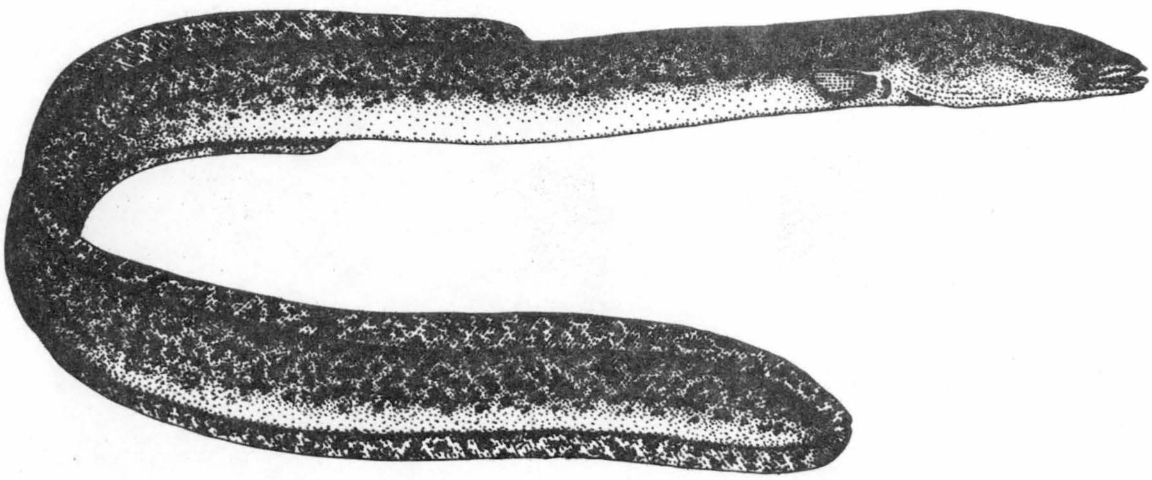
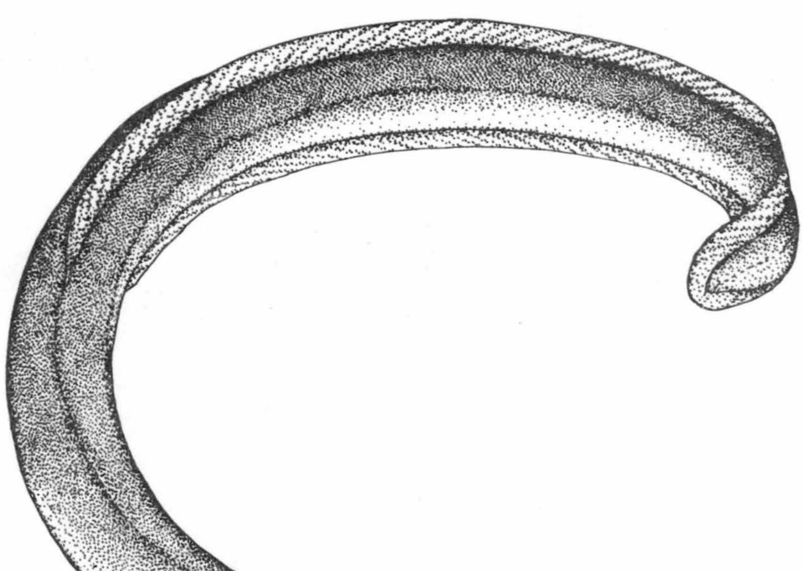


Long-finned eel *Anguilla reinhardtii*



Short-finned eel *Anguilla australis australis*

A BIOLOGICAL BASIS FOR THE TASMANIAN FRESHWATER EEL FISHERY

ROBERT DAMIEN SLOANE B.Sc. Hons (Tas.)

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Zoology.

University of Tasmania
Hobart

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Except as stated herein, this thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and, to the best of the author's knowledge and belief, this thesis contains no copy or paraphrase of material previously published or written by another person, except where due reference has been made in the text.

R.D. Sloane

CONTENTS

ABSTRACT

This thesis reports a five year investigation into various aspects of the biology of the freshwater eels Anguilla australis australis *and* Anguilla reinhardtii *in Tasmania, from the time of first entry of glass-eels into fresh water to the returning migration of adult eels to the sea.*

The invasion of fresh water by glass-eels of both species was studied in streams on the east coast of Tasmania. A. reinhardtii *glass-eels were found to enter fresh water mainly during February, March and April whereas* A. a. australis *glass-eels exhibited a more extensive influx from March through to November. For both species the stage of pigmentation of glass-eels was found to advance as the season progressed and length, weight and condition showed an initial decline with advancing pigmentation. The otoliths of invading glass-eels of both species appeared similar with a single summer growth ring indicating a larval life of between 12 and 18 months.*

*Upstream migrations of young pigmented eels (elvers) were found to occur each year during late spring and summer (October to March) in Tasmania. Elvers migrating at major stream barriers were of the short-finned species (*A. a. australis*); only a single specimen of* A. reinhardtii *was recorded. Elvers sampled from inland areas were both larger and older than those found near the sea indicating that eels migrate further upstream for several years in succession. Generally eels less than 10 years of age and smaller than 25 cm in length were involved in such migrations. Water temperature may be an important controlling factor in elver migrations; there was a very highly significant positive correlation between water temperature and elver catch at an upstream fish trap on the Plenty River.*

Extensive electrofishing surveys and analysis of commercial eel landings have indicated that A. a. australis inhabits coastal streams, lagoons, farm dams and lakes, and its distribution extends far inland in the major drainage systems. A. reinhardtii was found to be largely confined to some coastal lagoons and the lower freshwater reaches and estuaries of streams in north-eastern Tasmania. The distributions of both species may be limited by minimum water temperatures and substrate preference. The diet of small (less than 20 cm) eels was found to be similar for both species, a feature which may lead to direct competition during periods of low summer flow when feeding areas are restricted. November/December was found to be the maximum growth period for both eel species and slow winter growth resulted in the formation of annual growth rings in otoliths.

Maturing adult A. a. australis were found to migrate downstream during the months October to March. Seaward migrations of A. reinhardtii were limited by the restricted inland distribution of this species in Tasmania; migrations were recorded near the mouth of the Ringarooma River during March and April. Catches of A. a. australis recorded at a commercial eel trap on the Clyde River showed a very highly significant positive correlation with water temperature; temperatures above 12°C were associated with downstream migration. In the Clyde River, female A. a. australis were found to migrate downstream at a mean length of 94.5 cm, a mean weight of 1 700 g and at an average age of 22.1 years.

An account of the history of the commercial eel fishing industry in Tasmania is presented and the effects of eel exploitation, and of regulatory and policy changes are discussed. The relevant biological findings of the present study are related to the prospects for the future of this fishery in the light of overseas experience.

Chapter 1

GENERAL INTRODUCTION

Two species of freshwater eel have been reliably recorded from Tasmanian waters: a short-finned eel Anguilla australis australis Richardson and a long-finned eel Anguilla reinhardtii Steindachner. The former is known to be common in Tasmania (Schmidt 1928) but the status of the latter has never been clearly defined. A. reinhardtii was not recorded from Tasmania by Johnston (1891), or by Schmidt (1928), but Scott (1934, 1935, 1940, 1953) gave details of a few long-finned specimens from the North and South Esk Rivers near Launceston, which he identified as A. reinhardtii.

Schmidt (1927, 1928) and Ege (1939) have provided comprehensive historical reviews of the taxonomy and distribution of Australian and New Zealand freshwater eels, including descriptions and keys to the two species now known to occur in Tasmania. Basically, A. reinhardtii is a spotted or marbled eel with the dorsal fin extended well forward pre-anally, whereas A. australis australis is an unspotted, uniform grey-brown eel with the forward extent of the dorsal fin almost level with the vent.

In Tasmania, a commercial fishery based on the short-finned eel began in 1965 when 'fyke' nets were first introduced (Lynch 1977). The fortunes of this fishery have fluctuated; Lynch (1977) reported annual catches between 3.5 t and 92.3 t during the period 1966-77. The peak catch was recorded in the 1967-68 season when 23 fishermen operated.

Despite the potential importance of the eel fishery, very little is known of the biology of freshwater eels in Tasmania, with few published studies concerning basic life history, population and growth. Some preliminary work has been reported on the diet of the short-finned eel (Sloane 1976; Lake & Bennison 1977) and Lake and Fulton (1981) have estimated density and biomass of this species in a small coastal stream. Sloane (1976) also recorded some details of age and growth of the short-finned eel.

On the Australian mainland the short-finned eel(*A. a. australis*)is distributed from the Brisbane River in southern Queensland, south and east along the coast, to the vicinity of Mt Gambier in South Australia and the long-finned eel (*A. reinhardtii*) is found from Cape York in northern Queensland, south along the coastal strip to the vicinity of Melbourne (Schmidt 1928; Ege 1939; Beumer *et. al* 1981b). In Victoria, there is also an important commercial eel fishery with the short-finned species representing about 95% of the annual catch (Harrington & Beumer 1980). The commercial eel fishery began in Victoria in 1955 with the introduction of the european 'fyke' net. More recently, eel culture permits have been introduced which allow fishermen to stock bodies of water with undersized (less than 30 cm) eels (Anon. 1976). There are 20 licensed commercial eel fishermen in Victoria, producing an average annual catch of about 211 t (Harrington & Beumer 1980).

The published knowledge of the freshwater eels in Victoria is also very limited. Harrington and Beumer (1980) have emphasized the need for biological studies of Australian eels in order to form a firm management base. Beumer (1979) studied the feeding and movement of eels in Macleods Morass, and he is at present investigating, and already has considerable data relating to various aspects of the life history of freshwater eels in Victoria (Beumer 1976; Anon. 1977; Ord 1978). Cursory observations, mainly relating to the migrations of freshwater eels on the Australian mainland, have also been recorded, (e.g. Hall 1905; Kershaw 1911; Anderson & Whitley 1925; Powell 1930; Lewis 1942; Whitley 1956, 1957; Mann 1979).

In contrast, the knowledge of the closely related short-finned eel A. australis schmidtii Phillipps and the New Zealand long-finned eel A. dieffenbachii Gray is advanced. The Maori people exploited these eels before Europeans settled New Zealand and the commercial fishery is now well established (Jellyman 1977a; Todd 1981a).

Skrzynski (1974) reviewed the early research work on freshwater eels in New Zealand and more recently both Jellyman (1977b, c, 1979a, b) and Todd (1980, 1981c, d, e) have published extensively on aspects of the biology of juvenile and adult eels respectively. The knowledge of parasites and diseases afflicting the New Zealand freshwater eels is also well advanced (see Hewitt & Hine 1972; Hine & Boustead 1974; Hine 1978 for reviews); there are no similar published data relating to the Australian eels.

The New Zealand eel fishery has prospered since exports of eels began in 1965 (Castle 1972). Jellyman (1977a) reported a peak annual catch exceeding 2 000 t in 1972. A substantial fishery for glass-eels (the small transparent juveniles which invade fresh water from the sea) became established in New Zealand between 1970 and 1974 providing culture stock for several local eel farms and a limited export market to Japan (Jellyman 1977a, c, 1979a).

There are many lessons to be learned from the extensive New Zealand research into the biology of the freshwater eel as well as the history of the commercial eel fisheries based on Anguilla spp. in Europe, North America and Japan. It is the intention of the present study to provide a biological basis for the Tasmanian eel fishery by investigating the basic life history and biology of the local eels and relating these findings to the literature from other countries, particularly Victoria and New Zealand, where similar conditions exist and the same or similar Anguilla spp. occur.

The life histories of the European eel, A. anguilla (Linnaeus), the American eel, A. rostrata (Le Sueur), and the Japanese eel, A. japonica Temminck & Schlegel, have now been well established and all temperate eels are thought to conform to the same basic pattern, differing only in the location of the marine spawning grounds (Bertin 1956; Tesch 1977). The spawning grounds of the Australian and New Zealand Anguilla spp. probably lie between New Caledonia and Fiji, or even further to the east (Castle 1963, 1969).

The basic life cycle of a temperate eel species can be summarised as follows. After spawning the eel eggs hatch into transparent leaf-shaped larvae, called leptocephali, which are distributed by ocean currents. Near the continental shelf, the larvae metamorphose to the typical cylindrical shape of the adult eel and swim towards the coast. At this stage the young eels are still transparent and are referred to as glass-eels. The glass-eels become progressively more pigmented on entry into estuarine waters and the pigmented young eels (elvers) later migrate upstream into various freshwater habitats where they feed and grow. Eventually, after many years, the adult eels stop feeding and migrate downstream to the sea in order to return to the distant marine breeding grounds (Bertin 1956; Sinha & Jones 1975; Tesch 1977; Moriarty 1978).

The present study considers in turn each freshwater stage of the eel life cycle, from the first arrival of glass-eels, to the seaward migration of adult eels.

Chapter 2

INVASION AND UPSTREAM MIGRATION OF GLASS-EELS (*ANGUILLA* SPP.) IN TASMANIAN FRESHWATER STREAMS

2.1 INTRODUCTION

Although the invasion of fresh water by glass-eels (sometimes referred to as transitional, transparent, unpigmented or partially pigmented elvers) of the genus Anguilla is well known in many countries (see Deelder 1970; Tesch 1977) this phenomenon has not been documented in Tasmania. The only published record is that of a single glass-eel specimen examined by Scott (1953).

On the Australian mainland, glass-eel migrations are better known and some details of invading short-finned and long-finned glass-eels have been recorded (Ege 1939; Schmidt 1928). Beumer and Harrington (1980) have outlined methods of capturing glass-eels and elvers in Victoria. In New Zealand, Jellyman (1977c, 1979a) has studied the behaviour of migrating glass-eels of *A. australis schmidtii* and *A. dieffenbachii*.

Jellyman (1974) has outlined the confusion in terminology concerning juvenile eels. For the purposes of the present study the term glass-eel refers to juvenile eels which are not fully pigmented and have not attained the stage VI.B of Strubberg (1913), the stage at which the myoseptal arrangement of pigment begins to become indistinct (*v*.2.3.3).

2.2 MATERIALS AND METHODS

2.2.1 Sampling Techniques

Samples of glass-eels were collected by hand-netting and by electrofishing during 1977, 1978, 1979 and 1981. These methods provided a rapid assessment of glass-eel populations without having to monitor set nets over extended periods and also allowed several sites to be fished on any one day. Sampling by either method extended over a 30 minute period.

Hand-netting: A standard F.B.A. hand-net (0.5 mm mesh) was used to collect glass-eels which were buried amongst loose gravel and silt. It was found that glass-eels congregate in certain areas, particularly at the freshwater/estuary interface, and by loosening the substrate with a hand-net, the glass-eels could be readily scooped up.

Electrofishing: The apparatus used was powered by a Honda E800U generator and produced a 240 V direct-current pulsed at 100 pulses s^{-1}. This technique was employed where substrates were too coarse to permit sampling by hand-net. Glass-eels attracted to the anode were scooped up using an F.B.A. hand-net.

2.2.2 Sampling Sites

Sampling was concentrated on streams on the east coast of Tasmania (Fig. 2.1), where river mouth sand bars provide a relatively stable freshwater/estuary interface with only small tidal fluctuations. In general, fishing was conducted at the lowest permanent riffle zone above tidal influence (hereafter referred to as the first riffle). At Ansons River, samples were collected at a road ford which forms the upper limit of tidal

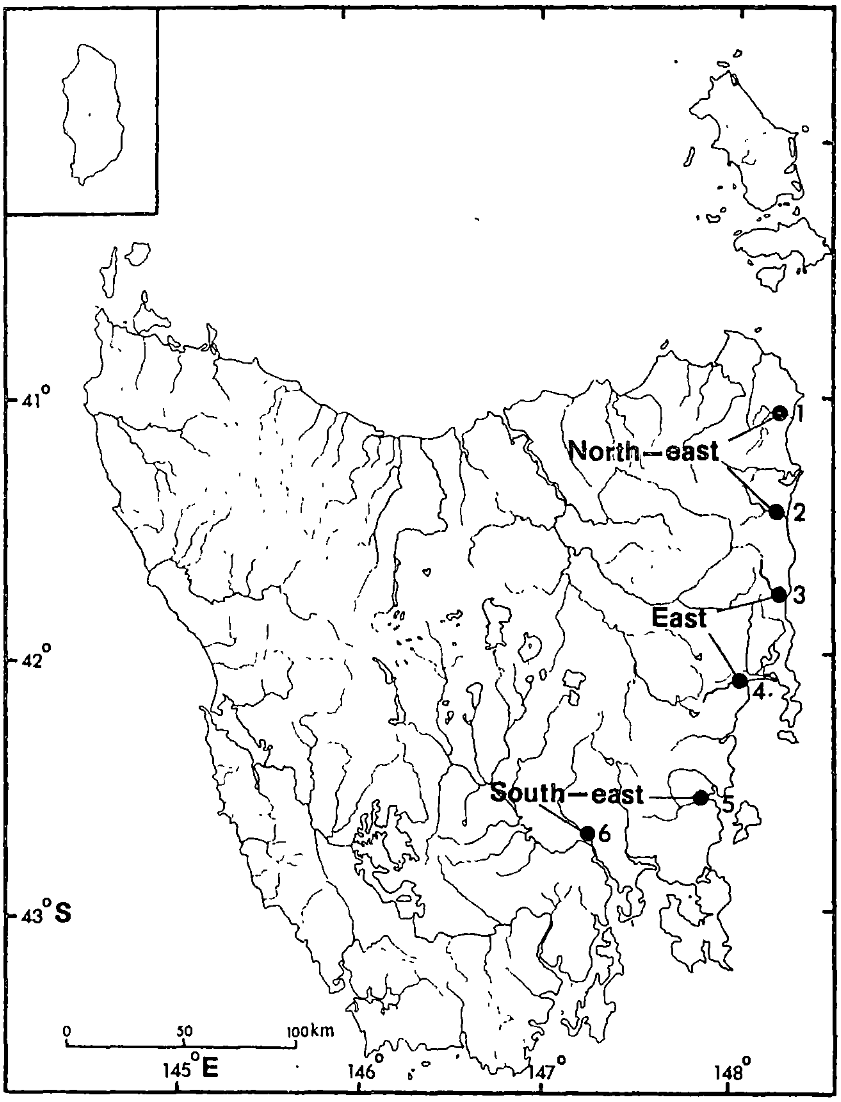


Fig. 2.1

Map of Tasmania showing glass-eel sampling localities:
(1) Ansons River
(2) Scamander River
(3) Douglas River
(4) Meredith River
(5) Prosser River
(6) Jordan River

influence.

For the purposes of analysis, the sampling streams have been grouped into three regions: North-east, East and South-east. A summary of the glass-eel sampling programme is given in Table 2.1. Additional samples were collected by electrofishing amongst <u>Zostera</u> beds at the mouth of the Douglas River estuary during June, August and October 1981.

2.2.3 Treatment of Samples

Glass-eel samples were usually preserved in 5% neutral formalin at the time of capture; however, some samples to be used for otolith examination were preserved in 70% ethanol. The water temperature was recorded at the end of each sampling period.

Each glass-eel was viewed under a dissecting microscope and the distance between the vent and the front of the dorsal fin (A-D) was measured using an eye-piece graticule. The stage of pigmentation was assessed according to the scale outlined by Strubberg (1913). The total length was determined to the nearest 0.5 mm and then each eel was blotted dry and weighed to the nearest 1 mg.

Condition (K) was calculated using mean weight ($\bar{w}$) and mean total length ($\bar{l}$) according to the equation: $K = 100\ \bar{w}/\bar{l}^3$.

Correction factors for preservation in 5% formalin and 70% ethanol were determined from measurements of 40 glass-eels held in each preservative. These glass-eels were initially measured and

Table 2.1 Monthly collecting regime for first riffle samples of glass-eels : hand-netting (H), electrofishing (E).

Sampling Locality		Month											
		J	F	M	A	M	J	J	A	S	O	N	D
North-east													
Ansons River	1977	-	-	-	-	-	-	-	-	-	-	H	-
	1978	-	-	H	H	H	-	H	-	H	H	H	-
	1979	H	-	H	-	H	-	H	-	-	H	-	-
	1981	-	H	H	-	-	H	-	H	-	H	-	-
Scamander River	1978	-	-	E	E	E	-	E	-	E	E	E	-
	1979	E	E	E	-	-	-	E	-	-	E	-	-
	1981	-	E	E	-	-	E	-	E	-	-	-	E
East													
Douglas River	1977	-	-	-	-	E	-	-	-	-	-	-	-
	1978	E	E	E	E	E	-	E	-	E	E	E	-
	1979	E	E	E	-	-	E	-	-	-	E	-	-
	1981	-	E	E	-	-	E	-	E	-	E	-	E
Meredith River	1977	-	-	-	-	H	H	-	-	-	-	H	-
	1978	H	H	H	H	H	-	H	H	H	H	-	-
	1979	H	-	H	-	-	-	H	-	-	H	-	-
South-east													
Prosser River	1977	-	-	-	-	H	-	-	-	H	-	-	H
	1978	-	-	-	-	-	-	H	H	H	H	H	-
	1979	H	-	H	-	-	-	H	-	-	-	-	-
	1981	-	H	H	-	-	-	-	H	-	-	-	-
Jordan River	1977	-	-	-	H	H	-	-	-	H	H	-	-
	1978	-	-	-	-	-	-	-	-	H	-	-	-

There is no P.15

weighed, anaesthetised in a 2% w/v solution of tricaine methanesulfonate. The eels were then individually labelled, placed in preservative and measured at regular intervals for a total period of 360 days.

Otoliths were removed and mounted whole in 'Depex' under a cover slip and viewed against a black background under reflected light from a fibre optic light source. Measurements were taken using an eye-piece graticule at 100x magnification.

2.3 RESULTS

2.3.1 Species Identification

Schmidt's index (Schmidt 1928) 100(A-D)/l, where A-D is the distance between the vent and the front of the dorsal fin (the value is negative when the origin of the dorsal fin lies behind the vent), and l is the total length, was used to separate the glass-eels into long-finned (A. reinhardtii) and short-finned (A. a. australis) species. A sample of 309 glass-eels from the Ansons and Douglas Rivers gave no overlap in the values of this index for the two species (Table 2.2). For A. reinhardtii the mean is 0.89% (n=120) and for A. a. australis the mean is 9.72% (n=189).

2.3.2 Time of Arrival

Pooled records of long-finned glass-eel (longfin) and short-finned glass-eel (shortfin) catches for the first riffle, together with water temperature records from all sampling streams are illustrated in Fig. 2.2. Longfins were recorded from mid-February until mid-July at water temperatures from 22^{o}C to 4.5^{o}C.

Table 2.2 Frequency of Schmidt's index for a sample of glass-eels from the Ansons and Douglas rivers (n = 309).

Species	Schmidt's index (%)													
	$^{-}2$–$^{-}1$	$^{-}1$–0	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
A. a. australis	3	13	80	78	14	1	-	-	-	-	-	-	-	-
A. reinhardtii	-	-	-	-	-	-	-	-	-	3	17	52	42	6

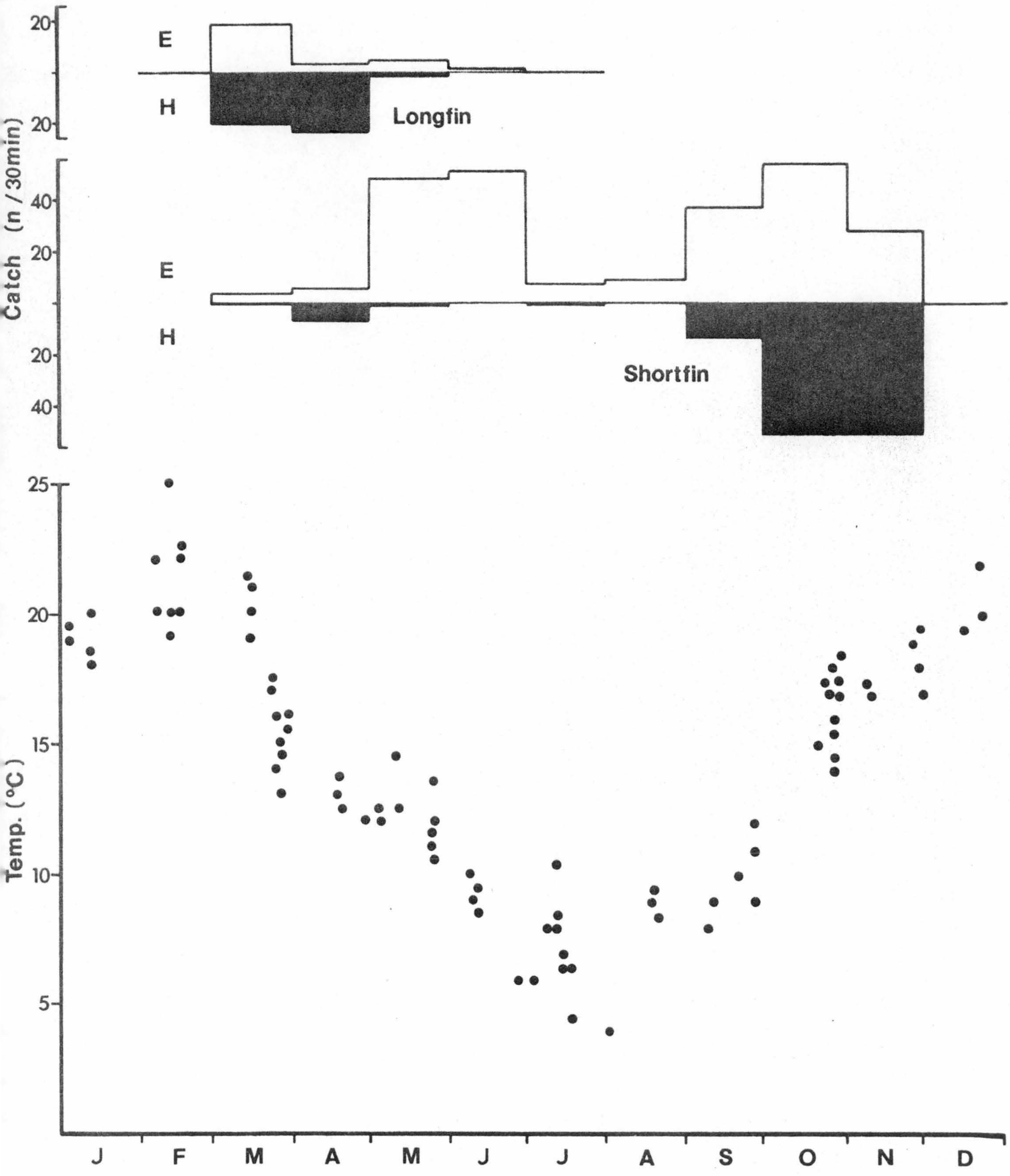


Fig. 2.2

Monthly glass-eel catch, A. reinhardtii (Longfin) and A. australis australis (Shortfin), for all first riffle samples and pooled water temperature (Temp.) records for all streams; electrofishing samples (E), hand-net samples (H).

Shortfins were recorded from mid-March until mid-December at water temperatures from 22°C to 4°C. The average numbers of glass-eels taken in each sample (Fig. 2.2) indicate that longfins were most abundant during March and April, whereas shortfins were plentiful during autumn and early spring with numbers in the catch declining during mid-winter (July and August).

The earliest records of longfins and shortfins for each region were as follows:

North-east (Ansons River): longfins and shortfins; 14 March
East (Douglas River): longfins; 20 February, shortfins; 26 March
South-east (Prosser River): longfins; 29 March, shortfins; 28 April

The highest proportion of longfins in the catch occurred early in the year and longfins predominated in samples taken during March and April in all regions (Table 2.3). The relative proportion of shortfins in the catch increased during the later months with August to December samples being entirely shortfins. Longfins were found to be more abundant in the North-east with numbers in the catch declining further south. Both species were recorded at all sample stations except the Jordan River where only shortfins were found.

2.3.3 Pigmentation

In general, the glass-eels collected conformed to the stages of pigmentation development outlined by Strubberg (1913). Some difficulties did arise when dividing the material into substages, but this must be expected within any classification based on a continuum. Where Strubberg's scale refers to pigmentation advancement in relation

Table 2.3 Monthly percentage frequency of A. reinhardtii (LF) and A. australis australis (SF) in the total glass-eel catch at the first riffle for each region : number of glass-eels (n); number of samples (N).

	North-east				East				South-east			
	N°	% LF	% SF	n	N°	% LF	% SF	n	N°	% LF	% SF	n
Jan.	2	-	-	0	4	-	-	0	1	-	-	0
Feb.	3	-	-	0	4	100	-	4	1	-	-	0
Mar.	6	85	15	158	5	97	3	107	2	100	-	2
Apr.	2	81	19	57	2	47	53	15	1	20	80	15
May	3	43	57	28	4	8	92	62	2	6	94	215
Jun.	2	-	100	48	2	5	95	42	1	3	97	97
Jul.	4	50	50	4	4	50	50	4	1	3	97	38
Aug.	2	-	-	0	2	-	-	0	2	-	100	37
Sep.	2	-	100	74	2	-	100	25	4	-	100	148
Oct.	5	-	100	368	5	-	100	154	2	-	100	82
Nov.	3	-	100	121	2	-	100	55	1	-	100	8
Dec.	1	-	-	0	1	-	100	1	1	-	-	0

to the position of the dorsal fin, shortfins had to be treated as 'imaginary' longfins. In the present study, Strubberg's four substages of VI.AII and VI.AIV have been combined to form two substages in each category and the three substages of VI.AIII have been treated as one to form a classification based on the stages V.B, VI.AI, VI.AII (1-2), VI.AII (3-4), VI.AIII (1-3), VI.AIV (1-2), VI.AIV (3-4) and VI.B; this abbreviated scale was used by Ege 1939. At the earliest stage of pigmentation encountered, stage V.B, the only superficial (associated with the skin) pigment spots are at the extreme tip of the tail and on the upper side of the snout. Glass-eels at this early stage are also characterized by an internal system of black chromatophores following the spinal column and a distinct 'tache cérébale' (Gilson 1908) on the dorsal surface of the head. Superficial pigment gradually spreads forward from the tail, along the back, then along the myosepta. The myoseptal pigment later doubles and eventually inter-myoseptal pigment spreads until at stage VI.B the original myoseptal arrangement becomes indistinct (Strubberg 1913).

Although stage VI.B is strictly no longer a glass-eel according to the earlier definition, this stage has been included in Tables 2.4, 2.5 and 2.6. Forty glass-eels preserved in 5% neutral formalin for 360 days showed no apparent shift in pigmentation stage; it has been assumed therefore, that the preservation of material did not affect the classification of pigmentation.

In all regions, the stage of pigmentation at the first riffle advanced as the season progressed (Tables 2.4 and 2.5),

Table 2.4 The number of A. australis australis glass-eels in successive pigmentation stages for all first riffle samples from each region, by month : pigmentation stages modified after Strubberg (1913).

Month	V.B.	VI.AI	VI.II (1-2)	VI.AII (3-4)	VI.AIII (1-3)	VI.AIV (1-2)	VI.AIV (3-4)	VI.B
North-east								
Mar.	8	6	8	1	-	-	-	-
Apr.	-	-	-	1	9	1	-	-
May	1	3	-	-	11	1	-	-
Jun.	6	18	8	9	3	4	-	-
Jul.	1	-	-	-	-	1	-	-
Sep.	-	-	1	4	45	23	1	-
Oct.	-	-	-	1	20	164	148	35
Nov.	-	-	-	-	1	30	74	16
East								
Mar.	-	-	-	-	2	1	-	-
Apr.	-	-	-	-	5	1	1	-
May	5	5	7	7	24	6	3	-
Jun.	-	6	4	3	9	10	8	-
Jul.	-	1	-	-	-	1	-	-
Sep.	-	-	1	1	19	4	-	-
Oct.	-	-	-	-	7	49	77	21
Nov.	-	-	-	-	-	2	18	35
South-east								
Apr.	-	-	-	5	5	2	-	-
May	6	64	14	15	64	20	19	-
Jun.	21	29	30	7	4	3	-	-
Jul.	-	7	13	6	11	-	-	-
Aug.	19	4	9	-	5	-	-	-
Sep.	-	15	23	24	72	14	-	-
Oct.	-	-	-	-	3	37	40	2
Nov.	-	-	-	-	-	-	7	1

Table 2.5 The number of A. reinhardtii glass-eels at successive pigmentation stages for all first riffle samples from each region, by month : pigmentation stages modified after Strubberg (1913).

Month	Pigmentation stage							
	V.B.	VI.AI	VI.AII (1-2)	VI.AII (3-4)	VI.AIII (1-3)	VI.AIV (1-2)	VI.AIV (3-4)	VI.B
North-east								
Mar.	31	16	11	4	18	33	20	2
Apr.	-	-	1	-	9	16	16	4
May	-	1	2	-	1	7	1	-
Jul.	-	-	-	-	-	2	-	-
East								
Feb.	2	-	1	-	1	-	-	-
Mar.	1	2	9	9	29	43	11	-
Apr.	-	-	2	2	-	1	1	1
May	-	-	-	-	-	2	3	-
Jun.	-	-	-	-	1	-	1	-
Jul.	-	-	-	-	-	2	-	-
South-east								
Mar.	-	1	1	-	-	-	-	-
Apr.	-	-	-	-	3	-	-	-
May	-	-	-	2	9	2	-	-
Jun.	-	1	1	-	-	1	-	-
Jul.	-	-	1	-	-	-	-	-

Table 2.6 The number of A. australis australis glass-eels at successive stages of pigmentation for samples collected at the Douglas River estuary mouth : pigmentation stages modified after Strubberg (1913).

Date	Pigmentation stage							
	V.B.	VI.AI	VI.AII (1-2)	VI.AII (3-4)	VI.AIII (1-3)	VI.AIV (1-2)	VI.AIV (3-4)	VI.B
11 June 1981	70	-	-	-	-	-	-	-
19 August 1981	20	27	29	20	8	4	-	-
26 October 1981	1	-	1	1	4	3	2	8

particularly so for shortfins after July. This trend is illustrated in Fig. 2.3, where the relative proportions of shortfins in each stage of pigmentation are presented for monthly samples of more than twenty individual glass-eels. Three samples collected at the Douglas River estuary mouth (Table 2.6) represent earlier pigmentation stages than found at the first riffle of streams in the East for comparable monthly samples (cf. Table 2.4).

