The Australian longfinned eel, *Anguilla reinhardtii*, in New Zealand

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1. Introduction

The Department of Conservation sought advice from NIWA on the known biology, ecology, distribution and likely conservation issues arising from the natural immigration of the Australian freshwater longfinned eel, *Anguilla reinhardtii* (see Jellyman et al. 1996). Preliminary advice under five headings was provided in April 1997 (Chisnall 1997). The present report provides a revision of that advice, and summarises information obtained from commercial eel catch sampling programmes undertaken at several New Zealand eel processing factories between 1995 and 98 (Beentjes & Chisnall 1997, 1998; Chisnall & Kemp 1998), and in eel fisheries investigations since then (Chisnall et al. 1998; Chisnall 1998; Jellyman et al. 1999; NIWA unpublished data).

2. Life cycle, migratory patterns, age and growth

2.1 INITIAL OBSERVATIONS

Although essentially a tropical eel, the Australian longfinned eel *(A. reinhardtii)* has a similar life cycle and basic ecology to both the shortfinned and longfinned eels in New Zealand *(Anguilla australis* and *A. dieffenbachii*, respectively). *A. reinhardtii* is a highly competitive predator in its native subtropical freshwater ecosystems, which usually contain several other large carnivores. In a dietary comparison with *A. australis* in Australia, fish (including galaxiids) were found to be the major dietary component of *A. reinhardtii* over a wide size range of eel (Beumer 1979).

A. reinhardtii spends most of its life in freshwater and migrates to the sea to spawn (catadromous), as do New Zealand eels. However, glass eel invasion and abundance in Australia is greatest in summer-autumn (Sloane 1984; Beumer & Sloane 1990) (suggesting a likely autumn-winter arrival in New Zealand), rather than the spring-summer for NZ glass eels (Jellyman et al. 1999). The oceanic dispersal of larvae from tropical spawning grounds results in a north to south recruitment along the eastern seaboard of the Australian continent and Tasmania (e.g. Beumer & Sloane 1990). Glass eels arriving in Australian freshwaters tend to be smaller than both New Zealand species, and length may be a useful differentiate between *Anguilla dieffenbachii* and *A. reinhardtii.*

A. reinhardtii is long-lived and attains a large size similar to that of *A. dieffenbachii* (Merrick & Schmida 1984).

A. reinhardtii is known to have diseases and parasitic infestations common to several eel species (e.g. trematodes such as *Austrohalipegus anguillicola;* diseases such as *Edwardsiella tarda* and *Photobacterium damsela;* see Hine

1980; Beumer et al. 1982; Cribb 1987, 1988; Eaves et al. 1990; Ketterer & Eaves 1992).

2.2 DATA FROM CONFIRMED *A. REINHARDTII* IN NEW ZEALAND

Visual identifications of *A. reinhardtii* were confirmed through vertebral counts (using x-rays) when possible. Data from confirmed records of *A. reinhardtii* were collated, and linear regressions were calculated for log-log relationships of weight, length, and age (Table 1). The length-at-age regression omitted 4 outliers to improve the correlation coefficient. In addition, several records were generated from personal accounts by commercial fishers over the last 20 years. Missing lengths, weights or ages were estimated from the Waikato regressions based on actual measurements (Tables 1, 2).

A general description of the regional distribution, size and age distribution, and recruitment of *A. reinhardtii* has emerged. Source sites of the samples assessed were widespread (nine confirmed locations, Figure 1), which may partly account for the disjointed appearance of the size distribution. Eels ranged between 300 and 1353 mm in length, 57 and 11300 g in weight, and 2 and 26 years of age (Table 2, Figures 2, 3A).

Although the age structure of the sample was widely distributed, most eels were < 10 years old (Figure 3). The few larger older eels in this sample may simply reflect the typical impact of fishing on the size distribution of the population (see Beentjes & Chisnall 1997, 1998). The largest *A. reinhardtii* from an early verbal report was estimated to have been recruited in 1958 (Fig. 3B). However, the data support the contention that *A. reinhardtii* have been arriving more frequently over the last decade.

2.3 GROWTH RATE

Growth of *A. reinhardtii* has been mostly 2-3 times faster in length and 4 times faster in weight than for co-existing *A. dieffenbachii* (Table 2, Figure 4). Most annual growth increments of *A. dieffenbachii* are around 27 mm for lowland waters (Chisnall et al in prep.). The fastest growth increment for *A. dieffenbachii* has been recorded in the Waikato River hydro reservoirs (160mm, Chisnall et al. 1998), and the slowest in streams in indigenous forest (12 mm, Chisnall & Hicks 1993) or in high country lakes (11 mm, Jellyman 1995).

