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MINISTRY OF AGRICULTURE AND FISHERIES

FISHERIES TECHNICAL REPORT

No. 109

REVIEW OF BIOLOGICAL KNOWLEDGE ON NEW ZEALAND FRESHWATER EELS (ANGUILLA SPP.)

W. SKRZYNSKI

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MINISTRY OF AGRICULTURE AND FISHERIES

WELLINGTON

Mr Max Burnet at his research work on eels - (top) electric fishing, (right) measuring and tagging his catch

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ABSTRACT

Two species of freshwater eels, the long-finned eel, *Anguilla dieffenbachii* and the short-finned eel, *Anguilla australis schmidtii* are widely distributed throughout New Zealand and the adjoining islands including the Chatham Islands.

Published ecological knowledge on both species is reviewed and current research projects are outlined. Emphasis is placed on topics of current interest related to heavy commercial exploitation of eels in the last few years.

These topics include the rates of growth and recruitment and the effects of eel removal on trout, the most important freshwater game fish in New Zealand.

INTRODUCTION

Ten years ago New Zealand freshwater eels were known mainly to fisheries experts, to anglers who thought that they endanger their sport, and to some Maoris who still used them as traditional food. In the last few years eels became one of the most important export earners within the New Zealand fishing industry.

A considerable amount of biological information on eels has been published. The report attempts to review this information and present the most important facts briefly. Some statements, especially those made by early authors, which did not appear to be adequately substantiated, are consciously omitted. Many questions important to the industry, for example, what is the annual rate of emigration of mature adults, remain unanswered. Some of these questions should be answered by the current research programmes (Appendix 1).

1. FRESHWATER EELS THROUGHOUT THE WORLD

There are about twenty species of freshwater eels throughout the world, several of them distributed close to the north of New Zealand in the central Pacific and South-east Asia.

All freshwater eels are closely related systematically and belong to the same genus Anguilla, the sole representative of the family Anguillidae. The most important and best known species are : the European eel, Anguilla anguilla; the American eel, Anguilla rostrata (distributed throughout the Atlantic Coast of North America and West Indies) and the Japanese eel, Anguilla japonica, extending through Japan south of Hakodate and on the China coast from Korea to Hong Kong.

The above three species are very closely related. They are recognisable only by internal examination, mainly by the different number of vertebrae, however, there are important biological differences between them. The American eel spawns earlier than the European eel, in January to February and has a more rapid larval growth with a metamorphosis from marine larvae (leptocephali) into adult-like elvers in one year. For the European eel the marine larval growth takes about three years (Bertin 1956). The larval growth of the Japanese eel lasts one year. The inter-tropical eels have the shortest larval life in the sea, of only 2-3 months for Anguilla bicolor distributed from the Indian Ocean to New Guinea (Bertin 1956).

There are large areas in the world where freshwater eels are absent, notably the whole of the West Coast of North America, all of South America except West Indies, the west coast of Africa and the south-west coast of Australia. This is explained by a study of ocean currents, sea temperatures and depths and the length of larval life of various eel species (Bertin 1956).

Further information:

Bertin L. 1956 : Eels, a biological study. Cleaver-Hume Press, London. 192 pp.

Eales J.G. 1968 : The eel fisheries of eastern Canada. Fisheries Research Board of Canada. Bulletin 166. 79 pp.

2. GEOGRAPHIC DISTRIBUTION AND IDENTIFICATION OF THE NEW ZEALAND SPECIES

The two species present in New Zealand are : the long-finned eel, Anguilla dieffenbachii Gray and the short-finned eel, Anguilla australis schmidtii Phillipps. The three part name of the short-finned eel indicates that it is a sub-species of A. australis.

The New Zealand sub-species is found throughout New Zealand and also in the Chatham Islands, Norfolk Island, New Caledonia and Fiji.

The other sub-species, Anguilla australis australis is found along the east coast of Australia from New South Wales to Victoria, in Tasmania and Lord Howe Island (Castle 1963). The differences between the two sub-species are minor and recognisable only by a specialist (Castle 1969). The long-finned eel is found only in New Zealand, the Chatham Islands and Auckland Islands (Griffin 1936).