2.3.4 Length, Weight and Condition

Correction factors determined for preservation in 5% formalin and 70% ethanol were used to convert all glass-eel measurements to live equivalents (Table 2.7). The mean live lengths and weights of shortfins from each region are given in Table 2.8. Fewer glass-eels are represented in Table 2.8 than Table 2.4, as not all samples were completely analysed for individual length, weight and stage of pigmentation. In each region the mean length of shortfins decreased with increased pigmentation from stage V.B. to VI.AIII. Similarly, stage V.B shortfins were the heaviest in all regions with stage VI.AIV, VI.AIII and VI.B being lightest in the North-east, East and South-east respectively. Analyses of variance showed the differences in mean length and mean weight for shortfins at different stages of pigmentation were very highly significant ($p < 0.001$ for length and weight) for each region:

North-east	(length)	$F = 8.27$ d.f.	5/409
	(weight)	$F = 65.30$ d.f.	5/409
East	(length)	$F = 11.08$ d.f.	5/431
	(weight)	$F = 19.77$ d.f.	5/420
South-east	(length)	$F = 17.53$ d.f.	5/550
	(weight)	$F = 32.40$ d.f.	5/508

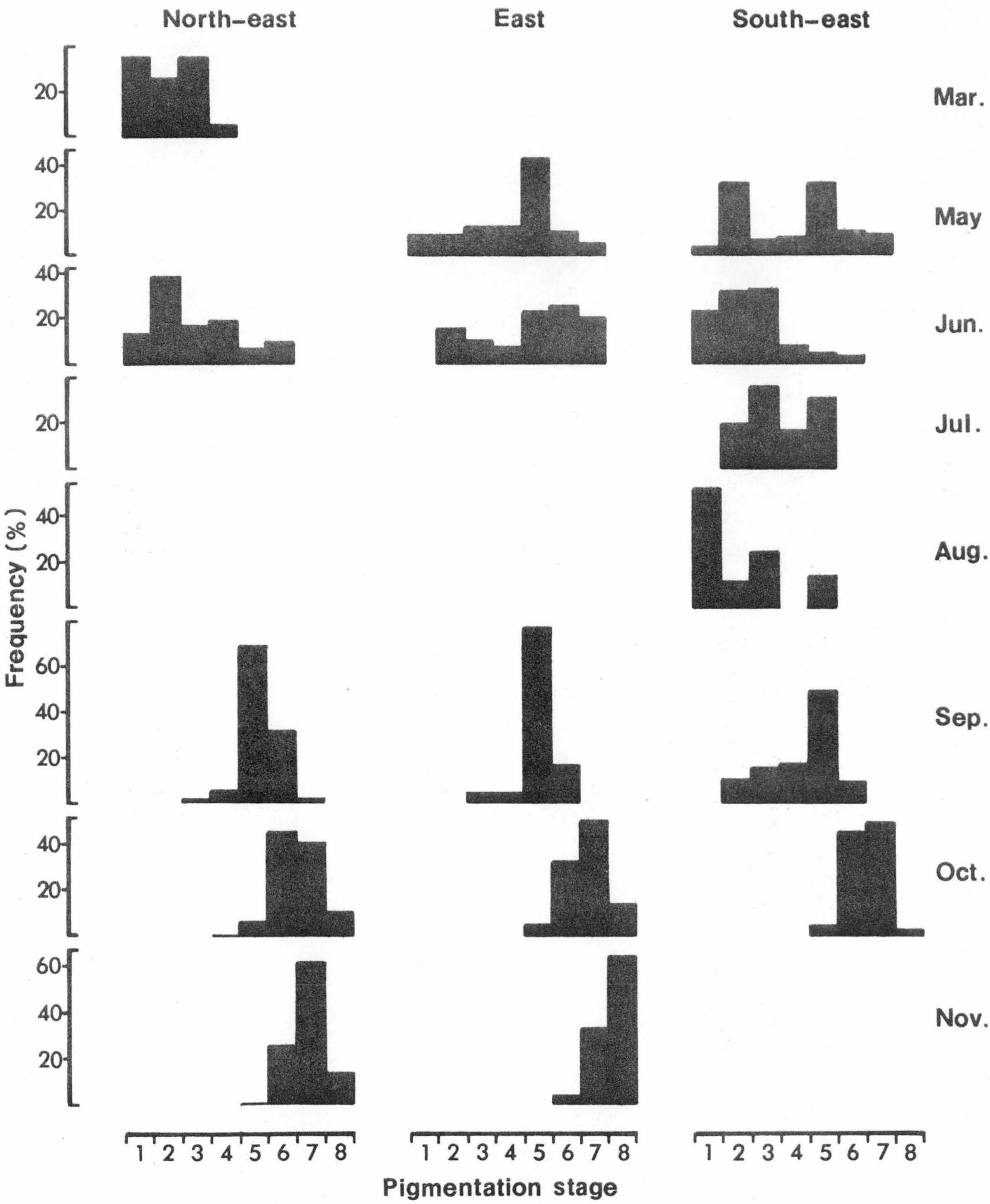


Fig. 2.3

Monthly percentage frequency of pigmentation stages of A. australis australis glass-eels from the North-east, East and South-east regions ($n \geqslant 20$); pigmentation stages modified after Strubberg (1913).

(1)	V.B.	(5)	VI.AIII (1-3)
(2)	VI.AI	(6)	VI.AIV (1-2)
(3)	VI.AII (1-2)	(7)	VI.AIV (3-4)
(4)	VI.AII (3-4)	(8)	VI.B

Table 2.7 Correction factors used to convert preserved glass-eel lengths and weights to live equivalents.

Days in Preservative	70% Ethanol Correction factor		5% Formalin Correction factor	
	Length	Weight	Length	Weight
0	1.00	1.00	1.00	1.00
1	1.06	1.01	1.03	0.90
2	1.05	1.01	1.03	0.95
3	1.05	1.10	1.03	0.96
6	1.05	1.18	1.03	0.97
10	1.05	1.17	1.03	0.97
20	1.06	1.06	1.03	0.99
50	-	-	1.04	1.00
360	-	-	1.04	1.00

Table 2.8 Size of A. australis australis glass-eels at successive stages of pigmentation for all first riffle samples from each region : number in sample (n); mean total length ($\bar{l}$); mean weight ($\bar{w}$) and condition (K). Pigmentation stages after Strubberg (1913).

Region		Pigmentation Stage					
		V.B.	VI.AI	VI.AII	VI.AIII	VI.AIV	VI.B
North-east							
	n	16	27	33	85	211	43
	$\bar{l}$ (cm)	5.98	5.96	5.92	5.70	5.75	5.81
	$\bar{w}$ (g)	0.232	0.225	0.213	0.168	0.144	0.148
	K	1.09	1.06	1.03	0.91	0.76	0.76
East							
	n	93	34	61	55	164	30
	$\bar{l}$ (cm)	5.93	5.71	5.70	5.65	5.78	5.90
	$\bar{w}$ (g)	0.218	0.171	0.164	0.160	0.173	0.188
	K	1.05	0.92	0.89	0.89	0.90	0.92
South-east							
	n	46	119	127	129	132	3
	$\bar{l}$ (cm)	6.14	5.85	5.96	5.74	5.77	6.05
	$\bar{w}$ (g)	0.22	0.17	0.176	0.147	0.147	0.136
	K	0.95	0.85	0.83	0.78	0.77	0.61

Condition factors were highest in the North-east and lowest in the South-east for shortfins in the early stages of pigmentation (V.B and VI.AI) and in all regions condition was found to decline with advancing pigmentation.

The lengths and weights of longfins for all samples have been considered together (Table 2.9) as numbers were not adequate to treat each region separately. The decline in mean length and weight for longfins was less marked, although the trend of declining condition with advancing pigmentation was apparent. Analyses of variance showed no significant difference ($p > 0.05$) in mean length at different stages of pigmentation for longfins ($F = 1.80$, d.f. 5/333) but the differences in mean weight were very highly significant ($p < 0.001$) ($F = 5.17$, d.f. 5/330).

At all stages of pigmentation, shortfins were distinctly longer and heavier than longfins, although a considerable overlap in both range of length and range of weight occurred. The length and weight range for the total collection of glass-eels is given below:
Shortfins, length 4.7 - 6.9 cm (n=1408), weight 0.07 - 0.35 g (n=1355)
Longfins, length 4.45 - 5.95 cm (n=339), weight 0.07 - 0.25 g (n=336)

2.3.5 Otoliths

The otoliths of early stage glass-eels of both species appeared similar when viewed under reflected light, with a dark centre surrounded by a distinct white ring and then a dark margin (Fig. 2.4). Details of the measurement of glass-eel otoliths (Table 2.10) indicate that for shortfins the relative width of the dark otolith margin

Table 2.9 Size of A. reinhardtii glass-eels at successive stages of pigmentation for all first riffle samples from all regions : number in sample (n); mean total length ($\bar{l}$); mean weight ($\bar{w}$) and condition (K). Pigmentation stages after Strubberg (1913).

	Pigmentation Stage					
	V.B	VI.AI	VI.AII	VI.AIII	VI.AIV	VI.B
n	34	21	45	71	162	6
$\bar{l}$ (cm)	5.07	5.07	5.04	5.05	5.08	5.28
$\bar{w}$ (g)	0.134	0.127	0.126	0.119	0.122	0.163
K	1.03	0.97	0.98	0.92	0.93	1.11

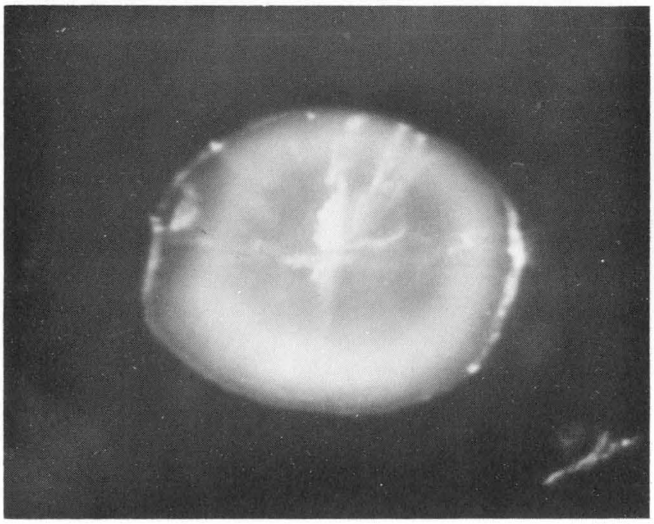


Table 2.10 Relative zone widths of otoliths from A. reinhardtii (Longfin) and A. australis australis (Shortfin) glass-eels, expressed as mean percentage of otolith radius. Pigmentation stages after Strubberg (1913).

Species	Month	Pigmentation stage	Sample number	Mean length (mm)	Mean otolith radius (mm)	Percentage of radius: Dark centre	White ring	Dark margin
Longfin	March	VI.AIII-VI.AIV	9	52.3	0.16	50	25	25
Shortfin	April	V.B-VI.AII	6	60.3	0.16	63	25	12
	June	V.B	8	57.4	0.15	60	27	13
	August	V.B-VI.AI	5	58.2	0.15	57	27	16
	August	VI.AII-VI.AIV	6	56.7	0.15	53	27	20
	October	V.B-VI.AIII	7	56.8	0.17	54	23	23
	October	VI.AIV	11	56.5	0.17	52	23	25*
	November	VI.AIV	3	61.3	0.19	48	21	31*

* Outer zone beginning to differentiate into white margin

increased from 12% of the otolith radius in April to 23% in October; the margins of well pigmented shortfins in October and November had begun to form a white edge indicative of differentiation into summer growth.

2.4 DISCUSSION

In Tasmania glass-eels move into fresh water during most months of the year. Shortfins can be found at the first riffle from mid-March to late December, whereas longfins exhibit a more restricted migration from mid-February to July. Ege (1939) recorded the ascent of A. reinhardtii from the sea into fresh water during February - April near Sydney and from April to July in New Caledonia. He recorded the ascent of A. australis in New South Wales at the Paramatta River from February to April, and at Maroubra Bay in August and November. Schmidt (1928) recorded A. australis glass-eels near Sydney in September; Castle (1963) described two specimens from the same locality in June. These records suggest a similar period of migration into fresh water for A. reinhardtii glass-eels in Tasmania, New South Wales and New Caledonia (February - July) and a similar migration period for A. australis glass-eels in New South Wales and Tasmania (February - November).

The time delay between the invasion from the sea and arrival at the first riffle is of interest. Jellyman (1977c, 1979a) suggested a transition period of about two weeks between invasion and migration into fresh water. He found that freshly invading glass-eels were approximately 90% stage V.B, whereas those migrating upstream were predominantly stages VI.AII and VI.AIII. In Tasmania the invasion of shortfins from the sea must take place at least from March to October as indicated by the catches at the Douglas River mouth and the early stages of pigmentation (V.B. and VI.AI) represented in the first riffle samples. Longfins appear to invade from the sea mainly during February, March and April.

In Victoria, Beumer and Harrington (1980) have reported that shortfins migrate from the sea into estuaries from May onwards and longfins enter estuaries from January to late May; essentially the same period as the Tasmanian invasion.

No clear relation is apparent between riverine water temperatures in Tasmania and the movement of glass-eels into fresh water. Longfins were caught at the first riffle predominantly during periods of high water temperature early in the season but small numbers were recorded at water temperatures as low as 4.5°C. The catch of shortfins at the first riffle dropped markedly during July and August when the lowest stream temperatures were encountered (Fig. 2.2).

Studies have shown that European glass-eels (A. anguilla L.) move into fresh water when the temperature reaches 6-8°C (Deelder 1952; Tesch 1971; McGrath 1976) and Matsui (1952) found that Japanese glass-eels (A. japonica) are caught in rivers when temperatures no longer fall below 8-10°C. Jellyman (1977c) found no evidence of a threshold temperature for invasion of New Zealand glass-eels (A. a. schmidtii and A. dieffenbachii) from the sea but suggested that sudden cold periods may interrupt invasion.

The pattern of water flow in Tasmanian east coast streams may well play an important role in restricting the period of invasion as these streams are characterised by low flows during December, January and February and river mouths are often barred by sand during these months. In mid-winter high river flows may again restrict movement into streams by effectively moving the freshwater/estuarine interface further seaward. The apparent delay between invasion from the sea and migration into fresh water, which has already been discussed, has been associated with a period of physiological adjustment to a lower saline medium (Creutzberg 1961). Deelder (1958) found that high freshwater discharges reduced salinity and effectively pushed the transition area further seaward. This may explain the poor glass-eel catches recorded at the first riffle during July and August in the present study. Samples collected at the Douglas River mouth indicate that glass-eels are abundant in Zostera beds at this time and invasion from the sea must be continuing.

The advance in pigmentation recorded for late season glass-eels of both species in the first riffle samples may reflect two factors. Firstly an accumulation of glass-eels at the first riffle during the season, the eels becoming progressively more pigmented with time spent in fresh water, and secondly, the arrival of eels later in the season which may be more pigmented due to an extended post-metamorphic sea life as suggested by Jellyman (1977c). The increase in the number of shortfins in the later stages of pigmentation (VI.AIV and VI.B) was particularly evident in October and November. This probably reflects the faster pigment development recorded by Strubberg (1913) at increased temperatures.

Any seasonal or annual variation in size of glass-eels has not been considered here, but a decline in weight, length and condition from stage V.B to VI.AIII was found for shortfins. Tesch (1977) reported length reduction to stage VI.AIII for A. anguilla irrespective of food intake. This shrinkage of glass-eels on entry into fresh water has been reported elsewhere (Strubberg 1913, 1923; Menzies 1936; Matsui 1952; Vladykov 1970) and has been related to completion of metamorphosis. Although a decline in condition from stage V.B to VI.AIII was evident for longfins, there was no significant change in mean length, suggesting growth may have resumed at an earlier stage. Similarly, Ege (1939) reported that resumption of growth had taken place at an early stage for a sample of longfins from the Paramatta River.

The higher condition factors recorded for shortfins in early pigmentation stages (V.B - VI.AII) in the North-east are more difficult to explain. Hydrographic conditions of the water where the last part of the larval life and the period of metamorphosis occur may be important. The sea to the north-east of Tasmania has a higher temperature regime than eastern and south-eastern waters (Rochford 1975), and warmer waters may enable glass-eels to maintain condition. The length of post-metamorphic sea life may also be a major factor with poorer condition glass-eels entering streams further from the region of the onset of metamorphosis. Strubberg (1923) explained the inferior weight of North Sea and Nile glass-eels compared with those from Western Europe in terms of longer migrations in the pelagic or semi-pelagic stages.

The distance from the region of the onset of metamorphosis should also be reflected in the region of first arrival of glass-eels. The earliest record of shortfins at the first riffle from the North-east region was 14 March and the earliest arrival in the South-east region was 28 April. This may well indicate that metamorphosis occurs to the north of Tasmania with North-east rivers receiving the earliest and best conditioned glass-eels. The data were not sufficient to make similar comparisons for longfins.

The different invasion periods recorded for longfins and shortfins in Tasmania and the difference in their adult distribution on the Australian mainland (see McDowall & Beumer 1980) casts interest on their likely origins and the means of their dispersal. It is reasonable to assume that the leptocephalus is the dispersal stage of the Australian and New Zealand eels and that the East Australian Current must play a major role in distributing the Australian forms at least. Unfortunately, mapping the size distribution of the leptocephali at sea in order to determine the likely breeding areas (cf. Schmidt 1925) has not been possible for south-west Pacific eels due to the paucity of larval collections (Jespersen 1942; Castle 1963).

The length of sea life is an important factor which must be considered in order to discuss larval distribution. Tasmanian glass-eel otoliths of both species exhibit one opaque summer ring as distinct from the two summer rings associated with a 2½ year sea life for the European eel (Sinha & Jones 1967a, 1975). Jellyman (1974) found only one summer ring in the otoliths of New Zealand glass-eels and postulated that invading glass-eels in July would have spent one summer at sea and would be about 1½ years old. Similarly, if a summer spawning season is assumed for south-west Pacific Anguilla spp., then shortfins arriving in Tasmania in July are probably also about 1½ years old. Longfins and early season shortfins arriving late in summer would be little more than 1 year old.

It is reasonable to assume that, as the leptocephalus grows with age, then these larvae and consequently the invading glass-eels further from the breeding grounds, will be larger (cf. Vladykov 1966). In this manner, consideration of the mean size of glass-eels may provide some insight into their origins and pattern of dispersal. Schmidt (1928) mentioned a small sample of some 'fairly young elvers' of A. australis from Long Bay near Sydney collected 29 September, length 4.7-5.7 cm (VI.AIII). Ege (1939) gave details of a sample of A. australis from Maroubra Bay, New South Wales collected 14 August, length 5.35 cm (n=108, Stage VI.AII - VI.AIV) and Castle (1963) described two specimens of A. australis from a rock pool near Sydney collected 12 June, length 5.25 and 5.79 cm. Schmidt (1928) examined four specimens of A. reinhardtii collected 12 March near Sydney, length 4.55-4.80 cm. Ege (1939) reported a sample of A. reinhardtii from the Paramatta River, New South Wales collected 19 February, mean length 4.98 cm (n=73, Stage VI.AII (1-2) and from New Caledonia on 11 March, length 5.02 cm (n=73, Stage VI.AI-VI.AIV). As the size of glass-eels varies with stage of pigmentation, with season and from year to year as well as with the strength and type of preservative and the time spent therein (Strubberg 1923), small differences in size will not be biologically meaningful when comparing the mean size of different samples, so only the major trends should be considered.

The expected trend for A. australis is apparent with larger glass-eels entering Tasmanian streams than those found in New South Wales. This suggests that Tasmania is more distant from the breeding grounds and the larvae are probably distributed by the East Australian Current. In fact, the smallest reported A. australis glass-eels, assigned to the New Zealand sub-species by Ege (1939), were collected at New Caledonia (mean length 5.08-4.89 cm, Stage V.B-VI.AIV). Jellyman (1974) recorded mean lengths of A. australis schmidtii from New Zealand. The mean lengths for North Island samples (5.91-6.01 cm, Stage VI.AII) are very similar to the size of similar stage A. a. australis glass-eels recorded in Tasmania and the mean lengths for the South Island (6.11-6.18 cm, Stage VI.AII) are slightly larger.

The collections of A. reinhardtii indicate that glass-eels enter Tasmanian waters at essentially the same size as they do in New South Wales and New Caledonia and thus, longfins do not conform to the same pattern as shortfins. It seems that the developmental time for shortfin and longfin larvae must be a critical factor in determining distribution and size at invasion. Tesch (1977) emphasised the importance in developmental time in explaining that Bermuda is populated by A. rostrata, although larvae of A. anguilla predominate in the surrounding sea. If it is assumed that A. reinhardtii has a short and precise larval life of about 12 months, then glass-eels might be expected to migrate into fresh water, producing similar size individuals along the whole eastern seaboard of Australia during late summer. The Tasmanian east coast must represent the furthest southward movement of this species, resulting in a limited invasion season at the peak of warm water influence. The longfin invasion (February - April) occurs when the influence of water of sub-tropical origin (20-21°C) is at its greatest off the east coast of Tasmania (Rochford 1975), suggesting that transportation of larvae by the East Australian Current is most likely. On the other hand, the larval life of A. a. australis is probably quite variable (12-20 months) resulting in a more substantial and prolonged glass-eel influx into Tasmanian waters (March - December).

The fact that longfins entering Tasmanian rivers are smaller than shortfins at the same time of year may reflect an earlier spawning season for the short-finned eel or a slower growth rate of long-finned larvae at sea. Tesch (1977) suggested that the larger size of American eel larvae compared to European eel larvae at the same time of year is probably due to the American eel spawning four weeks earlier.

Cairns (1941) and Castle (1969) have suggested that leptocephali of the New Zealand eels are most likely distributed by the East Australian Current and arrive off the south-west coast of New Zealand. However, Jellyman (1974) concluded from his analysis of mean size of invading glass-eels that the invasion route may be from the north via the Trade Wind Drift. The similar size of A. australis glass-eels entering Tasmania and North Island of New Zealand streams, their similarity in length of sea life and the more restricted invasion season in New Zealand, all indicate that transportation of the New Zealand larvae by the East Australian Current is unlikely. This view is strengthened by the absence of A. reinhardtii from New Zealand, of A. dieffenbachii from Australia and by the existance of a mean vertebral difference of one vertebra which led Schmidt (1928) to regard the Australian and New Zealand shortfins as separate sub-species. Both Ege (1939) and Schmidt (1928) considered this meristic difference to reflect geographical separation of the spawning areas of the two sub-species.

If the New Zealand Anguilla larvae are distributed by the East Australian Current it is difficult to rationalize the means by which A. dieffenbachii avoids entering streams on the eastern seaboard of Australia (particularly those of Victoria and Tasmania) especially when the apparent vagaries of this current system are considered (cf. Highley 1967; Boland & Hamon 1970; Boland 1973; Rochford 1975). It seems more likely that only the larvae of the Australian forms are distributed by the East Australian Current.

Chapter 3

UPSTREAM MIGRATION OF YOUNG PIGMENTED FRESHWATER EELS (*ANGUILLA* SPP.) IN TASMANIA

3.1 INTRODUCTION

The mass upstream migration of elvers (pigmented young eels) is a phenomenon which has been well documented for northern hemisphere Anguilla spp. (see Tesch 1977) and in New Zealand such migrations are also well known (Cairns 1941; Woods 1964; Jellyman 1977b). Although cursory observations of eel-fares have been reported from mainland Australia (e.g. Kershaw 1911; Whitley 1929; Walford 1930; Mann 1979) there has been no thorough documentation of the timing, species composition, quantities, size and age of eel migrants. In Tasmania, Anon. (1948) reported an observation of an upstream migration of young eels at Waddamana Power Station but gave no details of the time of year or the size of eels involved.

In view of the importance of elver migrations, serving to replenish eel stocks in inland waterways, the Tasmanian Inland Fisheries Commission has undertaken a pilot scheme to transfer elvers upstream at major hydro-electric dams (Sloane 1978b, 1981). Details of these elver catches and of catches made at other localities throughout Tasmania are presented in this chapter.

3.2 MATERIALS AND METHODS

At Trevallyn Power Station on the upper Tamar estuary (Fig. 3.1) in northern Tasmania, elvers congregate in the 'stop-log pits' below the turbines. During the summers of 1977-78 and 1978-79 elver traps were installed in the 'stop-log gallery' inside the power station. Initially three traps were used, each consisting

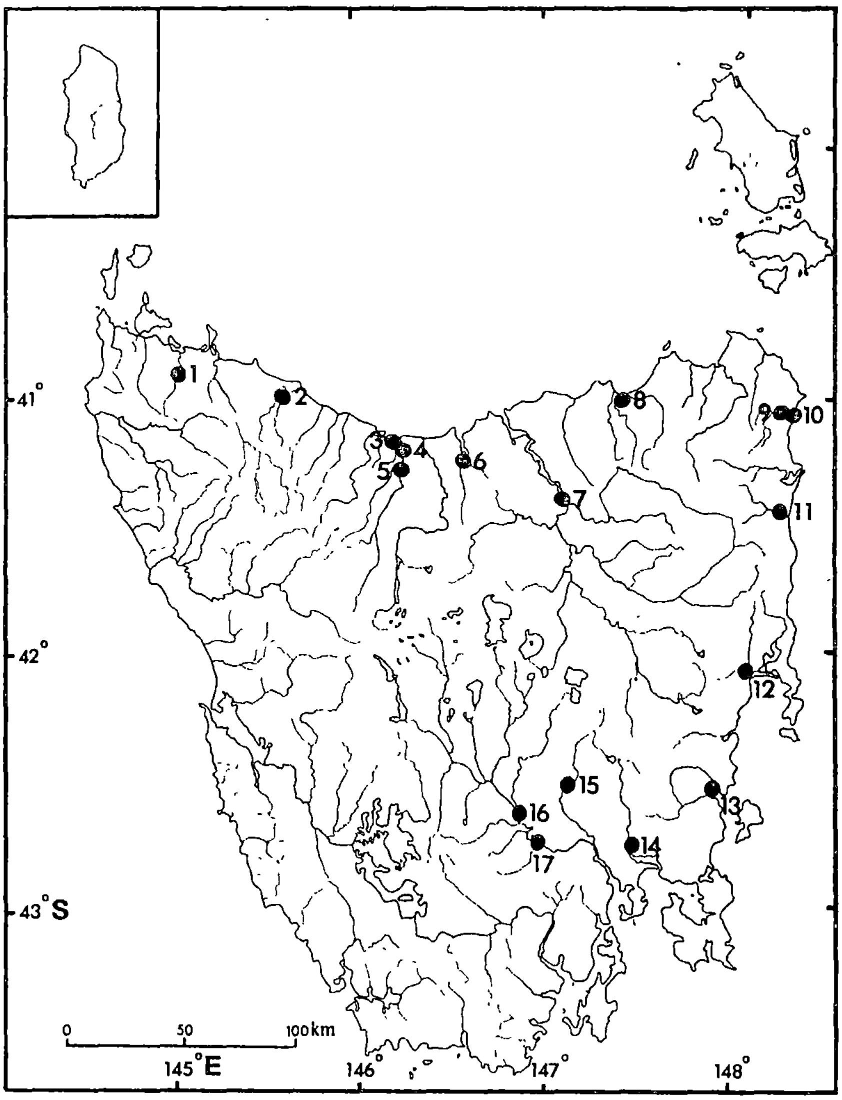


Fig. 3.1

Map of Tasmania showing elver sampling localities:

(1) Duck River weir
(2) Inglis River weir
(3) Buttons Creek weir
(4) Forth River weir
(5) Paloona Dam
(6) Rubicon River weir
(7) Trevallyn Power Station
(8) Brid River weir
(9) Ansons River weir
(10) Ansons River ford
(11) Scamander River weir
(12) Meredith River weir
(13) Prosser River
(14) Coal River weir
(15) Jordan River weir
(16) Meadowbank Dam
(17) Plenty River weir

of a netting ladder inside a 20 cm diameter P.V.C. pipe and a 200 l catching drum. The netting was draped into the water in the stop-log pits and a trickle of fresh water was passed down, with a small fraction splashing back into the catching drum. Elvers followed the running water, climbed the ladder inside the pipe and fell into the catching drum at the top. This type of trap was most successful at high tide when the tidal fluctuation in the stop-log pits reduced the climb to between two and three metres. The catching drums were generally emptied once each day, but during peak periods of migration, the drums were emptied more frequently (often two or three times during each high tide), to prevent elvers from suffocating. This system was modified in 1978-79, with two ladders leading to one 500 l recirculating catching tank. The elvers were strained through a net basket (1 mm mesh), weighed, carried out of the power station and transported to liberation points by road, using an oxygenated 1 000 l tank.

During the 1980-81 and 1981-82 summers the transfer programme was again modified and elvers were pumped from the stop-log pits at high tide during peaks in the run. The pump used was a 'Jet Ejector' model which has no moving parts and operates by suction created by water being forced into a compression chamber and thence into a delivery tube through jets; suction occurs in the delivery tube behind the jets, drawing material through the delivery pipe. In this manner, water (containing elvers) was pumped out of the stop-log pits, and the delivery tube was fed into a large basket which retained the elvers.

On the Derwent River in southern Tasmania, elvers congregated near an outlet pipe at the base of Meadowbank Dam where turbine cooling water enters the river. Here, the elvers were scooped up with dip nets, weighed and transported above the dam in an oxygenated 500 l tank. This transfer has been conducted each summer since 1979-80.

At other locations around Tasmania (Fig. 3.1), samples were collected by hand-net as the elvers climbed small artificial barriers (Coal River weir; Jordan River weir; Brid River weir; Ansons River ford). Elvers were scooped up using dip nets as they congregated near an upwelling of water below the power station tailrace at Paloona Dam. Samples were also collected by electrofishing below stream barriers where only small numbers of elvers could be collected by hand (Forth River weir; Duck River weir; Rubicon River weir; Scamander River weir; Ansons River weir).

At the Plenty River weir, elver samples and daily catch records were obtained during an upstream fish trap monitoring programme which has been described elsewhere (Sloane, in press). Flow data were obtained from the Tasmanian Rivers and Water Supply Commission and water temperatures were recorded each morning (0 800 h) at the Salmon Ponds trout hatchery, 2 km above the trap site.

Elver samples were preserved in 5% neutral formalin or anaesthetised in a 2% w/v solution of tricaine methanesulfonate and then frozen. The total length (to the nearest 0.5 mm) and blotted weight (to the nearest 10 mg) were measured for each individual.

Correction factors for the lengths and weights of elvers measured after preservation in formalin were determined by calculating the deviation from live length and weight for 40 individial elvers over a 30 day period (Table 3.1).

Otoliths were removed (frozen elver samples only) and ground using fine carborundum powder, then polished on a grinding glass lubricated with machine oil. The ground otoliths were mounted in 'Depex' and viewed against a black background under reflected light from a fibre optic light source.

3.3 RESULTS

3.3.1 Occurrence and Period of Migration

The elver run at Trevallyn Power Station commenced between 10 and 15 November during five consecutive years, 1977-81. The run was followed through to completion in 1979 and no eels were caught after 21 March. At Meadowbank Dam, some 44 km above tidal influence, the run of elvers commenced on 18 December 1978, early in December 1979 (exact start not recorded), 15 December 1980 and 8 December 1981. The number of elvers at Meadowbank diminished early in March during each of these years. At the Plenty River fish trap, elvers were only recorded from 28 November 1978 until 25 January 1979, although the trapping period spanned sixteen months from May 1978.

Elvers were seen climbing wet wall faces at stream barriers on the following occasions; Duck River weir (29 January 1981, 13 January 1982); Inglis River weir (27 January 1981); Buttons Creek weir (27

Table 3.1 Correction factors used to convert preserved elver lengths and weights to live equivalents.

Days in Preservative	5% Formalin Correction factor	
	Length	Weight
0	1.00	1.00
1	1.01	0.96
5	1.01	1.03
10	1.01	1.05
15	1.01	1.09
30	1.01	1.10

January 1981); Forth River weir (14 January 1982); Rubicon River weir (14 January 1982); Brid River weir (10 February 1981); Ansons River weir (18 January 1982); Scamander River weir (18 January 1982); Meredith River weir (6 February 1979); Coal River weir (11 November 1981); Jordan River weir (11 and 22 December 1978, 12 January 1979).

Elvers were found actively swimming upstream and congregating below road culverts at the Ansons River ford during daylight hours on 8 November 1977, 30 October 1978, 29 November 1978, 30 October 1979 and 27 October 1981. This ford forms the upper limit of tidal influence on the Ansons River. Similarly, elvers were seen actively swimming upstream through rocks at the upper limit of tidal influence on the Prosser River on 29 October 1978.

3.3.2 The Ascent

At Trevallyn and Meadowbank, elvers could be seen climbing during daytime but were generally more abundant at night. In the stop-log pits at Trevallyn it was found that catches could be more than doubled by turning out the lights in the stop-log gallery. At the smaller weirs, elvers were usually observed late in the afternoon (after sunset) and by torch light at night. Elvers generally entered the Plenty River trap at night, but during peak periods of catch in January, they could be seen migrating during daylight hours.

Elvers were often seen several metres above water level, climbing the wet concrete walls of the stop-log pits at Trevallyn and they experienced no apparent difficulty climbing the net bundle to enter the catching drums. At Paloona Dam and Meadowbank, after rain, elvers made their way up to 20 metres above the normal catching area by climbing along cracks and crevices in the concrete walls.

