximum possible in many waters (Graynoth & Taylor in press), this could be due to restrictions on feeding periods and competition and may not be because of a lack of food. Also, surplus food supplies may not be fully utilised by longfins. For example, in Te Waihora the populations of common bullies, flounders and other native fish may have expanded to utilise food sources previously eaten by shortfinned eels (Jellyman & Todd 1998). This has lead to a decrease in the growth rates of male eels and an increase in growth rates of large females which feed on bullies (Jellyman *et al.* 1995, NIWA unpubl. data). Therefore there is no guarantee that growth rates will always improve in heavily fished waters.

13.2.4 Abundance

Declining recruitment will also reduce the abundance of eels. Eels used to be extremely abundant in many New Zealand waters. Hobbs & Cairns (1938) and Cairns (1942) documented the capture and destruction of 11 624 longfins, from three small tributaries of the Oreti River in Southland during 1937/38. A survey carried out after trapping was completed showed the great bulk (>90%) of the eels had been removed. This equates to a stock of 155 eels per km assuming the streams totaled about 75 km in length. The eels were medium to large, ranging in length from 450–1000 mm, and averaged 1 626 g in weight. If 60% exceeded 700 mm in length (Burnet 1952a, Table 11), then the streams contained about 93 large female longfins per km. Further surveys using traps from 1947–48 found that stable streams with ample cover supported 300 large eels per km (calculated from Burnet 1952a) while those with moderate stability and cover supported 70 to 100 km^{-1}. Streams with open shingle beds and little cover such as the Whitestone and Wainuiomata yielded only 30 km^{-1}.

Electric fishing surveys in three coastal streams from 1996 to 1998 showed stocks ranged from 25 large eels km^{-1} in Te Maari Stream to 17 km^{-1} in Pigeon Bay Stream and to 6 km^{-1} in the Horokiwi Stream. Although stock densities of large eels are lower than in the 1930's and 1940's, this may be due to a combination of factors including differences in stream stability and the extent of cover in the study waters and commercial fishing in recent years.

13.2.5 Size structure

There is good evidence from the size of eels caught in trap and fyke nets (Appendix 7, Figure 20) and electric-fishing surveys (Figure 22) that the stock of large, female longfins has declined due to heavy fishing pressure. The percentage of large females in the catch ranged from about 45 to 90% in 1947/48 (Burnet 1952a) and has dropped to 0.8 to 6.9% in heavily fished waters in 1995/96 (Beentjes *et al.* 1997). The length frequency distributions of eels caught by commercial fishers in recent years throughout the country (Beentjes & Chisnall 1997, 1998, Beentjes 1999) are strongly skewed to the left, i.e. most eels just exceeded the size limit of 220g or about 450 mm and very few large eels were caught. Although in part this might be due to differences in size selectivity, with fyke nets catching more smaller eels than traps, the fact that large eels can still be caught using fyke nets in waters such as Lake Rotoiti and Lake Roxburgh (Figure 18) and in a few other lightly fished or remote locations, such as the Taieri River gorge and Waikaka Stream (tributary of the Mataura River) (Beentjes 1999), indicates that a real decline has occurred in the stocks of large female eels.

Comparisons between fished and unfished waters also support this conclusion. For example, the Heathcote River and Lower Waimakariri River contained smaller longfins than the unexploited Rakaia Lagoon (Appendix 7) (Eldon & Greager 1983, Eldon & Kelly 1985, Eldon *et al.* 1989). The authors concluded that commercial fishing in the Heathcote and Lower Waimakariri River had removed many large eels (>60 cm). Other data could be assembled from other locations (e.g. Te Waihora, Jellyman *et al.* 1995), but the trend is the same – a marked reduction in the abundance of the larger size classes, which are virtually all females, presumably mainly as a consequence of commercial fishing.

The numbers of large female longfins in the South Island commercial catch have also decreased over time, especially for the best long term dataset (Mossburn Enterprises, Invercargill) (Beentjes & Chisnall 1997). These eels have declined from 31% of the catch in the 1970's to 9% in the 1990's (Appendix 7). Small eels (<450 mm) comprised only 15% of the crop by weight when fishing started in the 1970's but increased to 53% during the 1990's.

13.2.6 Sex ratios and spawner escapement

The present longfin fishery depends upon male eels caught mainly in coastal regions while females are predominant in inland rivers and lakes (Cairns 1941, Beentjes *et al.* 1999). Studies are needed to clarify whether this pattern is a result of differential fishing pressure, differential migrations, competition and displacement (Beentjes 1999) or environmental factors. Present computer models assume that sex is genetically determined at the glass eel stage and that a 50:50 sex ratio is present. However, the sex of American and European freshwater eels is determined by environmental factors such as growth rates and eel densities (Krueger & Oliveira 1999). Although no studies have been carried out in New Zealand, it is possible that declining recruitment and densities may increase growth rates and the percentage of females present in the stock. This has important management implications because it may be possible to continue fishing in areas which only produce male eels while protecting waters containing females. For example a fishery for male shortfinned eels is permitted in Te Waihora on this basis (Jellyman *et al.* 1995, Annala & Sullivan 1997).

Simulation models of the escapement of spawning eels (Hoyle & Jellyman in press) have shown that longfin females are particularly vulnerable to capture by commercial fishers because the considerable age of female eels at migration means they are exposed to commercial fishing for up to 50 years.

13.3 Changes to the ecosystem due to reduced abundance of longfins

Large female longfins are the top predator in most New Zealand aquatic ecosystems. Ecological theory indicates removal of the top predator could lead to a reduced diversity of fish and invertebrates and have other complex and at present unknown impacts (Paine 1966). For example, when all eels were experimentally removed from the South Branch, a small spring fed stream near Christchurch, brown trout survival rates and densities increased while growth rates and condition factor decreased, resulting in a decline in the quality of the trout fishery (Burnet 1968). Other changes included a decline in abundance of sandy cased caddis larvae due to increased trout predation (Burnet 1969c).

There is some evidence that shortfins have displaced longfins in some waters and now provide a higher proportion of the catch. The proportion of longfins processed at Te Kauwhata decreased from 28 % in 1975 to 10% in 1985; while the proportion at Mossburn Industries (the largest South Island processor) decreased from 94% in 1974/75 to 60% in 1995/96 (Beentjes & Chisnall 1997). By contrast, another processor showed no change over 8 consecutive seasons (1987/88 – 1994/95). Also, there is no obvious decline in the catch of longfins caught by commercial fishers from 1975–92 (Jellyman 1993). In 1989 an "unidentified" eel species category was included on catch return forms and reporting by species effectively stopped in 1992.

If longfins continue to be harvested then either shortfins or the Australian longfin (*Anguilla reinhardtii*) may move into some, but not all, vacant niches (habitats). The relative abundance of longfins has declined in recent years in the Cust Main Drain and Te Waihora and this may be related to habitat modifications, fishing and the lack of recruitment. Electric fishing surveys in the Cust Main Drain, from 1955 to 1959, showed the stocks were dominated by longfins and less than 20% of large eels were shortfins (Burnet 1969b). However, longfins are now relatively scarce in this stream (Sagar & Glova 1998). In Te Waihora, longfins comprised 25 to 27% of the catch during the 1940's (Cairns 1941, Shorland & Russell 1948). Large numbers migrated to sea and the migration in April and May 1942 was estimated at 3850 mature females weighing about 23 tons (Hobbs 1947). The percentage of longfins declined to 1.9 and 1.0% of the eel catch in 1983/84 and 1984/85 (Jellyman *et al.* 1995) and then to 0.4% in recent years (Glova & Sagar in press) probably as a consequence of intensive commercial fishing.