The two New Zealand species were first described as Anguilla australis by Richardson in 1844-48 and Anguilla dieffenbachii by Gray in 1842. Other scientific names used in some publications to describe the short-finned eel are Anguilla schmidtii and Anguilla australis orientalis and for the long-finned eel: Anguilla aucklandii, Anguilla latirostris and Anguilla waitei (McDowall 1964).

The best means of identification of these two species is usually the length of the dorsal fin which on the long-finned eel extends much further forward than the ventral fin. All individuals above about 1 metre long or 2 kg in weight are likely to be long-finned.

All known differences useful for identification are listed in Table 1 and shown in Figs. 1 and 2 (after Cairns 1941).

TABLE 1

COMPARATIVE FEATURES OF LONG AND SHORT-FINNED EELS

Anguilla dieffenbachii (Long-finned Eel) Fig. 1	Anguilla australis schmidtii (Short-finned Eel) Fig.2
1. Dorsal fin much longer than ventral fin.	1. Dorsal fin approximately equal in length to ventral.
2. Vomerine teeth in a narrow band.	2. Vomerine teeth in a club-shaped formation.
3. Eye above and forward of angle of jaw.	3. Eye directly above angle of jaw.
4. Lips thick.	4. Lips thin.
5. Head broad.	5. Head narrow.
6. Nasal organs prominent.	6. Nasal organs small.
7. Mouth gape wide and jaws strong.	7. Mouth gape narrow and jaws small.
8. Tail broad, caudal fin well developed.	8. Tail narrow, caudal fin poorly developed.
9. Pectoral fins prominent.	9. Pectoral fins small.
10. Dorsal area of body black; ventral side a yellowish brown.	10. Dorsal part greenish-brown; ventral a dull white.
11. May reach over 180 cm in length and 18 kg in weight.	11. Seldom grows over 90 cm in length and 1.8 kg in weight.
12. Average length adult female, 85-95 cm. Average length adult male, 55-65 cm.	12. Average length adult female, 75-85 cm. Average length adult male, 35-45 cm.
13. Average weight adult female, 1.8-2.7 kg. Average weight adult male, 0.9-1.1 kg.	13. Average weight adult female, 1.1-1.4 kg. Average weight adult male, 0.25 kg.

Differences of colour are not reliable when used alone and may be altogether misleading.