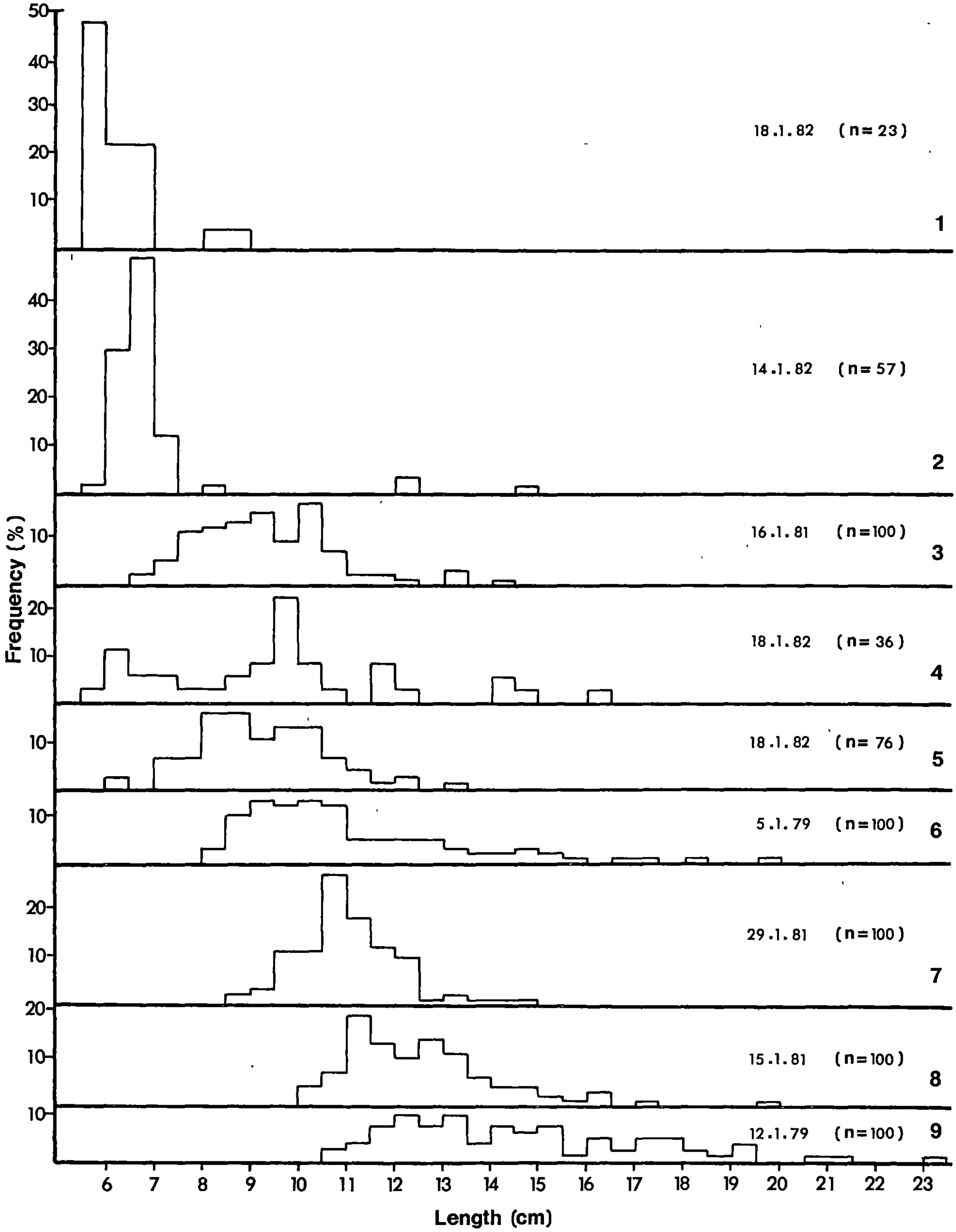
Elvers were observed as they struggled to negotiate small stream barriers, and in general, river flow gauging weirs proved the most difficult obstacles to surmount. Elvers would climb out of the water in the splash zone where the concrete surfaces were damp, but they could not re-enter the water crossing the sharp steel gauging lip. The 'V notch' type gauging weirs proved to be insurmountable to elvers under dry weather conditions. Only after rain could the elvers pass upstream by climbing around the concrete weir abutments, thus avoiding the steel lip.

3.3.3 Species Composition

Examination of many thousands of migrating elvers collected on the above mentioned occasions resulted in the identification of only a single specimen of A. reinhardtii, recorded at Meadowbank Dam on 27 February 1981 amongst a sample of 76 A. a. australis. All other elver samples consisted entirely of shortfins.

3.3.4 Length of Elvers

In general, the further inland the stream barrier, the larger were the migrating elvers at the same time of year (Fig. 3.2). This was particularly marked, even in the first few kilometres of a stream as the two samples from the Ansons River illustrate. The size of the estuary (or distance from the open sea) also appeared to be important; where three stream barriers (Ansons, Rubicon and


18.1.82 (n= 23)
1
14.1.82 (n= 57)
2
16.1.81 (n=100)
3
18.1.82 (n= 36)
4
18.1.82 (n= 76)
5
5.1.79 (n=100)
6
29.1.81 (n=100)
7
15.1.81 (n=100)
8
12.1.79 (n=100)
9
Frequency (%)
Length (cm)

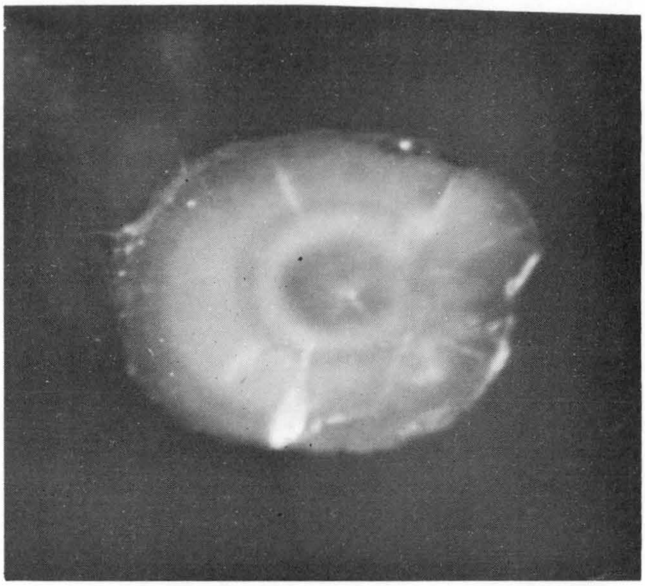
Trevallyn) are situated near the upper limit of tidal influence, the migrating elvers were larger where the distance from the open sea is greater (Fig. 3.2).

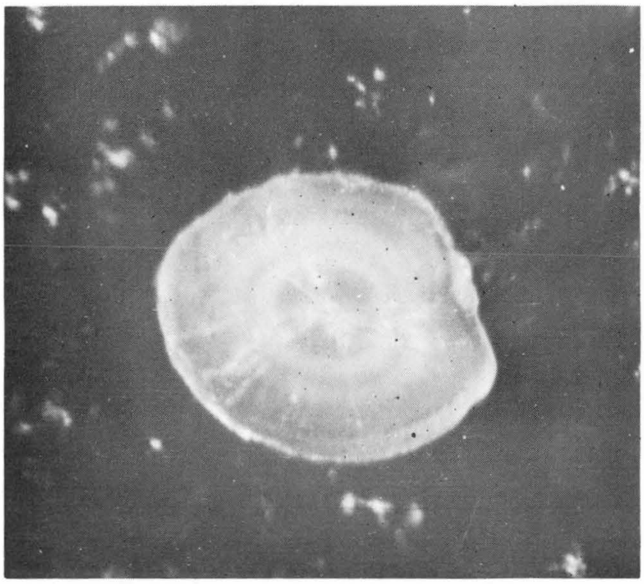
At barriers located near the estuary ($\leqslant$ 6 km inland) elvers less than 10 cm long were found to predominate. At barriers located more than 6 km inland, elvers larger than 10 cm in length predominated and the length range of elvers increased. Few elvers larger than 25 cm in length were normally involved in such migrations.

3.3.5 Elver Size and Age

When viewed under reflected light, the normal appearance of the otolith 'origin' exhibited by a shortfin elver is a dark centre surrounded by one broad white ring, indicative of sea life (v. 2.3.5). However, a small proportion (about 5.0%) were found to possess a different 'origin', with a dark centre and a broad white ring surrounded by a narrow indistinct dark zone and then a narrow second white ring (Fig. 3.3). This second narrow ring gives the otolith centre a similar appearance to that of the European eel (A. anguilla) which represents a 2½ year sea life (Sinha & Jones 1967a). This suggests that a number of Tasmanian shortfins may spend an extra year at sea, but it seems more likely that this second ring is formed as a result of some late summer growth of the earliest arriving shortfin glass-eels which may enter streams as early as March and April (v. 2.3.2).

If Tasmanian eels are assigned a 1 October birthdate as Jellyman (1979b) suggested for New Zealand eels, then age group





0 will refer to those eels which have not spent one full year in fresh water and this will include glass-eels which may have arrived as early as the previous March.

The length increase in elvers observed further inland, was also reflected in increased weight and age (Table 3.2). In general, the length frequency data did not clearly separate age groups and this is indicated by the overlap of length and weight ranges. Age group 0 elvers were only found at barriers near the upper limit of tidal influence and even here age groups 1, 2, 3 and 4 were represented. Further inland, age groups 2, 3 and 4 became more important and eels up to 10 years old were found to participate in summer upstream migrations.

3.3.6 Seasonal Changes in Elver Size and Age

Elver catches from Trevallyn and Meadowbank were analysed in order to investigate changes in the size and age of elvers during the migration season. At Trevallyn (Fig. 3.4) age group 0 elvers were only represented in significant numbers early in the season, with groups 1 and 2 being dominant in all samples taken during 18 November 1980 and 14 February 1981 inclusive. At Meadowbank (Fig. 3.5) age group 2 was the youngest year class represented and this group became numerically more important as the season progressed, whereas age groups 4 and 5 became less represented as the season progressed. At both locations, growth in each age group is indicated by a shift in the length distribution of each year class and by a change in mean length and mean weight of the dominant year groups during the migrating season (Tables 3.3 and 3.4).

Table 3.2 Age frequencies and sizes of <u>A. australis australis</u> elvers from various localities during January : number in sample (n), mean length ($\bar{l}$) and mean weight ($\bar{w}$).

Location	Distance Upstream		Age group 0	1	2	3	4	5	6	7	8	9	10
Weir Rubicon River	tidal	n	53	1		2	1						
		$\bar{l}$ (cm)	6.56	8.05		12.15	14.80						
		$\bar{w}$ (g)	0.26	0.51		1.97	3.39						
		%	92	2		4	2						
Trevallyn P.S. Tamar River	tidal	n	3	51	42	2	2						
		$\bar{l}$ (cm)	6.93	8.38	10.28	13.20	13.80						
		$\bar{w}$ (g)	0.35	0.61	1.18	2.64	2.26						
		%	3	51	42	2	2						
Weir Ansons River	6 km	n	9	30	33	4							
		$\bar{l}$ (cm)	7.07	8.46	10.10	12.30							
		$\bar{w}$ (g)	0.30	0.54	0.90	1.74							
		%	12	40	43	5							
Fish trap Plenty River	9 km	n			27	13	3	6	3	2	6	1	1
		$\bar{l}$ (cm)			10.90	12.90	14.75	15.99	17.17	17.90	20.02	22.80	24.50
		$\bar{w}$ (g)			1.44	2.56	3.75	4.94	6.82	7.23	9.59	13.90	20.42
		%			42	21	5	10	5	3	10	2	2
Paloona Dam Forth River	10 km	n		9	46	41	2	2					
		$\bar{l}$ (cm)		9.02	10.21	12.16	14.65	15.80					
		$\bar{w}$ (g)		0.59	0.90	1.49	2.44	2.71					
		%		9	46	41	2	2					
Meadowbank Dam Derwent River	44 km	n			18	68	12	1		1			
		$\bar{l}$ (cm)			10.59	11.83	13.65	16.80		21.20			
		$\bar{w}$ (g)			1.24	1.80	2.65	6.35		11.26			
		%			18	68	12	1		1			
Weir Jordan River	50 km	n			2	25	6						
		$\bar{l}$ (cm)			10.37	12.75	15.95						
		$\bar{w}$ (g)			1.36	2.55	4.73						
		%			6	76	18						
Total length range		(cm)	5.8-7.5	7.1-9.3	8.8-12.0	11.0-14.8	13.0-16.9						
Total weight range		(g)	0.16-0.41	0.32-0.95	0.54-1.95	0.87-3.93	2.02-5.24						
		n	65	91	168	155	26						

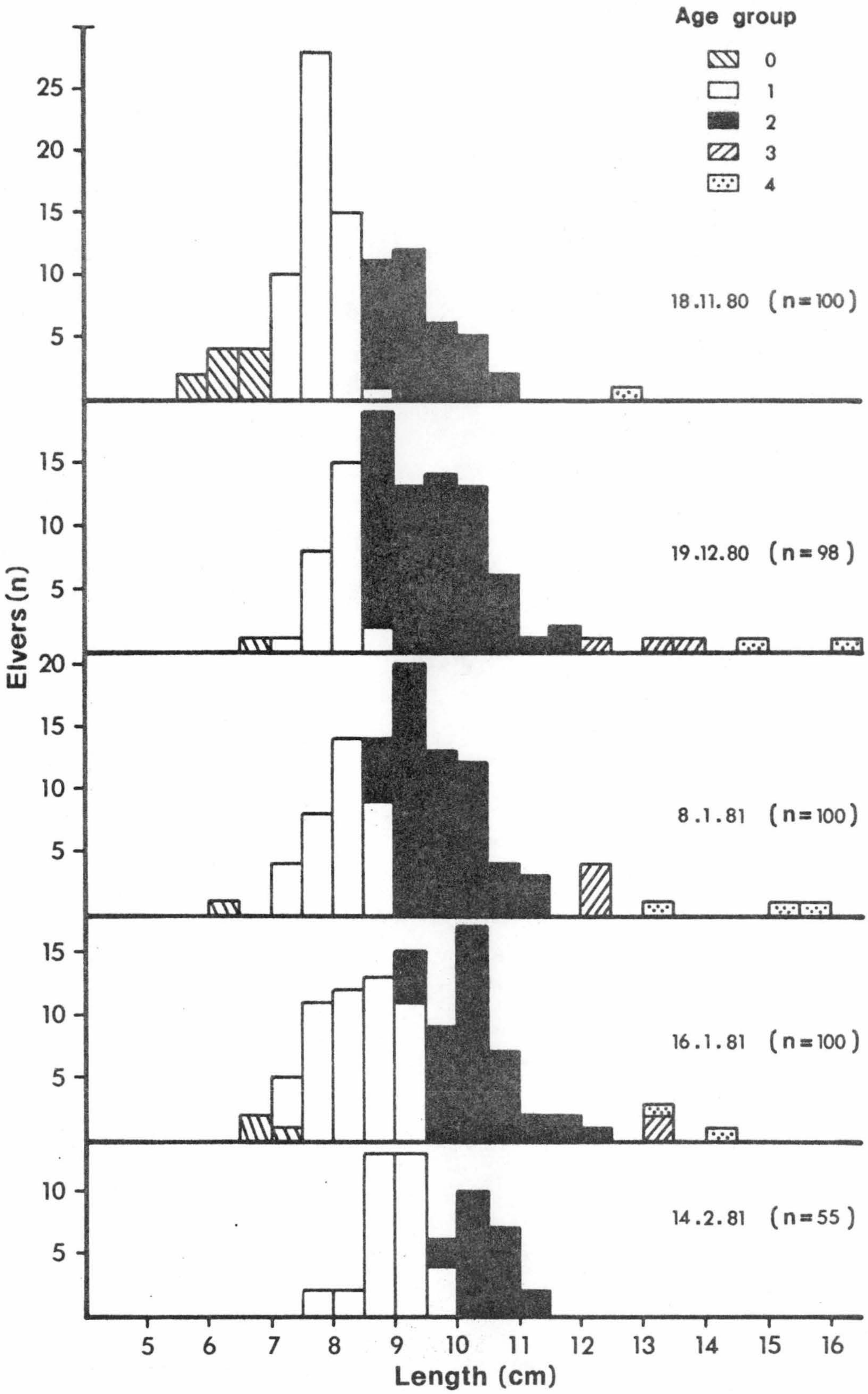


Fig. 3.4

Length and age frequencies of <u>A. australis australis</u> elvers during the 1980-81 season at Trevallyn Power Station.

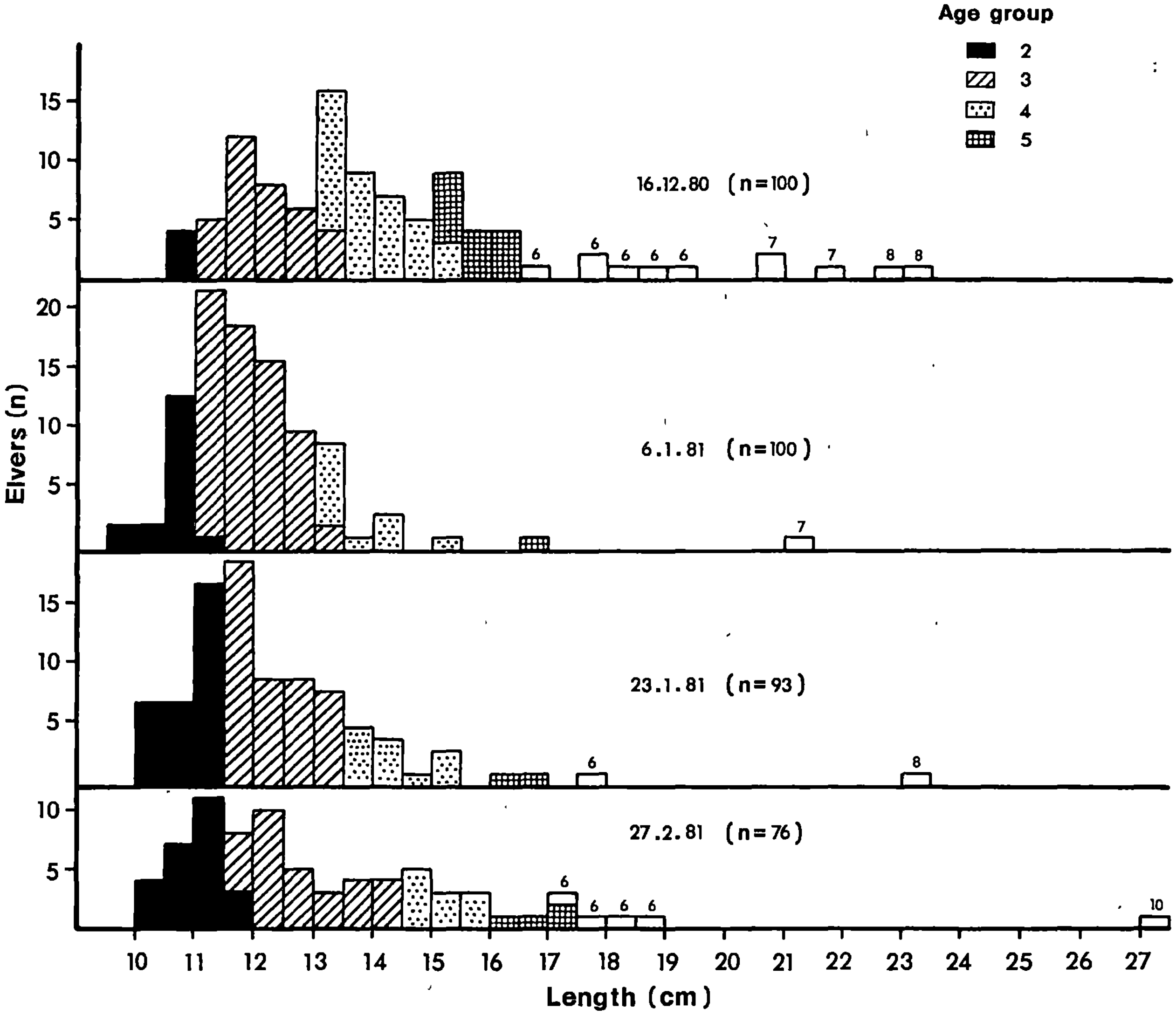


Fig. 3.5

Length and age frequencies of A. australis australis elvers during the 1980-81 season at Meadowbank Dam.

Table 3.3 Age and size of the dominant year classes of A. australis australis elvers from Trevellyn Power Station : number aged (n), mean total length ($\bar{l}$) and mean weight ($\bar{w}$). Values in parentheses = ± 95% C.L.

Date		Age group		
		0	1	2
18 Nov. 1980	n	10	54	35
	$\bar{l}$ (cm)	6.39 (0.22)	7.77 (0.10)	9.40 (0.22)
	$\bar{w}$ (g)	0.24 (0.05)	0.52 (0.02)	0.99 (0.08)
19 Dec. 1980	n		26	66
	$\bar{l}$ (cm)		8.07 (0.12)	9.60 (0.18)
	$\bar{w}$ (g)		0.52 (0.04)	0.89 (0.06)
8 Jan. 1981	n		35	57
	$\bar{l}$ (cm)		8.12 (0.16)	9.69 (0.17)
	$\bar{w}$ (g)		0.59 (0.04)	0.98 (0.05)
16 Jan. 1981	n		51	42
	$\bar{l}$ (cm)		8.38 (0.17)	10.28 (0.22)
	$\bar{w}$ (g)		0.61 (0.04)	1.18 (0.09)
14 Feb. 1981	n		34	21
	$\bar{l}$ (cm)		8.95 (0.17)	10.44 (0.20)
	$\bar{w}$ (g)		0.69 (0.05)	1.15 (0.11)

Table 3.4 Age and size of the dominant year classes of A. australis australis elvers from Meadowbank Dam : number aged (n), mean length ($\bar{l}$) and mean weight ($\bar{w}$). Values in parentheses = ± 95% C.L.

Date		Age group			
		2	3	4	5
16 Dec. 1980	n		35	36	14
	$\bar{l}$ (cm)		12.07 (0.21)	13.89 (0.22)	15.54 (0.27)
	$\bar{w}$ (g)		1.91 (0.13)	3.05 (0.19)	4.27 (0.27)
6 Jan. 1981	n	18	68	12	
	$\bar{l}$ (cm)	10.59 (0.17)	11.83 (0.14)	13.65 (0.46)	
	$\bar{w}$ (g)	1.24 (0.08)	1.80 (0.08)	2.65 (0.41)	
23 Jan. 1981	n	31	45	13	
	$\bar{l}$ (cm)	10.92 (0.15)	12.24 (0.19)	14.24 (0.38)	
	$\bar{w}$ (g)	1.30 (0.07)	1.92 (0.11)	3.16 (0.44)	
27 Jan. 1981	n	25	31	11	
	$\bar{l}$ (cm)	10.95 (0.17)	12.72 (0.32)	15.10 (0.28)	
	$\bar{w}$ (g)	1.11 (0.08)	1.82 (0.22)	2.95 (0.34)	

3.3.7 Factors Influencing Migration

At Trevallyn Power Station it became apparent that the run of elvers was determined by turbine output rather than by any natural environmental influence. This is illustrated in Fig. 3.6 where the combined No. 1 and No. 2 turbine loadings have been multiplied by the running hours for each day and graphed against the elver catch for the same period. Clearly, the significant catches correspond to low flows through the power station tailrace.

When elver data from the Plenty River upstream fish trap (Sloane, in press) is compared with stream flow, water temperature and moon phase (Fig. 3.7), the migration appears to bear no relation to moon phase but does relate to the temperature/flow data. The flow graph is basically a mirror image of the temperature graph as freshes in the stream correspond with periods of reduced water temperature; consequently, the effects of these two factors are difficult to separate. In general, periods of high stream flows and reduced water temperatures appear to inhibit the elver migration.

Further analysis of the data indicated no clear relation between lunar days and elver catch, with 17.0%, 38.2%, 21.3% and 23.4% of the catch recorded in the first, second, third and last lunar quarters respectively. The trend of increasing elver catch with increasing water temperature was very highly significant ($p < 0.001$; $r=0.445$, $n=59$). The trend of increasing elver catch with decreasing flow was significant ($0.01 < p < 0.05$; $r=-0.305$, $n=59$).

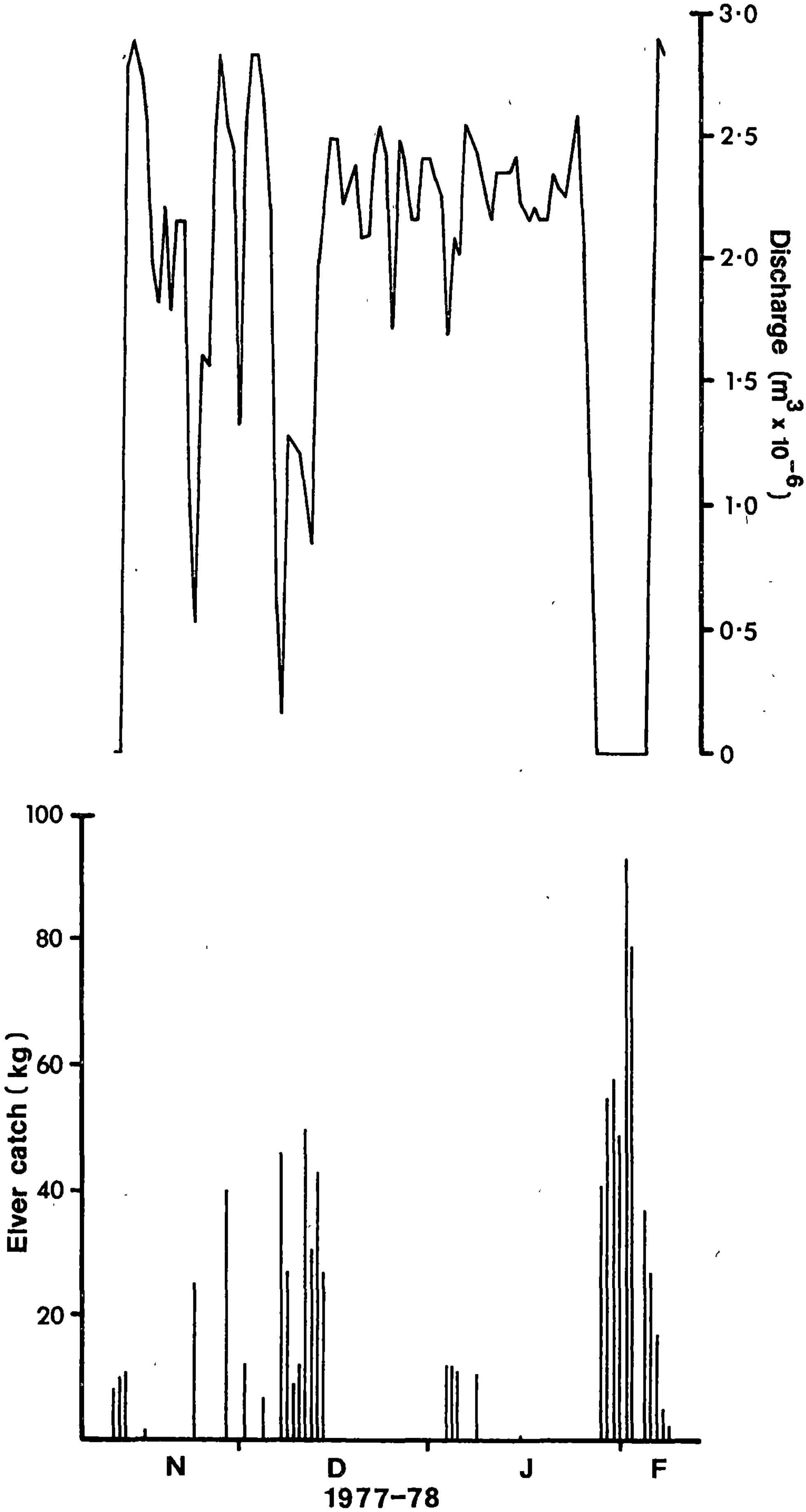


Fig. 3.6

Daily catch of A. australis australis elvers and combined No.1 and No.2 turbine discharge at Trevallyn Power Station during the 1977-78 season.

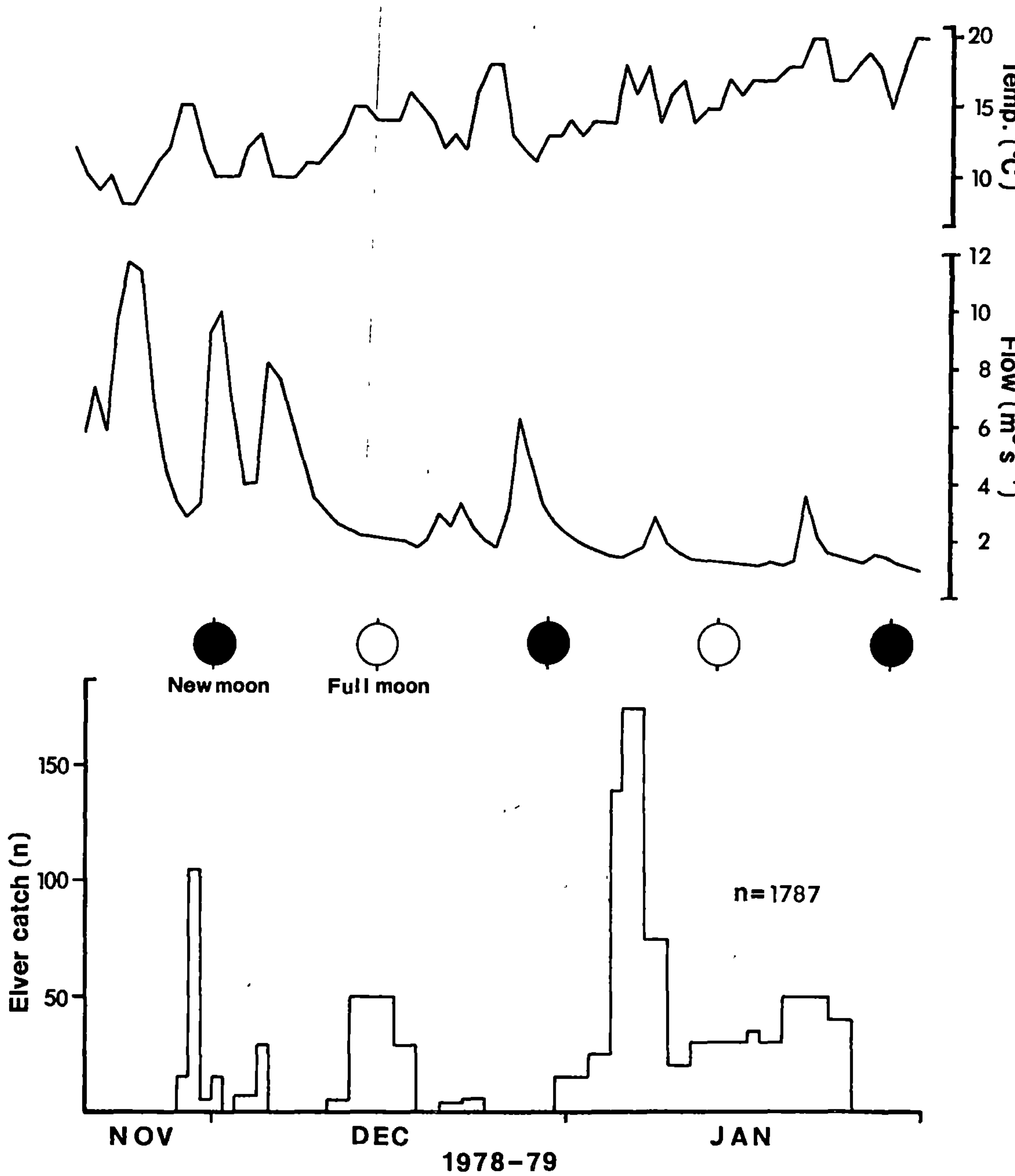


Fig. 3.7

Daily catch of A. australis australis elvers at the Plenty River weir during the summer of 1978-79, with mean daily river flow and water temperature (recorded at 08 00 h); days of new moon and full moon are indicated.

The elver run at the Plenty River weir commenced when the water temperature first reached 15°C and elvers were recorded at temperatures ranging from 10°C to 20°C. The same temperature (15°C) was recorded at the start of the elver run at Trevallyn in November 1977 and 1978 (no data other years). At other localities the temperatures recorded during visits when elvers were found to be migrating ranged from 18°C to 22°C.

3.4 DISCUSSION

The upstream migration of young pigmented eels takes place during late spring and summer in Tasmanian streams and only the short-finned eel (A. a. australis) migrates inland in significant numbers. Summer upstream migration of the New Zealand sub-species A. a. schmidtii has been documented by Jellyman (1977b), who found January and February to be the main months for such migrations. In Tasmania, elver migrations continue throughout the summer at some locations; at Trevallyn Power Station elvers were seen from mid-November to mid-March every year. A five month elver ascent was reported by Smith (1955) for A. rostrata and by Tesch (1977) for A. anguilla.

The absence of A. reinhardtii from elver migrations in Tasmania is somewhat surprising as longfins have been collected by the author in several of the rivers studied (v. Chapter 4). Longfin glass-eels have been found to enter streams early in the year, mainly during March and April and after July they are no longer found at the freshwater/estuarine interface (v. 2.3.2). This indicates that some upstream movement of longfin juveniles may occur during autumn. However, the author has found feeding eels of this species to be mainly restricted to the estuaries and lower freshwater reaches of streams and consequently upstream migration of longfins is probably very limited in Tasmania. On the Australian mainland A. reinhardtii is known to find its way well inland and upstream migrations have been observed (Whitley 1929; Powell 1930; Walford 1930; Mann 1979).

The elver catches indicate that many shortfins spend several years in the upper estuarine area (some probably spend their entire feeding life here). Age group 0 elvers were mainly found at the limit of tidal influence and none of this group were recorded at more than 6 km inland. Similarly, few group 1 elvers were captured more than 6 km from tidal influence. This indicates a very limited movement upstream with the majority of elvers migrating only short distances into fresh water in the first two years. Further inland, the size and age of elvers increased and the length and weight ranges of elver samples broadened.

This pattern of migration appears to be consistent with those recorded for other Anguilla spp. Jellyman (1977b) suggested that 'a considerable proportion' of A. a. schmidtii juveniles spend at least the first two years in upper estuarine regions in New Zealand. Moriarty (1978) examined a sample of A. anguilla from an elver trap 15 km from tidal influence and found that half the catch consisted of 1 and 2 year olds and the rest were older (up to 10 years); elvers rarely reached this trap in their first year. Deelder

(1970) illustrated that further upstream, migrating eels *A. anguilla* show an increase in size and age and this was also recognised by Jellyman (1977b) for the two New Zealand species. This increase may be exaggerated where the migration is hindered by numerous weirs (Tesch 1977).

During the migration season, growth of elvers apparently occurs and the mean length and weight for age was found to increase as the season progressed. At Trevallyn Power Station, age group 0 elvers participated, but only early in the season; this limited migration time probably results in the short distance travelled upstream by eels in their first year. At Meadowbank, the increased numerical importance of group 2 elvers later in the season indicates that the dam is some distance from the normal distance travelled by elvers in their first two years in fresh water. Consequently, elvers in their third summer (group 2 elvers) spend some time reaching the dam and their numbers swell as the season progresses.