Lake Taharoa was the only site in which *A. reinhardtii* length and weight increments were similar (upper quartile) to that of *A. dieffenbachii.* This lake is known to have restricted prey availability (e.g., Chisnall & Bellingham 1998). Thus, this lack of a difference in growth rate between the two longfinned eels suggests that if food is limiting one will not out-compete the other.

2.4 SEXUAL MATURITY AND SIZE

The rapid growth rates attained by *A. reinhardtii* within the same waters as *A. dieffenbachii* indicate that maturity can be attained rapidly. At least half of the sample of *A. reinhardtii* examined were within the size range of female *A. dieffenbachii* (see Todd 1980). Six of the 51 *A. reinhardtii* examined were identified as females, and all were at the first stage of development (see Beentjes & Chisnall 1997, 1998). These ranged between 760 and 890 mm length (mean 840 mm), 1560 and 3000 g weight (mean of 2083 g), and were 7-26 years old (mean of 16 years) (Appendix 1). There have also been five unsubstantiated reports of females up to 11 kg (see Appendix 1).

The size range of mature female *A. reinhardtii* was therefore similar to that of *A. dieffenbachii,* but the rate of maturity for *A. dieffenbachii* is slower; 12-36 years with overall mean > 22 years (see Beentjes & Chisnall 1998).

There have been a few reports of *A. dieffenbachii* attaining up to 2 m and 50 kg, but these are rare (more common historically, e.g. Cairns 1942), and in recent times few exceed 1200 mm (maximum 1024 mm, Todd 1980; 1067 mm, Hobbs 1947). Exceptional size of *A. dieffenbachii* that has occurred in several North Island hydro lakes was attributed to low population density and high food availability (e.g. Chisnall et al. 1998; Boubee et al in press). In world comparisons, *A. reinhardtii* is the only other freshwater anguillid species that attains such large size (up to 1650 mm and 22 kg, McDowall 1990; cf. Tesch 1977).

3. Potential distribution in New Zealand's freshwater ecosystems

3.1 INITIAL OBSERVATIONS

A. reinhardtii has an ecology that almost overlaps that of *A. dieffenbachii.* It is known to occur in a variety of habitats but is more common in riverine waters than in still waters. Therefore its distribution in New Zealand seems limited only by oceanic dispersal of its larval stage. Unsubstantiated reports on distribution have described an apparent 30-year history confined to reports from the North Island, particularly Northland. Recent observations (last ten years) describe an increased occurrence further south to include the Waikato River and Taranaki Rivers on the west coast, and the Hauraki plains and Hawkes Bay Rivers on the east coast.

Despite several verbal reports of this species occurring in the Malborough Sounds to as far south as Fiordland, there has been no subtantiating evidence supplied (several supposed *A. reinhardtii* specimens from the South Island were identified as morphologically unusual *A. australis).*

A. reinhardtii is likely to occupy all known habitats of New Zealand eels within its range of dispersal, and to compete particularly with *A. dieffenbachii* in its comparable inland penetration.

Catches of *A. reinhardtii* reported by a Waikato commercial fisherman (Russel Brock) in early winter 1996 (May) showed that this species formed around 12% of his catch of longfinned eels over one week in the Waikato River. Catch sampling data from North Island eel factories over the 1995-96 season, revealed several *A. reinhardtii* amongst catches from the Piako River (Hauraki); most of these eels were smaller than 500 mm and difficult to identify from morphological features alone. These individuals were a small component of what was believed to be a substantial number of *A. reinhardtii* in the catch (pers. observation). It is possible that because *A. reinhardtii* is not readily identified at smaller sizes, they may be established in larger numbers than catch rates indicate.

3.2 REGIONAL DISTRIBUTION FROM CONFIRMED RECORDS

Since 1997, further verbal and substantiated observations of *A. reinhardtii* have confirmed the regional distribution described previously and extended it beyond the upper half of the North Island as far south as the Manawatu (Figure 1). Small numbers of *A. reinhardtii* have been captured from hydro Lake Arapuni, Lake Taharoa, and the Patea River estuary, all on the west coast. Unsubstantiated verbal reports include all of Northland, the Bay of Plenty, and the Wairarapa (Figure 1). It would seem reasonable to assume *A. reinhardtii* is now also distributed throughout these regions. *A. reinhardtii* have been found more frequently in river main-stems than in upland reaches, and were most common in catches during winter and spring flooding. *A. reinhardtii* have been most easily observed in catches landed from the Hauraki plains. It was anticipated that the further market sampling programmes undertaken by NIWA for the Ministry of Fisheries at North Island eel processing plants would gather substantial information on *A. reinhardtii*. Unfortunately, there were very few *A. reinhardtii* landed commercially throughout the long dry summer of 1997-98 (attributed to the strong El Nino, Chisnall & Kemp 1998). However, many *A. reinhardtii* were landed from Northland during the heavy rainfalls experienced in June 1998 (mid-winter), after the catch sampling programme had been completed for the season (Thomas Richards Ltd., John Jameson pers. comm.).