The percentage of longfins has also decreased in the Horokiwi Stream from an average of 56% at different locations (range 12–89%) in 1952 (Burnet 1952b) to 32 % (range 27–40%) in 1996/98 (NIWA unpubl. data). Similar decreases in the abundance of longfins after commercial fishing have been observed in a tributary of the Waikato River (Chisnall 1994).

13.4 Management initiatives that would increase recruitment

13.4.1 Reduce harvest and increase reserves

If the commercial harvest ceased immediately, it could take perhaps 50 years to restore recruitment to pre-fishing levels because of the slow growth and reduced stocks of large female eels. Exact predictions of recovery rates are not possible because of the lack of studies on stock-recruitment relationships and other topics. For example information is needed on the feasibility and effectiveness of different management options and new and improved computer models will also be required.

Even if eel managers set a lower target of 50% of original recruitment, we suspect that the commercial harvest will still need restriction. Size limits by themselves are of little use because eels have high survival rates and most eels that are not caught will eventually mature and migrate to sea. For example, the current South Island maximum legal size of 4 kg (~1150 mm) does little to improve relative spawner biomass – at exploitation rates of 5% and 10% the size limit increases spawner biomass by 22% and 32% respectively (Figure 22). Only when it was reduced to 1 kg or less did it substantially increase the spawner biomass (160 and 500% at 1 kg) but as a consequence considerably reduced the yield per recruit.

The best policy would seem to be to establish unfished reserves in productive waters to encourage the rapid growth and maturity of large female longfins (Chisnall & Hicks 1993, Hoyle & Jellyman in press). For example, provided downstream passage problems can be resolved (Chisnall *et al.* 1999), fishing for longfins could be prohibited in the Waikato hydro-lakes. Eels can also be trapped and transferred to more productive and safe areas (Jellyman & Beentjes 1998).

However, glass eels from adults originating in reserve areas will randomly disperse to unsuitable and fished locations throughout New Zealand and hence numbers may continue to decline. Indeed it is suspected that stock dilution and dispersion to modified habitats was the key factor causing the extinction of the anadromous New Zealand grayling (McDowall 1990).

13.4.2 Improve eel passage at hydro lakes

Hydro lakes could also act as reserves if the problems of upstream passage and downstream migration could be solved. Some redress of the problem of upstream passage is possible through installation of eel ladders over low head structures or by the catch and transfer or lift system at high dams. At some sites the catch and transfer is preferred as this enables a specific and targeted stocking of waterways to occur (Chisnall et al. 1998). It is also particularly useful where there are other barriers upstream.

Various diversion techniques for downstream migrating eels have been applied in overseas situations, of which strobe lights appear to be the most effective and may have application in some New Zealand situations. A recent example of successful downstream passage occurred at the Patea Dam during 1998 when a local eel fisher observed mutilated eels downstream of the dam and recognized this as the onset of a heke (downstream migration). The fisher was able to contact the local power authority who agreed to a controlled release of water over several succeeding nights. During this time a large number of longfins apparently escaped down the spillway of the dam.

13.4.3 Habitat improvement and other measures

Habitat improvement may help preserve adult eels stocks and increase recruitment provided it is strongly linked with controls on harvesting. However the potential benefits of any programme would need very careful examination. For example, the construction of new wetlands or swamps may just benefit shortfinned eels and not longfins.

It should be noted that while the Japanese have made good progress in spawning eels and rearing leptocephali it seems unlikely that an economic technology can be developed to restock New Zealand waters with longfinned glass eels.

13.5 Summary and recommendations

- The recruitment of glass eels has declined in the Te Maari and Horokiwi Streams in the North Island and in the Pigeon Bay Stream, Arahura and Ashley Rivers in the South Island. The rate of decline varies but averages about 7% per annum. As a result the glass eels runs are now estimated to be less than a quarter of the size of runs in the late 1970's and earlier.

- Age distribution studies on juvenile eels confirmed there are major annual variations and short term trends (Francis & Jellyman 1998) in glass eel runs. However data from adult eels cannot be used to estimate the magnitude of these variations because of sampling error.

- There is no useful information on historical trends in the density of juvenile eels, and studies on trends in age structure and length frequency distribution were unrewarding due to the absence of high quality time series data. Although some changes were detected in the Horokiwi Stream the reasons for these changes remain unknown and uncertain.

- If recruitment continues to decline, this will have profound impacts on the population dynamics of longfins and on the eel fishery. The extent of the decline will depend upon fisheries management policies and habitat restoration measures as well as on the stock – recruitment relationships for these fish. If recruitment continues to decline, it will directly affect eel abundance, commercial yields and the numbers of eels migrating, and may indirectly influence survival, growth rates and sex ratios.

- There is good evidence that commercial fishing has caused a reduction in the abundance of large female eels which are particularly vulnerable to overfishing. Models and field data from the Horokiwi Stream indicate that eel biomass is in decline and this will also lead to substantial reductions in commercial yields and the number of eels migrating to breed. However, the mean weight of eels caught will initially increase and then decline. At some stage fishing for longfins may become uneconomic and fishers may rely on shortfins, with longfins as a small bycatch. Although most of the data used for modelling are from South Island streams and rivers, there is no reason to suppose that stock depletion is a South Island problem only – rather, the species should be managed as a New Zealand -wide stock. In this regard, it is unfortunate that quota to be allocated for South Island eels in 2000, will not differentiate between the two species.

- Ideally, further information should be collected on stock-recruitment relationships, growth and survival rates and factors influencing the sex ratios of the populations. To obtain further evidence of the extent of stock depletion, it would be desirable to undertake surveys using baited traps in the waters studied by Cairns (1942) and Burnet (1952a) from 1937 to 1948, and electric fishing surveys of the waters electricfished in the 1950's (Table 11, Appendix 7).

- It will be difficult to restore longfin recruitment to former levels without severe restrictions on the fishery and the establishment of extensive reserves. However, unless some prompt action is taken, there could be serious implications both for the eel fishery and for the aquatic ecosystem.

Consequently it is recommended that:

- The results of this report and supporting studies be discussed with fisheries managers, customary and commercial fishers, and interested parties such as the Ministry of the Environment and the Department of Conservation.

- Action is taken to reduce the commercial harvest of longfins and to establish additional reserves.

- Further studies are undertaken to assess the current status of the longfinned stock. Glass eels runs should be monitored during the peak months, and their abundance determined. Surveys are needed to determine the populations of eels in fished and unfished habitats and to monitor the effectiveness of new reserves and restrictions on harvest.

14. Methods for monitoring trends in longfin recruitment

14.1 Introduction

The second objective was to review existing information and determine the feasibility of monitoring trends in longfin recruitment. Longfins could be monitored at various stages in their life history: as glass eels, elvers, juveniles and adults. Detailed sampling strategies are beyond the scope of the present report and only brief outlines are presented. Monitoring programmes will need to take into account the issue of variability in annual recruitment. This includes the variability in glass eel runs between waters (Figure 2), between years and the autocorrelation in runs between adjacent years (Francis & Jellyman 1999). There are significant problems in obtaining accurate estimates of run size and sampling errors also need consideration. It will certainly take many years before statistically significant trends can be reliably detected. In the absence of definitive proof of decreased recruitment (i.e. "measured" reductions from field data as opposed to inferred reductions from model extrapolations), fishery managers may need to adopt a precautionary principle and take early action to sustain the resource.