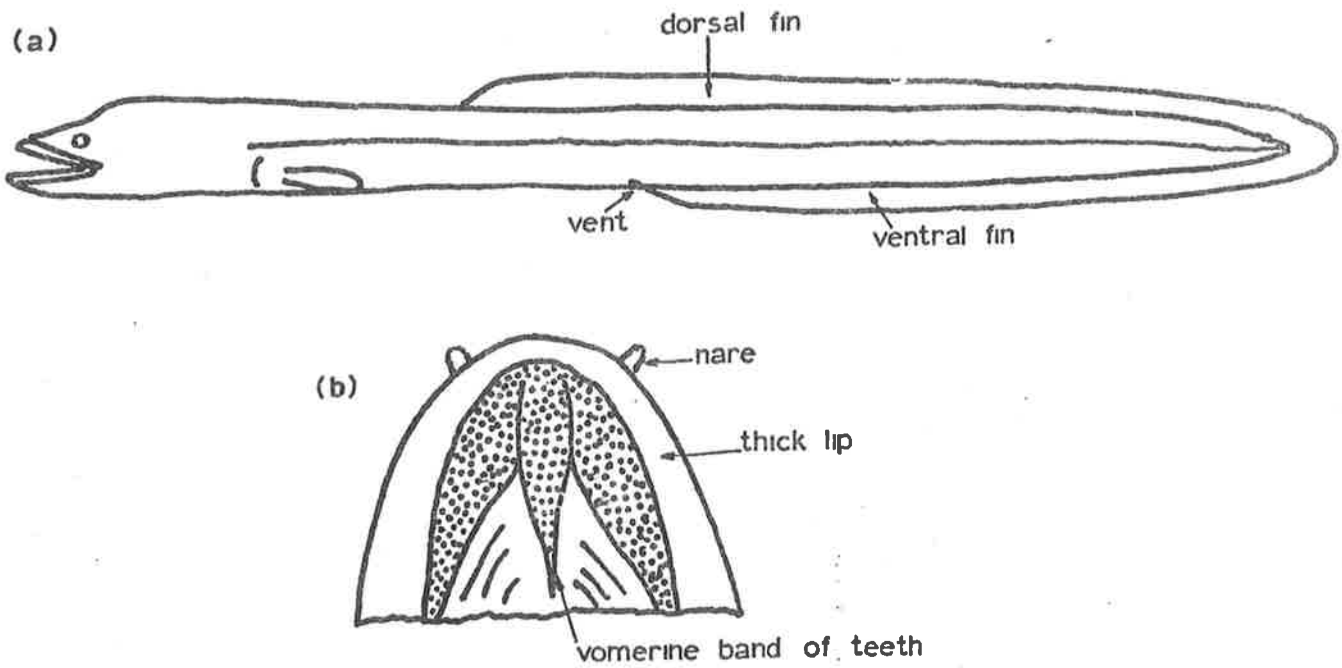


Fig. 1. Long-finned eel : (a) outline of eel showing position of dorsal fin and eye, (b) upper jaw (note the central or vomerine band of teeth and thick lips)

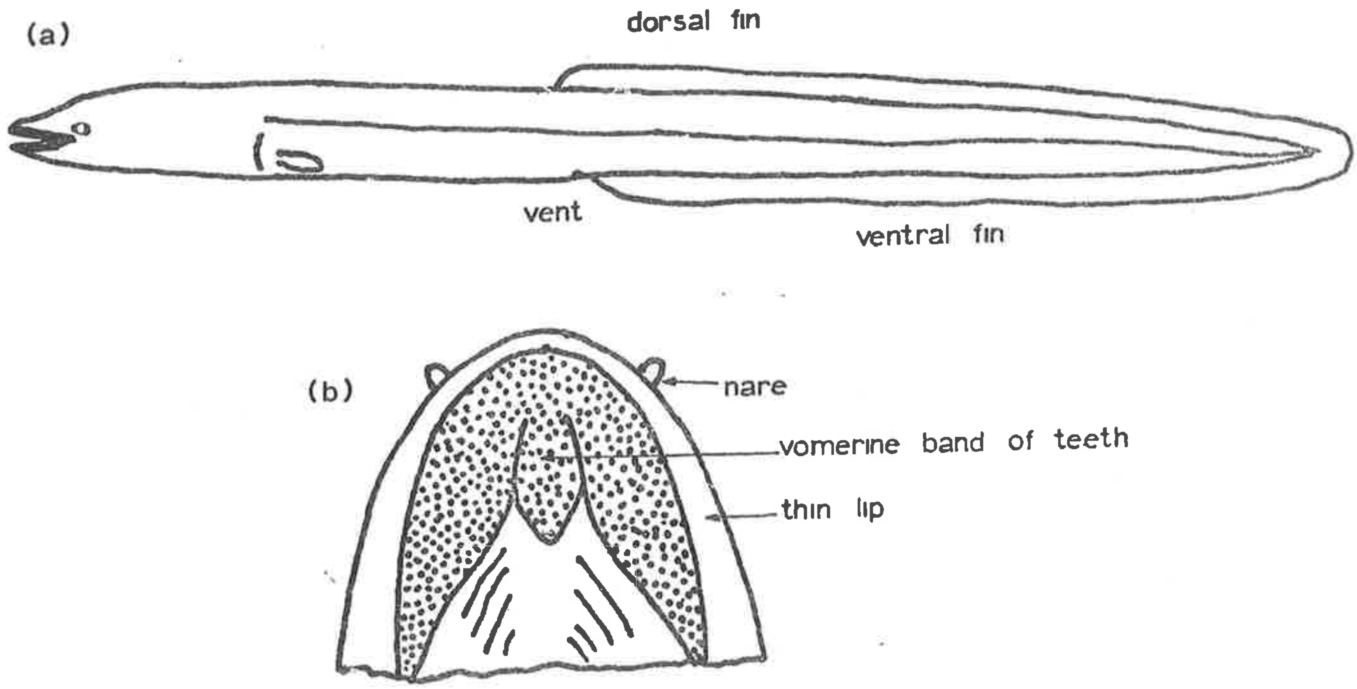


Fig. 2. Short-finned eel : (a) outline of eel showing position of dorsal fin and eye, (b) upper jaw (note the central or vomerine band of teeth and thin lips)

Further information:

Cairns D. 1941 : Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.