3.3 POSSIBLE ARRIVAL MECHANISM

The East Australian Current (EAC) is probably the main transport agent for larval dispersal from spawning grounds in the tropics. This current flows in an anticlockwise direction as part of the subtropical gyre in the South Pacific (centred near Fiji) (e.g. Chiswell et al. 1997). The EAC has a high degree of eddy variability affecting recirculation and potentially also influencing eel recruitment to New Zealand. The intensity and persistence of recent El Ninos as indicated by the Southern Oscillation Index (SOI) (e.g. Mullan 1997), may well have disrupted the EAC in favour of transporting *A. reinhardtii* larvae to New Zealand. If this was the main transport mechanism, we could expect to see modes of age frequencies (corresponding to year of recruitment) peak during the increased incidence of westerly winds characteristic of the El Nino phase of the SOI. Although *A. reinhardtii* occurred during 5 out of the 6 strongest El Nino years since the 1950s (Fig. 3B), the data are too sparse to support a causal relationship.

4. Diet of *A. reinhardtii* in the lower Waikato Basin

4.1 INITIAL OBSERVATIONS

The dietary habits of *A. reinhardtii* are expected to be similar to that of *A. dieffenbachii;* i.e., an opportunistic feeder, principally nocturnal, becoming an increasingly aggressive carnivore as size of eel increases.

There is therefore a likely dietary overlap with both New Zealand eels, which may be particularly important as juveniles. Intensive commercial eel fisheries generally cause the eel population to become predominantly juvenile, which in turn can increase competition for food. New Zealand eels may thus be vulnerable to being out-competed by *A. reinhardtii,* particularly at this lifestage in the wild eel fishery. There were no obvious checks in growth observed in otolith sections from *A. reinhardtii,* which contrasts with the bottleneck in the growth of juveniles observed for New Zealand eels in the Waikato River (Chisnall 1989).

There are reports that *A. reinhardtii* eat catfish *(Tandanus tandanus)* in Australia (Merrick & Schmida 1984). There are no similar reports for *A. dieffenbachii,* which could prey on juvenile brown bullhead catfish *(Ictalurus nebulosus)* in our waterways once a suitable size for piscivory is attained. As New Zealand eels do not consume catfish, the potential food availability for the three eel species may remain higher in areas populated by catfish (e.g. Waikato) with interspecific competition lower than elsewhere. However, fast growth (growth 4 times faster than New Zealand eels in Waikato waterways) of this species may allow it to displace New Zealand eels in habitats where space is a limiting factor. Any impact on prey species by *A. reinhardtii* is likely to be comparable to that of New Zealand eels (with the exception of catfish), i.e. the sustainable biomass of eels in habitats will generally remain at similar levels but the resource may become partitioned between the three eel species.

4.2 ACTUAL GUT CONTENTS

It is difficult to assess actual diet in the wild. This is because eels are generally nocturnal feeders and digest their food overnight, and the method of capture used by commercial fishers (fyke nets), retains prey organisms that eels may eat within the nets. In addition, because of logistical difficulty in landing parts of catches, most of the *A. reinhardtii* examined had been held for extended periods prior to assessment, which caused most gut contents to become fully digested or unrecognisable.

Of 34 *A. reinhardtii* examined, 24 stomachs were empty, and little food remained even within intestines. Several of these eels did have undigested snail shells in intestinal tracts, which were mostly *Pantipodarum* and occasional *Physastra variabilis* and *Physa* species. Seven eels had clearly identifiable remains within stomachs; an eel from Lake Taharoa (length of 760 mm) had eaten 5 common bullies *(Gobiomorphus cotidianus)* and 3 common smelt *(Retropinna retropinna);* an eel from Lake Arapuni (length of 514 mm) had consumed a medium-sized koura *(Paranephrops planifrons)* and large numbers of *Potamopyrgus antipodarum;* one eel from the Waikato River (length of 790 mm) had eaten 8 common bullies, another (length of 644 mm) had eaten 3 common bullies, and 3 others (lengths ranged between 464-554 mm) had also eaten fish (unidentified).