14.2 Glass eels

Trends in glass eel recruitment could be monitored using an index of glass eel abundance. There are several possible methods

14.2.1 Electric fishing for glass eels

Newly arrived glass eels. The sampling strategy would be largely determined by the outcomes of NIWA's current glass eel sampling programme. As these data indicate substantial regional differences in the abundance of longfin glass eels, then it will be important to spread monitoring over a number of sites (combinations of North Island, South Island, east coast and west coast).

Given that the NIWA programme contains information of five years recruitment data for 11 streams/rivers nationally, there are obvious benefits in continuing to monitor the same sites (or a selection of them). Therefore a similar strategy to the present NIWA sampling would be appropriate with sampling over peak months.

Older glass eels. It is also possible to sample post glass eels (age class 0) by electric fishing during other times of the year. For this, representative streams could be chosen, and a consistent electric-fishing sampling strategy (quantitative electric-fishing) used to achieve results that were comparable between years. Such sampling could either be carried out throughout the whole catchment to incorporate the full longitudinal range occupied by age class 0 eels, or, could be restricted to lower reaches only (say, the lower 10% by length of any waterway). The latter technique would reduce sampling time considerably, but would assume that all, or a known proportion, of age class 0 eels were contained within the reach sampled. Comparison of the longitudinal distribution of age class 0 eels over 3 years will be possible from NIWA's PGSF eel programme, and should give some confidence in the validity of such an assumption.

The density of glass eels in streams and rivers is inversely related to depth (NIWA unpublished data), so an effective sampling strategy would be to sample runs and riffles only, ignoring pools. To achieve comparability between years, sampling should be carried out at similar times and preferably under similar flow conditions. Because of their small size, post glass eels can generally be differentiated by eye from small individuals of older cohorts. However, a small amount of ageing would be desirable to separate age classes 0 and 1. Ageing would use a combination of break and burn technique (Hu and Todd 1981) and toluidine blue staining (Graynoth 1999).

The present NIWA programme sampling streams on Banks Peninsula, Pauahatunui (Wellington) and Raglan, has generated abundance data for age class 0 longfins for 3 consecutive years. These sites were chosen as they were small enough to enable electric fishing throughout the catchment. Continued sampling of recruitment into at least one of these sites would be a high priority. As it is expected that some aspects of longfin recruitment will be funded within NIWA's PGSF eel programme, close liaison between NIWA and the Ministry of Fisheries should be maintained.

14.2.2 Monitor the Waikato River using whitebait fishers

The Waikato River is understood to have the largest migrations of glass eels of any New Zealand river – consequently some sampling here would be of importance.

Unfortunately, the combination of poor clarity and high conductivity, mean that electric fishing is not a sampling option in the lower river. Three possible options are outlined.

- Use of diaries. An option would be to issue selected commercial whitebait (*Galaxias* spp.) fishers with diaries to record the duration of any glass eel migrations (as concentrated migrations can last for several days – Cairns 1941). Disadvantages with this scheme are that observations would be largely "opportunistic" as whitebait fishers may only fish preferred times, and daily fishing is confined to daylight hours (6 am – 9 pm – daylight saving time).

- Employ some whitebait fishers to carry out consistent observations and sampling over a number of years. A suitable time-stratified sampling strategy could be derived using data from Jellyman (1979), and be carried out consistently each year. Careful records of the actual time fishing would need to be kept, together with a sample of approximately 100 g (500 glass eels) per site per sampling night to estimate species proportions. The Department of Conservation presently have 7 regular whitebait fishers recording whitebait catches on the Waikato River – some of these would probably be available to carry out a catch-sampling programme for glass eels, although this would require different nets as glass eels escape through the mesh of normal whitebait nets. A stratified sampling programme could be devised that sampled for fixed periods with standard nets, preferably during spring tides associated with new moon (Jellyman 1979). Recent glass eels investigations in Australia have used a similarly concentrated sampling around full and new moon periods (Gooley *et al.* 1999).

- Deploy artificial substrate collectors. Researchers in Australia have had considerable success in sampling glass eels by deploying artificial substrate collectors ("sheep") in some rivers. These samplers are essentially a steel plate to which synthetic fibres are attached in a dense mat. Samplers are left to "age" in water for several months before being set in rivers. Like the brush substrate collectors used in Lake Ellesmere (Jellyman & Chisnall 1999), these "sheep" can be set at any depth, and retrieved at regular intervals to provide an index of glass eel abundance. They would be especially useful in habitats too deep or saline to electric fish.

14.3 Elvers

14.3.1 Elver transfer / enhancement programmes

The abundance of elvers (> age class 0) can also be used as an index of recruitment. As the proportion of age classes among samples of migrating elvers varies between years (Jellyman & Ryan 1983) elvers should ideally be designated to specific age classes, although samples containing mixed age classes would still be useful in indicating gross changes in elver abundance between years. Depending on sample variability, the proportion of particular age classes present could be generated from an age-length key (Kimura 1977) or a maximum likelihood model. In the absence of ageing though, the overall abundance of longfin elvers over time would still be an important measure of recruitment variation.

Careful documentation is required of the actual quantities of elvers captured during enhancement activities, together with regular samples taken during the season, to calculate species composition and hence the total quantity of longfin elvers caught throughout the season. Provision of these data (quantity of elvers caught/transferred per day, size range, species composition) are requirements for users of Special Permits. However, as indicated in Objective 1, it is essential that a measure of the effort involved in capture be included to provide a measure of relative/absolute abundance. **Of prime importance though is the installation of a permanent trapping facility at Karapiro Dam to provide a consistent measure of elver abundance between years.** Provided that accurate records are kept, these elver transfer data will provide an important database of the abundance of longfin elvers, against which future changes can be measured.

Similarly, data from elver passes are of importance, and have the advantage of being collected by a consistent method. Samples of elvers must be collected regularly to estimate species composition, and these should initially be collected from both below and above the pass as some types of passes favour passage of shortfins (Beentjes *et al.* 1997).

14.4 Juveniles and adults

14.4.1 Trends in past recruitment from the abundance and age composition of sub-commercial sized eels

The most useful study will be to estimate the numbers of sub-commercial sized eels present in important fisheries around the country, and see whether the age class distribution shows signs of poor recruitment over recent years. To study larger rivers like the Mataura for example, new sampling techniques would be necessary. For example it might require the use of an electric fishing boat (not available within New Zealand but could possibly be hired from Australia) and mark-recapture techniques to estimate stock sizes. Alternatively, electric fishing could be confined to shallow areas as Glova *et al.* (1998) found that >80% of the biomass of longfins <30 cm is found in runs and riffles, so exclusion of pools is relatively unimportant. If it were shown that small eels are relatively scarce, as in the three coastal streams and the Arahura and Ashley Rivers, this will confirm the results of the present study that longfin recruitment is in decline. Some of this work is planned using the Public Good Science Fund.