The mean length and weight for age of elver samples (Table 3.2) illustrate the growth of the shortfin during its early years in Tasmanian fresh waters. The means lie within the length ranges for age group 0, 1 and 2 elvers given by Jellyman (1977b) for the New Zealand shortfin, indicating that the growth rate in early years is similar in both countries.

It is difficult to isolate the environmental factors which may control elver runs. Day length, water temperature, river flow and social interaction between elvers may all be contributing factors. In New Zealand, Cairns (1941) and Jellyman (1977b) found remarkable constancy in the timing of the first appearance of elvers, with the elver migration on the Waikato River commencing almost to the day over many years. In Tasmania, elvers first appeared at Trevallyn on nearly the same day every year, suggesting that day length may be an important initiating factor.

Water temperatures greater than or equal to $10^{o}C$ can be associated with elver migrations in Tasmania. Various authors (e.g. Sorensen 1951; Smith 1955; Mann 1963) have associated the attainment of a threshold temperature with the initiation of summer upstream eel migrations. Jellyman (1977) suggested that temperatures less than $10^{o}C$ could inhibit elver migrations and Sorensen (1951) and Mann (1963) found that elver activity decreased when the water temperature fell. At the upstream fish trap on the Plenty River, interruptions in the elver run may have been caused by falls in water temperature, but this was difficult to separate from increases in river flow. Lowe (1951) found that floods may stop elver runs, particularly early in the season.

There is little doubt that water flow plays an important role in the capture of elvers at Trevallyn Power Station. Here, the water from the No. 1 and No. 2 turbines (the two used for elver trapping) combines and passes through a tail race leading to the estuary. Apparently, when the turbine outputs were high, ($> 2\times10^{6}$ m^{3} day $^{-1}$) elvers did not enter the No. 1 and No. 2 stop-log pits in significant numbers; this is probably due to a physical inability of elvers to swim against the current through the tail race rather than because of a reduced attraction at high flows. Whenever the turbine loadings were reduced, elvers entered the tail race and congregated in the stop-log pits where they were blocked from proceeding any further upstream.

The starting day of the elver run was found to vary at different locations in Tasmania. The earliest records were from barriers located on or near estuarine waters with the elver runs further inland being delayed for a month or more. This may reflect a social interaction, the upstream movement being initiated at the head of the estuary or ultimately by the invasion of glass-eels from the sea as suggested by Cairns (1941). The elver migration may thus proceed as a wave initiated by vast quantities of elvers moving into the lower freshwater reaches, causing other young eels to move further upstream, the migration gradually losing its impetus with fewer and larger eels migrating progressively further inland. Lowe (1951) concluded that no upstream migration took place until a certain number of elvers had collected at the river mouth; this she called the minimum threshold number.

The elver transfer programme in Tasmania has now been considerably streamlined, the pumping system used at Trevallyn having the capacity to remove as much as 100 kg (c. 0.14×10^6 elvers) during a high tide when elvers are plentiful. Hydro-electric schemes store winter water which is discharged during summer producing a much greater than normal summer flow. This may effectively attract more elvers from the sea than would the original river system, producing a potential for stocking other waters. In fact, the quantities involved at both Meadowbank and Trevallyn are substantial, with a target of 1.0 t of elvers set for annual transfer. This represents about 1.4×10^6 elvers at Trevallyn and 0.5×10^6 at Meadowbank; a conservative estimate of the total annual run of elvers at these locations would be $3.0\text{–}5.0 \times 10^6$ at Trevallyn and $0.5\text{–}1.0 \times 10^6$ at Meadowbank, which compares favourably with some of the most important elver runs in Europe. Tesch (1977) estimated that about 1.0×10^6 glass and pigmented eels annually enter the Elbe in Germany and cited a figure of about 5.0×10^6 eels migrating in the Ems annually. Lowe (1952b) provided corrected annual figures of between 5.0 t and 10.0 t ($10\text{–}20 \times 10^6$) for elvers migrating in the River Bann, Northern Ireland.

Tesch (1977) reviewed the European literature relating to eel stocking experiments and concluded that elvers introduced at the rate of 4-5 individuals per hectare per year serve to increase yields by 1 kg ha^{-1} in waters where there are few or no eels. On these figures the elver runs at major power stations in Tasmania have considerable potential for expanding the local eel fishery. The absence of the commercially less viable eel, <u>A. reinhardtii</u>, from these elver runs, further enhances the stocking potential.

Chapter 4

THE DISTRIBUTION AND ABUNDANCE OF FRESHWATER EELS (*ANGUILLA* SPP.) IN TASMANIA

4.1 INTRODUCTION

Although a few specimens of the long-finned eel, A. reinhardtii, have been described from northern Tasmanian rivers by Scott (1934, 1940, 1953) the status of this species in Tasmania has never been clearly defined. Frankenberg (1974) acknowledged the presence of A. reinhardtii in Tasmania but considered that the records of this species represented only "intermittent extensions southward of its normal range". Scott (1934) suspected that the long-finned eel was more widespread than generally believed and cited claims by fishermen that A. reinhardtii was common in Tasmania, preferring streams with a sandy or gravelly bottom, rather than the muddy substrates preferred by the ubiquitous short-finned species A. a. australis.

A. australis was first described by Richardson (1848) from a Tasmanian specimen and this species is now known to be widespread with Lynch (1977) reporting commercial catches based on this species in Tasmania. The most recent distribution map of the short-finned eel in Tasmania (Frankenberg 1974) illustrates that there are few published records of this species despite its apparent abundance.

This chapter describes a comprehensive survey of the distribution and abundance of the two species of freshwater eel in Tasmania, based on electrofishing surveys, commercial catches, collections of juvenile eels and other miscellaneous samples.

4.2 MATERIALS AND METHODS

4.2.1 Distribution

Maps showing the recorded distribution of A. a. australis (shortfin) and A. reinhardtii (longfin) in Tasmania were prepared from the following sources: electrofishing surveys of rivers conducted by the author during February and March 1978 and during January and February 1979, some details of which have already been published (Sloane 1978a, 1979); other quantitative and qualitative electrofishing surveys conducted by the author during the years 1977 to 1981; commercial catches examined by the author during this period; glass-eel and elver samples collected by the author, many of which have been described elsewhere (v. Chapter 2 & 3); other miscellaneous eel samples collected by or examined by the author, e.g. hand-net, light and spear and rod and line catches; published records and collections held by the Department of Zoology, University of Tasmania; Queen Victoria Museum and Art Gallery and the Tasmanian Inland Fisheries Commission.

The distribution maps, Figs. 4.1 and 4.2, are based on a 10 000 m National Grid with a single dot representing all collections made within one grid square.

4.2.2 Species Distinction

Juvenile eels of the two species cannot be distinguished by colour as pigmentation is incomplete. Here, Schmidt's index is a convenient character to distinguish the long-finned from the short-finned species (v. 2.3.1).

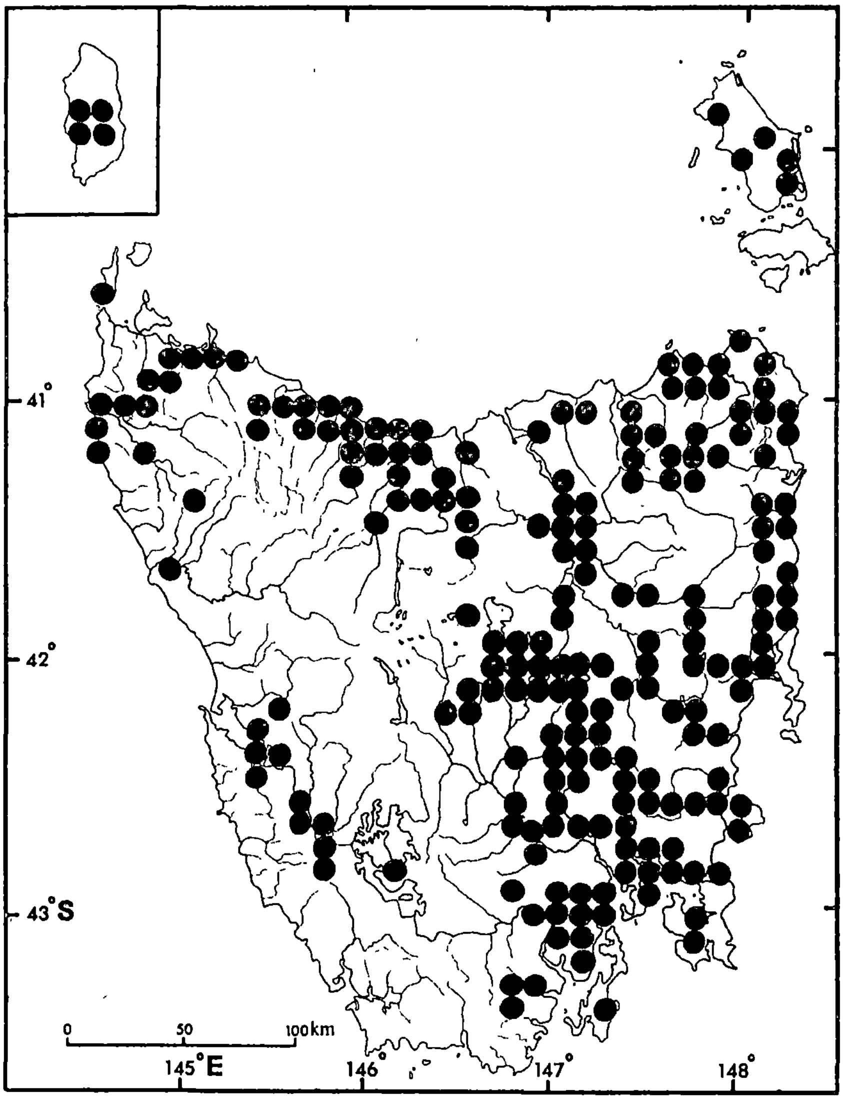


Fig. 4.1

The Tasmanian distribution of Anguilla australis australis, based on a 10 000 m National Grid with a single dot representing all collections made within one grid square.

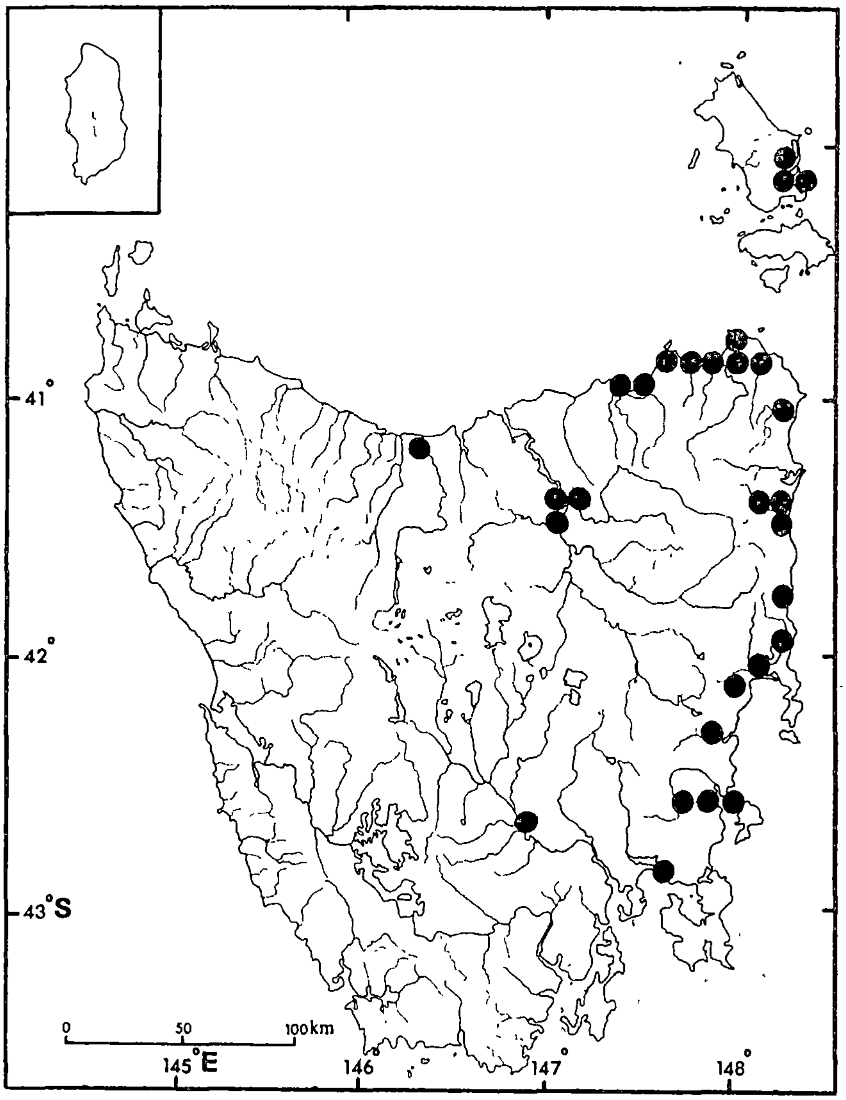


Fig. 4.2

The Tasmanian distribution of Anguilla reinhardtii, based on a 10 000 m National Grid with a single dot representing all collections made within one grid square.

During the 'feeding eel' stage of life, the two Anguilla spp. found in Tasmanian waters are quite easily distinguished by their colouration; A. reinhardtii is a marbled or spotted green coloured eel whereas A. a. australis is a uniform dull brown or grey colour on the dorsal surface.

Later in life, A. reinhardtii loses its spotted appearance and becomes a uniform green-black on the back as it approaches its adult migration. This causes frequent misidentification by fishermen, with migrant A. reinhardtii adults being referred to as 'shortfins' because they lack spots. Such misidentification may have led Johnston (1883) to report some very large eel specimens from the South Esk and Ringarooma rivers as A. australis (the only Tasmanian eel species he recognised). Again, Schmidt's index allows a ready distinction to be made between the two species, and at this stage in life, the upper jaw dentition also provides a convenient distinguishing character. The maxillary teeth bands are broader in A. australis and lack the toothless groove exhibited by A. reinhardtii; also, the vomerine band is shorter and less pointed in A. australis (Schmidt 1928).

Occasionally colour abnormalities, xanthochromatism, (yellow or orange colouration) and albinism (white colouration), and fin deformities were encountered, but the combined use of colour, Schmidt's index and upper jaw dentition provided ready distinction between the two species.

4.2.3 Density and Biomass

All density and biomass estimates for eel populations in rivers were determined by electrofishing. The apparatus used was powered by a Honda E800U generator and produced a 240 V direct-current pulsed at 100 pulses s^{-1}.

Each stream section was fished in an upstream direction for a distance of between 100 and 200 m with a thirty minute interval between successive runs. In some small streams 'exhaustive' electro-fishing was conducted with fishing continuing until successive runs yielded no further fish. Successive electrofishing runs conducted at a number of sites on the Douglas River provided estimates of the efficiency of the electrofishing apparatus in clear, stony, east coast streams (v. 5.4.1). A two run efficiency for the same electrofishing apparatus of 60.2% of total estimated number and 77.2% of total estimated weight recorded by Lake and Fulton (1981) in Parsons Bay Creek was used to estimate total numbers and weights for similar lowland streams.

All density and biomass estimates were conducted during the summer months, December to March, under conditions of low river flow.

4.2.4 Commercial Eel Catch

Analyses of annual catch, seasonal catch and catch per unit effort were based on monthly catch returns made available by the Tasmanian Inland Fisheries Commission. These catches are based on a fyke net (mesh 15-39 mm, opening height and width not exceeding 670 mm) fishery with a legal minimum size limit of 30 cm.

4.3 RESULTS

4.3.1 Distribution

A. reinhardtii was found to be common in coastal north-eastern and eastern Tasmania including Flinders Island (Fig. 4.2). The record of this species from the Derwent River in southern Tasmania represents only a single specimen recorded amongst many thousands of migrating A. a. australis elvers at Meadowbank Dam. The only other longfin record from southern Tasmania is from the mouth of the Carlton River where only glass-eels of this species were found. Although adult longfins were recorded from northern Tasmania in the Mersey, North Esk, South Esk and Tamar rivers, this species is rarely encountered in these waters.

A. a. australis was found to inhabit the majority of Tasmanian coastal streams including those of King and Flinders islands and to extend far inland in the major river systems. Shortfins were not recorded from the western Central Plateau, with a single specimen from the Ouse River below Lake Augusta representing the furthest inland record. A very small number of shortfins remain in Great Lake and shortfins are common in other lakes in the Central Highlands at elevations of less than 1 000 m. Few streams on the west coast of Tasmania were sampled due to the difficulty of access, but shortfins were found to be abundant in the Arthur, Pieman and Gordon river systems, indicating a continuous Tasmanian coastal distribution. The only areas, other than in the western Central Plateau, where shortfins appear to be scarce, are streams where heavy-metal pollution from mining activities has been, or still is, prevalent, particularly in the upper South Esk system in the north and the King and Queen rivers in the west.

A more detailed map showing the relative numbers of longfins and shortfins recorded at various locations in north-eastern Tasmania is given in Fig. 4.3. Commercial catches indicate that longfins predominate in the estuaries of the Boobyalla, Ringarooma and Great Musselroe rivers. A coastal swamp, known as 'The Marshes' on the Ringarooma River has yielded 95% longfins. In the nearby Dorset Lagoons this species also predominates. Longfins were only found in the estuaries, some coastal lagoons and the lower freshwater reaches of streams in this region. In contrast, shortfins were found to be abundant in the same areas as well as further inland in the major river systems, associated tributary streams and farm dams. Some coastal lagoons, e.g. Bowlers Lagoon, are populated solely by shortfins whereas others, e.g. Big Waterhouse Lagoon, support both species.

4.3.2 Abundance

Eel density and biomass estimates recorded for Tasmanian streams during summer (December - March) are presented in Table 4.1 together with data for Parsons Bay Creek from Lake and Fulton (1981). For detailed descriptions of the locations and accounts of the other fish species present see Sloane (1976) for the Coal and Jordan rivers and the present study (v. 5.3) for the Douglas River. Further eel density estimates are presented in Table 4.2. For details of these locations and the numbers of other fish species recorded see Sloane (1978a, 1979).

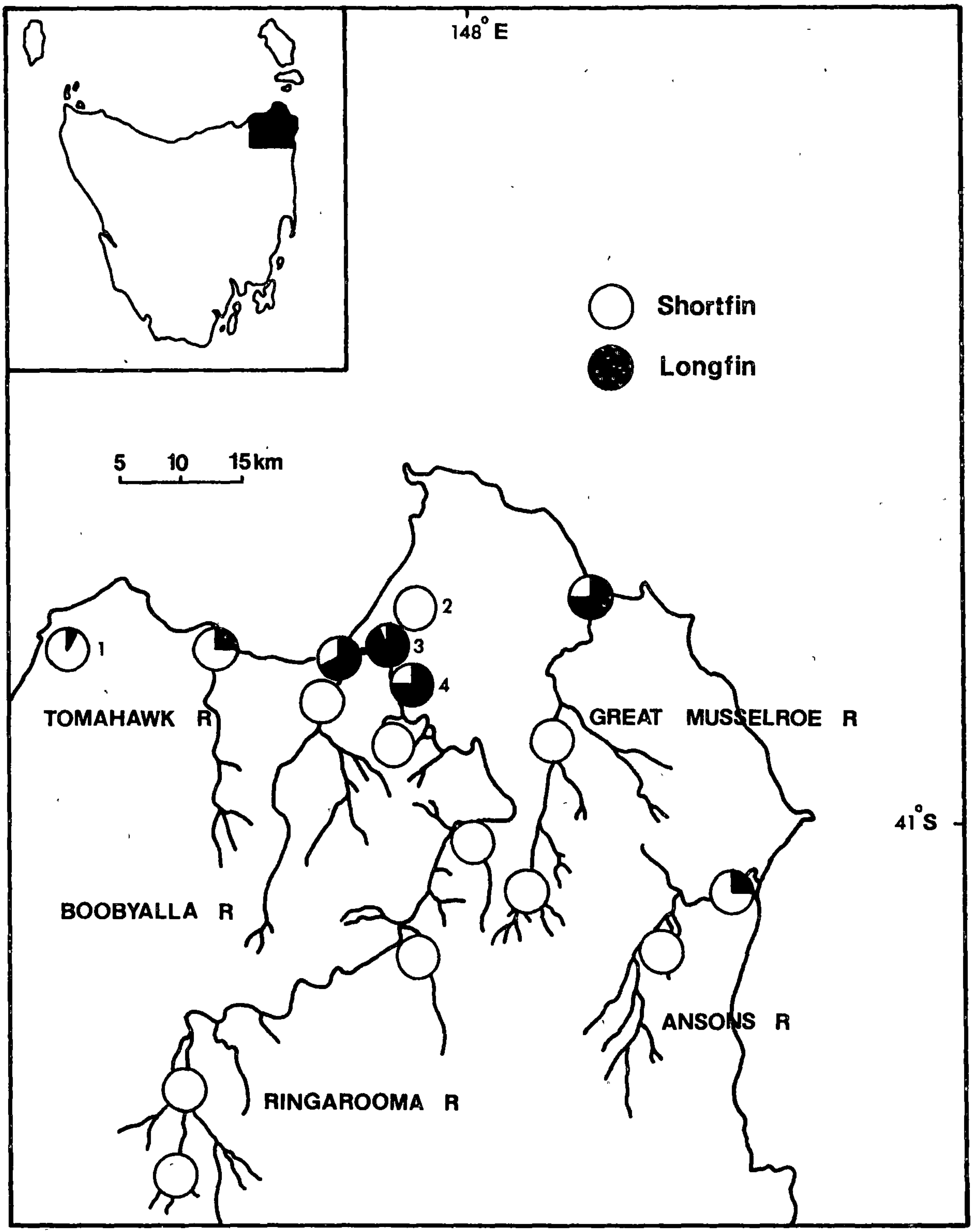


Fig. 4.3

Map of North-eastern Tasmania showing the relative numerical proportion of A. reinhardtii (Longfin) and A. australis australis (Shortfin) at various localities.

(1) Big Waterhouse Lagoon
(2) Bowlers Lagoon
(3) The Marshes
(4) Dorset Lagoons

Table 4.1 Density (D) n m^{-2} and biomass (B) g m^{-2} estimates for A. australis australis (Shortfin) and A. reinhardtii (Longfin) recorded during summer (December - March): sites 1 to 6 are listed in order of increasing distance from the sea; values in parentheses indicate the percentage of the total D or B.

Data for Parsons Bay Creek after Lake and Fulton (1981); Coal and Jordan rivers after Sloane (1976).

Species	River		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Shortfin	Coal R.	D	0.06 (70.6)	0.01 (46.7)	0.02 (40.0)	0.01 (1.0)		
		B	5.37 (47.7)	1.76 (49.0)	5.72 (43.3)	1.50 (9.7)		
	Jordan R.	D	0.06 (18.2)					
		B	4.04 (19.3)					
	Parsons Bay Ck.	D	0.98 (28.8)	0.50 (16.0)	0.12 (48.0)	0.42 (54.5)	0.22 (81.5)	0.04 (100)
		B	23.01 (75.8)	15.19 (66.0)	14.50 (82.4)	18.00 (75.6)	11.36 (91.8)	1.07 (100)
	Douglas R.	D	0.15 (3.9)	0.04 (10.3)	0.04 (22.2)	0.02 (33.3)	0.29 (100)	
		B	2.23 (1.8)	0.04 (0.2)	0.09 (0.9)	0.20 (14.2)	8.02 (100)	
	Apsley R.	D	0.28 (28.6)	0.17				
		B	-	4.01				
	Meredith R.	D	0.22					
		B	4.82					
	Great Musselroe R.	D	0.06 (52.1)					
		B	5.94					
Longfin	Douglas R.	D	0.40 (10.3)	0.04 (10.3)	0.02 (11.1)	* (3.3)	0 (0)	
		B	114.66 (91.9)	23.82 (95.6)	8.88 (93.5)	0.07 (5.0)	0 (0)	
	Meredith R.	D	0.02					
		B	1.75					
	Scamander R.	D	0.01 (3.2)					
		B						

$* < 0.005$

Table 4.2 Density (n m^{-2}) estimates for A. australis australis recorded during summer (January-February): sites 1 to 4 are listed in order of increasing distance from the sea, values in parentheses indicate the percentage of the total fish density.

River	Eel Density Site 1	Site 2	Site 3	Site 4	River	Eel Density Site 1	Site 2	Site 3
Dasher R.	0.01 (25.0)				Elizabeth R.	0.01 (4.1)		
Rubicon R.	0.09 (75.6)	0.14 (97.1)	0.11 (92.9)		Lake R.	0.01 (4.1)	0.01 (21.2)	
Meander R.	* (2.9)				Break O' Day R.	0.07 (7.6)		
Clayton Rvt.	0.48 (75.3)				St. Patricks R.	0.01 (16.2)		
Coiler Ck.	0.39 (31.9)	0.11 (80.4)	0.40 (100)	1.40 (90.4)	Pipers R.	0.02 (33.3)		
Lobster Ck.	0.27 (30.2)				Brid R.	0.01 (20.0)	0.06 (16.1)	
Adams Ck.	0.13 (67.1)				Gt. Forester R.	0.03 (12.2)		
Penguin Ck.	0.09 (17.5)				Legerwood R.	0.05 (64.3)		
Sulphur Ck.	0.11 (2.7)				Ringarooma R.	* (20.5)	0.02 (57.7)	
Deep Ck.	0.02 (26.3)				Weld R.	0.01 (6.3)		
Camp Ck.	0.06 (4.8)				Scamander R.	0.02 (15.3)		
Cam R.	0.03 (10.3)				Prosser R.	0.07 (64.0)	0.18 (84.7)	0.11 (66.7)
Edith Ck.	0.20 (69.2)	0.53 (58.7)			Carlton R.	0.16 (26.6)	0.26 (46.3)	
Guide R.	* (16.7)				Clyde R.	0.01 (20.0)		
Gawler R.	0.01 (6.4)				Plenty R.	0.05 (37.6)		
Riana Ck.	0.03 (4.1)				Tyenna R.	0.01 (9.6)		
Leven R.	* (5.9)				Styx R.	* (3.1)		
Duck R.	0.01 (30.8)	0.04 (39.7)			Judds Ck.	0.01 (9.4)		
Emu R.	0.01 (21.8)				Mountain Ck.	* (4.8)		
Flowerdale R.	* (3.0)				Kellaways Ck.	0.08 (20.9)		
Inglis R.	0.01 (15.6)				Russel R.	0.13 (28.9)		
Mersey R.	0.02 (41.9)				Esperence R.	0.01 (6.0)		
St. Pauls R.	* (1.8)							

* < 0.005

For shortfins, biomass estimates were highest for Parsons Bay Creek where the maximum of 23.01 gm^{-2} was recorded by Lake and Fulton (1981). For streams studied by the author, biomass estimates of between 4 gm^{-2} and 6 gm^{-2} were typical. Biomass estimates for 19 sites on 7 Tasmanian rivers ranged between 0.04 gm^{-2} (site 2, Douglas River) and 23.01 gm^{-2} (downstream site on Parsons Bay Creek). Density estimates for shortfins were also found to vary between rivers and within rivers. From 81 sites on 52 rivers where shortfins were found, densities ranged from less than 0.005 eels m^{-2} to 1.4 eels m^{-2}. The estimated density of shortfins was less than 0.1 eel m^{-2} at 60% of these sites.

For longfins, 114.66 gm^{-2} and 23.82 gm^{-2} recorded in the lower reaches of the Douglas River represent the highest biomass estimates for either species in Tasmania. Density estimates for longfins were less than 0.05 eels m^{-2} except at the lowest station on the Douglas River (0.40 eels m^{-2}).

Commercial catches have been used to provide some idea of the abundance of _A. a. australis_ in standing water bodies. Based on the number of fishermen lodging returns, an annual average of six fishermen have landed 5.2 t of shortfins each, at a rate of 3.1 kg per net day since the start of eel fishing in Tasmania in 1965. The highest catch/effort was recorded in 1966-67 when six fishermen lodged a total return of 35.1 t at a rate of 6.3 kg per net day. The lowest catch/effort was recorded in 1974-75 season when two fishermen lodged a total return of 5.8 t at a rate of 1.5 kg per net day. The highest annual catch was landed in 1967-68 when twelve fishermen lodged a total return of 94.5 t at a rate of 3.9 kg per net day. Some details of eel yields from Tasmanian lakes are listed in Table 4.3 together with catch/effort data.

4.4 DISCUSSION

A. reinhardtii is well established in the lower freshwater reaches and estuaries in Tasmania's north-east and east coast rivers and should no longer be regarded as rare. Scott's notion (Scott 1934) that longfins prefer streams with a sandy or gravelly bottom rather than muddy substrates is not entirely substantiated by the present study; although longfins are abundant in the lower freshwater reaches of gravelly and stony east coast streams they are also found in estuaries, coastal lagoons and tidal marsh lands.

A. a. australis is found in all Tasmania's major river systems from the estuaries to small inland tributaries. Shortfins appear to be abundant in all Tasmania's coastal streams and they are commonly found in farm dams, coastal lagoons and inland lakes. Thus, shortfins appear to occupy virtually all available estuarine and freshwater habitats ranging from fast stony streams to eutrophic ponds.

Woods (1964) considered that minimum stream temperatures may be important in determining inland eel distribution in New Zealand. In Tasmania, Breton (1846) reported that during the winter of 1835, Great Lake was frozen over and after the lake

Table 4.3 Summary of A. australis australis landings recorded by the fyke net fishery in several Tasmanian lakes.

	Year	Months Fished	Quantity Landed (kg)	Kg ha^{-1}	Catch per net day (kg)
Lake Crescent	1965-66	6	15270	6.46	5.54
(2365 ha)	1966-67	5	4544	1.92	5.49
	1967-68	3	6551	2.77	2.52
	1972-73	2	5807	2.46	2.65
Lake Sorell	1967-68	4	22126	4.64	5.09
(4770 ha)	1968-69	3	8591	1.80	-
	1972-73	1	4890	1.03	4.79
Lake Leake	1965-66	4	9623	14.58	6.50
(660 ha)	1966-67	5	10770	16.32	4.41
	1967-68	2	2070	3.14	1.73
	1973-74	1	2727	4.13	1.51
Lagoon of Islands	1966-67	2	8499	9.83	17.74
(865 ha)	1967-68	2	1545	1.79	4.23
	1969-70	2	6135	7.09	-
	1970-71	2	3042	3.52	-
Lake Tiberias	1971-72	1	7594	7.79	15.82
(975 ha)	1976-77	2	7032	7.21	5.87
	1977-78	2	697	0.71	0.58
	1978-79	4	1904	1.95	1.06

had thawed, 'multitudes' of dead eels were washed onto the shores. This indicates that winter minimum water temperatures may be important in restricting the distribution of eels on the western Central Plateau in Tasmania.

Density and biomass estimates for longfins, although few, indicate that this species was found predominantly in the lower reaches of fresh water at relatively low densities but sometimes very high biomasses. Although no estimates are available for the quantities of longfins in north-eastern estuaries, commercial catches and observations made by the author indicate that the longfin is the dominant eel species in these areas.

In New Zealand streams, eel densities of 0.008 - 0.188 eels m^{-2} were recorded by Woods (1964) but the areas he studied were mainly populated by the long-finned species, A. dieffenbachii. Hopkins (1971) estimated eel density in two North Island streams, recording 0.24 eels m^{-2} - 0.26 eels m^{-2} for the Hinau Stream and 1.46 eels m^{-2} - 1.74 eels m^{-2} for the Hinaki Stream during February. From the numerical proportions of each eel species in his February samples, A. a. schmidtii occupied about 73% of eel numbers in the Hinau Stream and 63% in the Hinaki Stream (Hopkins 1970). Eel densities for A. a. schmidtii would thus lie within the range recorded for A. a. australis for Tasmanian streams, but the total eel densities (both New Zealand species combined) recorded for the Hinaki Stream are greater than any recorded in Tasmania.

Eel biomass estimates from New Zealand are also confused by the inclusion of both eel species. Burnet (1952) electrofished three North Island streams and obtained mean biomass estimates of 470 lb acre^{-1} (52.7 gm^{-2}) for the Horokiwi Stream, 285 lb acre^{-1} (32.0 gm^{-2}) for the Wainui-o-mata Stream and 404 lb acre^{-1} (45.3 gm^{-2}) for the Mangoroa Stream. His figures indicate that in these streams A. a. schmidtii represented only about 10%, 1% and 2% of the total eel weight respectively. Burnet (1969c) gave estimates of eel biomass in three Canterbury (South Island) streams, 243 kg ha^{-1} (24.3 gm^{-2}) to 254 kg ha^{-1} (25.4 gm^{-2}) for the South Branch Stream, 130 kg ha^{-1} (13.0 gm^{-2}) for Doyleston Drain and 135 kg ha^{-1} (13.5 gm^{-2}) for the Main Drain. His figures indicate that A. a. schmidtii represented about 53%, 69% and 20% of the total eel numbers respectively in these streams. Hopkins (1970) estimated biomasses of 16.02 gm^{-2} and 19.79 gm^{-2} for Hinau Stream and 130.22 gm^{-2} and 87.35 gm^{-2} for Hinaki Stream for both eel species combined in his February samples.

Although the total eel biomass (both species combined) estimates for New Zealand streams are consistently higher than Tasmanian estimates, the values for A. australis in the two countries appear to be of the same order. Tesch (1977) reviewed world-wide biomass estimates for Anguilla spp. and concluded that the biomasses recorded from running waters in New Zealand are far greater than those recorded from other countries. Tesch (1967) gave figures of 1.5 to 100 kg ha^{-1} (0.15 gm^{-2} to 10 gm^{-2}) for streams in Lower Saxony and stated that 43 kg ha^{-1} (4.3 gm^{-2}) was well above average. Larsen (1955,1961) estimated an eel biomass of 75 kg ha^{-1} (7.5 gm^{-2}) for a stream in Denmark and gave an average of 850 eels ha^{-1} (0.085

eels m^{-2}) for 20 Danish streams. These figures indicate that density and biomass estimates for the European eel, A. anguilla, are of the same order as estimates for A. a. australis in Tasmania.

Tesch (1977) also reviewed European eel yields and cited values between 1.2 and 45.4 kg ha^{-1} for coastal waters with the highest yields obtained from warmer waters in the south. For inland lakes in Europe, eel yields ranged from less than 1 kg ha^{-1} to 20 kg ha^{-1} with the highest yield from Lough Neagh, Northern Ireland. For the American eel, A. rostrata, Smith (1966) recorded yields of 1.5 kg ha^{-1} to 5.1 kg ha^{-1} in Lake Crecy, New Brunswick.