These few data tend to support the previous suggestion that both longfinned eel species would have a similar diet. It would be particularly useful to determine at what size *A. reinhardtii* becomes piscivorous. *A. dieffenbachii* reaches this phase at around 450 mm or 220-250 g (e.g., Jellyman 1989). If *A. reinhardtii* take fish at a smaller size, they would certainly have competitive advantage over *A. dieffenbachii.*

5. Conservation issues

It appears that *A. reinhardtii* is here to stay. To date, age distribution (determined from otolith-derived growth models and estimated from size records) ranges from 2 to 26 years of age, reflecting at least 26 years confirmed history of self-introduction to New Zealand freshwaters. Thus, *A. reinhardtii* is now a confirmed Australasian species and should be considered as a component of the New Zealand indigenous fauna.

Fast growth of *A. reinhardtii* suggests that it is likely to be highly competitive with both other eel species and may be particularly interactive with *A. dieffenbachii* as the top predator. Similar choice of habitats, overlapping diet, and intensely territorial behaviour of large individuals, suggests that *A. reinhardtii* may become the top predator in New Zealand freshwater ecosystems. This is most likely to become apparent if *A. reinhardtii* penetrate upper catchment waterways where habitat becomes confined.

Because *A. reinhardtii* is such a successful predator, prey of mid- to large-sized eels such as koura and indigenous fish (e.g. galaxiids, bullies and other eels) may be impacted, particularly where this eel competes with (possibly displacing) *A. dieffenbachii* in small waterways (headwaters of catchments). Introduced fish such as trout, carp, rudd and mosquitofish are also likely to form components of *A. reinhardtii* diet.

There is little potential for natural parasitic infestations and diseases of A. *reinhardtii* in Australia to be introduced to New Zealand eels, because A. *reinhardtii* has self-introduced as larvae from spawning zones, not as adults from Australian waters.

6. Principal recommendation

The principal recommendation for managing *A. reinhardtii* is to maintain and enhance the spawning success of *A. dieffenbachii* to improve its competitive viability.

The transfers of migrant female *A. dieffenbachii* entrained in hydro-reservoirs to lower waterways below obstructions, should be encouraged. Exclusive reserves could be set aside in productive waters for this purpose (where fishing is prevented or restricted, e.g. only shortfinned eels permitted to be taken). Such reserves for *A. dieffenbachii* should be where the species grows fastest; not as currently occur - most reserves are within national forest parks (e.g. Chisnall & Hicks 1993; Jellyman 1995), and are often in the headwaters of exploited waterways, allowing mature eels to be exposed to commercial exploitation as they migrate.

The present South Island maximum takeable size of 4 kg individuals should be lowered to further improve escapement of female *A. dieffenbachii* (see table 9 in Chisnall & Hicks 1993). Such upper thresholds to the fishery should be implemented in the North Island (currently no limit). A restriction of fishing during the downstream migration of mature eels should also be introduced.