14.4.2 Replicate sampling of areas previously fished

Where useful historic data exist in papers, reports and in the NZFFDB, replicate sampling could be carried out in the future to determine the current abundance and age structure of eels present. It would be essential to use the same methods and to conduct surveys at same time of the year. Some suggested locations are shown in Table 13.

Table 13: Re-sampling survey locations in order of priority

Location	Method	Reference	Date sampled
Southland streams	Traps	Burnet 1952a	1947–48
Wellington and Waikato streams	Traps	Burnet 1952a	1948–49
Wainuiomata River and Mangaroa Stream	Electric fishing	Burnet 1952b	1952
Ellesmere drains	Electric fishing	Burnet 1959, 1969b	1954, 1956
South Branch Waimakariri	Electric fishing	Burnet 1968, 1969a	1959, 1960
Upper Wanganui River	Traps and electric fishing	Woods 1964	1960, 1961, 1962
Paraparaumu	Electric fishing	Woods 1964	1964
Clutha tributaries	Electric fishing	Pack & Jellyman 1988	1983–84
Rakaia Lagoon	Fyke nets	Eldon & Greager 1983	1980–81
Lake Pounui	Fyke nets	NIWA unpubl. data	1974–1978
Lake Wanaka	Traps	Burnet 1952a	1947

14.5 Summary

Possible studies of recruitment of glass eels could include:

- quantitative sampling (electric fishing) of glass eels during their arrival season at a series of locations throughout both islands
- establishing an index of glass eel abundance for a site on the Waikato River
- deployment of artificial substrate collectors
- quantitative sampling (electric fishing) of age class 0 eels (older glass eels) during summer in 3 streams currently being sampled by NIWA, and at additional representative rivers

Possible studies of the abundance of elvers could include:

- estimating the overall abundance of longfin elvers from elver passes. Installation of permanent trapping facilities is required to obtain accurate samples from elver transfer programmes
- estimating the abundance of specific age classes of longfin elvers from ageing of samples collected from elver transfer programmes or elver passes

Possible studies of the abundance of juvenile and adult eels could include:

- estimating trends in past recruitment from the abundance and age composition of sub-commercial sized eels in important fisheries around the country
- replicate sampling of areas previously fished

Of these suggestions, it is recommended that:

- quantitative sampling (electric fishing) of glass eels during their arrival season at a series of locations throughout both islands (stratified by peak arrival times)

- Some glass eel monitoring of the Waikato River be implemented

- better data be collected from elver transplant programmes, including measures of effort; given the variability in equipment used, installation of a permanent capture facility at Karapiro Dam is regarded as high priority, to obtain a consistent index of recruitment between years (note that if this could be done consistently and accurately, it could obviate the need for monitoring of the glass eels migration in the Waikato River)

- a programme be implemented to estimate trends in past recruitment from the abundance and age composition of sub-commercial sized eels in important fisheries around the country.

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17. Publications

Nil

18. Data storage

Nil, as the project was a desk-top survey of existing databases. The Excel database of elver transfers, jointly owned by NIWA and various power authorities, is held at NIWA Christchurch and Hamilton.

Appendix 1: **Percentage of longfin glass eels pre-1981. No. = total number of glass eels in sample. Rivers listed in geographic order, north to south.**

Island	Coast	River	Date	No.	% longfin	Reference
North	West	Hoteo	Oct 1971	351	1	Jellyman 1974
		Waikato	Aug 1970- Nov 1970 Sep 1971- Nov 1971 Aug 1972- Sep 1972 Aug 1973- Sep 1973 Aug 1974- Sep 1974	10 525	12	Jellyman 1979
		Marakopa	Oct 1928	9	11	Ege 1939
		Warea	Aug 1928- Oct 1928	104	90	Ege 1939
		Waiwakaiho	Aug 1970	374	51	NIWA unpubl.
		Waitara	Sep 1989- Nov 1979	1965	44	NIWA unpubl
		Opunake	Nov 1970	13	31	Jellyman 1974
		Pukepuke Lagoon	Sep 1972	749	2	Jellyman 1974
		Waimeha Stream	Jul 1970- Nov 1970	240	3	Jellyman 1974
		Makara Stream	Aug 1971- Dec 1971 Aug 1972- Nov 1972	2560	13	Jellyman 1977
	East	Browns Bay	? 1970	8	0	Jellyman 1974
		Tauranga	? 1971	110	2	Jellyman 1974
		Opotiki	Nov 1971	843	13	Jellyman 1974
		Waiapu	Nov 1926	167	1	Ege 1939
		Whangaparoa	Sep 1978	155	35	Jones *et al.* 1983
		Whangaparoa	Jul 1979- Oct 1979	467	11	Jones *et al.* 1983
		Whangaparoa	Sep 1980- 10/80	542	8	Jones *et al.* 1983
		Raukokere	Sep 1978	141	73	Jones *et al.* 1983
		Waioeke	Sep 1978	51	22	Jones *et al.* 1983
		Waioeke	Sep 1979	50	38	Jones *et al.* 1983
		Motu	Sep 1978	105	74	Jones *et al.* 1983
		Motu	Aug 1979	86	42	Jones *et al.* 1983
		Otara	Sep 1979	50	92	Jones *et al.* 1983
		Wairoa	Aug 1951	41	19	Jellyman 1974
		Wairoa	Dec 1995	6	50	NIWA unpubl.
		Tukituki	Nov 1929	1371	1	Ege 1939

Appendix 1: (*continued*)

		Whareama	Oct 1970	270	4	Jellyman 1974
		Pirinoa	Oct 1970	8	12	Jellyman 1974
		Lake Wairarapa	Sep 1977- Oct 1977	1625	<1	NIWA unpubl.
		Lake Pounui	Nov 1974- Jan 1975	20	25	Jellyman & Ryan 1983
		Lake Pounui	Nov 195- Jan 1976	10196	<1	Jellyman & Ryan 1983
		Lake Pounui	Nov 1976- Jan 1977	82677	<1	Jellyman & Ryan 1983
		Lake Pounui	Nov 1977- Jan 1978	14466	<1	Jellyman & Ryan 1983
South	West	Hokitika	Dec 1927	205	93	Ege 1939
		Waiatoto	Oct 1970- Nov 1970	144	91	Jellyman 1974
	East	Wairau	Oct 1971	11	9	Jellyman 1974
		Waipara	Nov 1956	140	3	Jellyman 1974
		Ashley	Oct 1956	39	38	Jellyman 1974
		Ashley	Oct 1980	306	0	NIWA unpubl.
		Waimakariri	Oct 1925	294	1	Ege 1939
		Waimakariri	?	98	0	Jellyman 1974
		Waimakariri	Sep 1974	40	65	NIWA unpubl.
		Styx	Nov 1927	236	0	Ege 1939
		Lake Ellesmere	Sep 1974	48	46	NIWA unpubl
		Purau	Sep 1965- Oct 1965	494	3	Jellyman 1974
		Rakaia	Nov 1928	44	23	Ege 1939
		Mataura		20	95	Ege 1939
		? Southland		144	100	Ege 1939

Appendix 2: Percentage of longfin glass eels per month at each site sampled, 1995–99. < = sample size <10. - = not sampled. N = total of both species combined.