In summarising world-wide trends in eel yields, Tesch (1977) considered that in lakes, yields between 10 and 40 kg ha^{-1} are high, average yields lie between 3 and 10 kg ha^{-1} and low yields are less than 3 kg ha^{-1}. On this basis the initial yields obtained from some Tasmanian lakes can be considered as being high, however, eel fishing was not permitted in the majority of these lakes after 1975. Consequently, yields for sustained fishing effort over many years cannot be predicted. The limited catch/effort data presented do indicate a decline in catch in successive seasons in several of the waters listed.

Chapter 5

THE DISTRIBUTION, ABUNDANCE, GROWTH AND FOOD OF FRESHWATER EELS (*ANGUILLA* SPP.) IN THE DOUGLAS RIVER, TASMANIA

5.1. INTRODUCTION

In order to investigate the apparent difference in the distribution of A. reinhardtii and A. a. australis in more detail, eel abundance, growth and diet were studied in the Douglas River where both eel species occur. This catchment lends itself to such a study as the river is clear and shallow in summer and has been subjected to minimal human interference.

Previous Tasmanian studies which include information on the distribution and diet of eels, relate only to the shortfin species (Sloane 1976; Lake & Bennison 1977). In Victoria, Beumer (1979) has studied the movement and diet of both A. reinhardtii and A. a. australis in a standing water body, but there are no similar published studies relating to running waters.

5.2 THE STUDY AREA

The Douglas River drainage basin (Fig.5.1) has an approximate area of 70 km^2. The basin drains south, then east from Thompsons Marshes east of Fingal Tier and enters the sea near Bicheno on the east coast of Tasmania. The river originates at 550 m a.s.l., in marsh land and passes through a steep, boulder strewn gorge with several 10-30 m water falls, then crosses the narrow east coastal plain, flowing through a series of deep (2-5 m) pools. The short (1.0 km) estuary maintains a more or less constant level all year round and at its mouth water flows across a sandy beach to the sea. The mouth is often barred by sand and frequently

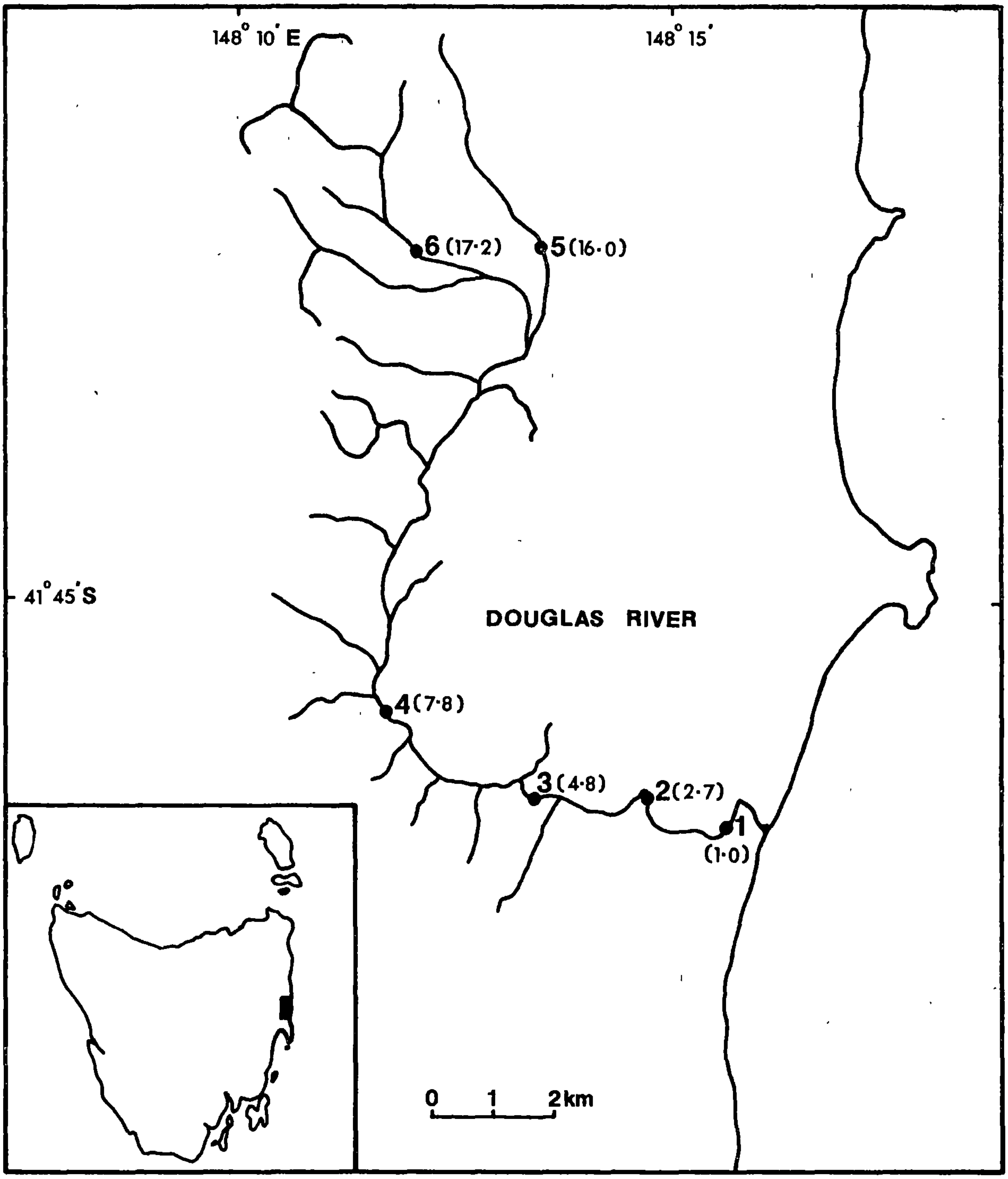


Fig. 5.1

Map of the Douglas River catchment showing the location of sampling sites: numbers in parentheses indicate distance from the sea (km).

there is no discernible flow across the beach for several months in mid-summer. The Douglas River has not been flow gauged, but exhibits a similar flow regime to other east coast streams with high flows during winter and spring, reverting to low flows during summer (January to March).

The Douglas River system represents a unique area for study as the river catchment has so far escaped the extensive agricultural and forestry activities to which all other east coast streams have been subjected. The river has not been dammed by any artificial barriers and a major road crosses the river at only one point, near the sea, providing the only access point to the river except for a logging track which crosses the extreme headwaters. The catchment is naturally vegetated, with only the lowest 2.5 km of stream bank cleared for pasture. A sparse population of brown trout (Salmo trutta L.) represents the only exotic fish species found in the Douglas River.

Fish population sampling was conducted at 5 sites during March 1981 when the river was at its lowest summer level for several years. Sampling areas were chosen at stream sections where the maximum depth of water did not exceed 1 m and were located at various distances from the sea (Fig. 5.1). The lowest station (site 1) consisted of a narrow run which separated the lowest pool from the estuary. Sites 1 to 4 were similar, all selected as narrow sections of stream with a rock and stone bed, no overhanging vegetation and without significant beds of aquatic macrophytes (such sites were not difficult to find as the lower 10 km of the river consisted of areas of this nature interspersed by some broad, shallow flats and deeper pools). Site 5 situated in the headwaters represented a considerable departure from the nature of the other sites. The river at this point was overhung by tea tree and had a silty bed with a scattering of flat rocks and small patches of aquatic macrophytes. An additional site (site 6) on an unnamed tributary creek exhibited essentially the same character as site 5. The steepness of the Douglas River gorge and the size of boulders and falls in the stream bed prevented access to the river between sites 4 and 5 with sufficient gear to conduct quantitative sampling.

5.3 MATERIALS AND METHODS

Density and biomass estimates of the eel population in the Douglas River were determined by electrofishing at five sites during summer (24-26 March 1981). The apparatus used was powered by a Honda E800U generator and produced a 240 v direct-current pulsed at 100 pulses s^{-1}. Each site was delineated by a stop net (1 cm mesh) at the upstream and downstream extremities and each site was electrofished in an upstream direction with three runs separated by 20 minute intervals. Fish captured on each successive run were removed and killed by immersion in a 2% w/v solution of tricaine methanesulfonate. The fresh weight (to 0.1 g) of each fish was recorded and the total lengths of all eels were measured (to 0.5 mm).

The efficiency of the electrofishing apparatus was assessed independently for eels and other fish by relating the actual recorded catch to the estimated total catch determined by the Moran-Zippin method (Youngs & Robson 1978). This method assumes that the sampling effort is constant and there is an equal probability of capture for each fish in a given run; the estimated total catch was determined by the intercept of a regression relating the actual catch per run to the total previous catch.

The diets of longfins (A. reinhardtii) and shortfins (A. a. australis) were assessed from a sample of eels collected by electrofishing in an area approximately half way between sites 1 and 2 on 6 February 1979. Each eel was killed, weighed and measured and its stomach was removed and stored in 70% ethanol. The importance of dietary items was assessed by the numerical (percentage composition by number) and the occurrence (frequency of occurrence in all non-empty stomachs) methods outlined by Windell and Bowen (1978). The Schoener (1970) index:

$$\alpha = 1-0.5\ (\sum_{i=1}^{n} |p_{xi} - p_{yi}|)$$

where n = number of food categories, p_{xi} = proportion of food category i in the diet of species x and p_{yi} = proportion of food category i in the diet of species y (proportions expressed as decimal fractions), was used in order to assess the overlap in diet between the two eel species and between different size groups of eel. This index gives values from 0 (no overlap) to 1 (complete overlap) and the overlap in diet is considered to be biologically significant when the value exceeds 0.60 (Wallace 1981).

Sagittal otoliths were used for age determination of both eel species. Otoliths were removed from all eels sampled on

6 February 1979 and 24-26 March 1981. Additional samples of small eels (< 20 cm) were collected by electrofishing near site 1 on 11 February, 26 March, 11 June, 20 August, 26 October and 22 December 1981 and on 19 January and 19 April 1982.

Otoliths were prepared for viewing by a modification of the technique described by Hu and Todd (1981). The otoliths were broken before burning, and after burning were placed broken face down against the surface of a glass slide, embedded in 'Silicone Sealant' 781 (Dow Corning Corporation, U.S.A.). The reverse (non-viewing) side of each prepared slide was painted with a flat black plastic paint. Otoliths were then viewed under a stereo-microscope using reflected light, with a drop of paraffin oil placed on the slide to reduce glare. A single fibre optic light source was used to enable careful adjustment of light intensity and direction, in order to provide the best possible contrast between the white and dark zones of the burnt otolith halves. A number of small otoliths, from eels < 20 cm, were prepared by the grinding technique outlined previously (v. 3.2). Some even smaller otoliths, from eels < 8 cm, were mounted whole in the mounting medium 'Depex'.

5.4 RESULTS

5.4.1 Electrofishing Efficiency

Estimates of the efficiency of the electrofishing apparatus, in terms of the percentage of the total estimated fish numbers and weights, taken in successive runs, are shown in Table 5.1. For cases where the actual recorded catch exceeded the estimated

Table 5.1 Efficiency estimates (percentage of estimated total catch) for successive electrofishing runs at five sites on the Douglas River (24-26 March 1981): estimated total number of fish (n); estimated total weight of fish (w).

Category	Site	Area (m^2)	Est. n	1 Run %	2 Run %	3 Run %	Est. w(g)	1 Run %	2 Run %	3 Run %
Eels	Site 1	66	118	78.0	90.7	101.7	7682	97.2	99.5	100.4
	Site 2	420	28	67.9	82.1	100.0	10021	80.2	98.0	98.1
	Site 3	525	30	60.0	86.7	93.3	4549	90.1	94.7	103.5
	Site 4	520	8	87.5	100.0	100.0	140	99.1	100.0	100.0
	Site 5	84	24	79.2	100.0	100.0	673	79.4	100.0	100.0
	All Sites	1615	208	74.5	90.4	100.0	23065	87.9	97.9	100.0
Other fish	Site 1	66	220	38.2	63.6	76.8	518	69.8	86.5	99.2
	Site 2	420	113	59.3	77.0	94.7	443	56.0	79.2	91.7
	Site 3	525	62	61.3	85.5	93.5	277	64.5	87.3	95.6
	Site 4	520	22	95.5	100.0	100.0	592	87.8	100.0	100.0
	Site 5	84	0	-	-	-	-	-	-	-
	All Sites	1615	417	50.4	72.4	85.4	1830	71.5	89.2	97.1

catch, the actual catch has been used to determine density and/or biomass. At sites 4 and 5 where no fish were taken in the third run, the two run catch totals have been used as estimates of the total fish population.

For eel numbers, 74.5%, 90.4% and 100% of the estimated total population at all sites were recorded in 1, 2 and 3 electro-fishing runs respectively. The corresponding weight values were 87.9%, 97.9% and 100%. Combined estimates for other fish species were 50.4%, 72.4% and 85.4% for numbers and 71.5%, 89.2% and 97.1% for weights, taken in successive runs. For both categories ('eel' and 'other fish') the percentage of estimated total weight exceeded the percentage of estimated number, reflecting the greater susceptibility of larger fish to electrofishing capture (Vibert 1967; Lagler 1978).

In each electrofishing run, the efficiency of capture of eels in terms of both weights and numbers exceeded the efficiency of capture of other fish. This may reflect a sampling bias towards eels and/or a greater susceptibility of eels to capture due to their shape or habit. The efficiency of capture for both eels and other fish categories, varied between sites.

5.4.2 Fish Population

In Table 5.2 estimates of the density (number of fish m^{-2}) and biomass (weight of fish m^{-2}) are given for each fish species at each site. <u>A. reinhardtii</u> clearly dominated the biomass estimates for sites 1, 2 and 3, representing 91.9%, 95.6% and 93.5% of the total

Table 5.2 Estimated fish density (D) n m^{-2} and biomass (B) g m^{-2} for five sites on the Douglas River (24-26 March 1981).

Fish species	Site 1		Site 2		Site 3		Site 4		Site 5	
	D	B	D	B	D	B	D	B	D	B
Anguilla reinhardtii	0.40	114.66	0.035	23.82	0.02	8.88	*	0.07	-	-
Anguilla australis	0.15	2.23	0.035	0.04	0.04	0.09	0.02	0.20	0.29	8.02
Galaxias maculatus	2.83	4.54	0.25	0.64	0.10	0.19	-	-	-	-
Galaxias truttaceus	0.02	0.13	0.01	0.05	0.01	0.09	0.01	0.11	-	-
Pseudaphritis urvillii	0.03	0.50	0.01	0.36	0.01	0.20	*	0.12	-	-
Favonigobius tamarensis	0.43	0.34	-	-	-	-	-	-	-	-
Salmo trutta	0.02	2.34	-	-	*	0.05	0.03	0.91	-	-
Total	3.88	124.74	0.34	24.91	0.18	9.50	0.06	1.41	0.29	8.02

* < 0.005

fish biomass respectively. Galaxias maculatus (Jenyns), a catadromous native fish, dominated the fish numbers at these sites, representing 72.9% 73.5% and 55.6% of the total fish numbers at sites 1, 2 and 3 respectively. At site 4 the brown trout, Salmo trutta, dominated fish numbers (50%) and weights (64.5%). A. a. australis was the only fish species collected at site 5.

The density and biomass estimates for A. reinhardtii, G. maculatus and Pseudaphritis urvillii (Cuvier and Valenciennes) showed a marked decline with increasing distance from the sea, and the goby (Favonigobius tamarensis Johnston) was only found at site 1, just above the freshwater/estuarine interface.

Qualitative electrofishing at site 6, in a headwater tributary stream, showed the short-finned eel to be abundant and a small population of Galaxias brevipinnis Günther was also present. Other freshwater fish which were recorded on different occasions during sampling at the Douglas River but which did not feature in the March 1981 survey, were the grayling, Prototroctes maraena Günther and the lampreys, Geotria australis Gray and Mordacia mordax (Richardson).

5.4.3 Seasonal Changes in Eel Abundance

Table 5.3 illustrates the relative proportions of longfins (A. reinhardtii) and shortfins (A. a. australis) recorded by electrofishing near site 1 during various months of the year. The number of longfins captured exceeded the number of shortfins only during

Table 5.3 The numerical percentage (%) of *A. australis australis* (Shortfin) and *A. reinhardtii* (Longfin) in the eel catch obtained by electrofishing near Site 1 on the Douglas River during various months : total number of eels in each sample (n); water temperature (°C).

	1981–1982							
	Jan.	Feb.	Mar.	Apr.	Jun.	Aug.	Oct.	Dec.
% Longfin	47.2	49.0	60.9	38.5	18.8	37.1	31.2	29.3
% Shortfin	52.8	51.0	39.1	61.5	81.2	62.9	68.8	70.7
n	53	49	64	65	64	35	77	82
°C	20.5	22.0	16.0	12.5	8.5	7.5	17.5	22.0

the March sample. In January and February the numbers of each species were almost equal and at all other times shortfins predominated. The smallest proportion of longfins in the catch (18.8%; n=64) was recorded during mid-winter (June) at a water temperature of 8.5°C.

5.4.4 Eel Length-Weight Relationship

The relationship between length and weight for 80 shortfins and 71 longfins, taken from the Douglas River on 24-26 March 1981, can be expressed as follows:

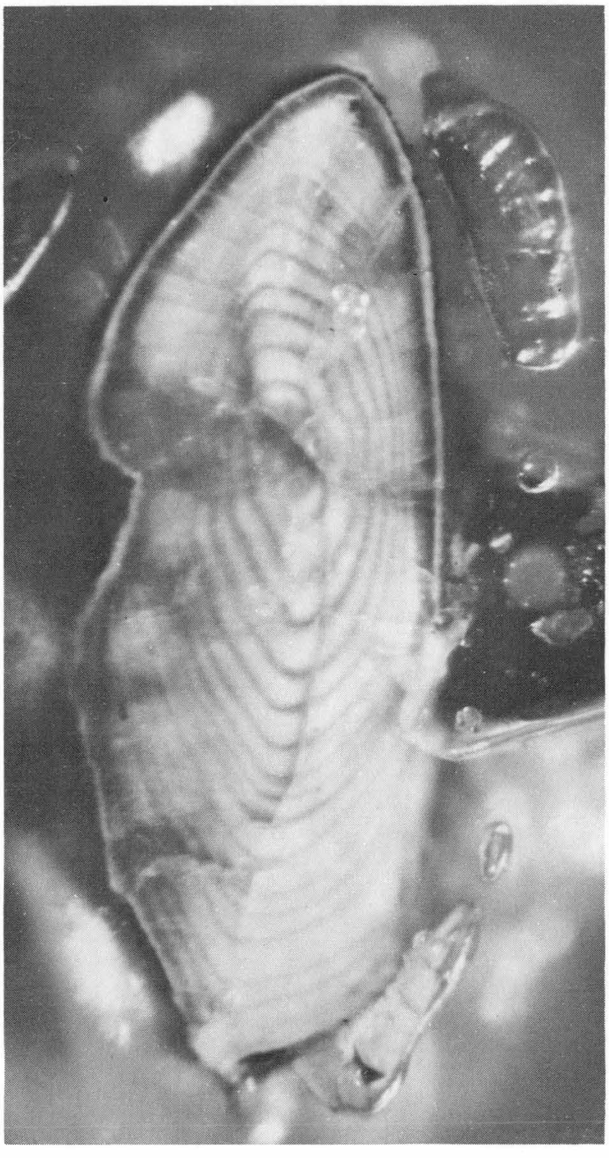
shortfins; $\log w=3.400 \log l-3.477$ ($r=0.992$, $p< 0.001$)

longfins; $\log w=3.548 \log l-3.567$ ($r=0.998$, $p< 0.001$)

Where w is weight (g), l is total length (cm) and r is the correlation coefficient. Computed weights for eels of the same length are therefore higher for longfins e.g. a 30 cm longfin from the Douglas River would weigh c. 47 g whereas a shortfin of the same length would weigh c. 35 g.

5.4.5 Age and Growth of Eels

Burnt, ground and whole mounted otoliths showed similar zonation, when viewed under reflected light against a black background, with alternate broad white and dark narrow zones. These zones correspond to the broad opaque and narrow hyaline (transparent) zones in the otolith (Jellyman 1979b). Burnt otoliths (Fig. 5.2) showed the best definition between adjacent zones and so were used in order to confirm that only one hyaline zone is laid down annually, during winter.



The mean marginal growth increments (calculated as the ratio of the width of the outer opaque zone to the width of the last-but-one opaque zone) for longfins and shortfins (< 20 cm) together with water temperature records for the Douglas River are illustrated in Fig. 5.3. In the 26 October sample, otoliths from 65% of longfins (n=17) showed a distinct hyaline ring near the outer margin, whereas all shortfins (n=17) taken on the same day exhibited a hyaline ring close to the margin.

The growth in length of the two dominant age groups for shortfins (age 0 and 1 year) and longfins (age 3 and 4 years) over a 15 month period, February 1981 to April 1982 (Fig. 5.4), reinforces the validity of the aging technique and illustrates that the main period of growth for both longfins and shortfins was from the end of October to the end of December. During these months, water temperatures in the Douglas River increased from about 15°C to 22°C (Fig. 5.3). It was therefore assumed that the hyaline rings in the otoliths of both longfins and shortfins are consistent with annual winter rings and the 1 October 'birthdate' used by Jellyman (1979b) for New Zealand eels, is an appropriate 'birthdate' for Tasmanian eels. Age determinations for all eels studied from the Douglas River were based on these assumptions: age 0 refers to eels which have not spent one full year (from 1 October to 1 October) in freshwater; age 1 refers to eels which have spent one full year in fresh water; age 2 - two full years, etc.

Growth curves for Douglas River longfins (n=169) and

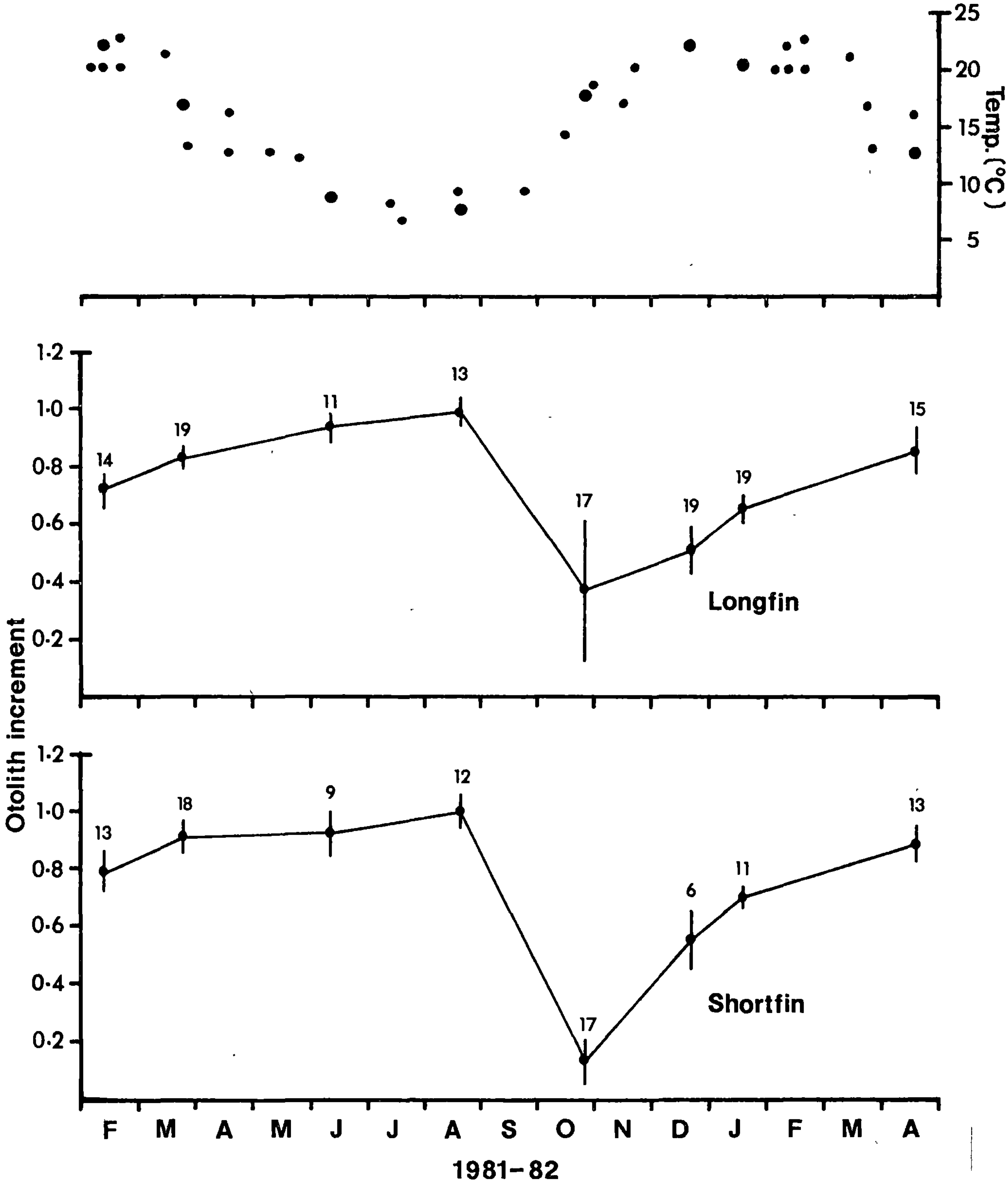


Fig. 5.3

Mean marginal growth increments (see text) of A. reinhardtii (Longfin) and A. australis australis (Shortfin) otoliths (February 1981 to April 1982) and water temperature records for the Douglas River. Vertical lines represent 95% confidence limits of the means with numbers in each sample given above. Temperature records on sampling days are larger solid circles.

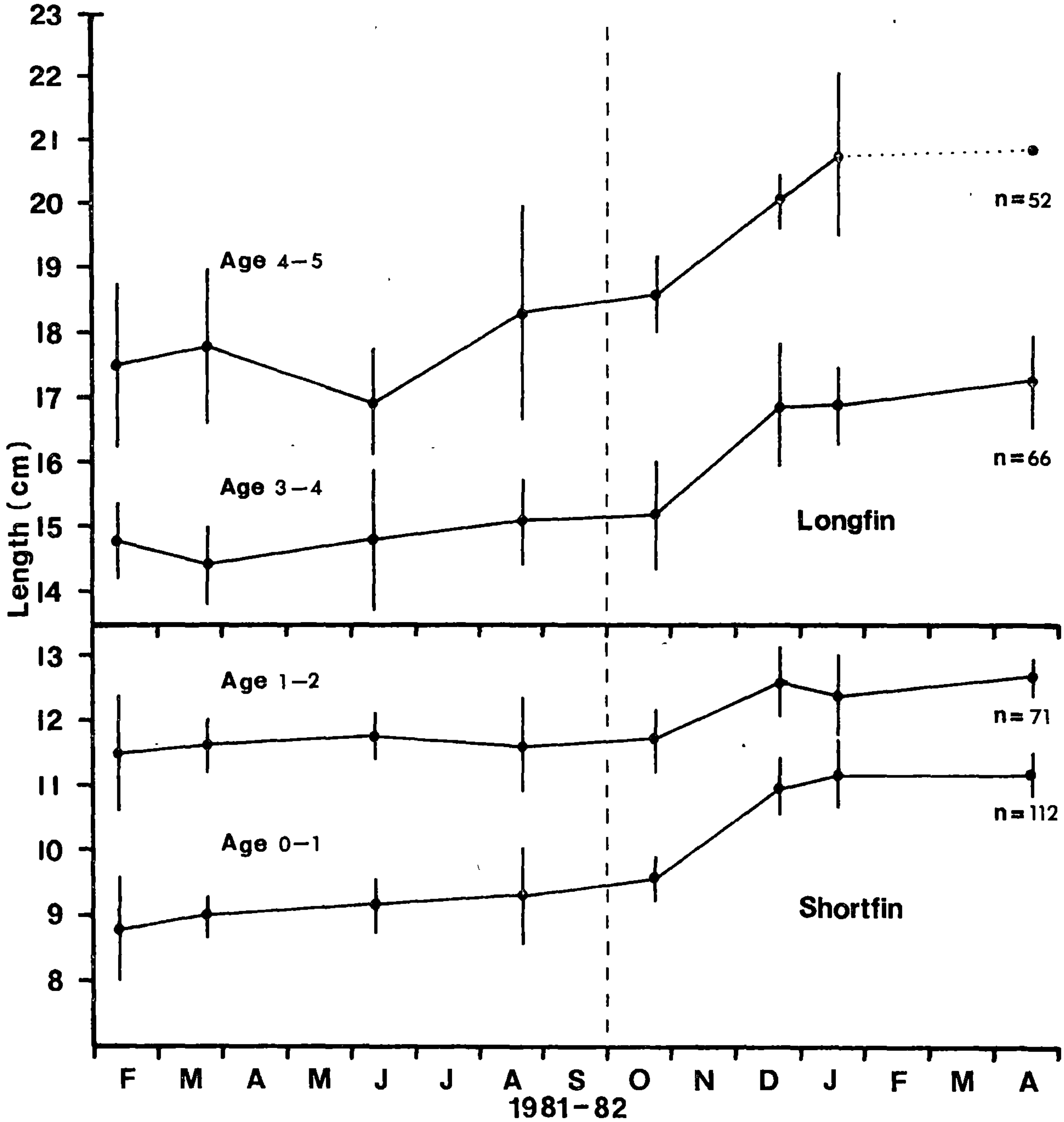


Fig. 5.4

Growth in length of dominant A. reinhardtii (Longfin) and A. australis australis (Shortfin) year classes; vertical dotted line indicates 1 October 'birthdate', solid vertical lines represent 95% confidence limits (n⩾5) of length means (solid circles).

shortfins (n=132) collected during summer, February 1979 – March 1981, are illustrated in Figs. 5.5 and 5.6 respectively. The mean length and range in length for an additional sample of longfin glass-eels (n=101) and shortfin glass-eels (n=3) are included at age -1. Glass-eels arriving at this time of year (February/March) have been classified as age -1 as they do not attain the status of age 0 until after 1 October in the year of their arrival. The growth curves indicate a slower rate of growth for shortfins than for longfins, especially after the third year in fresh water. As the majority of eels were too small to accurately determine their sex in the field, both male and female eels have been considered together.

For shortfins, age 0 (30.3%) and age 1 (13.6%) were found to be the dominant age groups, but age 0 was not represented for longfins and age 1 (2.4%) and age 2 (4.1%) were poorly represented. Age 3 (16.0%) and 4 (13.6%) were the dominant age groups for longfins. For eels taken during the Douglas River survey (24-26 March 1981), shortfins which had spent more than 10 years in fresh water were only found at site 5 where they represented 37.5% of the ageable shortfins (n=24). Longfins which had spent more than 10 years in fresh water were found at all sites where this species occurred (sites 1 to 4), representing between 12.8% (n=39; site 1) and 75% (n=12; site 3) of the ageable longfins.

Several large longfin female eels were included in the samples from the Douglas River. During the March survey, one longfin exceeding 100 cm was recorded at each of sites 1, 2 and 3. The largest, T.L.=118.0 cm (weight = 5 400 g; age = 40 years) was taken

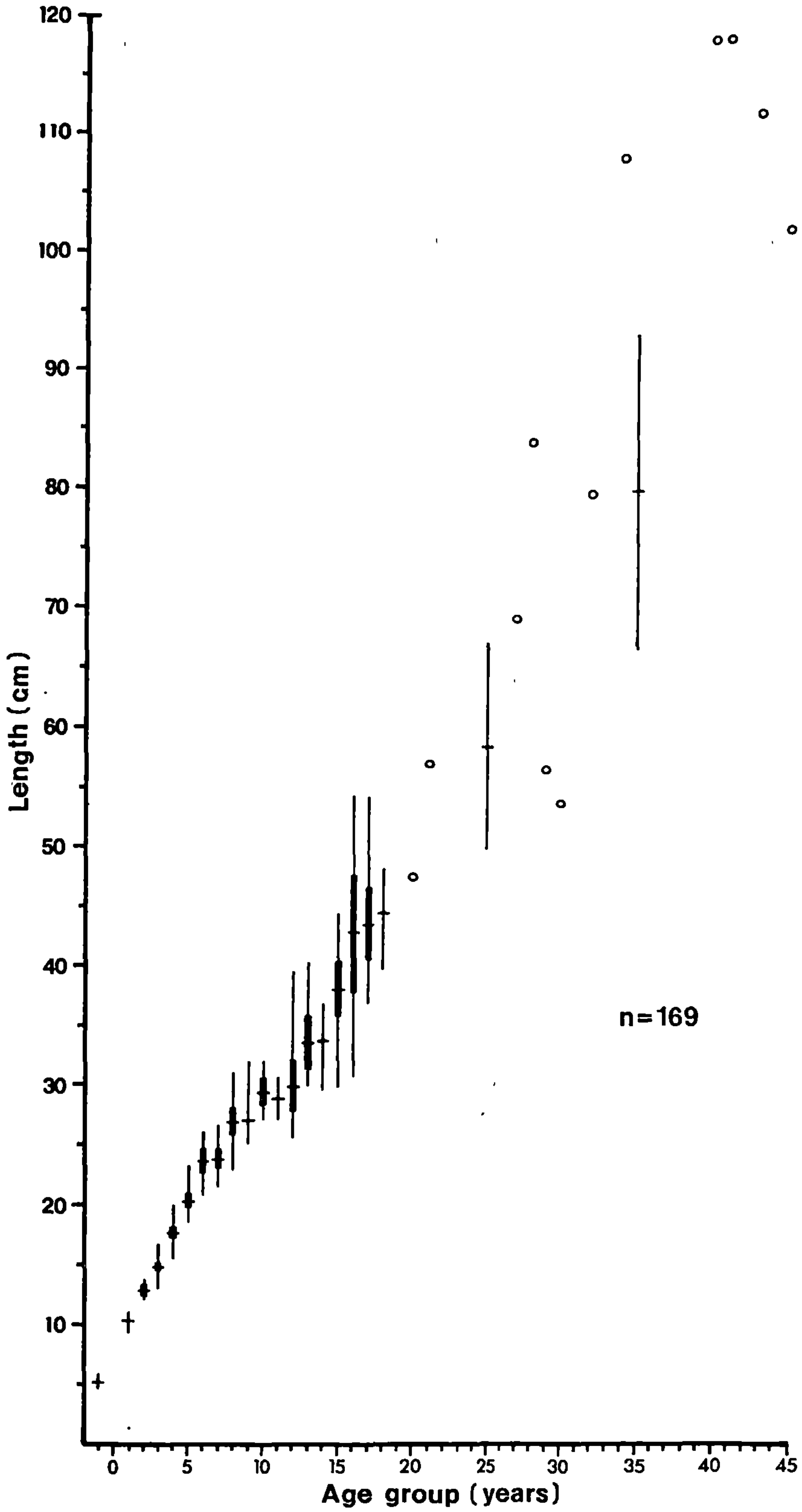


Fig. 5.5

Growth curve for A. reinhardtii (combined February 1979 and March 1981 data): mean length at age and range in length are represented by horizontal and vertical lines respectively; vertical bars indicate 95% confidence limits of the means (n≥5) and open circles represent single values.