7. Acknowledgments

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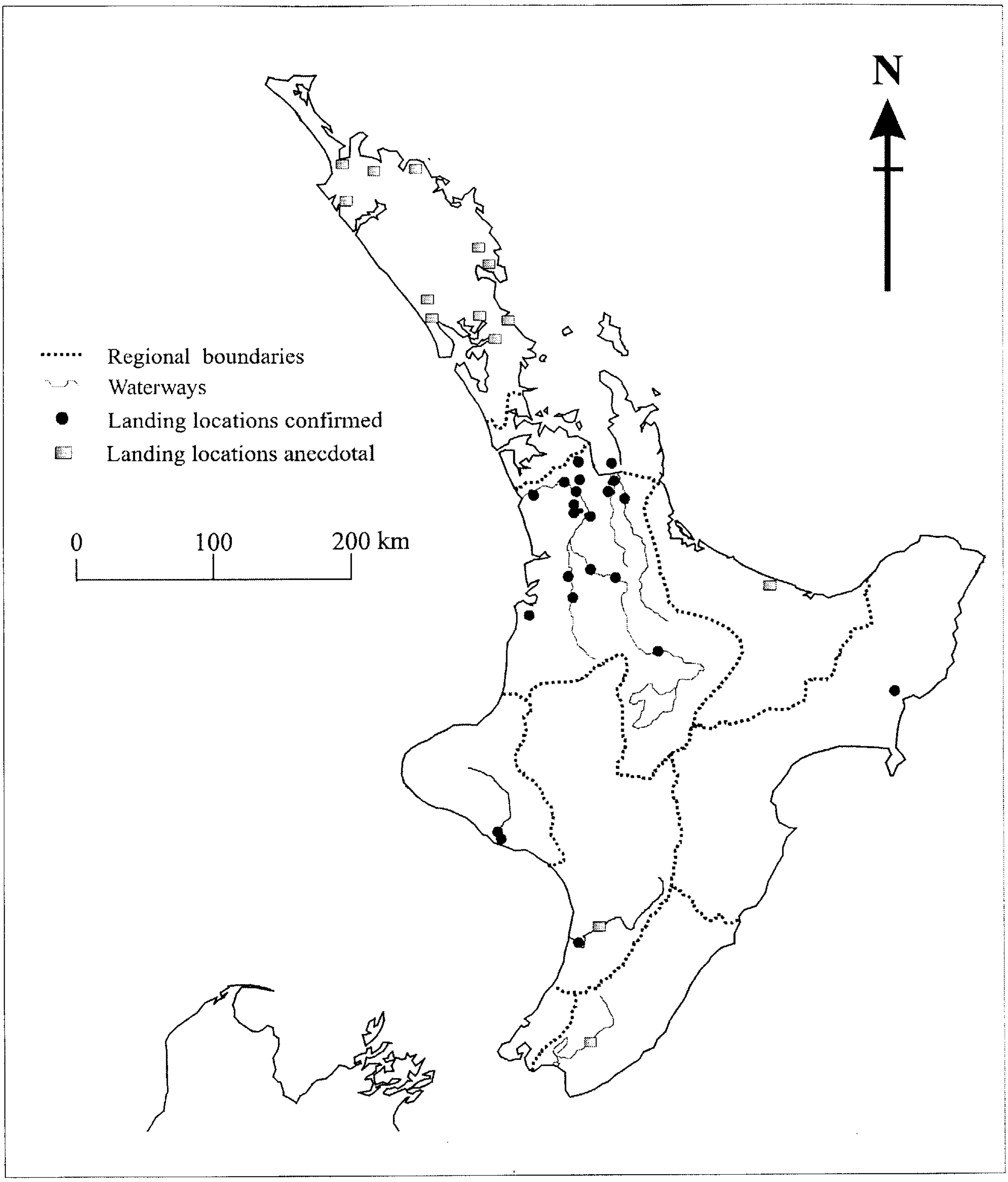

Figure 1. Locations of landings of the Australian longfinned eel *(Anguilla reinhardtii);* either confirmed by assessment of specimens or verbal reports of sightings by fishers. Regional boundaries based on catchments (Appendix 1).