		Month							Total	
Site		**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**%**	**N**
NORTH ISLAND										
<u>West Coast</u>										
Kerikeri Stream	1995	–	–	–	52	32	18	<	38	702
	1996	–	–	38	13	3	26	–	14	510
	1997	–	–	40	22	3	7	–	20	849
	1998	–	8	8	5	14	20	–	8	1464
	1999	0	10	19	5	4	6	–	6	981
Waitetuna Stream	1995	–	–	–	94	92	86	93	93	247
	1996	–	–	<	87	52	52	–	69	336
	1997	–	–	90	81	46	44	–	61	702
	1998	–	31	39	54	38	39	–	42	669
	1999	<	18	48	24	13	19	–	21	614
<u>East Coast</u>										
Temata Stream	1995	–	–	–	–	55	25	–	39	156
	1996	–	–	<		33	0	–	3	64
	1997	–	–	–	–	–	<	–	33	23
	1998	–	–	<	6	0	0	–	2	44
	1999	<	13	20	41	19	<	–	22	203
Tapu Stream	1995	–	–	–	58	–	–	–	58	19
	1996	–	–	100	<	<	100	–	0	14
	1997	–	–	–	–	<	–	–	0	7
	1998	–	–	<	0	0	0	–	0	5
		–								
Tepuru Stream	1995	–	–	–	41	<		–	41	32
	1996	–	–	0	4	0	0	–	2	40
	1997	–	–	–	–	–	0	–	0	5
	1998	–	–	0	–	–	–	–	0	1
		–								
Tairua Stream	1995	–	–	–	–	8	10	14	10	676
	1996	–	–	<	13	8	4	–	5	879
	1997	–	–	–	–	17	6	14	10	781
	1998	–	–	<	16	4	1	–	3	661
	1999	32	44	35	14	12	6	–	17	1030

Appendix 2: *(continued)*

SOUTH ISLAND										
<u>West Coast</u>										
Mill Stream	1995	–	–	–	<	82	78	–	82	60
	1996	–	–	100	65	20	33	–	32	38
	1997	–	–	<	65	2	<	–	16	73
	1998	–	–	–	50	<	<	–	50	24
	1999	–	–	<	<	16	7	–	10	260
Serpentine Stream	1995	–	–	–	<	67	69	–	69	49
	1996	–	–	100	<	19	18	–	18	240
	1997	–	–	<	52	15	8	–	34	169
	1998	–	–	–	65	22	20	–	32	79
	1999	–	–	<	0	18	10	0	8	530
Flowery Creek	1996	–	–	53	46	41	–	–	52	224
	1997	–	–	93	<	58	98	–	70	169
	1998	–	<	79	76	–	<	–	79	110
	1999	0	<	–	83	63	46	–	65	367
Arahura River	1996	–	–	65	51	66		–	63	286
	1997	–	–	96	72	64	18	–	74	416
	1998	–	<	<	68	85	95	–	84	142
	1999	0	<	66	77	52	34	31	54	394
<u>East Coast</u>										
Ashley River	1995	–	–	–	–	–	4	–	4	107
	1996	–	–	<	1	2	1	–	2	1266
	1997	–	–	42	17	2	0	–	11	381
	1998	–	0	0	1	1	0	–	1	578
	1999	<	,	25	3	14	0	0	12	416
Charteris Bay Stream	1995	–	–	–	<	1	3	–	3	237
	1996	–	–	<	1	0	2	–	1	469
	1997	–	–	–	9	1	5	–	3	174
	1998	–	–	0	0	0	–	–	0	67
	1999	–	0	<	12	26	4	–	14	96
Purau Stream	1995	–	–	–	21	9	13	–	12	219
	1996	–	–	5	3	1	2	–	2	516
	1997	–	–	<	24	5	–	–	13	107
	1998	–	–	0	0	0	–	–	0	6
	1999	–	0	<	<	47	0	-	55	31

Appendix 3: Densities (n. 100 m^{-2}) of early stage glass eels (5B-6A23) caught by single-pass electric fishing, 1995–99. (NIWA PGSF study). S = shortfin, L = longfin.

Site	Year	Species	Month 6	7	8	9	10	11	12	Total eels	Mean density
NORTH ISLAND											
West Coast											
Kerikeri River	1995	S				6.4	11.9	15.9	0.7	226	8.8
	1996	S			65.8	102.4	33.4	17.0		246	53.0
	1997	S			89.2	184.1	73.0	130.7		564	118.7
	1998	S		304.3	109.4	319.6	62.4	35.9		1349	229.6
	1999	S	55.0	107.6	108.8	369.5	155.3	14.9		375	152.8
	1995	L				3.4	1.0	1.2	0	98	1.8
	1996	L			107.7	4.7	0	0		94	20.2
	1997	L			58.5	46.4	1.6	1.1		140	29.5
	1998	L		25.1	81.1	13.8	0.0	0.0		115	19.6
	1999	L	0	12.2	26.5	17.1	5.0	1.0		57	10.1
Waitetuna River	1995	S				10.3	3.6	10.3	0.6	10	3.4
	1996	S			0	6.6	34.4	13.1		45	11.3
	1997	S			15.4	56.6	140.9	442.3		190	99.5
	1998	S		62.0	312.0	111.7	416.8	133.6		391	104.0
	1999	S	15.2	25.5	20.4	265.7	199.4	63.4		257	117.5
	1995	L				91.0	16.1	30.0	1.9	51	17.2
	1996	L			0	36.7	4.9	4.0		66	16.5
	1997	L			143.6	246.5	5.7	18.8		256	134.0
	1998	L		27.8	194.7	119.8	144.8	5.5		278	73.9
	1999	L	0	5.5	20.4	65.5	11.4	1.7		83	22.7
East Coast											
Temata Stream	1995	S					4.4	4.3		40	4.2
	1996	S			10.0	0.6	1.4	4.7		12	1.8
	1997	S					0	0.6		1	0.4
	1998	S			0	15.5	10.5	0		43	7.13
	1999	S	0	18.6	22.2	16.7	39.1	0		90	21.7
	1995	L					0	0		0	0
	1996	L				0	1.8	1.4		7	1.1
	1997	L					0	0		0	0
	1998	L			0	0	0	0		1	0
	1999	L	2.5	2.9	4.4	2.2	2.5	0		12	2.7
Tapu Stream	1995	S				4.3				6	4.3
	1996	S				10.0	1.1			6	2.6
	1997	S					6.0			3	6.0
	1998	S			11.8	2.5	0			5	5.3
	1995	L				0				0	0
	1996	L				0	0			0	0
	1997	L					0			0	0
	1998	L			0	0	0			0	0

Appendix 3: (*continued*)

TePuru Stream	1995	S				1.3	0			3	0.7
	1996	S				1.6	3.1	13.3		13	2.9
	1997	S						4.8		4	4.8
	1998	S			2.9					1	2.9
	1995	L				0.6	1.4			5	1.1
	1996	L				0	0	0		0	0
	1997	L						0		0	0
	1998	L			0					0	0
Tairua River	1995	S					10.4	28.7	4.4	214	15.5
	1996	S			0	19.0	139.6	57.0		254	59.3
	1997	S					100.0	373.2	133.6	455	211.6
	1998	S			6.2	29.3	2337.1	510.0		844	213.7
	1999	S	18.0	37.3	60.5	308.6	326.3	29.6		335	134.6
	1995	L					0.3	0.7	0.4	7	0.5
	1996	L			0	0	2.0	0		2	0.5
	1997	L					2.1	12.5	0	3	1.4
	1998	L			0	0	0	0		21	5.3
	1999	L	4.0	16.9	21.9	20.8	9.7	0		69	14.1