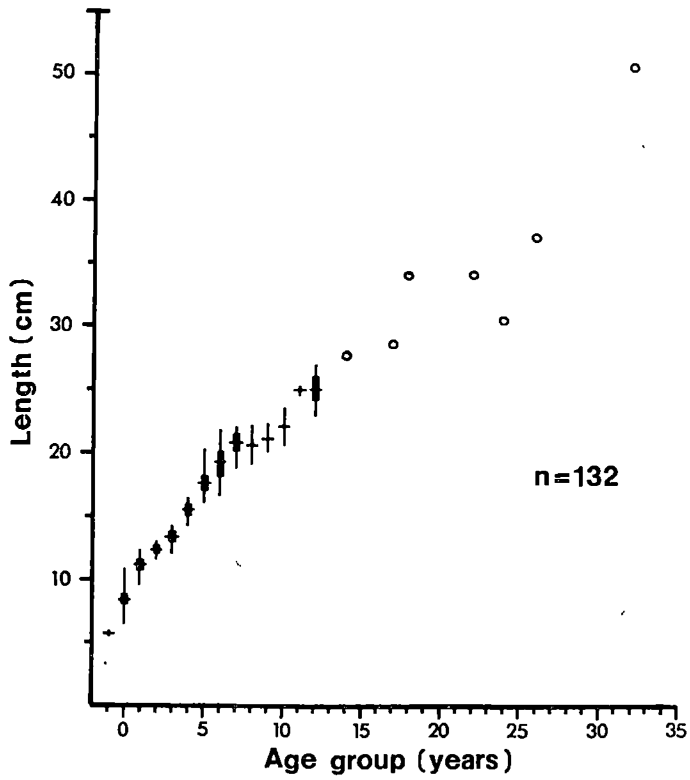


Fig. 5.6

Growth curve for A. australis australis (combined February 1979 and March 1981 data); mean length at age and range in length are represented by horizontal and vertical lines respectively, vertical bars indicate 95% confidence limits of the means (n≥5) and open circles represent single values.

at site 2. An even larger longfin, T.L. = 118.1 cm (weight = 6 120 g; age = 41 years) was taken during the February 1979 sampling. The largest shortfin, T.L. = 50.7 cm (weight = 240 g; age = 32 years) was recorded at site 5.

5.4.6 Diet of eels

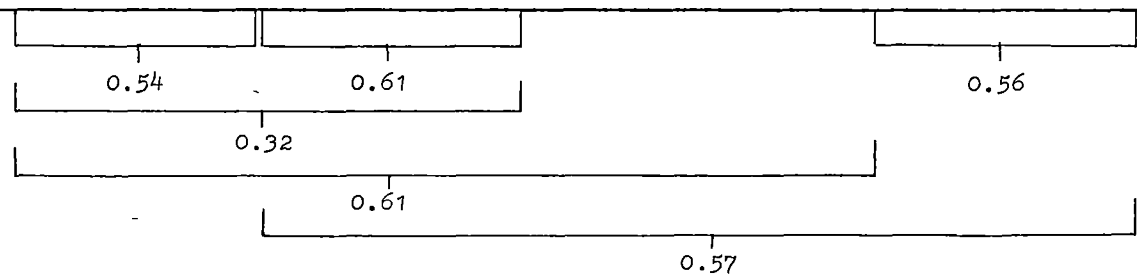
The principal food items found in the stomachs of longfins and shortfins sampled on 6 February 1979 are summarized in Table 5.4. Only one shortfin exceeding 40 cm in length was taken and the stomach of this eel was found to be empty. Shortfins showed a higher proportion of empty stomachs than longfins of the same size and all longfins examined which exceeded 40 cm in length (n=20) contained food in their stomachs.

The three numerically most important items in the diet of shortfins less than 20 cm in length were; Diptera > Ephemeroptera > Trichoptera. For longfins of the same size these insect groups also formed the most important items in the diet but in a different order; Trichoptera > Ephemeroptera > Diptera. In the diet of both eel species the Diptera were dominated by Simuliidae, the Trichoptera by Rhyacophilidae and the Ephemeroptera by Baetidae.

In the 20-40 cm length group, the diet of shortfins was dominated by Trichoptera and Ephemeroptera, with the decapod <u>Paratya australiensis</u> found to be numerically more important than found for smaller shortfins. In this size range (20-40 cm) longfins fed predominantly on <u>P. australiensis</u> with Diptera also being well represented. Diptera were not consumed by larger longfins (> 40 cm),

Table 5.4 The percentage composition by number, of items found in the diet of *Anguilla* spp. from the Douglas River (6 February 1979), for various size groups of eel : values in parentheses indicate the frequency of occurrence of dietary items. Values of the Schoener index are given below for the comparisons indicated.

Food Item	*A. reinhardtii* Size Group (cm) < 20		20–40		> 40		*A. australis australis* Size Group (cm) < 20		20–40	
Gastropoda			2.4	(10.3)	0.6	(5.0)	11.0	(12.5)		
Decapoda *Paratya*	9.1	(18.2)	41.0	(65.5)	69.1	(65.0)	3.0	(16.7)	17.9	(38.9)
Halicarsinus			0.6	(3.4)	0.6	(5.0)			3.6	(11.1)
Plecoptera	1.3	(4.5)			1.2	(5.0)	2.0	(4.2)		
Ephemeroptera	29.9	(36.4)	13.3	(31.0)	15.8	(25.0)	21.0	(33.3)	25.0	(38.9)
Odonata			0.6	(3.4)						
Diptera	22.1	(18.2)	29.5	(20.7)			47.0	(45.8)	17.9	(16.7)
Trichoptera	35.1	(45.5)	9.0	(20.7)	3.0	(20.0)	14.0	(33.3)	32.1	(27.8)
Coleoptera					1.2	(10.0)	2.0	(4.2)		
Anguillidae			1.8	(10.3)	2.4	(15.0)				
Galaxiidae	1.3	(4.5)	3.6	(17.2)	1.2	(10.0)				
Teleostei (Misc.)	1.3	(4.5)	1.8	(10.3)	1.2	(10.0)				
Terrestrial					3.6	(20.0)			3.6	(11.1)
% Empty	29.0		27.5		0.0		36.8		33.3	
No. of fish	31		40		20		38		27	



which fed primarily on P. australiensis.

Fish were only found in the diet of longfins, and occurred more frequently in the diet of larger eels. Fish occurred in 9% of the stomachs of longfins less than 20 cm, in 18% of longfins 20-40 cm and in 30% of longfins larger than 40 cm. Although not important numerically, fish dominated stomachs in which they occurred, in terms of food bulk. Of 16 fish remains found in the stomachs of longfins, 7 were identified as Anguilla spp. and of these, four were sufficiently intact to be identified as shortfins (A. australis).

Values of the Schoener index (Table 5.4) indicate that the overlap in diet between small (< 20 cm) longfins and small (< 20 cm) shortfins was biologically significant (α=0.61). The only other comparison which gave a significant overlap in diet was between 20-40 cm longfins and large (> 40 cm) longfins (α=0.61). All other comparisons indicate diets which did not overlap significantly; the greatest dissimilarity in diet occurred between small (< 20 cm) and large (> 40 cm) longfins (α=0.32).

5.5 DISCUSSION

5.5.1 The Fish Population

Lake and Fulton (1981) have pointed out the importance of obtaining an estimate of the efficiency of an electrofishing apparatus in order to estimate fish density and biomass. They obtained efficiencies of 60.2% of estimated fish number and 77.2%

of estimated total fish weight in two successive electrofishing runs in Parsons Bay Creek, Tasmania. These are lower than the efficiencies estimated for the Douglas River using a similar electrofishing machine in the present study. Estimates of electrofishing efficiency were found to differ between sites and for different fish categories; ideally, separate efficiencies should be determined for each fish species at each site. The high overall efficiency estimates for the electrofishing apparatus in the Douglas River probably reflect the water clarity, the shallow nature of the sampling sites and the rocky nature of the stream bed.

In the Douglas River, total fish density and biomass were highest at the sites nearest the sea. Lake and Fulton (1981) observed a smilar trend in Parsons Bay Creek and suggested that this was partly due to the migration of fish from the sea into fresh water. In the Douglas River, high fish densities in the lower fresh water reaches (site 1) were largely due to the abundance of several fish species dependant on migration to and from the estuary, particularly G. maculatus and the goby F. tamarensis. Gobies were only recorded at site 1 and G. maculatus diminished in numbers further inland. High biomass estimates in the lower reaches (sites 1 and 2) were dominated by the presence of large longfins (A. reinhardtii).

5.5.2 The Eel Population

The density and biomass estimates for shortfins (A. a. australis) in the Douglas River lie within the range recorded in other Tasmanian streams (v. 4.3.2). The high biomass estimate for longfins (115 gm^{-2}) recorded at site 1, exceeds any other eel biomass estimate recorded in Tasmania and represents a very high value for temperate Anguilla spp. (see Chapter 4 for further discussion of eel density and biomass).

In the Douglas River both the density and biomass estimates for longfins declined markedly with increasing distance from the sea. In contrast, the highest shortfin estimates were recorded at the furthest site from the sea (site 5). This contrasts with the trend of eel density and biomass decreasing further inland which has been demonstrated for lowland streams in southern Tasmania where the shortfin was found to be the only eel species present (Sloane 1976; Lake & Fulton 1981). In New Zealand the number of eels has been found to decrease with increasing distance from the sea, with the long-finned species A. dieffenbachii predominating in upland streams (Hardy 1950; Woods 1964).

5.5.3 Eel Age and Growth

Jellyman (1979b) used whole mounted, ground and burnt otoliths to determine the age of New Zealand eels of various sizes, and demonstrated that the zonation in burnt otoliths of small eels (< 20 cm) was annual, the hyaline ring being laid down at the end of winter. This was also found to be true for both species of eel in the Douglas River, although the formation of the hyaline ring may be completed several weeks later in longfins. In a sample of eels collected on 26 October, all shortfins had completely formed a hyaline ring near the otolith margin, but only 65% of longfins had done so.

Late spring/early summer was found to be the main period of growth for both eel species, a time of increasing water temperatures (c. 15°C to 22°C) in the Douglas River. Beumer (1979) studied the same eel species (A. reinhardtii and A. a. australis) in Macleods Morass, Victoria and found that eels were more active during spring and summer and exhibited a relatively low number of empty stomachs at this time of year. Burnet (1969c) reported no winter growth in tagged New Zealand eels (A. a. schmidtii and A. dieffenbachii).

A number of studies have reported growth of temperate Anguilla spp. at temperatures as high as 28°C (Matsui 1969; Jellyman & Coates 1976; Kuhlmann 1979). However, the maximum water temperature recorded in the Douglas River was only 22.5°C, suggesting that summer water temperatures would be unlikely to inhibit eel growth. That the high eel growth period in late spring/early summer was not maintained during mid-summer, may be attributable to low summer water levels reducing the available feeding areas. The peaks in eel activity in Macleods Morass during spring/summer reported by Beumer (1979) coincided with inundation of marginal areas resulting from late winter and spring rains.

The growth of shortfins in the Douglas River was found to be slower than that of longfins. For example, a 25 cm shortfin from this river may have spent about 12 years in fresh water, whereas a longfin of the same length may have spent only 7 years. Sloane

(1976) recorded much faster growth for shortfins in the Coal and Jordan rivers in southern Tasmania, with eels 25 cm in length having spent only 5-6 summers in fresh water (according to the assumptions made in the present study). Burnet (1969c) also found great differences in growth rates between the two New Zealand eel species and great differences for the same species in different rivers. Burnet's tag data showed great variability in individual eel growth rates (Burnet 1969c) , a feature which has been widely reported for other Anguilla spp. (e.g. Frost 1945; Smith & Saunders 1955; Deelder 1957; Gunning & Shoop 1962; Sinha & Jones 1967a). Such variability is indicated by the Douglas River study and was particularly evident for large longfins.

5.5.4 Eel Year Class Strength

During summer, the dominant year classes for shortfins were age 0 and age 1, but, age group 0 was not represented for longfins and age 1 and age 2 were only poorly represented. This is surprising, as the youngest year class might be expected to predominate particularly in the lower fresh water reaches. This may suggest a failure in longfin glass-eel recruitment into the Douglas River. Poor glass-eel recruitment in particular years has been reported elsewhere for other Anguilla spp. (Jellyman 1977a; Tesch 1977; Matsui 1980). However, this seems unlikely as the age structure of the Douglas River eel population was based on combined February 1979 and March 1981 figures which would put the 1977, 1978, 1979 and 1980 longfin glass-eel recruitment in doubt. The 1977 glass-eels correspond to the three year olds collected in 1981 and although this year class was not represented in February 1979 as age

1, the same year class dominated the age groups present in March 1981, representing 21.1% of ageable longfins (n=71).

If failure of glass-eel recruitment does not explain the relative scarcity of the 0, 1 and 2 age groups for longfins, an alternative explanation must be sought. Longfin glass-eels were found to invade the first freshwater riffle of the Douglas River during late summer and autumn, but were not found after mid-winter (v. 2.3.2). The onset of lower winter temperatures may result in a movement of juvenile longfins back into the estuary or into the deep pools in the lower freshwater reaches. Young longfins may spend several years in these areas, re-invading the fresh water shallows mainly during their fourth year (age 3). The increase in the relative numbers of longfins in the freshwater shallows near the head of the estuary observed during summer may reflect such a movement.

5.5.5 Eel Diet

In the Douglas River the diets of small (< 20 cm) longfins and shortfins were similar during summer, the three numerically most important food groups being shared by both species. For both longfins and shortfins the most important dietary items ingested were found to be dependent on eel size. A change in diet with size of eels has been recognised for other Anguilla spp. (e.g. Cairns 1942; Jubb 1961; Boetius & Boetius 1967; Ogden 1970). Beumer (1979) did not observe such a change for the eels in Macleods Morass, but his study was confined to eels larger than 30 cm.

The diet of both eel species in the Douglas River was found to be similar to the diet of stream dwelling shortfins reported from southern Tasmania with insects and crustaceans forming the major food groups (Sloane 1976; Lake & Bennison 1977). Although fish were not found in the stomachs of shortfins in the Douglas River, longfins in all size groups were found to feed on these. Larger longfins showed an increased dependence on fish in their diet, a trend which has been observed in A. anguilla (Moriarty 1972, 1973; Sinha & Jones 1967b; Pritchett 1974; Ezzat & El-Seraffy 1977) and for A. rostrata (Boetius & Boetius 1967; Ogden 1970). Beumer (1979) found fish to be important items in the diet of both longfins and shortfins in Macleods Morass and indicated that whole fish were normally ingested by eels larger than 50 cm. He recorded cannibalism by both eel species and suggested that this was a characteristic of anguillid diets (cf. Cairns 1942; Sinha 1965; Sinha & Jones 1967b; Pritchett 1974). In the Douglas River longfins were found to feed on eels, but all the devoured eels which could be identified to species were found to be shortfins.

5.5.6 Eel Habitat

A decline in longfin eel abundance with increasing distance from the sea has been recognized as a widespread trend in north-eastern Tasmania (v. 4.3.1). A number of factors may contribute to this trend, including the habitat preference mentioned by Scott (1934), longfins preferring a gravelly or sandy, rather than a muddy, bottom. However, in the Douglas River, sites 1 to 4 were chosen as being very similar in character, all with a stony substrate and yet longfin biomass declined from _c_. 114.7 gm^{-2} to 0.1 gm^{-2} in a distance of only 7 km.

Beumer (1979) captured the majority of longfins in the deeper area of Macleods Morass (0.3 - 5.1 m). In the Douglas River, water deeper than about 2 m is largely confined to the estuary and the main pools of the lower 2 km of fresh water. Although longfins were found to reside in shallow stream sections during summer, a dependence on deep water may be associated with a retreat to such areas to avoid low winter temperatures. This may be expected as the east coast of Tasmania represents the southern limit of the distribution of the longfin, a species which is generally regarded as a sub-tropical rather than a temperate eel. Larsen (1972) studied seasonal changes in the density of _A. anguilla_ in two Danish streams and found that eel density in shallow biotopes was closely related to water temperature, suggesting that eels migrate to the lower, deeper reaches of streams during winter.

The decline in abundance of longfins further upstream was paralleled by a decline in abundance of several catadromous fish species in the Douglas River, particularly _G. maculatus_. It is therefore possible that the decline in longfin abundance further from the sea may also be related to the decline in abundance of a suitable small forage fish as well as avoidance of low winter temperatures.

A trend of older eels being found further from the sea was apparent for both species within their ranges in the Douglas River. In particular, shortfins more than 10 years old were only found in the headwaters (site 5). Shortfins up to age 10 have been reported in Tasmanian elver migrations (v. 3.3.6) indicating that the shortfin population at the lower sites (1 to 4) on the Douglas River lies within the age associated with summer upstream migration. This may reflect the unsuitability of this part of the river to shortfin colonization with the distinct change in habitat, from a steep stony stream to a slow silty stream, being related to shortfin residence at site 5. The New Zealand short-finned eel, A. a. schmidtii, may have a similar habitat requirement as this sub-species is thought to prefer 'more stable' stream sections (Burnet 1969a).

5.5.7 Eel Inter-relationships

The slow growth rate recorded for shortfins in the Douglas River may reflect the unsuitability of this type of stream for this eel. The apparent unsuitability may be largely related to preferred habitat but may also reflect direct competition between longfins and shortfins. The overlap in diet between small shortfins and small longfins recorded during summer coincided with a period of reduced eel growth which may have resulted from low water levels limiting the available feeding areas. The occurrence of Anguillidae in the diet of longfins suggests that predation by longfins on shortfins may also be an important facet of eel competition in the Douglas River.

Chapter 6

PRELIMINARY OBSERVATIONS OF MIGRATING ADULT FRESHWATER EELS (*ANGUILLA* SPP.) IN TASMANIA

6.1 INTRODUCTION

Published information relating to the seaward migrations of maturing adult freshwater eels in Australia has been confined to cursory observations only (e.g. Kershaw 1911; Anderson & Whitley 1925; Whitley 1956; Mann 1979). In contrast the knowledge of migrating eels in New Zealand is extensive, particularly with the addition of the work published recently by Todd (1980, 1981c, d, e).

In Europe adult migrating eels (A. anguilla) have been the subject of many detailed studies (see Deelder 1970; Tesch 1977) and river weirs which trap downstream migrant eels (silver eels) have been operated on many river systems for generations. One of the best examples is the eel weir at Toome on the River Bann (Northern Ireland) which has been described by Frost (1950). In Canada this type of fishery has also been established; a trap on the Richelieu River in Quebec has been profitably operated for more than 100 years (Eales 1968).

During the year ended 30 June 1979, a fishery based on the capture of downstream migrating adult eels was begun in Tasmanian rivers. This fishery was initially unsuccessful with five fishermen landing only 1.5 t in the first year. The unsuitability of gear used and the lack of knowledge of the habits of migrating eels contributed to this poor return.

The research described in this chapter was initiated in order to obtain basic information on the timing and periodicity of such migrations and details of the quantities, age and size of the eel migrants in order to assess the viability of this new fishery in Tasmania.

6.2 MATERIALS AND METHODS

Data relating to the period of downstream migration of eels were compiled from commercial catch returns and observations made by the author. Detailed records of daily eel catch were recorded from a commercial eel trap situated on the Clyde River near Bothwell during the 1981-82 season. The trap consisted of two loose stone 'wings' which served to funnel water and eels into a narrow 'eye', elevating the water level at this point by about 40 cm. A wooden trough built into the 'eye' carried the water to a 2 m x 2 m x 1 m catching box made of 2 cm steel mesh (capable of holding eels greater than about 30 cm in length - the legal minimum size). Some information was obtained from similar traps situated on the Jordon River and Ouse River (two 'eyes' operated on the same principle). During the 1979-80 season details of catch were recorded at a trap on the Macquarie River which operated on the same principle but used steel mesh leaders to guide the eels. Migrating eel records for the Clyde River during the 1980-81 season were obtained from eel catches made in an irrigation channel which leaves the Clyde above Bothwell; eels were caught by setting a fyke net in a constricted section of the channel. Catch details from Trevallyn Dam and Lake Tiberias were obtained from monthly fyke net catch returns made available by the Tasmanian Inland Fisheries Commission. For localities mentioned in the text see Fig. 6.1.

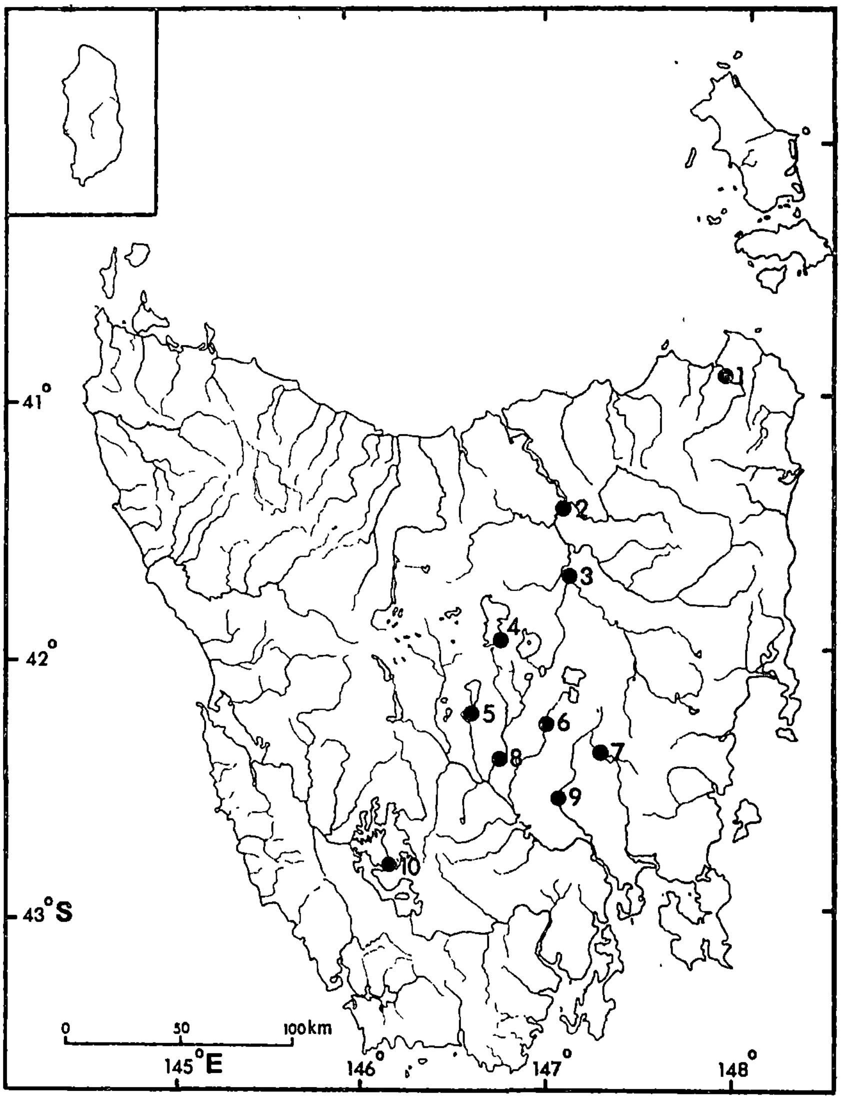


Fig. 6.1

Map of Tasmania showing localities mentioned in the text.
(1) Ringarooma River
(2) Trevallyn Dam
(3) Macquarie River
(4) Tods Corner, Great Lake
(5) Dee Lagoon
(6) Clyde River
(7) Lake Tiberias
(8) Ouse River
(9) Jordan River
(10) McPartlan Canal

During the 1981-82 season the eel trap on the Clyde River was usually visited every two days (more frequently during peaks of migration, less frequently during periods of low catch) and the captured eels were netted out of the catching box and weighed. Maximum and minimum water temperatures were recorded on each visit to the trap and daily flow records for the Clyde River at Bothwell and Lake Crescent were obtained from the Tasmanian Rivers and Water Supply Commission. Sub-samples of the Clyde River catch were examined at a local eel processing factory. The eels were first killed and deslimed in an ammonia solution. The total length was then recorded to the nearest 1 mm and the weight was determined to the nearest 1 g. Some eels were filleted with the gut and head being retained for further analyses. Gonads were separated from the gut samples, placed on blotting paper to remove excess moisture and weighed to the nearest 0.1 g. The gonadosomatic ratio (G.S.R.) was calculated from the equation:

G.S.R. = 100 x gonad weight/deslimed eel weight

Sagittal otoliths were removed from eel heads, stored dry in seed envelopes and later prepared for viewing by a modification of the method outlined by Hu and Todd (1981) (v. 5.3). Under reflected light, the broad white rings on the burnt otoliths halves were interpreted as summer growth and the alternate narrow dark rings as winter growth. As in previous chapters (v. 3 and 5), eels were assigned age groups according to the number of full years spent in fresh water, assuming a 1 October 'birthdate'.

6.3 RESULTS

6.3.1 Characteristics of Migrating Eels

Migrating shortfins, A. a. australis, and longfins, A. reinhardtii, were found to differ markedly in appearance from the non-migrant 'feeding eel' stage. Shortfins seen far inland at the start of their downstream migration appeared dark brown/black on the back and metallic bronze on the flanks. The ventral surface was usually white/grey or pale silver. Nearer the sea migrating shortfins usually appeared dark green/black (sometimes a striking olive green) on the back and the ventro-lateral and ventral surfaces appeared bright silver. The migrating form could also be distinguished by enlarged eyes and black pectoral fins.

As the longfin approached its adult migration the marbled or spotted black-on-green colouration of the feeding eel was found to disappear and the back, flanks and fins became a uniform black. On the underside the migrating form appeared pale grey or white and sometimes a faint silver colour.

6.3.2 Period of Downstream Migration

In the Central Highlands of Tasmania qualitative observations of eel migrations were made at two locations. Eels moving downstream from Lake Echo pass through a hydro-electric turbine before entering Dee Lagoon. Chopped up remains of migrating eels were observed in the canal below the power station and along the immediate shores of the lagoon during the period early December to the end of January, in consecutive seasons, 1980-81 and 1981-82. At Tods Corner, Great Lake, pieces of chopped up eels were observed during the period 14 November to 17 December 1979. These eels were apparently chopped up by the pump which conveys water through a pipeline from Arthurs Lake to Great Lake. The eel fragments examined at both locations were found to be maturing adult shortfins. The exact period during which migrating eels were seen at these locations depended upon the hydro-electric outputs which varied from day to day.

To date, the most successful commercial trapping for migrating eels has been conducted on the Clyde River above Bothwell. During the 1978-79 season this river was fished unsuccessfully using fyke nets set across the main stream; only 0.4 t were taken. A net set in the main irrigation channel above Bothwell was fished during part of January and February 1981. 1.1 t of migrating shortfins were caught between 10 January and 6 February even though 9 days were lost during this period due to closure of the channel.

During the 1981-82 season detailed records of the quantities of eels entering the migrating eel trap on the Clyde River were recorded (Fig. 6.2). The trap commenced operation on 14 November 1981 and was closed down on 7 May 1982. 5.2 t of migrating shortfins were caught between 16 November and 24 April with the majority (53%) of the catch taken during January. An identical trap situated 50 km further downstream was fished during the same period for a total catch of less than 0.2 t, indicating that nearly all the Clyde eel migrants were caught in the trap near Bothwell.

An eel trap on the Jordan River caught a small quantity (0.2 t) of migrating shortfins during the first two weeks of operation

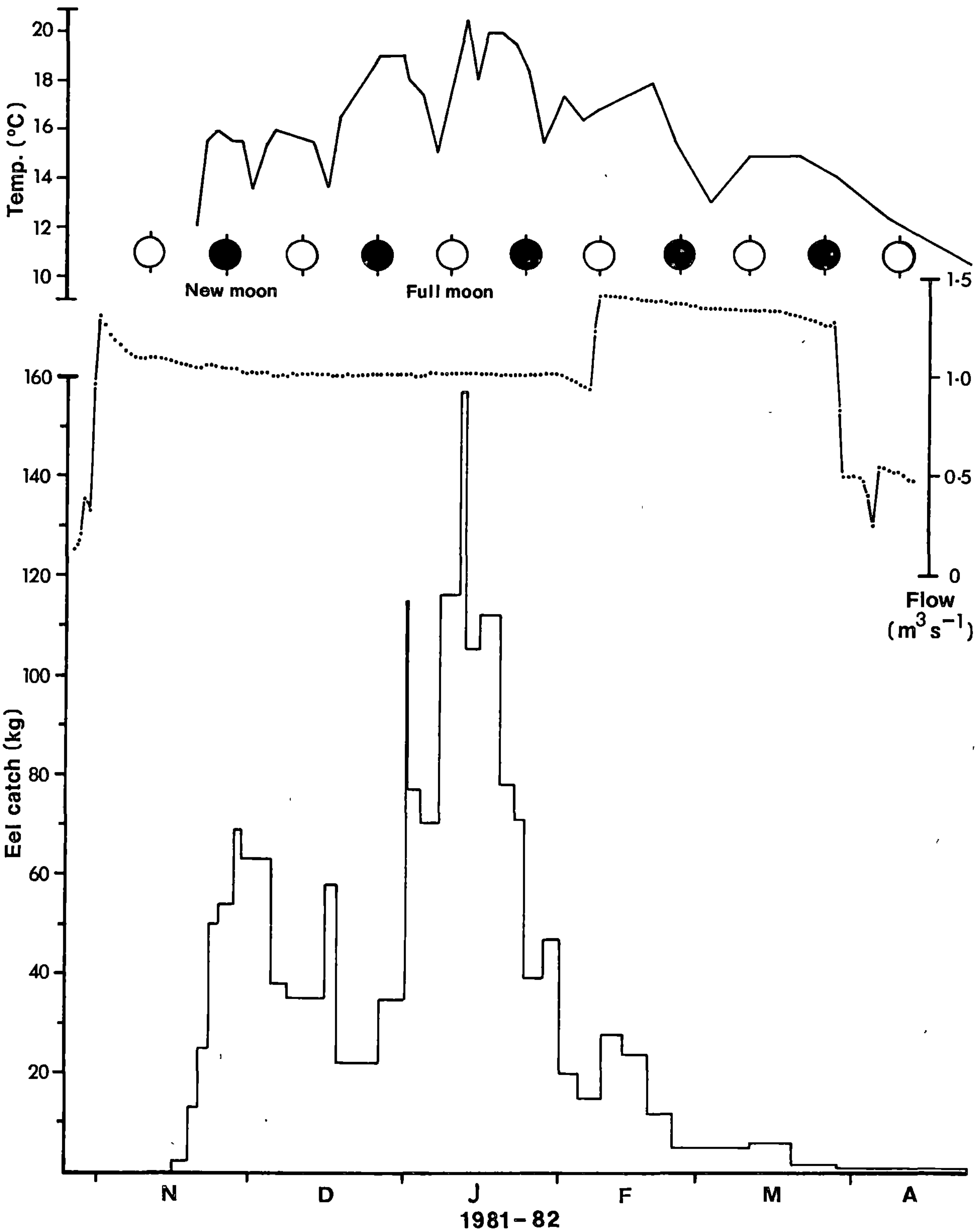


Fig. 6.2

Daily A. australis australis catch records for the Clyde River migrating-eel trap, with mean water temperatures and mean daily flow; days of full and new moon are indicated.

(4-20 October 1981) after which time the river ceasing flowing until the following winter with no further eels being taken. Large catches of silver shortfins were made from Lake Tiberias (975 ha) at the source of the Jordan River by fyke netting during October 1971 (7.6 t) and during October and November 1976 (7.1 t).

A trap on the Ouse River, installed late in the 1981-82 season (12 February 1982) caught small quantities of migrant shortfins during March.

On the Macquarie River in northern Tasmania 0.7 t of migrating shortfins was captured in an eel trap fished from the beginning of November 1980 until the end of March 1981. More than half the total catch was recorded during the first three weeks of operation. Several floods during the trapping period prevented successful capture of the eel migrants.

Further downstream on the South Esk River system (which includes the Macquarie River) catches of silver eels have been taken in fyke nets set in Trevallyn Dam (165 ha). Details of the monthly catch from this water for the last four seasons, 1978-79 to 1981-82, are summarized in Table 6.1. January (22.4%), February (22.7%) and March (38.0%) have been the most productive months and virtually the entire eel catch in these months has been reported to consist of silver shortfins, the majority of which apparently migrate downstream from inland lakes and headwater streams. The author viewed a catch of about 1.0 t of eels from this water caught during the first week of January 1982. One eel was a large(20 kg) longfin female in

Table 6.1 Monthly A. australis australis catch (%) and catch per unit effort (Kg eel per net day), based on commercial fyke net catch returns from Trevallyn Dam for the seasons 1978-79 to 1981-82: total catch 30 tonnes.

Month	Catch	Catch/effort
October	0.7	1.25
November	2.7	0.73
December	4.8	1.02
January	22.4	1.87
February	22.7	2.55
March	38.0	2.72
April	8.7	1.35

migrating condition and the remainder of the catch consisted of silver shortfins.

In south-west Tasmania, migrating eel adults have been observed passing down McPartlan Canal from Lake Pedder to Lake Gordon during summer. Only a small sample collected early in March 1980 has been examined by the author. These were large shortfin females in migrating condition.

A commercial eel fisherman used fyke nets to trap down-stream eel migrants near the mouth of the Ringarooma River in north-eastern Tasmania during the 1978-79 and 1979-80 seasons. Longfins were caught migrating into the sea mainly during March and April, with the largest catch (approximately 2.0 t) recorded during the first week in April 1980.