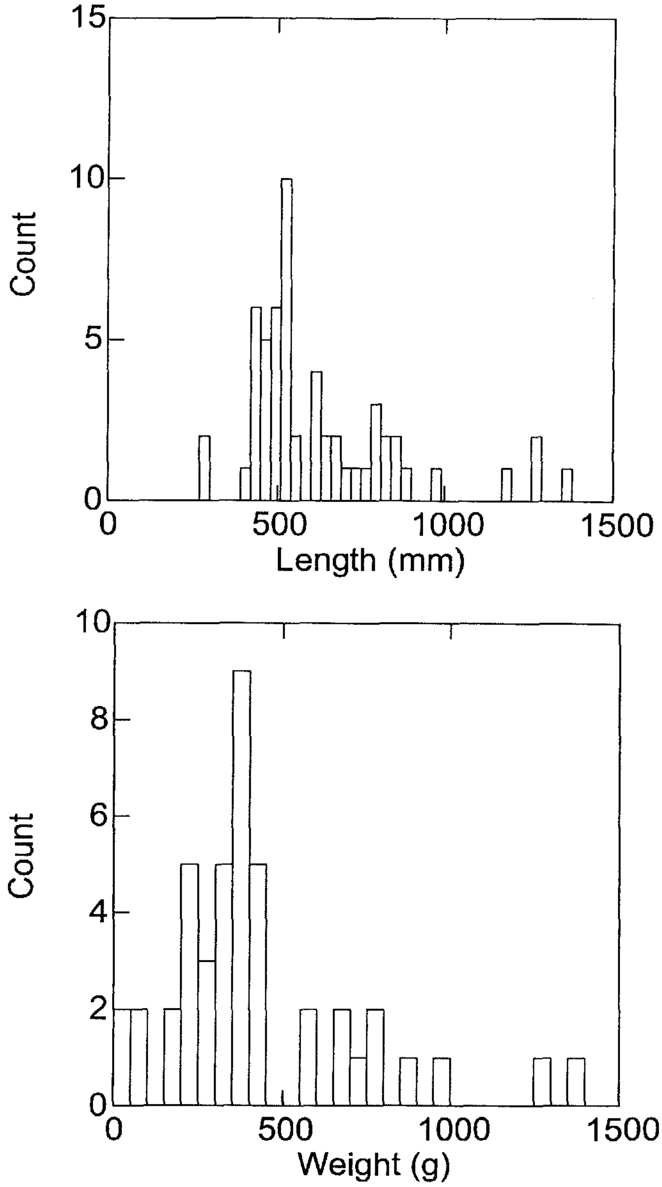

Figure 2: Length and weight distributions of the Australian longfinned eel *(Anguilla reinhardtii)* (see Appendix 1).

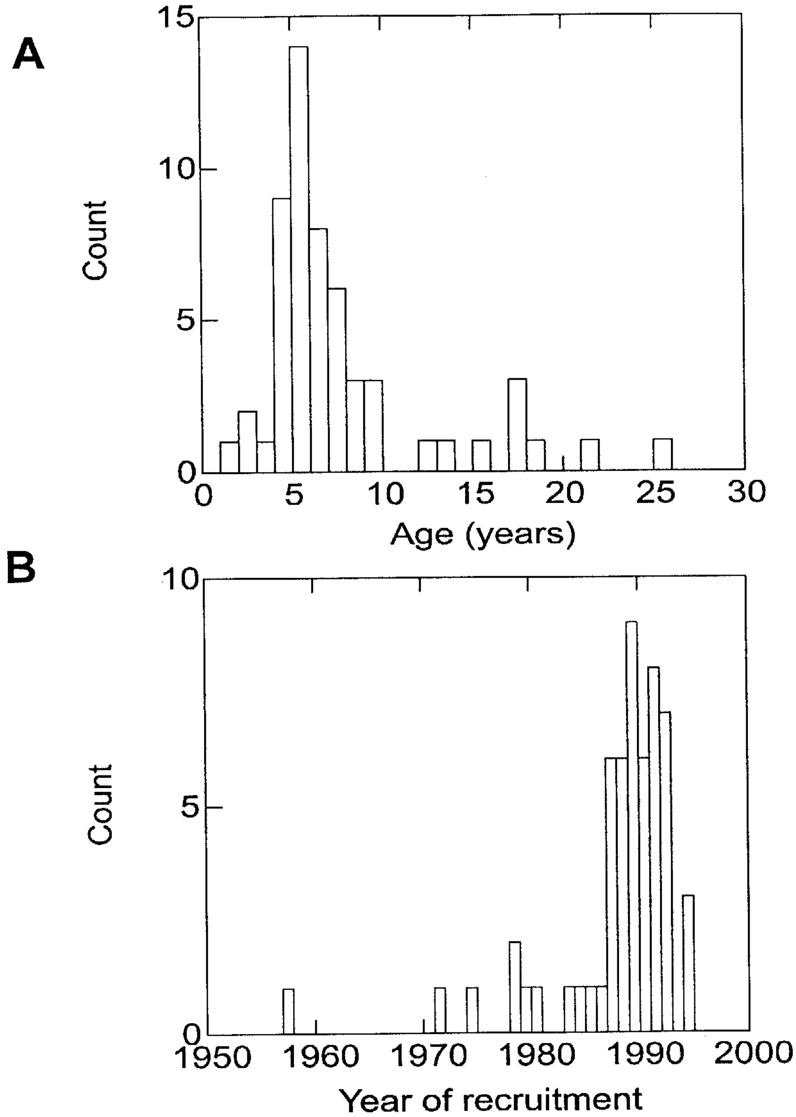

Figure 3: Age distributions of the Australian longfinned eel *(Anguilla reinhardtii)* caught throughout the North Island since the 1970's (see Figure 1, Table 2). A, age structure; B, estimated year of recruitment based on year of capture minus age class.