SOUTH ISLAND

West Coast

Mill Stream	1995	S				0	1.3	0.3		5	0.4
	1996	S			0	0	4.3	0		3	0.7
	1997	S			0	46.2	87.1	2.5		61	31.3
	1998	S				23.3	10.0	5.0		12	12.0
	1999	S			10.0	0	95.6	776.4		147	143.8
	1995	L				0.1	4.0	0.3		18	1.3
	1996	L			0	0	0	0		0	0
	1997	L			0	35.0	1.6	0		6	3.1
	1998	L				23.3	0	25.0		12	12.0
	1999	L			3.3	3.8	11.1	7.4		9	13.4
Serpentine Creek	1995	S				0	1.2	0.7		9	0.8
	1996	S			0	4.5	69.2	32.9		119	18.6
	1997	S			0	47.4	80.3	3.3		91	28.1
	1998	S				17.1	22.4	129.8		54	33.8
	1999	S	0	0	11.7	860.1	232.0	259.8		292	235.9
	1995	L				1.0	1.7	1.2		17	1.4
	1996	L			0	0	6.2	0		8	1.2
	1997	L			3.3	45.0	1.5	0		41	12.7
	1998	L				39.1	3.0	3.7		25	15.6
	1999	L	0	0	1.7	0	22.2	5.0	0	11	7.3
Flowery Creek	1996	S			8.1	77.1	18.5	0		101	15.3
	1997	S			4.0	0	200.0	5.0		43	11.8
	1998	S		0	3.0	55.9		0		23	7.4
	1999	S	0	0	–	50.0	104.0	174.3		85	78.3

Appendix 3: (*continued*)

	1996	L			8.8	66.7	9.3	0		78	47.8
	1997	L			8.0	0	90.0	0		22	24.4
	1998	L		7.5	12.0	186.7		0		87	28.0
	1999	L	0	3.6	–	223.8	52.7	9.9		117	83.7
Arahura River	1996	S			7.7	700.0	12.8	0		106	9.8
	1997	S			3.2	78.7	166.7	19.0		264	15.6
	1998	S		0	0	42.5	22.2	3.0		23	7.0
	1999	S	0	0	37.7	46.8	131.5	114.8	76.7	139	54.7
	1996	L			14.5	725.0	21.9	0		168	32.5
	1997	L			37.0	31.9	77.8	0		257	31.7
	1998	L		2.5	7.1	75.8	88.7	17.9		113	34.4
	1999	L	0	3.6	73.6	165.1	58.0	7.4	0	112	43.5
East Coast											
Ashley River	1995	S						10.4		21	10.4
	1996	S			0.4	479.4	149.6	48.0		914	101.7
	1997	S			15.7	159.1	120.7	12.0		222	80.1
	1998	S		107.4	183.3	368.3	891.0	2.7		576	99.8
	1999	S	0	1.7	78.6	290.5	125.4	0	0	248	62.8
	1995	L						2		2	0.4
	1996	L			1.0	3.9	0.4	0		10	1.1
	1997	L			11.2	32.3	1.5	0		41	14.8
	1998	L		0	0	2.2	7.7	0		3	0.5
	1999	L	2.0	0	25.0	7.1	15.6	0	0	37	8.2
Charteris Bay Stream	1995	S				0.1	8.6	6.4		84	5.5
	1996	S			1.7	137.9	89.8	40.0		312	62.3
	1997	S				15.8	130.1	90.0		107	55.2
	1998	S			83.3	66.3	18.5			67	39.0
	1999	S	0	0	4.6	75.0	13.3	0		44	15.0
	1995	L				0.4	0.1	1.2		5	0.3
	1996	L			0	1.6	0	5.0		2	0.4
	1997	L				1.7	0	0		2	1.0
	1998	L			0	0	0			0	0
	1999	L	0	0	2.9	10.0	8.3	0		10	3.4
Purau Stream	1995	S				1.9	11.0	4.7		115	7.1
	1996	S			3.7	64.0	25.9	0		204	15.2
	1997	S			10.0	8.1	28.6			64	13.2
	1998	S			0	5.0	2.8			6	2.1
	1999	S		0	0	8.0	13.3	0		12	3.8
	1995	L				0.3	1.1	0		12	0.7
	1996	L			0.2	3.2	0.5	0		9	0.7
	1997	L			5.0	2.6	2.6			14	2.9
	1998	L			0	0	0			0	0
	1999	L		0	3.8	3.8	6.7	0		12	3.8

Appendix 4: Percentage of longfin elvers among samples from throughout New Zealand, excluding data from recent elver transfer programmes.

Location	Date	N	% longfin	Length range (mm)	Reference
Huntly, Waikato River: day	Nov 1985–Apr 1986	731	26	–	Schicker *et al.* 1989
Huntly, Waikato River: night	Nov 198 –Apr 1986	14467	11	–	Schicker *et al.* 1989
Karapiro Dam, Waikato River	Feb 1962	357	26	–	Woods 1964
Karapiro Dam, Waikato River	Mar 1963	314	24	–	Woods 1964
Karapiro Dam, Waikato River	Jan-Feb, 1970,71,74	3646	38	68–151	Jellyman 1977b
Hora Hora, (= Karapiro) Waikato River	1930s	1000	30		Cairns 1941
Matahina Dam, Rangitikei River	Jan. 1974	168	21	81–125	Jellyman 1977b
Mokau River	Jan. 1974	232	82	8130	Jellyman 1977b
Mangawhero River	1962	39	5		Woods 1964
Patea Dam, Patea River	Jan 1985	?	23		Beentjes *et al.* 1997
Shannon Dam	Feb. 1971	233	82	94–136	Jellyman 1977b
Lower Makara Stream. Wellington	Feb. 1972	169	4	74–102	Jellyman 1977b
Mid Makara Stream. Wellington	Jan-Feb. 1972	44	39	72–104	Jellyman 1977b
Lake Pounui, Wairarapa	Nov. 1974 - Jul 1975	6754	4.3		Jellyman & Ryan 1983, NIWA unpubl. data
Lake Pounui, Wairarapa	Aug 1975–Jul. 1976	48986	2.3		Jellyman & Ryan 1983, NIWA unpubl. data
Lake Pounui, Wairarapa	Aug 1976–Jul. 1977	107332	0.3		Jellyman & Ryan 1983, NIWA unpubl. data
Lake Pounui, Wairarapa	Aug 1977–Jul. 1978	101666	0.4		Jellyman & Ryan 1983, NIWA unpubl. data
Arnold Dam, Arnold River	Jan. 1971	216	88	97–158	Jellyman 1977b
Hurunui River	Feb-Mar	43	?		Hardy 1950
Lake Coleridge Power Stream	Jan. 1971	80	100	129–219	Jellyman 1977b
Aviemore Dam, Waitaki River	Feb. 1971	26	100	116237	Jellyman 1977b
Aviemore Dam, Waitaki River	1993/94–1994/95	6	100?		Beentjes *et al.* 1997
Waitaki Dam, Waitaki River	Feb. 1971	65	91	126–223	Jellyman 1977b
Waitaki Dam, Waitaki River	1993/94–1994/95	8	100?		Beentjes *et al.* 1997
Roxburgh Dam, Clutha River	Jan-Feb 1971	207	99	108 – 315	Jellyman 1977b
Roxburgh Dam, Clutha River	Feb – Mar 1996	10	100	125–220	Beentjes *et al.* 1997
Mararoa Weir, Waiau River	Feb 1996	79	97	91 – 167	Beentjes *et al.* 1997

Appendix 5: Elver transfers at North Island hydro dams and weirs

The following data have been compiled from a variety of sources, but mainly from eel industry personnel and power generation companies. Concerns about the quality of the data have been expressed previously, and some of the assumptions in compiling the data have been discussed. Some estimates differ from those previously published (Beentjes *et al.* 1997), generally because different average sizes of elvers have been used when extrapolating to the total number of elvers transferred. Given the extensive effort involved in assembling these data, the data are presented here so that future comparisons can be made. No commentary is provided on the collection facilities, as this has been adequately covered in previous publications (see Beentjes *et al.* 1997, Chisnall *et al.* 1998).