6.3.3 Factors Influencing Migration

Daily catch records from the Clyde River eel trap, together with mean water temperatures recorded at the trap site and mean daily flow records for the Clyde River at Lake Crescent, are illustrated in Fig. 6.2. The quantity of eels taken was found to bear no relation to lunar periodicity with 20%, 27%, 27% and 26% of the total catch recorded during the first, second, third and last quarters of the moon respectively. The two largest catches for any single lunar phase occurred during the second quarter (16.8% of total catch) and third quarter (14.6% of total catch) during January.

The flow of the Clyde River is regulated by a control gate at Lake Crescent which was opened on 1 November 1981 maintaining a virtually constant 1 cumec (m^3 s^{-1}) flow during November, December and January. On 6 February the flow increased to 1.3 cumecs until late in March when the discharge was reduced to less than 0.5 cumecs. Flow recordings for the Clyde River at Bothwell record the equivalent fluctuations approximately 3 days after the Lake Crescent gauge, indicating that the water takes several days to reach the trap situated 3 km above Bothwell. The Bothwell recordings are influenced by the main irrigation channel which leaves the river just downstream from the eel trap and consequently do not depict the flow at the eel trap as accurately as the Lake Crescent recordings.

The initial movement of eels into the trap occurred during a period of increasing water temperature and the main peak in eel catch during January coincided with the highest mean water temperature record of 20.5°C. The highest water temperature maximum was 25°C recorded during the period 11 to 13 January. There was a very highly significant ($p < 0.001$) positive correlation between mean water temperature and weight of eels captured ($n=39$, $r=0.682$).

6.3.4 Size, Sex and Age of Migrating Eels

Three samples of migrating eels from the Clyde River were examined for length and weight, and G.S.R. and age were determined for a proportion of the eels in two of these samples. The three eel samples were the only silver eel catches made available at the processing factory which were not contaminated by feeding eels or eels from other sources. The period over which each eel sample was trapped and the length and weight means and ranges are presented in

Table 6.2. All the eels measured were shortfin females except for one male, T.L. = 49.5 cm, weight = 223 g.

The grand means for the total sample of female shortfins (Table 6.2) indicate an average weight of c. 1 700 g and an average length of c. 94.5 cm. Analyses of variance showed that there was a very highly significant ($p < 0.001$) difference in mean length between the three samples ($F = 10.02$, d.f. = 2/186) and a highly significant ($0.01 < p < 0.001$) difference in mean weight between the three samples ($F = 5.51$, d.f. = 2/186). Eels in the earliest sample, from December, were larger than the eels taken during January. The percentage length and weight frequencies for the total female eel sample (Fig. 6.3) approximate normal distributions, and indicate that female shortfins in the Clyde River system were normally found to migrate downstream at a length of 80-110 cm and a weight of 1.0 to 2.5 kg.

The mean G.S.R. for a sub-sample of 65 female shortfins trapped during the period 5 December 1981 to 11 January 1982 was 2.35 ± 0.10 (95% C.L.). G.S.R. values ranged from 1.50 to 3.33. Age determinations recorded for the same sub-sample of eels varied between 18 and 30 years with a mean of 22.13 years. The age frequency distribution for Clyde River eels (Fig. 6.4) indicates a skewed distribution with 76% of eels in the six lowest age groups, 18 to 23 years. Age 20 was the dominant age group.

Burnt sagittal otoliths provided a clear distinction between dark winter and white summer growth rings. The majority of eel otoliths (about 80%) were characterised by 5 to 10 closely spaced

Table 6.2 Length and weight of female *A. australis australis* from the Clyde River migrating eel trap.

Sample period	n	Mean total length (cm)	Mean deslimed weight (g)	Length range (cm)	Weight range (g)
5.12.81 - 1.1.82	85	96.17	1788.1	85.0 - 110.0	1166 - 3038
1.1.82 - 11.1.82	54	92.51	1611.8	82.2 - 105.0	1031 - 2749
11.1.82 - 20.1.82	50	93.75	1640.7	80.4 - 100.6	1015 - 2386
All samples	189	94.48	1698.7	80.4 - 110.0	1015 - 3038

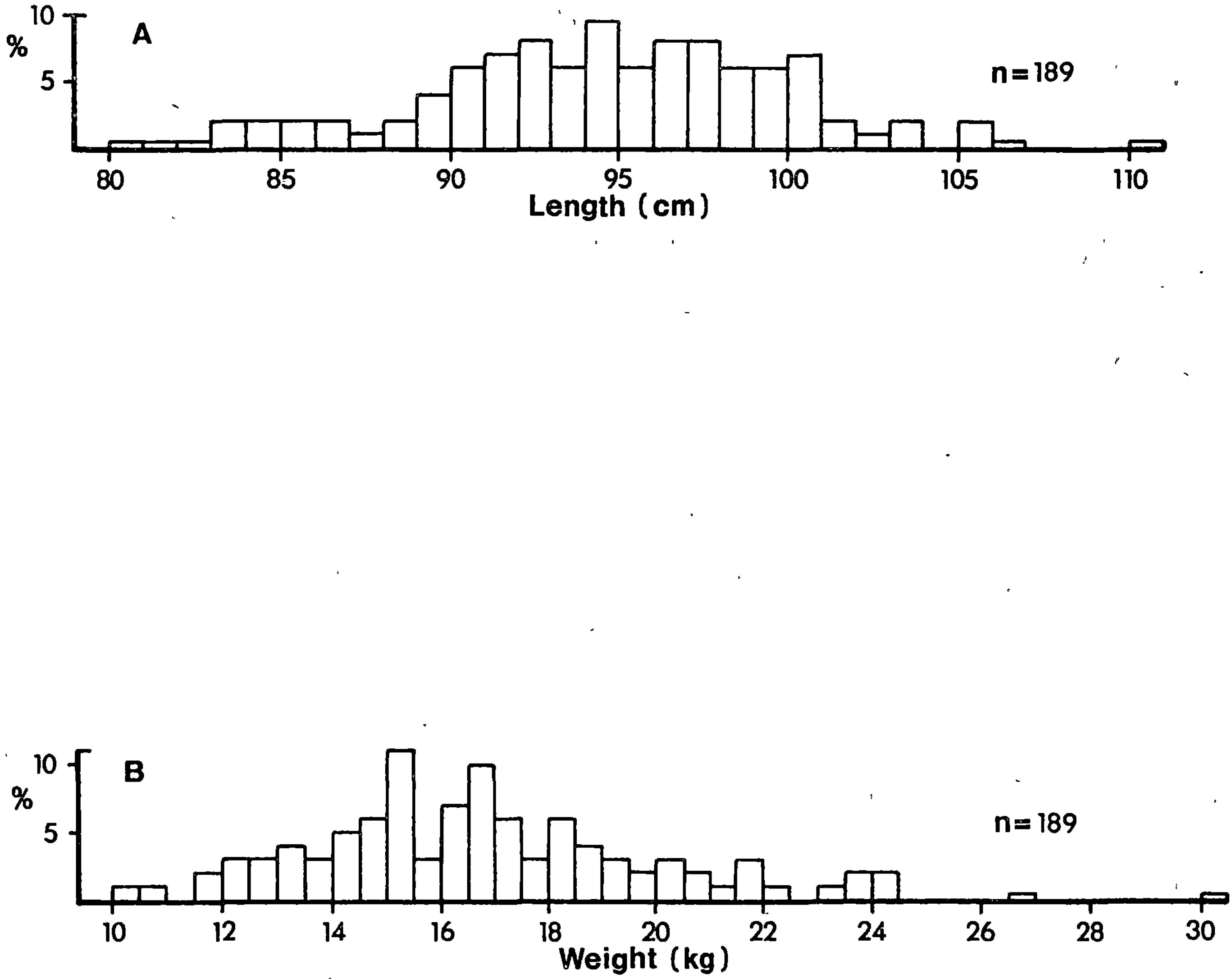


Fig. 6.3

Length frequency distribution (A) and weight frequency distribution (B) of female A. australis australis from the Clyde River migrating eel trap (5 December 1981 to 20 January 1982).

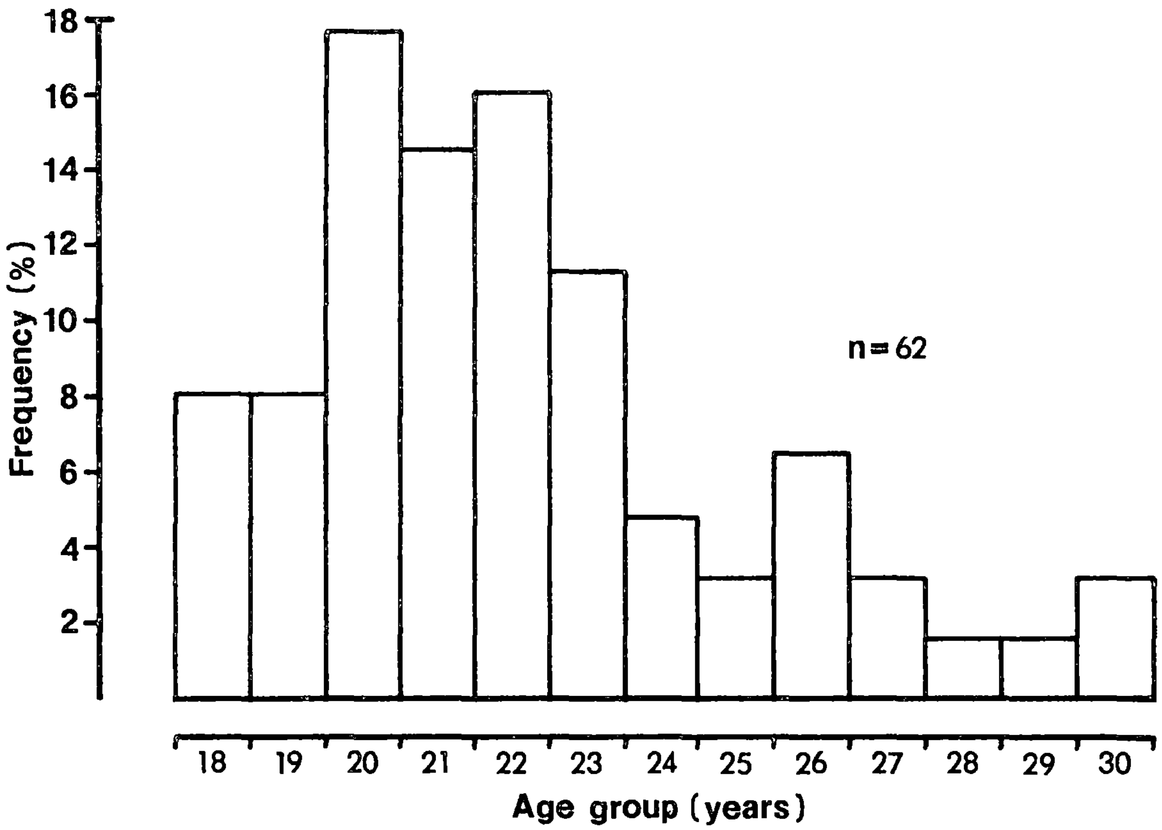


Fig. 6.4

Age frequency distribution of female A. australis australis from the Clyde River migrating eel trap (5 December 1981 to 11 January 1982).

dark rings surrounded by further broadly spaced rings. This is interpreted as representing 5-10 years of slow river growth followed by a number of years of faster growth in Lake Sorell or Crescent (headwater lakes) and their associated marshes. The mean lengths for age of female shortfins (Fig. 6.5) illustrate that older migrating eels in the Clyde River were not necessarily larger, as the length for age means did not vary significantly ($p > 0.05$) from the overall sample length mean ($F = 1.13$, d.f. = 12/49).

6.4 DISCUSSION

In Tasmania, migrating shortfin and longfin eels can be distinguished from the non-migrant feeding eel stage by their appearance. The enlarged eyes, dark pectoral fins and silver bellies which distinguish migrant shortfins have been reported for *A. a. schmidtii* in New Zealand by Todd (1981c) and are known to be associated with seaward migrations of other temperate *Anguilla* spp. (Tesch 1977). The disappearance of the marbled colouration of *A. reinhardtii* in the silver eel stage has also been reported for other *Anguilla* spp. (Ege 1939; Jubb 1961).

The downstream migration of maturing adult eels in Tasmania, with particular reference to shortfin females, was found to occur from October to April, a similar period to that indicated for New Zealand eels (Cairns 1941; Hobbs 1947; Burnet 1969b; Todd 1981d). Incidental records from around Tasmania indicate an early migration season, from October to January, in inland areas (e.g. Tods Corner, Dee Lagoon and Lake Tiberias) with silver eels being

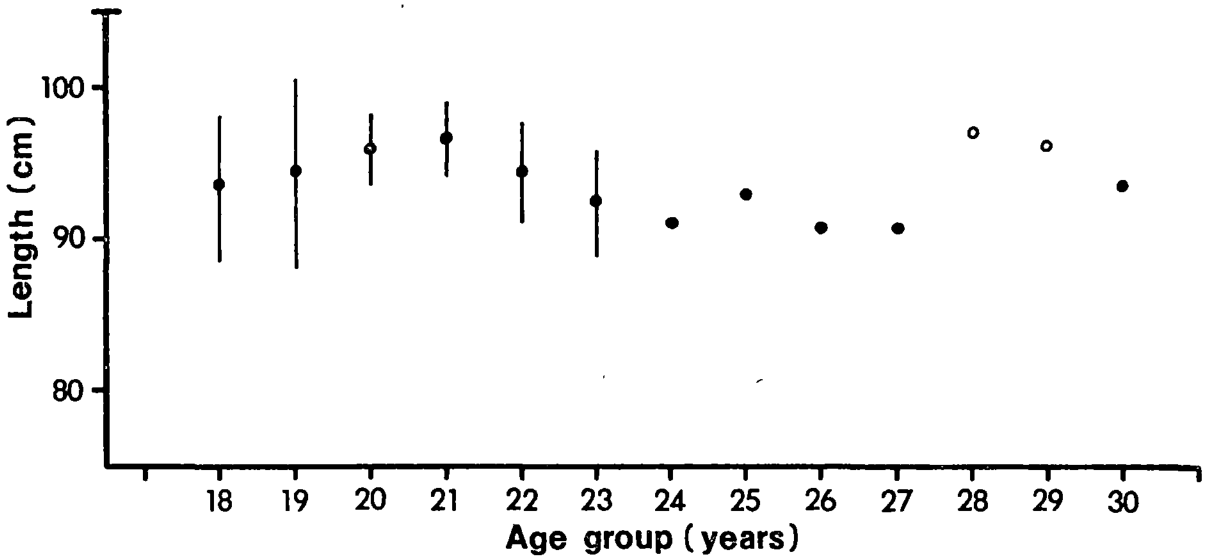


Fig. 6.5

Mean length at age for 65 female A. australis australis from the Clyde River migrating eel trap (5 December 1981 to 11 January 1982); solid circles indicate means, open circles single values and vertical lines represent 95% confidence limits (n ≥ 5).

caught during late summer, February and March, near the sea (e.g. Trevallyn Dam). Burnet (1969b) suggested that in New Zealand the period of eel migration from upstream areas may take place several months earlier than migrations into the sea, particularly for the long-finned eel *A. dieffenbachii* which occurs further inland. Tesch (1977) used commercial silver eel catches in order to illustrate that the European eel (*A. anguilla*) migrates earlier from inland areas.

Female shortfins caught at the Clyde River trap did not show the distinctive silver colouration exhibited by the eels from Trevallyn Dam, suggesting that the eels migrating from inland areas early in the season were less sexually advanced than those caught late in the season near the sea. The state of sexual development of the Clyde River migrants as indicated by the values of G.S.R. was not as advanced as that of *A. a. schmidtii* females recorded by Todd (1981c); this may be related to the inland situation of the Clyde River trap.

The average age of migrating shortfin females from the Clyde River (22.1 years) is very similar to the ages recorded by Todd (1980) for *A. a. schmidtii* in New Zealand; he found that eels migrated from the Makara Stream, Lake Onoke and Lake Ellesmere at an average age of 19, 23 and 24 years respectively. However, the Tasmanian shortfins were found to be much larger as the corresponding average lengths reported by Todd (1980) were 73.7, 76.4 and 61.5 cm respectively. Tesch (1977) reviewed the data on the size and age of European silver eels and reported average lengths ranging from 54.0

to 61.0 cm at 8 to 12 years of age; subsequently, Rossi and Colombo (1979) have recorded female A. anguilla migrating from north-western Adriatic lagoons at a similar size but at an average age of 5 to 8 years. Gray and Andrews (1971) recorded migrating females of the American eel, A. rostrata, length 53.0 to 93.0 cm at 9 to 18 years of age.

Todd (1980) found that the New Zealand long-finned eel A. dieffenbachii was much larger at migration than other temperate Anguilla spp. with females migrating from the Makara Stream at a mean length of 106.3 cm, and from Lake Ellesmere at 115.6 cm (age 25 to 60 years). Details of the size of migrating Australian longfins (A. reinhardtii) have not been recorded but this species probably migrates at a size similar to or larger than A. dieffenbachii. Specimens weighing up to 20 kg and exceeding 150 cm in length have come to the author's attention and have been reported from Tasmania by Scott (1934, 1940, 1953). Several large resident (non-migrant) longfins 100 to 120 cm in length aged between 35 and 45 years have been recorded by the author (v. 5.4.5). Commercial eel fishermen in north-eastern Tasmania have reported that longfins migrate into the sea during March and April at an average weight of c. 8 to 10 kg for females and 2 kg for males. This would indicate a length of about 130 cm for females and 85 cm for males (computed from the Douglas River longfin length-weight relationship, v. 5.4.4).

Tesch (1977) concluded from his review of size and age that the average length of eels at migration varied less than the average age, supporting the view of Frost (1945) and Deelder (1970) who considered that the onset of migration in the European eel is associated with attainment of a certain length rather than age. In the present study, data from the Clyde River support this view, as there was a larger coefficient of variation (100 S.D./$\bar{x}$) for the age mean ($\pm$ 13.5%) than for the length mean ($\pm$ 5.4%) and the mean lengths of migrating eels were not found to differ significantly between age groups.

The analysis of three sub-samples of eels taken during the migration at the Clyde River trap indicates that larger females may migrate first. This could be due to the early migration of a greater proportion of eels which have been held up or prevented from migrating in previous seasons. Todd (1980) found that female New Zealand eels much older and larger than the normal age and size of migrants, had continued to grow in subsequent years. Early migrations of larger male European eels have been observed by Deelder (1970) and Parsons et al. (1977); Tesch (1977) suggested that this may be due to a lower level of physical fitness delaying the smaller eels during migration. Parsons et al. (1977) found female silver eels migrating during the middle of the season were smaller than those at the beginning or end of the season, a finding supported by the data in the present study.

From the detailed analysis of commercial silver eel catches in Europe over many years it has been well established that the largest catches are made during the last quarter of the moon, when the half-moon is on the wane (Tesch 1977). However, this pattern was not substantiated by the 1981-82 catch data from the

Clyde River, where almost equal proportions of the catch were recorded during each lunar quarter. River flow is also known to be an important controlling factor in silver eel migrations (Frost 1950; Lowe 1952a) but flow remained relatively constant during the period of eel migration in the Clyde River.

In contrast, water temperatures fluctuated considerably during the trapping period and may have played an important part in controlling the eel migration. The start of the eel run corresponded with a period of increasing water temperature and subsequent falls in water temperature may have retarded the run. The catch of migrating eels in the Clyde River appeared to be confined to the period of high stream temperatures associated with the summer months, the migration being delineated by mean daily water temperatures falling below about 12°C. This situation is in marked contrast to the findings relating to migrations of the European silver eel, where temperatures falling below a threshold minimum are associated with the onset of the autumnal migrations (Tesch 1977). Tesch (1979) considered it doubtful that silver eels (A. anguilla) exhibit any spawning migration at temperatures above 17°C.

From the appearance of the growth rings in the otoliths of the Clyde River migrants there is little doubt that the majority of eels had spent their last 10 to 15 years at the source of the river in Lake Sorell (4 770 ha) and Lake Crescent (2 365 ha) where eel fishing has not been permitted since 1975. Environmental conditions associated with these lakes may well be important to the timing of migrations in the Clyde. Certainly, the outlet flow from these lakes, which is regulated during summer by a control gate at the head of the river, must be an important controlling factor, as eels are only likely to migrate downstream when the gate is open. However, at other times of the year, particularly during winter, the lake spills and eels could escape.

Intermittent stream flows may be important to the timing of eel migrations in a number of Tasmanian waters. In southern Tasmania the Jordan River may sometimes stop flowing for nine months or more. Presumably under these conditions eels migrate whenever the river flows during the warmer months of the year. According to commercial eel fishermen this may happen very infrequently and the large catches of silver eels made at Lake Tiberias during 1971 and 1976 occurred at such times.

The first attempts to establish traps for migrating eels in Tasmanian streams were unsuccessful. Several of the rivers selected were too large for initial experimentation and were subjected to spring and autumn flooding. The use of fyke nets in this fishery was found to be unacceptable due to the capture of platypus (Lynch 1979), and eels invariably passed over the net leaders which became clogged by debris. The simple trap built on the Clyde River during the 1981-82 season has proved to be an ideal design, providing an inexpensive method of assessing the commercial potential of the migrating eel run in a small river. The Clyde trap has also demonstrated that streams which drain substantial lake systems and have a regulated riparian summer flow are likely to provide suitable sites for commercially viable eel traps.

Chapter 7

THE TASMANIAN EEL FISHERY, SOME FACTS AND FIGURES

7.1 THE FYKE NET FISHERY

The eel fishery in Tasmania has been based primarily on the capture of feeding eels using the European fyke net (Lynch 1977). Although permits for the use of baited traps are issued in Tasmania, this method of capture has generally been unsuccessful and has not contributed significantly to commercial eel landings. Some large catches of silver eels (adult eels in migrating condition) have been landed by the fyke net fishery in certain Tasmanian lakes (*v.* 6.3.2), and these captures have been included in the statistics relating to the fyke net fishery.

The Tasmanian eel fishery is seasonal in nature (Fig. 7.1) with the six warmest months of the year (October to March inclusive) representing the most productive period. The Tasmanian catch is dominated by the short-finned species *A. a. australis* which has constituted 97% of the total eel landings to date. *A. a. australis* has been reported to represent between 95% and 98% of the Victorian eel catch (Anon. 1976; Harrington & Beumer 1980).

The short-finned eel is more readily marketed than the long-finned eel (*A. reinhardtii*) due to the smaller size and uniform skin colour of the former. Limited markets exist for large longfins (heavier than 3 kg) in Hong Kong and Taiwan (Harrington & Beumer 1980) where large eels are valued for their supposed aphrodisiac qualities. In Tasmania the short-finned eel is generally purged, eviscerated and frozen for export. Some eels are smoked for the limited Australian market (Gray 1977), and a local processor has successfully marketed small quantities of long-finned eel in the

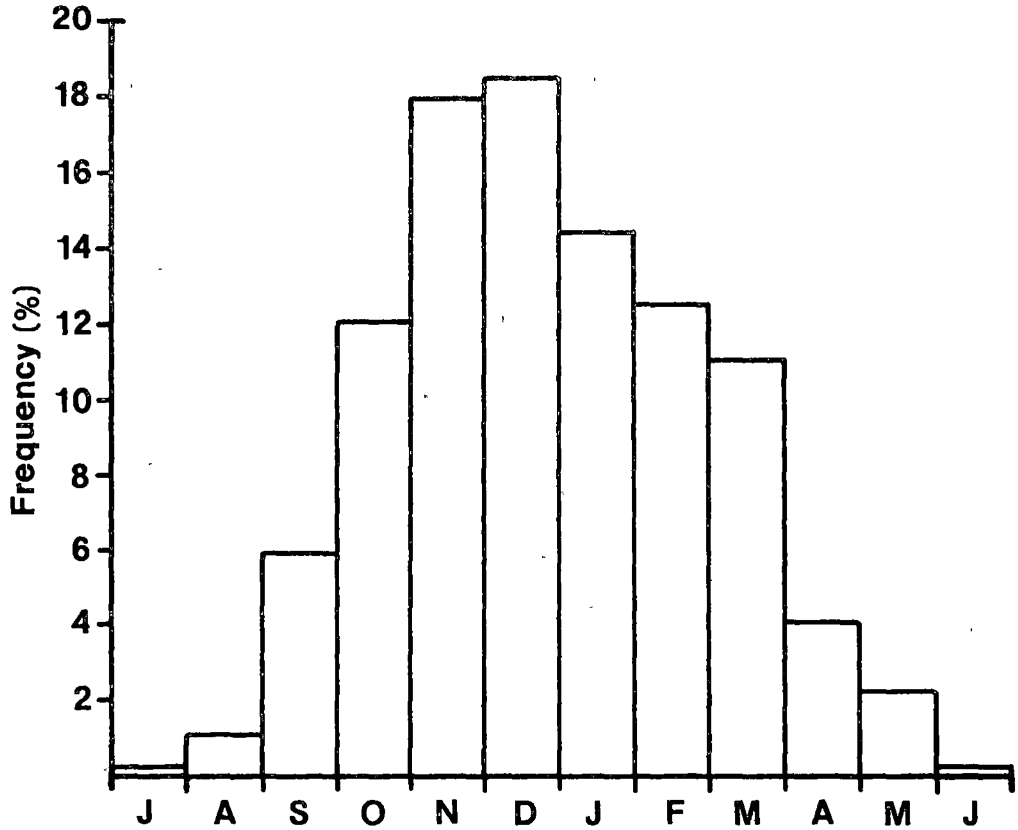


Fig 7.1.

Percentage of total eel catch landed per month for the Tasmanian fyke net fishery (1965-66 to 1981-82); total catch approximately 480 tonnes.

form of smoked eel pâté and smoked eel fillets; long-finned eels have also been sold as shark bait.

The fortunes of the Tasmanian eel fishery have fluctuated since its inception in 1965-66 (Fig. 7.2). The largest eel landing of about 95 t was recorded in the 1967-68 season when 12 fishermen lodged returns. Lynch (1977) reported that 23 fishermen were licenced to fish for eels in the 1967-68 season and that a number of experienced Dutch and German fishermen left the industry after that year, resulting in the subsequent catch reduction.

Catch per unit effort statistics (Table 7.1) indicate an initial boom period in the 1965-66 and 1966-67 seasons with eels landed at a rate of about 5-6 kg per net day. The subsequent decline has resulted in annual catch rates between 1.6 and 2.8 kg per net day over the last five seasons (1977-78 to 1981-82 inclusive). Harrington and Beumer (1980) have reported lower eel catch rates of between 1.1 and 1.8 kg per net day during the last decade in Victoria.

The extent to which the reduction in catch per unit effort reflects the experience of the fishermen or a reduction in eel standing stock is difficult to determine. However, reductions in catch per unit effort for a number of individual waters reported in the present study (v. 4.3.2), suggest that this trend has probably been caused mainly by stock reduction of previously unexploited waters.

A number of major regulatory and policy changes in

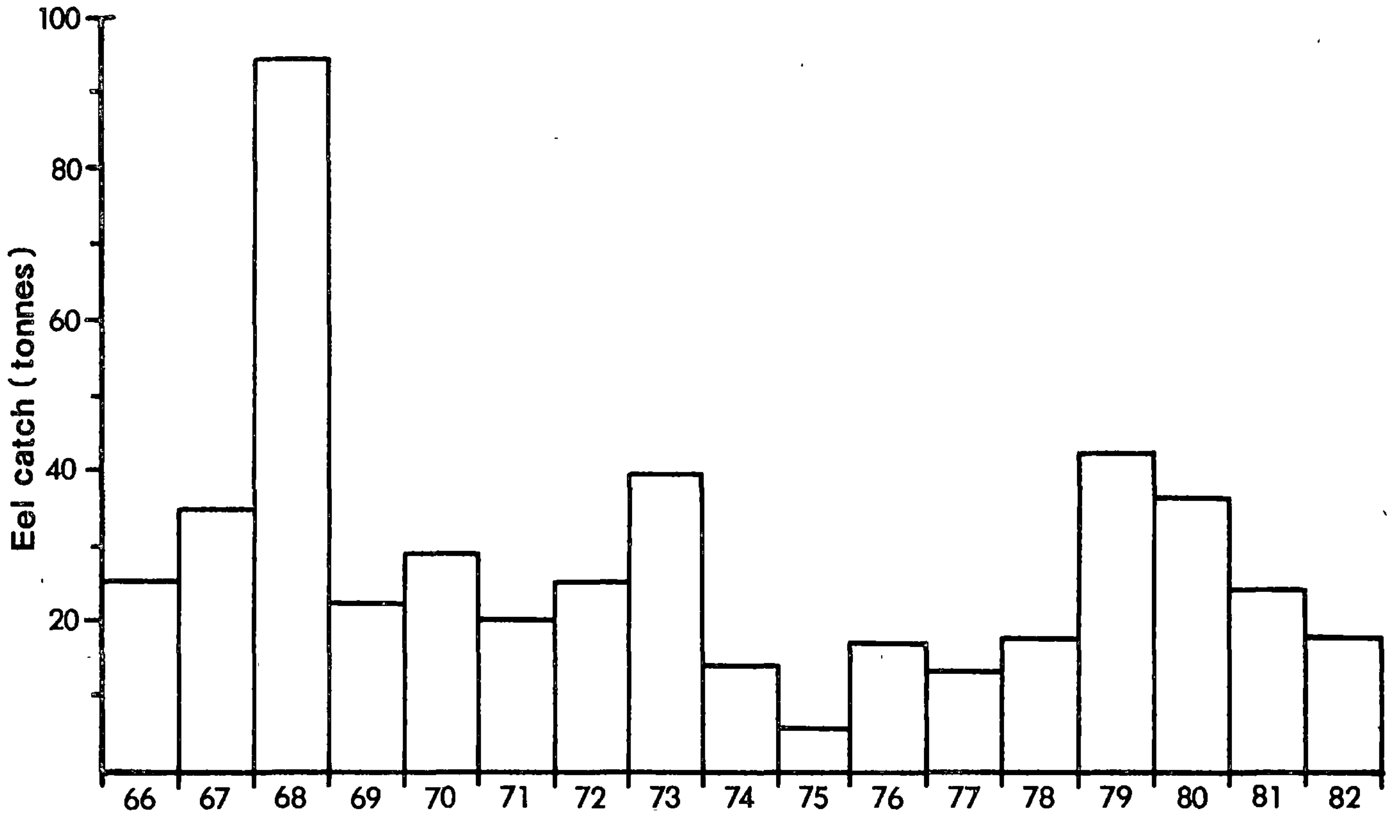


Fig. 7.2

Total annual eel catch for the Tasmanian fyke net fishery; year ending 30 June 1966 (66) to year ending 30 June 1982 (82).

Table 7.1 Summary of eel catch (kg) for the Tasmanian fyke net fishery : A. australis australis (Shortfin), A. reinhardtii (Longfin).

Year ending 30 June	Shortfin catch	Longfin catch	Total catch	Number of fishermen	Catch per fisherman	Catch per net-day
1966	25,480	-	25,480	3	8,493	5.234
1967	35,030	50	35,080	6	5,847	6.262
1968	94,490	-	94,490	12	7,874	3.879
1969	22,330	-	22,330	8	2,791	2.672
1970	29,020	-	29,020	5	5,804	3.955
1971	20,140	-	20,140	3	6,713	2.918
1972	25,230	-	25,230	3	8,410	3.757
1973	34,300	5,170	39,470	6	6,578	2.789
1974	12,240	1,670	13,910	3	4,637	1.642
1975	5,840	-	5,840	2	2,920	1.452
1976	17,160	-	17,160	2	8,580	3.485
1977	13,360	-	13,360	5	2,672	3.761
1978	17,480	250	17,730	8	2,216	1.672
1979	39,340	3,170	42,510	10	4,251	1.743
1980	34,100	2,270	36,370	9	4,041	2.008
1981	24,730	-	24,730	8	3,091	2.869
1982	17,940	130	18,070	6	3,012	2.258
Mean	27,542		28,290	5.8	5,172	3.080

eel management over the years may also have contributed significantly to catch decline. Details of the regulations governing the Tasmanian fyke net fishery in the 1981-82 season are given in Appendix I. A summary of the most important regulatory and policy changes and the year of their application is given in Appendix II.

The slump in the Tasmanian eel fishing industry during the 1968-69 season (see Fig. 7.2) corresponded with an increase in licence fee from $4 to $50 and a general tightening of eel fishing regulations. During this year the eel fishing season was restricted in certain waters and there was a reduction in the number of licensed eel fishermen from 23 to 8, resulting from the Inland Fisheries Commission's policy of discouraging further applicants due to conflicts which arose in the previous year (see Lynch 1968).

Another slump in eel landings occurred after the improved catches of the 1972-73 season. This corresponded with the introduction of many further restrictions in the 1973-74 season after an increase in licence fee to $100 in the previous year. The most important restrictions related to net dimensions (several fishermen had been successfully using the larger 760 mm diameter fyke nets during the 1972-73 season) and the use of fyke nets (combinations, proximity to inflows and outflows and 24 hour inspections). The use of non-licensed assistants in the fishery was also outlawed and there was an important change in policy in that the use of fyke nets in rivers was no longer permitted. Previously, some very large catches had been made using fyke nets in rivers; in the North Esk River 33.8 t of eels were landed during the 1967-68 season and between 1966 and

1972, 67.0 t were taken from this river. The fishery collapsed to record the lowest ever annual catch in the 1974-75 season (5.8 t) with only two fishermen lodging returns.

A liberalization of regulations in 1977-78, with an increase in the size of fyke nets allowed and the establishment of an assistant eel fisherman's licence, may have been responsible for some revival in the fishery with an increased catch being recorded in 1978-79.

7.2 EEL CULTURE

In 1972 the Tasmanian Inland Fisheries Commission (I.F.C.) agreed in principle to a proposal to establish eel farming in Tasmania (Lynch 1972). In 1973 the first fish farm licence for the culture of short-finned eels was issued at a fee of $150 per annum. This permitted the licensee to collect elvers under the supervision of an I.F.C. employee, and raise them in a series of dams. The venture was not successful and the licensee later established an eel processing factory, relying on the capture of wild eels (Gray 1977). No further eel farming licenses have been issued in Tasmania.