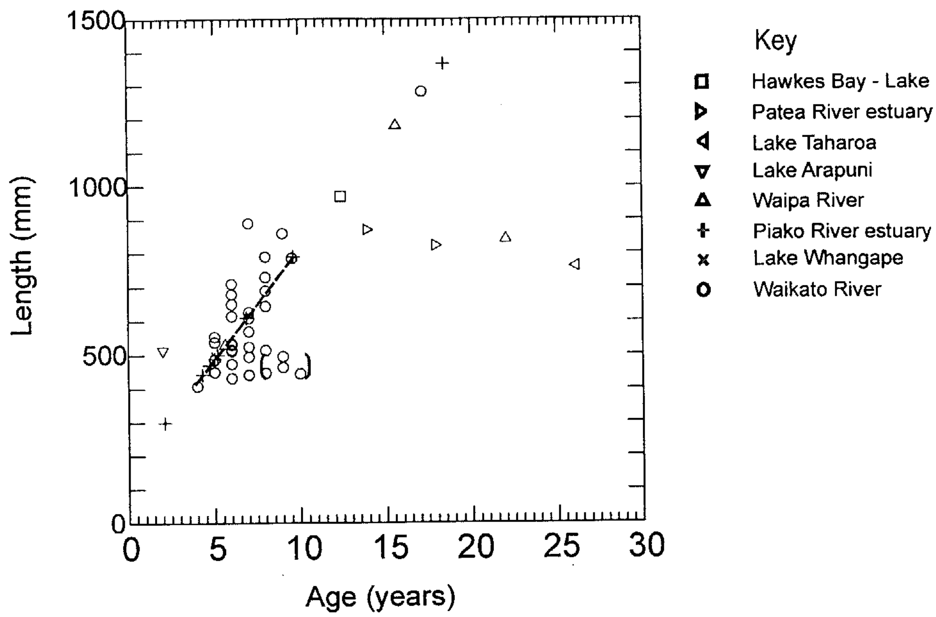

Figure 4: Age-at-length of the Australian longfinned eel *(Anguilla reinhardtii)* caught throughout the North Island since the 1970's. The regresssion line (least squares linear model, Table 1) is fitted to Waikato data only. Brackets show the four outliers omitted from the regression.

Table 1. Regression coefficients from *ln* weight-*ln* length and age-length relationships for confirmed records of *Anguilla reinhardtii*, in the Waikato River. The age-length and weight relationships are based on actual assessed specimens, but omitting 4 outliers (*see* Figure 4). Probability for regressions < 0.001.

Regression	N	a	b + s.e.	r2
*ln*weight-*ln*length	40	16.131	3.528±0.098	0.971
Age-length	29	163.814	65.097±16.571	0.364
*ln*weight-age	29	3.799	0.382±0.1	0.349
age-*ln*weight	29	0.748	0.914±0.240	0.349

Table 2. Source locations and measured or estimated parameters for records of *Anguilla reinhardtii* from throughout the North Island. Length and weight increments calculated from length minus size of glass eel (60 mm) and weight, divided by age. Estimates were based on regressions for Waikato River data (see Table 1).*, omits estimated data (Appendix 1).

Location	Eel N	Length range (mm)	Weight range (g)	Age range (years)	Mean annual increments' Length s.e. (mm)	Weight s.e. (g)
Waikato River	36	408-1280	186-9070	4.0-17.0	77.2±3	98.1±14.6
Lake Whangape	1	495	379	5	-	
Piako River	11	300-1363	65-11300	2.0-18.0	-	
Waipa River & streams into Lake Waikare	3	530-1180	391-6800	6.0-22		
Lake Arapuni	1	514	443	2	227	221.5
Lake Taharoa	1	760	1560	26	26.9	60
Patea River estuary	2	822-870	1820-2000	14-18	50.1±7.7	121.9±20.8
Hawkes Bay	1	970	1800	12		
TOTAL	**56**	**300-1353**	**65-11300**	**2.0-26**		

Appendix 1: Confirmed records of Australian longfinned eels *(A. reinhardtii)*, captured since the 1970's. Group, catchment based codes for locations; U, unidentified; F, female; Estlength, estimated length; Estweight, estimated weight; Estage, estimated age: all estimates based on regressions for Waikato River data *(see* Table 1).