Table A5-1: Seasonal catches of elvers at Lake Waikare weir, 1996/97. LF = longfin. N = number of both species combined

Month	No. LF	N
January	84909	424545
February	1665	148700
March	0	8504
April	0	2898
Total	86574	584647

Table A5-2: Seasonal catches of elvers at Piripaua elver pass, 1996/97 – 1998/99. Numbers are for both species combined. Note: insufficient samples were examined to estimate species proportions, and estimates of total numbers were made assuming a mean weight of 1 g per elver

	Season			
Month	**1996/97**	**1997/98**	**1998/99**	**Grand total**
December		1369	643	2012
January	215	2017	1377	3609
February	1340	2841	592	4773
March	612	948	490	2050
April	2	164	39	205
Total	2169	7339	3141	12649

Table A5-3: **Seasonal catches of elvers at Karapiro Dam, 1994/95 – 1998/99. LF = longfin. N = number of both species combined. Note that the 1994/95 estimates of species proportions for 1994/95 are from a single sample only; quantities of 110 kg and 770 kg for 1992/93 and 1993/94 respectively are not included as monthly catch data were not available; data for 1994/95 include transfers of 120 kg to Lake Waikare which accounts for most of the differences between present data and those of Beentjes et al. 1997 – other smaller differences reflect small differences in mean weight of elvers used to estimate total elver numbers.**

	Season											
	1994/95		**1995/96**		**1996/97**		**1997/98**		**1998/99**		**Grand total**	
	No. LF	N	No. LF	N	No. LF	N	No. LF	N	No. LF	N	No. LF	N
October							2 000	4 000			2 000	4 000
November						1 000		1 000				2 000
December			8 000	125 000	19 000	140 000	345 000	648 000	19 000	145 000	390 000	1057 000
January			48 000	487 000	155 000	578 000	392 000	643 000	258 000	657 000	853 000	2366 000
February	113 000	359 000	17 000	297 000	68 000	347 000	138 000	356 000	22 000	133 000	357 000	1493 000
March	4 000	14 000	1 000	69 000	3 000	144 000	17 000	58 000	1 000	82 000	26 000	366 000
May					1 000	4 000						
Total	7 000	373 000	74 000	978 000	246 000	1214 000	894 000	1710 000	300 000	1017 000	1628 000	5288 000

Table A5-4: Seasonal catches of elvers at Patea Dam elver pass, 1992/93 – 1998/99. LF = longfin. N = number of both species combined. Note that data for 1998/99 are subsamples only and do not represent the total number of elvers using the pass

	Season							
	1993/94		1995/96		1998/89		Grand total	
Month	**No. LF**	**N**	**No. LF**	**N**	**No. LF**	**N**	**LF**	**N**
January	1400	8000	100	500	3400	19500	4900	28000
February	400	2500	1300	7300	900	5400	2600	15200
March	1300	7500	300	1400			1600	8900
April			100	800			100	800
May			100	300			100	300
Month unknown	10900	62000	1400	8000			12300	70000
Total	14000	80000	3300	18300	4300	24900	21600	123200

Table A5: Seasonal catches of elvers at Matahina Dam, 1983/84–1998/99. LF = longfin. N = number of both species combined.

Month	1983/84 No. LF	1983/84 N	1984/85 No. LF	1984/85 N	1985/86 No. LF	1985/86 N	1986/87 No. LF	1986/87 N	1987/88 No. LF	1987/88 N	1988/89 No. LF	1988/89 N	1989/90 No. LF	1989/90 N	1991/92 No. LF	1991/92 N	1992/93 No. LF	1992/93 N	1993/84 No. LF	1993/84 N
January	12600	21000																		
February	5940	13500									1800	18000	1760	6000	2920	9950	630	4690	28130	95920
March															3120	13350	2950	12590	18020	77010
April	720	1500													130	560	28870	12330	3630	15620
May																	490	2100	190	810
June																				
July																				
August																				
Month unknown			5290	23000	1400	6000	11100	18500	0	0			11730	40000						
Total	19260	36000	5290	23000	1440	6000	11100	18500	0	0	1800	18000	13490	46000	6170	23860	6930	31700	49970	189360

Table A5: *(continued)*

Month	1994./95 No. LF	1994./95 N	1995/96 No. LF	1995/96 N	1996/97 No. LF	1996/97 N	1997/98 No. LF	1997/98 N	1998/99 No. LF	1998/99 N	Grand total No. LF	Grand total N
Ocobert							20	70			20	70
November												
December							20	50			20	50
Januaary			26190	44000			64860	122310	22320	46020	125970	233330
February	5130	17500	22580	77000	1320	3030	36410	189080	91090	743420	197710	1178090
March	4560	19500	5500	23500	3120	8210	74860	343710	9770	125050	121900	622920
April	580	2500			360	2460					8290	34970
May						30					680	2940
Month unknown					35100	47380					64660	134880
Total	10270	39500	54270	144500	39900	61100	176170	655220	123180	914490	519250	2207250

Appendix 6: Records of South Island elver transfers

There are few records of elvers from South Island sites, and the few data that do exist are summarised here. Also included is an update of elver passage facilities, together with comments about their suitability as long-term monitoring sites.

Table A6-1: Quantities and numbers of elvers caught and transferred in the South Island

Location	Period	Weight of elvers caught (kg)	Approximate numbers of elvers caught	Probable % longfins
Clutha River (Roxburgh Dam)	Jan-Mar 1997	1.6	400	100
	Jan-Mar 1998	22	11000	100
Mataura River (Falls)	Feb 1998	250–280	105000–116500	96
	Feb 1999	40	16500	96
Waiau River (Mararoa Weir)	Jan-Mar 1999	97.8	407600	96–100
	Jan-Mar 2000	47.6	23800	96 – 100
Waitaki River (Waitaki Dam)	Dec-Mar 1993–94	–	6	100
	Dec-Mar 1994–95	–	2	100
	Dec-Mar 1995–96	–	1	100
	Dec-Mar 1996–97	–	3	100
	Dec-Mar 1997–98	–	47	100

Roxburgh Dam, Clutha River

In an investigation of elvers at Roxburgh dam, Boud & Cunningham (1960) stated that "large numbers of young eels migrate up the Clutha River" and cited that the strainers (9 x 20 inches), were sometimes completely full of small eels. In a study of fish of the lower Clutha River, Pack and Jellyman (1988) found no evidence of an elver migration at the dam during two consecutive years (1984–85); they suggested that recruitment might be intermittent, with very high flows such as they experienced, preventing elvers from reaching the dam.