7.3 MIGRATING-EEL FISHERY

Lynch (1977) stated that the I.F.C. considered it desirable to establish a new fishery based on the capture of adult migrating eels with a licensee having an exclusive right to trap eel migrants in a particular river. In April 1978 legislation was passed which enabled the I.F.C. to grant an exclusive right to take eels by calling tenders for the trapping of eels for a period of two years.

The process of tendering for a migrating eel licence was not popular with commercial eel fishermen and in July 1980 the regulations were amended to enable the I.F.C. to issue licences to take migrating eels commercially, by means of a weir type structure, at a fee of $100 per annum. The current regulations governing the migratory eel fishery are set out in Appendix III.

Lynch (1979) reported that only 1 523 kg of migrating eels were caught in the first season and there was an initial and unacceptable mortality of platypus due to the unsuitability of the gear used (mainly fyke nets). The first full season (1981-82) under the new regulations using weir type structures approved by the I.F.C., resulted in a catch of about 5.4 t. Almost the entire catch came from a single trap on the Clyde River which was the first trap to be successfully operated throughout an eel migration season (v. chapter 6).

7.4 ELVER FISHERY

The capture and export of eels less than 30 cm in length has been prohibited in Tasmania since 1970. The I.F.C. has undertaken a programme of transferring elvers upstream above major hydro-electric dams, during summer, since 1977 (Sloane 1978b, 1981). This programme has been conducted exclusively by the I.F.C. and other than a small quantity of elvers (9 500) used to stock Bowlers Lagoon in north-eastern Tasmania (Lynch 1979), all eels have been liberated in the river systems at the first access point above the dams. The programme was initiated in order to ensure elver recruitment for the wild eel fishery (Sloane 1978b).

7.5 EXPLORATORY PERMITS FOR TIDAL WATERS

Since 1971, the Tasmanian Fisheries Development Authority has issued exploratory licences permitting the use of fyke nets to catch eels in tidal waters (Table 7.2). In general, catches have been low, c. 4.7 t per annum, and eel exporters consider estuarine eels to be of inferior quality (poor condition and low fat content).

Table 7.2 Summary of eel (Anguilla spp.) catch statistics for T.F.D.A. exploratory permits : no data available (NA).

Calendar year	Eel catch (tonnes)
1971	NA
1972	0.1
1973	1.0
1974	0.2
1975	6.2
1976	NA
1977	NA
1978	10.7
1979	11.0
1980	5.3
1981	2.7

Chapter 8

PROSPECTS FOR THE FUTURE OF THE TASMANIAN EEL FISHERY

8.1 SUMMARY OF RELEVANT BIOLOGICAL FINDINGS

In order to assess the prospects for the future of the Tasmanian eel fishery it is important to consider the biological findings relating to each life history stage of freshwater eels in Tasmania. The most important findings are summarized below.

1. Eel Origins

The long-finned eel, A. reinhardtii (longfin), and the short-finned eel, A. a. australis (shortfin), probably originate from separate marine spawning grounds in the tropical Pacific. The larva or leptocephalus is the distributional phase, with the East Australian Current being the vector for larval transportation.

2. Glass-eels

Glass-eels of both species invade Tasmanian rivers from the sea, the longfin entering fresh water mainly during February, March and April and the shortfin invading in all seasons but particularly during April, May, June and September, October and November. Shortfin glass-eels are larger than longfin glass-eels but both species appear to spend only one full year at sea, arriving in fresh water at between 12 and 18 months of age.

3. Elvers

An upstream migration of pigmented young eels (elvers) occurs each year during summer (November to March). This serves to replenish eel stocks in inland waterways and the upstream migrating eels found at major dams in Tasmania are almost exclusively shortfins.

Larger and older elvers are found at barriers further from the sea with most eels remaining in the estuaries and lower freshwater reaches during their first two to three years. Elver runs at major low level dams in Tasmania may contain several million elvers each year and the elvers are easily captured and transported.

4. Eel Distribution and Abundance

Longfins are mainly found in estuaries, coastal lagoons and the lower reaches of streams in north-eastern and eastern Tasmania. Shortfins are widespread and abundant in coastal streams, dams, lagoons and major rivers. Their range extends well inland, as shortfins are found in the major lakes of the Central Highlands. Eel numbers and weights (per m^2 of water surface) in Tasmanian streams are generally much lower than those recorded in New Zealand, but are comparable to estimates for other temperate freshwater eels. Commercial eel landings have indicated that many of Tasmania's lakes had initial standing stocks of eels which may be considered high by world standards.

5. Compatibility of Eel Species

Although the distributions of longfins and shortfins overlap in only a small part of the shortfin's range, they may compete for food in areas where they do occur together. Predation by longfins on shortfins may also be important.

6. Migrating Adult Eels

A seaward migration of maturing adult eels takes place mainly during summer in Tasmania. Shortfins migrating from inland areas are predominantly female and their migrations may begin several months before movement into the sea occurs. Shortfins adopt a classical 'silver eel' appearance at migration, but are generally older and larger than other temperate eel migrants. The seaward migration of longfins goes largely unnoticed, but seems to occur during late summer. Longfins are generally much larger than shortfins at migration. Migrating males are smaller than females in both species.

7. General Life History

Tasmanian eels conform to the basic life history pattern recognised for other temperate freshwater eels. However, all stages of the life cycle in Tasmania differ in detail from the known biology of other temperate eels, probably largely in response to local conditions.

8.2 JUVENILE EEL FISHERY

Elver migrations at Trevallyn Power Station and Meadowbank Dam have been estimated at $3.0\text{-}5.0\times10^6$ and $0.5\text{-}1.0\times10^6$ elvers per annum respectively. At Paloona Dam on the Forth River, preliminary investigations have also indicated that considerable quantities of elvers are present each year (Sloane 1981); major dams on the west coast rivers of Tasmania have not been investigated. Although relatively small quantities of glass-eels enter streams on the east coast of Tasmania, the extent of the elver migrations at Trevallyn and Meadowbank indicate that the Tamar and Derwent estuaries probably support commercial quantities of glass-eels.

In Victoria, glass-eels and elvers have been collected for rearing in concrete ponds and for stocking lakes; commercial fishermen captured about 80 kg of glass-eels from estuarine waters during 1977 (Ord 1978). Harrington and Beumer (1980) have described methods of capture of glass-eels and elvers in Victoria where fish culturists are permitted to take undersize eels (<30 cm). In New Zealand a fishery for glass-eels became established in the Waikato River between 1970 and 1974, the catch being used to stock several New Zealand eel farms and to supply a limited export trade to Japan (Castle 1972; Jellyman 1979a). Castle (1972) expressed concern at the long term implications for the wild eel fishery, of exploiting juvenile eels.

In Europe juvenile eel migrations have long been exploited, originally as a food and more recently for restocking purposes (Tesch 1977). Glass-eels and elvers are the basic element in the Japanese eel culture industry, with farms now relying on overseas stock to support their requirements. Juvenile eels have been imported into Japan from as far away as France and North America (Forrest 1976; Egusa 1979). Egusa (1979) reported that the demand for local juvenile eels in Japan increased rapidly after about 1963 with the maximum selling price of about $7 per kg in 1968 escalating to $300 per kg in 1969 and to $700 per kg in 1973. During the same period elvers from France were sold for $30 to $50 per kg (Egusa 1979).

Prices paid for juvenile eels on the international market fluctuate considerably depending on immediate demand and the suitability of the eel species involved, so it is difficult to put a value on the combined Trevallyn and Meadowbank elver runs which total about 5.0 t. Suffice it to say that elvers at major low level dams in Tasmania could be worth several hundred thousand dollars on the international market.

Victorian eel fishermen have also shown considerable interest in obtaining Tasmanian elvers as stock for 'extensive' culture waters in Victoria. Local fishermen consider that Tasmanian elvers could be sold to Victorian fish culturists at about $10-30 per kg depending on size. However, there are at present no licences issued in Tasmania to take undersized eels ($<$30 cm) and the export of such eels from Tasmania has been banned since the early 1970s. This ban has been maintained because of the obvious importance of these young eels, which ultimately determine recruitment to the wild eel fishery.

The commissioning of Trevallyn Power Station in 1955 and the completion of Meadowbank Dam in 1967, greatly reduced eel recruitment to the two major river systems supporting eel fishing in Tasmania, and the Inland Fisheries Commission's porterage programme was initiated in order to alleviate this problem. The New Zealand eel fishery faces similar problems with major hydro-electric dams effectively limiting recruitment into the wild eel fishery in inland lakes (Jellyman 1981).

In Europe, extensive elver porterage operations and the provision of elver ladders have been used to ensure future eel stocks (e.g. Menzies 1936; Kipper and Mileiko 1962). In 1974 an experimental elver ladder was installed on the lowest dam on the St Lawrence River to allow elvers access to Lake Ontario (Whitfield & Kolenosky 1978). Transplantation of elvers into waters with little or no eel recruitment is also widely practised in the northern hemisphere, particularly in Europe. The Polish eel catch is apparently sustained almost entirely by elver stocking (Leopold 1980).

Unfortunately, elver recruitment to some of the most productive eel waters in Tasmania has been interrupted for a number of years due to the proliferation of major hydro-electric schemes and although an elver porterage scheme is under way, only a small part of the annual accumulation of elvers is being salvaged. This is particularly disturbing when the value of these eels on the international market and their importance to the future of the Tasmanian wild eel fishery are considered.

Jellyman (1981) has asked who should pay for elver passes and porterage operations. In Tasmania at present the Inland Fisheries Commission is providing this service, but ultimately the fishery should pay. The Tasmanian Hydro-Electric Commission must also bear some responsibility and, in general, the clearing of elvers from power station tailraces is of benefit to it. The problem may be more easily resolved by the culture permit and/or migrating-eel licence system where fishermen have a vested interest in distributing the young eels since they will ultimately benefit from the future catch.

In order to succeed elver transfer programmes require: the co-operation of the local hydro-electric authority in terms of facilities, access and supervision; the controlling authority to undertake elver capture and limited distribution based on funding recouped from the fishery; the assistance of commercial eel fishermen to undertake the main elver distribution.

8.3 FYKE NET FISHERY

In Victoria an annual catch in excess of 200 t supports 15 full-time fishermen (Harrington & Beumer 1980), representing an annual catch per fisherman of about 13 t. In New Zealand the largest eel fishery is centred in the Waikato basin and produces 400-500 t of eels annually, supporting 15 full-time and numerous part-time fishermen (Todd 1981b). Catch per fisherman in Tasmania has fallen to between 2 and 4 t since 1976 and the annual catch in recent years only represents sufficient income to support 3 full-time fishermen at the most.

There is little doubt that changes in management policy have contributed to a decline in the fyke net fishery in Tasmania since 1967-68. Sharp declines in the number of fishermen operating and the catch landed after 1967-68 and 1972-73 can be related to major regulatory and policy changes. The largest annual eel landing of about 95 t in the 1967-68 season was taken entirely from major inland lakes and rivers where fyke netting is now prohibited. Consequently there is little prospect for expansion of this fishery in the future unless there are major reversals in policy, particularly relating to fyke netting in rivers and in dams and lakes which contain trout.

Lynch (1968) outlined the major problems experienced with the basically unrestricted fyke netting which occurred during the 1965-66 and 1966-67 seasons. The main conflicts were that eel nets occupied trout fishing sites on the lake edges and prevented trout from shoring, nets were congested in some areas with eel fishermen competing with each other for sites and non-target species such as platypus, trout and galaxiids were killed in eel nets (Lynch 1968). Apparently the later rationalization of fishing areas, controls on net size, restrictions on net placement, limitation of the eel fishing season and positioning of platypus screens across fyke net entrances, did not alleviate these problems sufficiently to prevent the closure of prime trout waters and rivers to fyke netting.

Harmful effects of the indiscriminate use of fyke nets on non-target species in New Zealand and Victoria have been documented (Anon. 1981; Beumer et al. 1981) and Beumer et al. (1981) have pointed out that screening fyke net entrances with a mesh grid can be an effective method of preventing most non-target fish, bird and mammal species from entering nets. If screens are not used, fyke nets can be set in order to minimize the impact of non-target species. Setting fyke nets so that the entrance and wings do not protrude above the water surface can greatly reduce the capture of water birds (Anon. 1981; Beumer et al. 1981) and maintaining a portion of the net bunt above water level may greatly reduce drowning of platypus provided the nets are checked at least every 24 hours (Jackson 1979; Beumer et al. 1981).

A major problem now facing the fyke net fishery in Tasmania is that numerous regulations have been introduced primarily to protect non-target species and trout fishing interests and, despite the closure of the rivers and trout waters to fyke netting, these regulations still govern the fishery today. Consequently, in inland marshes, farm dams and coastal lagoons to which fyke netting has been largely confined, regulations relating to the use of fyke nets in combination, the setting of nets near inflows and outflows and the size of nets, may considerably limit the effectiveness of the fishery and probably need no longer apply.

8.4 EEL CULTURE

There is a considerable potential for an 'extensive' eel culture system (releasing young eels in large bodies of water and letting them grow naturally) in Tasmania as numerous farm dams, coastal lagoons and inland marshes could be seeded with young eels. Investigations of elver runs indicate that young eels which could be used in this way are wasted at hydro-electric installations each year.

In Victoria, development of both 'extensive' and 'intensive' culture systems has been seen to be essential if present eel exports are to be maintained (Harrington & Beumer 1980). In New Zealand, Todd (1981a) reported a decline in eel export tonnage after 1978 reflecting a reduction in eel catch rate and suggested that an increased emphasis on eel farming and 'fattening' of wild eels would be needed in order to maintain and increase present exports.

The 'extensive' culture permit system began in Victoria in the mid 1970s but the success of such ventures will not be known for several years. A culture permit allows the holder to catch and stock with undersized eels ($<$30 cm), and provides an exclusive right to fish for eels in the water to which the permit relates. Permits are issued for a minimum of five years at an annual fee of $250 and relate mainly to Crown waters. Permits can also be granted for private waters at a reduced fee (Anon. 1976; Harrington & Beumer 1980).

The Victorian culture permit system could readily be applied to many waters in Tasmania. A similar system could also be incorporated into the new migrating eel fishery, allowing licence holders to collect elvers and stock headwater lakes and marshes.

'Intensive' eel culture (feeding and rearing eels in small ponds) probably has limited potential for application in Tasmania, as year round water temperatures above 15°C and preferably between 25°C and 28°C are desirable (Matsui 1969, 1980; Usui 1974; Forrest 1976). Any intensive eel culture in Tasmania would require heated water and considerable expertise in the field of eel parasites and diseases, an area which has been sadly neglected in Australia.

Six intensive eel farms were established in New Zealand between 1969 and 1972 but these ventures did not prove to be economically viable at the time. Success was limited by variations in annual glass-eel catches, disease outbreaks and a poor percentage of marketable sized eels after 18 months of culture (Jellyman & Coates 1976; Jellyman 1977a). Elvers collected at hydro stations during the eels' summer upstream migration have proved to be unsatisfactory for 'intensive' eel culture in New Zealand, mainly due to the disease fauna acquired during freshwater residence (Hine & Boustead 1974; Jellyman & Coates 1977). However, in Japan, some eels of this size are used for culture (Matsui 1980).

In 1975 the intensive culture of A. a. australis began at the Racovolis Prawn Culture Centre in Port Broughton, South Australia (Anon. undated) but subsequent progress of this venture has not been reported. Similar limited experimentation with intensive eel culture has been conducted in Victoria (Anon. 1976; Ord 1978) but findings have not yet been published.

8.5 MIGRATING-EEL FISHERY

Although the migrating-eel (river weir) fishery is in its infancy in Tasmania, the method holds considerable potential for future development. Preliminary findings indicate that small rivers which drain substantial inland lakes and marshes may provide ideal sites for eel traps. The first full year of trapping on the Clyde River during the 1981-82 season produced more than 5 t of eels from a single inexpensive trap, more than the average annual catch for individual fyke net fishermen since 1977. Once established, such traps require only routine maintenance and regular bagging of the catch; the operation is far less labour intensive than the fyke net fishery.

This new fishery also provides a ready solution to the trout fishing/eel fishing conflict outlined by Lynch (1968), as migrating eels can be trapped without the need to fish for resident eels in prime trout waters. The trapping season does not coincide with the main period of trout movement, which occurs early in winter when brown trout spawn in Tasmania, so no conflicts are envisaged.

Migrating silver eels provide a top quality export product, of uniform size and high fat content (McCance 1944; Hopkirk et al. 1975; Forrest 1976). The fishery is also attractive as only the mature eels are taken each year, without the fear of overfishing which has been associated with fyke net fisheries (Eales 1968; Gaygalas 1969; Castle 1972). In the past, the majority of downstream eel migrants have been wasted each year as they are chopped up by hydro-electric turbines, so development of fisheries above such installations will not affect the reproductive stock. Presumably eels migrating from unexploited waterways throughout the eel species' range will provide adequate recruitment for the future (Anon. 1959; Eales 1968). Westin and Nyman (1979) have pointed out that the high fecundity of freshwater eels should result in a high degree of independence between spawning stock size and recruitment. In terms of the fears voiced by Castle (1972) concerning overfishing in the New Zealand eel fishery, the Tasmanian migrating eel fishery would be merely drawing 'annual interest' rather than depleting 'capital'.

The future of this fishery in Tasmania is dependent on one element, stocking the prime eel waters with young eels in order to ensure that stocks are adequately replenished. Studies of the Clyde River migrating eels have indicated a 5 to 10 year period of upstream migration and slow growth, before the productive lake feeding grounds are reached. The completion of Meadowbank Dam in 1967 should begin to affect this fishery within the next 5 to 7 years unless direct stocking of the headwater lakes and marshes is permitted. Hopefully, reducing the number of years taken to reach the prime feeding grounds will reduce the age at which eels migrate, as it is generally believed that size rather than age determines the adult eels' return to the sea (Deelder 1970; Tesch 1977).

Stocking prime trout waters with young shortfin eels should not produce any clash with trout fishing interests in waters where natural bait fishing is prohibited (where bait fishing is permitted, eels often take baits meant for trout) as studies conducted in Tasmania have not produced any evidence of significant eel/trout competition (Sloane 1976; Lake & Bennison 1977).

8.6 EEL MARKETS

Although a detailed appraisal of eel marketing is beyond the scope of the present study, local fish processors have indicated that they believe there is considerable room for expansion of Tasmanian eel exports. One of the biggest problems facing the marketing of Tasmanian eels has been a lack in the continuity of supply. Harrington and Beumer (1980) have indicated that they believe that the marketing prospects for Australian eels are good, and indeed, Victorian processors have expressed considerable interest in obtaining Tasmanian eels. Todd (1981a) has indicated concern that traditional New Zealand export markets are being threatened by increased competition from farmed eels, particularly from Italy, France and Britain, and from the expanding eel fishery on the eastern seaboard of America where eels are caught well into the New Zealand (and Australian) season.

It appears that there is still a keen demand for increased Tasmanian eel production although international eel markets may be nearing the point of saturation. With the increased overseas reliance on farmed eels, there will probably always be a strong demand for wild silver eels on the international market.

8.7 CONCLUSIONS AND RECOMMENDATIONS

The fyke net fishery in Tasmania, in its present form, can only support about 3 full-time fishermen. Full-time participation in the industry could be encouraged by reducing the present number of licences to about five, with an additional licence for each of King and Flinders Islands.

Restrictions relating to the placement and arrangement of fyke nets need no longer apply to the fishery as many waters have been set aside in order to protect wildlife and trout fishing interests. Consideration should be given to the removal of platypus screens from fyke nets in certain waters and to the use of larger nets (1 metre entrance diameter and 10 metre wings) in specific deep waters and estuaries.

The trapping of migrating eels may provide a lucrative alternative to the fyke net fishery in the future and investigations of the viability of migrating-eel weirs in selected streams should be encouraged. Preliminary research relating to the timing, periodicity and quantities involved in downstream eel migrations should be expanded.

The future of the eel fishery in Tasmania is dependent upon procuring adequate eel recruitment and for this reason it is essential that existing elver porterage operations be continued and expanded. The quantities of elvers at all major low-level dams should be investigated further.

The quantities of elvers needed to replenish eel stocks in particular waters can be calculated according to the area of water available for eel growth. Wherever possible, the migrations of young eels to prime feeding and growing areas should be short-circuited by direct stocking of those waters.

Surplus elver stocks could be made available for 'extensive' culture in dams, lagoons and lakes which are not deemed to be prime trout waters.

Once requirements in these areas have been met, consideration could then be given to the export of elvers as stock for the culture industry, preferably within the existing range of the eel species involved.

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APPENDIX I

TASMANIAN INLAND FISHERIES COMMISSION REGULATIONS

GOVERNING THE COMMERCIAL EEL FISHERY, 1981-82 SEASON

13—(1) The Commission may sell and issue an eel licence to a person to take eels commercially by means of a fyke net or an eel trap. Licenses to take eels commercially. Substituted by S.R. 1977, No. 191, and amended by S.R. 1978, No. 105, S.R. 1978, No. 195, and S.R. 1979, No. 115.

(2) The price for the sale of an eel licence is $100 plus $2 for each additional fyke net or eel trap after the first fyke net or eel trap used by the licensee at the same time.

(3) An eel licence—

(*a*) shall be in accordance with Form 2;

(*b*) authorizes the licensee to use not more than 50 fyke nets, 50 eel traps, or a combination of both, to a total of not more than 50, for the purpose of taking eels commercially in the waters specified in the licence;

(*c*) is subject to the following conditions:—

(i) Every fyke net or eel trap to which the licence relates shall be marked with an identification tag carrying the number of the licence;

(ii) A fyke net or eel trap shall not be set within 20 metres of any other fyke net or eel trap;

(iiA) The licensee shall be present when a fyke net or eel trap to which the licence relates is set or hauled;

(iii) The licensee shall cause every fyke net or eel trap to be inspected at least once in every 24 hours and shall cause to be removed from that fyke net or eel trap any fish found therein on such inspection;

(iv) The licensee or an assistant eel fisherman who is so directed by him shall forthwith cause to be returned unharmed to the water any fish other than eels found in the net or trap;

(v) The licensee shall, within 15 days after the expiration of every month during the currency of the licence, lodge with the secretary a return, in accordance with Form 3, of the eels taken by him during the preceding month;

(vi) No fyke net or eel trap shall be set in any river, creek, or other watercourse within 100 metres of the place at which that river, creek, or other watercourse flows into or becomes tidal waters;

(vii) No fyke net or eel trap shall be set within a distance of 100 metres from any part of the mouth of any river, creek, or other watercourse;

(viii) No fyke net or eel trap (including the leader or wing) shall be set within a distance of 25 metres from any part of the entrance or outlet of any river, creek, or other watercourse, or any inlet or drain flowing into or out of any lake, swamp, or marsh;

(ix) No fyke net (including a leader) or eel trap or any combination of a fyke net (including a leader) or eel trap shall be set more than half-way across the width or across the centre of any river, creek, or other watercourse; and

(x) A fyke net or eel trap shall be securely fitted at all times with a screen covering the opening of the fyke net or eel trap having a mesh size of 10 centimetres; and

(*d*) shall expire on 30th June in every year.

(4) No eel licence confers on a licensee the right to take or to retain any fish of a kind or species other than eels, goldfish, tench, or English perch.

(5) An officer shall release from a fyke net or eel trap used by the holder of an eel licence any fish of a kind or species other than eels that the officer finds while he is examining the net or trap.

(6) A licensee who fails to comply with a condition to which his eel licence is subject is guilty of a breach of these regulations and, in addition to any other penalty to which he may be subject, the Commission may, by notice in writing, to the licensee, cancel the licence.

(7) The provisions of subregulations (3), (5), (10), (15), (16), and (17) of regulation 11 apply to an eel licence as if it were an angling licence except that in the application of the provisions of sub-regulations (15) and (16) of that regulation to an eel licence the words " The Commission " shall be substituted for the words " An authorized person ".

(8) A fyke net or eel trap shall be securely fitted at all times with a screen, covering the opening of the fyke net or eel trap, having a mesh size of 10 centimetres.

(9) In this regulation:—

" fyke net " means a net—

(*a*) having an opening height not exceeding 670 millimetres;
(*b*) having a width not exceeding 670 millimetres;
(*c*) any mesh which has a measurement not less than 15 millimetres and not more than 39 millimetres; and
(*d*) any wing or leader which has a length not exceeding 10 metres and a drop not exceeding 1200 millimetres;

" eel trap " means a trap—

(*a*) having a height not exceeding 500 millimetres;
(*b*) having a length not exceeding 2 metres;
(*c*) having a width not exceeding 500 millimetres;
(*d*) having no wings or leaders; and
(*e*) having a mesh of a least 39 millimetres.

13A—(1) The Commission may sell and issue an assistant eel fisherman's licence to a person to assist the holder of an eel licence (in this regulation referred to as " his principal ") in the exercise of the authority conferred by that licence. Assistant eel fisherman's licence. Inserted by S.R. 1977, No. 191.

(2) The price for the sale of an assistant eel fisherman's licence is $5.

(3) An assistant eel fisherman's licence shall be in accordance with Form 2A.

(4) It is condition of an assistant eel fisherman's licence that the holder shall comply with the directions given to him by his principal for the purposes of ensuring that the conditions of the eel licence held by that principal are complied with.

(5) The provisions of subregulations (3), (5), (10), (15), (16), and (17) of regulation 11 apply to an assistant eel fisherman's licence as if it were an angling licence except that in the application of the provisions of subregulations (15) and (16) of that regulation to an assistant eel fisherman's licence the words " The Commission " shall be substituted for the words " An authorized person ".

APPENDIX II

REGULATORY AND POLICY CHANGES RELATING TO THE TASMANIAN FRESHWATER EEL FISHERY

1965-66 SEASON:

Commercial fishing for eels was permitted using fyke nets and eel traps.

1966-67 SEASON:

20 fishermen licensed.

1967-68 SEASON:

Licence fee of $4 plus $1 for each trap or net after the first. Licence subject to conditions at the Inland Fisheries Commission discretion (in regard to: duration; times and places fished; type and site of nets or trap; marking nets or traps; disposal of other fish and reports of catch). Lynch (1968) outlined I.F.C. policy and problems with the eel fishery.

23 fishermen licensed.

1968-69 SEASON:

Marking of nets and traps with I.D. tags regulated.

Licence fee increased to $50, plus $1 per trap or net after the first.

Fyke nets limited to 30.

Lake Sorell, Dee Lagoon and Pawleena Dam closed to eel fishing from 1 July to 31 December.

Dimensions of nets set out in leaflet (diam. 450 mm, length $\leqslant$ 4 m, mesh 15-40 mm, wings $\leqslant$ 3 m, drop $\leqslant$ 600 mm).

I.F.C. discouraged further applications for eel licences.

8 fishermen licensed.

1969-70 SEASON:

Legal minimum size of 12 inches introduced.

Ban on export of live elvers.

3 fishermen licensed.

1970-71 SEASON:

An eel licence form was introduced with the number of nets and traps and water to be fished specified on the licence.

5 fishermen licensed.

1971-72 SEASON:

14 fishermen licensed.

1972-73 SEASON:

Licence fee increased to $100, plus $1 per additional net or trap after the first.

The number licensed restricted to 13.

9 fishermen licensed (plus 3 Bass Strait Islands).

1973-74 SEASON:

A number of restrictions introduced: fyke nets or eel traps not to be set within 20 m of another (use of nets and traps in combinations banned); nets inspected and cleared at least every 24 hours.

Fyke net dimensions regulated (opening diam. 450 mm, length $\leqslant$ 4 m, mesh 15-40 mm, wings $\leqslant$ 3 m, drop $\leqslant$ 600 mm).

The use of non-licensed assistants banned.

Fishing not permitted within 100 m of a river mouth or within 20 m from an entrance or outlet of a river, creek or drain flowing into or out of a lake or marsh.

The use of fyke nets in rivers was disallowed.

2 fishermen licensed.

1974-75 SEASON:

Fyke nets to be cleared every 12 hours.

3 fishermen licensed.

1975-76 SEASON:

Fyke nets to be cleared every 24 hours.

All prime trout waters closed to eel fishing (highland lakes and farm dams stocked with trout).

7 fishermen licensed.

1976-77 SEASON:

Lynch (1977) reviewed eel fishery.

7 fishermen licensed (plus 3 Bass Strait Islands).

1977-78 SEASON:

Licence fee increased to $100 plus $2 per additional trap or net.

Number of fyke nets changed to 50.

Fyke nets or eel traps not be be set in a river or creek within 100 m of tidal waters, or set more than half way across a water course.

Fyke nets and eel traps to be fitted at all times with a screen covering the opening having a mesh size of 10 cm (platypus screen).

Fyke net size increased (opening height $\leqslant$ 670 mm, width $\leqslant$ 670 mm, mesh 15-39 mm, wings $\leqslant$ 3 m, drop 670 mm); eel trap size specified (height $\leqslant$ 500 mm, length $\leqslant$ 2 m, width $\leqslant$ 500 mm, no wings or leaders, mesh $\geqslant$ 39 mm).

An assistant eel fisherman's licence introduced; fee $5.

9 fishermen licensed (plus 3 Bass Strait Islands).

1978-79 SEASON:

The number of eel traps limited to 50 and a combination of fyke nets and eel traps limited to a total of 50.

Fishery limited to 10 licences plus assistants.

10 fishermen licensed (plus 3 Bass Strait Islands).

1979-80 SEASON:

The eel fisherman to be present when a fyke net or eel trap is set or hauled (assistant not allowed to fish for an absent licensee).

Waters to be fished allocated as municipalities.

9 fishermen licensed (plus 4 Bass Strait Islands).

1980-81 SEASON:

Fyke net wings increased to $\leqslant$ 10 m, drop $\leqslant$ 1 200 mm.

9 fishermen licensed (plus 4 Bass Strait Islands).

1981-82 SEASON:

Fyke nets (1 m entrance diam., $\leqslant$ 10 m wings) permitted on a trial basis in Trevallyn Dam.

7 fishermen licensed (plus 4 Bass Strait Islands).

SOURCES OF INFORMATION

Inland Fisheries Regulations and amendments.

Inland Fisheries Commission Reports year ending 1965-1981.

Reviews of the Tasmanian eel fishery (Lynch 1968, 1977).

APPENDIX III

TASMANIAN INLAND FISHERIES COMMISSION REGULATIONS GOVERNING THE MIGRATING-EEL FISHERY, 1981-82 SEASON

Insertion in Principal Regulations of new regulations 13B and 13C.

11—After regulation 13A of the Principal Regulations, the following regulations are inserted:—

Migrating eel licences.

13B—(1) Subject to this regulation, the Commission may sell and issue a licence to take migrating eels commercially by means of a weir type structure approved by the Commission.

(2) Notwithstanding subregulation (1), where the holder of a migrating eel licence, other than a licence sold and issued pursuant to this subregulation, makes an application to the Commission for another migrating eel licence in respect of the same inland waters to which the first-mentioned licence relates at least one month before the first-mentioned licence ceases to be in force, the Commission shall, unless the application is withdrawn, sell and issue to the applicant another migrating eel licence—

(*a*) in respect of—

(i) the inland waters to which the first-mentioned licence relates; and

(ii) the weir type structure approved by the Commission for the purposes of, and erected in the place specified in, the first-mentioned licence; and

(*b*) that shall be in force from the date of the expiry of the first-mentioned licence for the same period as that licence.

(3) The price for the sale of a migrating eel licence is at the rate of $100 a year payable in instalments—

(*a*) the first of which, being an instalment in respect of the 1st year of the licence, is payable before the issue of the licence; and

(*b*) the others of which are payable in accordance with the condition in the licence relating to the amounts of those instalments and the times of their payment.

(4) An application for a migrating eel licence—

(*a*) shall be in writing;

(*b*) shall specify—

(i) the inland waters in which the applicant wishes to take migrating eels or to continue to take those eels, as the case may be;

(ii) the place where the weir type structure by means of which he proposes to take those eels is to be erected or is erected, as the case may be; and

(iii) the type and dimensions of that structure.

(5) A migrating eel licence—

(*a*) shall be in accordance with form 2B;

(*b*) authorizes the licensee to catch migrating eels in the inland waters specified in the licence by means of the weir type structure approved by the Commission and erected in the place specified in the licence for such period, exceeding one year but not exceeding 5 years, as the Commission may determine and as is specified in the licence;

(*c*) is subject to the following conditions:—

(i) an officer shall, at any time, have access to the weir type structure referred to in paragraph (*b*) and may examine that structure at any time;

(ii) the licensee or an employee of the licensee shall, at the request of the Commission or an officer, open or remove that structure;

(iii) the licensee shall, within 15 days after the expiration of every month during the currency of the licence, lodge with the secretary a return giving details of the weight and species of migrating eels taken by him during the preceding month;

(iv) a condition of the kind referred to in subregulation (3) (*b*);

(v) such other conditions (if any) as are specified in the licence; and

(*d*) shall be signed in ink by the licensee.

(6) A migrating eel licence does not confer on a licensee the right to take or to retain any fish of a kind or species other than migrating eels, goldfish, tench, or English perch.

(7) An officer shall release from a weir type structure used by a licensee any fish of a kind or species other than migrating eels, goldfish, tench, or English perch, that the officer finds while he is examining the structure as mentioned in subregulation (5) (*c*) (i).

(8) A licensee who fails to comply with a condition to which his migrating eel licence is subject is guilty of a breach of these regulations.

Penalty: Not less than $200 and not more than $300 and, in addition, for a continuing breach, not less than $30 in respect of any one day during which the breach is continued, together with a special penalty of not more than $30 in respect of every fish to which the breach relates.

(9) The Commission may, by notice in writing to a licensee, cancel his migrating eel licence—

(*a*) in addition to any penalty to which the licensee is liable under subregulation (8) for a breach of a condition of that licence; or

(*b*) if the licensee is convicted of a breach of Part III of the Act or of these regulations.

(10) The Commission shall not issue more than one migrating eel licence in respect of any particular inland waters.

(11) Nothing in subregulation (10) prevents the Commission from issuing a migrating eel licence in the place of such a licence in respect of any particular inland waters that has been cancelled as mentioned in subregulation (9) or that has otherwise been cancelled under these regulations or that has expired.

(12) Nothing in a migrating eel licence affects, or derogates from, the provisions of the regulations with respect to the navigation of boats or similar craft made under any Act.

Exclusive rights under migrating eel licences.

13C—A person, other than the holder of a migrating eel licence or an employee of the holder of the licence, shall not fish in a weir type structure erected pursuant to the licence.