Location	Group	Date	Fisher	Sex	Length (mm)	Estlength (mm)	Weight (g)	Estweight (g)	Ageclass (yrs)	Estage (yrs)	Diet	Vertebral Count	Recruitment year
Waikato River	1	29-Apr-96	Russel Brock	U	445		206		10			107	1986
Waikato River	1	31-May-96	Russel Brock	U	530		385		6			108	1990
Waikato River	1	31-May-96	Russel Brock	U	496		410		9			108	1987
Waikato River	1	31-May-96	Russel Brock	U	495		358		7			108	1989
Waikato River	1	3-May-96	Russel Brock	U	450		204		5			108	1991
Waikato River	1	31-May-96	Russel Brock	U	570		569		7			108	1989
Waikato River	1	3-May-96	Russel Brock	U	442		189		7			108	1989
Waikato River	1	31-Sept-96	Russel Brock	U	730		1371		8			108	1988
Waikato River	1	31-Sept-96	Russel Brock	U	512		361		6			107	1990
Waikato River	1	31-Sept-96	Russel Brock	U	408		186		4			106	1992
Waikato River	1	31-Sept-96	Russel Brock	U	432		222		6			108	1990
Waikato River	1	31-Sept-96	Russel Brock	U	690		879		8			107	1988
Waikato River	1	3-May-96	Russel Brock	U	650		772		6			109	1990
Waikato River	1	31-Sept-96	Russel Brock	U	447		227		8			108	1988
Waikato River	1	31-Sept-96	Russel Brock	U	524		421		7			109	1989
Waikato River	1	31-Sept-96	Russel Brock	U	516		392		6			108	1990
Waikato River	1	31-Sept-96	Russel Brock	U	487		364		5			106	1991
Waikato River	1	31-Sept-96	Russel Brock	U	534		428		6			109	1990
Waikato River	1	17-Jun-96	Russel Brock	U	790		2185		8				1988
Waikato River	1	17-Apr-97	Russel Brock	U	785		1623			10			1987
Waikare steams	4	mid 96	Bob Clarke	F		1180	6800			16			1980
Naike flooding	1	mid 96	Bob Clarke	F		1280	9070			17			1979
Waikato River Cam-Mere	1	mid 70's	Bob Clarke	F		1280	9070			17			1958
Firth of Thames	3	Early 97	Chester	F		1363	11300			18			1979
Lake Whangape	2	23-Feb-97	RusselBrock	U	495			379		5			1992
Paiko River	3	1-Jun-97	Norm Dunlop	U	610			792		7		107	1990
Paiko River	3	1-Jun-97	Norm Dunlop	U	500			393		5		107	1992
Paiko River	3	1-Jun-97	Norm Dunlop	U	470			316		5		108	1992
Paiko River	3	1-Jun-97	Norm Dunlop	U	790			1972		10		106	1987
Paiko River	3	1-Jun-97	Norm Dunlop	U	300			65		2		106	1995
Paiko River	3	1-Jun-97	Norm Dunlop	U	300			65		2		104	1995
Paiko River	3	1-Jun-97	Norm Dunlop	U	470			316		5		109	1992
Paiko River	3	1-Jun-97	Norm Dunlop	U	443			256		4		106	1993
Paiko River	3	1-Jun-97	Norm Dunlop	U	472			320		5		107	1992
Paiko River	3	1-Jun-97	Norm Dunlop	U	489			363		5		109	1992
Lake Arapuni	5	1-Jan-97	Ben Chisnall	U	514		443		2		Y, Koura and potym.	107	1995
Lake Taharoa	6	8-May-98	Ben Chisnall	F	760		1560		26		Y, bullies and smelt		1972
Waikato River-HuntlyMeremere	1	13-Jun-97	Codna Kemp	F	890		3000		7				1990
Waikato River-HuntlyMeremere	1	13-Jun-97	Corina Kemp	U	710		1264		6				1991
Waipa River	4	7-Apr-97	Mike Holmes	F	840		2100		22				1975
Waipa River	4	7-Apr-97	Mike Holmes	U	530		391			6			1991
Patea River estuary	7	4-Apr-98	Grant Williams	F	822		1820		18				1980
Patea River estuary	7	4-Apr-98	Grant Williams	F	870		2000		14				1984
Hawkes Bay Lake	8	Mid 97	Levin eel processors	F		800		1800		12			1985
Waikto River?	1	Mid 98	Russel Brock	U	615		677		6		E		1992
Waikto River?	1	Mid 98	Russel Brock	U	538		277		5		E		1993
Waikto River?	1	Mid 98	Russel Brock	U	626		672		7		E		1991
Waikto River?	1	Mid 98	Russel Brock	F	859		2019		9		E		1989
Waikto Riven	1	Mid 98	Russel Brock	U	679		982		6		E		1992
Waikto River?	1	Mid 98	Russel Brock	U	644		714		8		3 large bullies, potym. Intestines		1990
Waikto River?	1	Mid 98	Russel Brock	U	474		261		6		1, fish		1992
Waikto River?	1	Mid 98	Russel Brock	U	514		308		6		E		1992
Waikto River?	1	Mid 98	Russel Brock	U	609		590		7		E		1991
Waikto River?	1	Mid 98	Russel Brock	U	464		250		9		1, fish		1989
Waikto River?	1	Mid 98	Russel Brock	U	554		409		5		1, fish		1993
Waikto River?	1	Mid 98	Russel Brock	U	514		326		8		E		1990