To facilitate passage of elvers past Roxburgh, a floating elver trap was trialed in February 1996 but proved unsuitable, and only 40 elvers were caught (Beentjes *et al.* 1997). In January 1997 a permanent elver trapping facility (ramps and holding tanks) was installed below Roxburgh Dam (Chisnall *et al.* 1998). Only 1.6 kg of elvers were caught of which 1.3 kg were transferred to Lake Dunstan, immediately above Clyde Dam (Table 19). In 1998, problems with lamprey climbing and blocking the ramps reduced the catch of elvers, 22 kg of which were transferred to Lakes Dunstan and Wanaka (Dave Richardson pers. comm.). During 1999 all elvers were caught within the turbine intakes, as the elver ladder was not operational, due to uncertainties about who was responsible for its operation. About 200 kg was transferred to Lakes Dunstan and Wanaka during 1999 (Dave Richardson pers. comm.). Annala *et al.* (1999) reported that 1, 4.3 and 59.2 kg were collected during 1996–97, 1997–98, and 1998–99 respectively – these figures are underestimates.

In summary, while elvers have been caught and transferred to the Clutha Lakes in 1997 and 1998, the relative quantities are not directly comparable and cannot be used as an index of recruitment. The existing permanent ramp does however, provide a facility that, if operational throughout the entire elver migration season each year, could provide quantitative data on numbers, size and age of migrating longfin elvers and hence an index of longfin recruitment. The capture of elvers in both 1997 and 1998 suggests that annual migrations of elvers occur on the Clutha River and sampling indicated that these migrations were 100% longfin.

Waitaki Dam, Waitaki River

Historically, large numbers of elvers have been reported from the Waitaki River e.g. "In January small eels from 100 mm to 300 mm arrived at the Waitaki hydro dam in their thousands" (Waitaki Valley Acclimatisation Society 1986). Based on results of a previous sample (Jellyman 1977b), these elvers would be virtually all longfins. Although elver passes were installed at both the Waitaki and Aviemore power stations in summer 1992–93, these have not functioned as intended (Beentjes *et al.* 1997). Even in years when longfin elvers have been observed accumulating at the base of the Waitaki Dam in considerable numbers, only a few elvers have been found to use the pass. Thus only 59 elvers were recorded as using the passes during the period 1993–94 to 1997–98 (Beentjes *et al.* 1997, Graeme Hughes, Central South Island Fish and Game pers. comm.), and recommendations have been made for alterations to both passes.

Mararoa Weir, Waiau River

Small numbers of elvers have been collected from the Mararoa Weir and Monowai power stations (Waiau River, Beentjes *et al.* 1997), and again the majority of these (97%, n = 79) were longfins. There are anecdotal reports of large quantities of elvers arriving at the Mararoa Weir during the years immediately following its installation. A fish pass was constructed at Mararoa weir in 1998 to assist trout, and native fish species to ascend the weir. Elvers have also been observed to use this fish pass but only in very small numbers as the flow is too swift to allow elvers to ascend (George Ryan pers. comm.). A Meridian Energy funded programme to catch elvers from below Mararoa Weir and transfer to Lake Te Anau, began in early 1999. Elvers are caught using a combination of venturi suction system and dip nets, weighed and transferred to Lake Te Anau. Catch and transfer of elvers in the 1999–00 season is in progress with some transfer having taken place in early January (48 kg). This programme could provide an index of longfin elver recruitment if it continues but requires standardisation of methods and recording of effort.

Mataura Falls, Mataura River

More recently, there has been more interest in capture and transfer of elvers from the Mataura Falls. Elvers were caught in buckets below the falls and transferred above the falls in February 1998 and 1999. This transfer was an *ad hoc* initiative by commercial fishers but 250 kg of elvers were transferred. In 1999 an elver pass was installed by

Carter Holt Harvey which by-passed the Falls enabling elvers to climb a combination of natural rock and concrete and drop into the Paper Mill turbine water intake channel where they can easily migrate upstream. Numbers of elvers using the pass are not monitored, and estimates of elvers using the pass range from 40 to 190 kg (Annala *et al.* 1999). With standard techniques of capture and effort implemented, the Mataura River could be used as an index of longfin recruitment.

Paerau Weir, Taieri River

NIWA installed an elver Pass at Paerau Weir on the upper Taieri River in February 1999. It is not known how effective this pass is but if it is monitored in the future it could provide an index of longfin recruitment.

Table A6-2: Size and age of longfin elvers from South Island rivers, and species. * only mean size available for this sample; s.e = standard error

		Length and weight data						Age data				
Location	Period	N	Mean length (mm)	s.e.	Range	Mean weight (g)	s.e.	N	Mean age (yr)	s.e.	Range	Species composition % longfin
Clutha River (Roxburgh Dam)	Jan-Feb 1971	207	149	2.8	108–315	–	–	29	6.1	0.3	4–10	99
	Feb 1996	10	192	10.1	125–220	–	–	10	9.1	0.7	5–12	100
	Feb 1997	101	151	1.7	112–192	4.0	0.2	55	11.9	0.6	3–22	100
	Feb 1998	98	124	1.0	102–155	2.0	0.1	51	3.7	0.2	2–8	100
Waiau River (Mararoa Weir)	Feb 1996	33	126	3.8	91–167	–	–	33	5.2	0.4	2–11	100
	Feb 1996*	44	132	2.9	–	2.2	–	–	–	–	–	95.5
Mataura River (Falls)	Feb 1998	24	129	2.6	110–163	2.4	0.2	24	2.8	0.2	2–5	96

Appendix 7: Percent length frequency of longfins caught using traps or fyke nets (>450 mm). Medium 450–700 mm, Large >700mm . "Fished" refers to whether the water has been commercially fished. * indicates a virtually unfished resource.

Water	Year	Fished	Medium	Large
Traps				
Various waters (Cairns 1942)	1938	No	77	23
Lake Wanaka	1947	No	9.9	90.1
Kakapo Stream	1947	No	17.2	82.8
Lillburn River	1947	No	40.6	59.4
Whitestone River	1947	No	45.3	54.7
Wanuiomata River	1948	No	32.2	67.8
Waipa River	1948	No	55.4	44.6
Fyke Nets – scientific				
Lake Pounui	74/78	No	76	23
Rakaia Lagoon	80/81	No	42	58
Lake Roxburgh	1983	No*	24	76
Waimakariri estuary	83/84	Yes	88	12
Heathcote River	1989	Yes	69	31
Lake Rotoiti	1991	No	38.5	61.5
Lake Wanaka	1995	Yes	59.2	40.8
Fyke Nets – commercial				
Mossburn Enterprise samples	1970's	No*	69	31
Mossburn Enterprise samples	1980's	Yes	90	10
Mossburn Enterprise samples	1990's	Yes	91	9
Aparima River	95/96	Yes	99.2	0.8
Oreti River	95/96	Yes	98.0	2.0
Clutha River	95/96	Yes	98.9	1.1
Taieri River	95/96	Yes	95	5
Waitaki River	95/96	Yes	94.6	5.4
Rakaia and Waimakariri Rivers	95/96	Yes	93.7	6.3
Grey River	95/96	Yes	95.2	4.8
Buller River	95/96	Yes	95.7	4.3
North Island waters	95/96	Yes	93.1	6.9