Cairns D. 1950 : New Zealand freshwater eels. Tuatara 3 : 43-52.

3. LIFE HISTORY OF NEW ZEALAND EELS

The life history of all freshwater eels is remarkably similar, despite their wide distribution and the disparity in the length of larval life from two months to 3 years (Bertin 1956).

The life history consists of three distinct phases separated by two transformations (metamorphoses):

(a) Phase of marine larval drift from the place of spawning in the ocean depths to the mouths of the rivers.

(b) First metamorphosis from a leaf-like leptocephalus to an adult like elver (which takes place at sea near the coast).

(c) Freshwater juvenile phase or phase of growth lasting several years in lakes or rivers.

(d) Second metamorphosis (attainment of sexual maturity) accompanied by distinct morphological changes (enlargement of eyes, rapid increase in the size of gonads and degeneration of digestive apparatus, change in colour).

(e) Migratory adult phase or phase of reproduction (marine) of unknown duration from the time of leaving the river mouths to spawning in ocean depths and presumed subsequent death.

(a) Spawning and marine larval drift

The origin of the eel has fascinated people since the beginning of the European civilisation. Aristotle in 350 B.C. wrote that eels come from the entrails of the earth and many other fantastic theories have been advanced since. Only at the end of the eighteenth century were the correct observations on migrations noted and the eel ovary described for the first time. The male organ was described only in 1874 (Bertin 1956).

In 1896 Italian scientists collected the flat, leaf-like larvae of the eel, the leptocephali and established that they are young eels by observing their transformation into elvers in a tank. It took almost twenty years from 1904 to 1922 to discover the area where the European eels are born at depths from 400 to 500 metres. This work was conducted by a Danish biologist Johannes Schmidt, who later studied fresh water eels world-wide, including New Zealand eels (Schmidt 1928).

The area where the New Zealand eels spawn is not definitely known, but its location can be inferred by comparison of the spawning conditions of the European eel and the conditions in the south-west Pacific (Castle 1963 and 1969). "It seems likely that the breeding area for these species is well to the east of New Caledonia - that is, between Fiji and Tahiti" (Castle 1963). In contrast to the many thousands of the leptocephali of the European eel collected in the Atlantic, only 16 leptocephali and two glass eels have been collected in the Pacific (Castle 1963). Only two of the above specimens can be assigned to Anguilla australis schmidtii and one to the Australian sub-species of the short-finned eel. No long-finned leptocephali have been described.

Eels have a very large reproductive capacity, one female being capable of producing several million eggs. However, the mortalities of young larvae in their complex migration must be enormous (Castle 1972).

The length of marine larval life for the New Zealand species is suspected to be about one year (Castle 1969). The study of the marine larval life of the New Zealand eels would require vast manpower and financial resources.

Further information:

Bertin L.	1956	:	Eels, a biological study. Cleaver-Hume Press, London. 192 pp.
Castle P.H.J.	1963	:	Anguillid leptocephali in the south west Pacific. Zoology Publication from Victoria University of Wellington 33. 14 pp.
Castle P.H.J.	1969	:	Early life history and general distribution of eels in Report on Eel Seminar. Fishing Industry Board.

(b) First transformation and freshwater life
and
(c) The transformation from the leptocephalus into an adult-like eel takes place near the coast. The young elvers are almost completely transparent (glass eels). Glass eels are caught in the mouths of rivers. On reaching fresh water they quickly become pigmented and assume a completely adult-like appearance.

The growth in fresh water is the longest period in the life cycle of the eel and it culminates in a sexual maturation and finally a migration to the sea. During this period eels can be readily observed and studied and also achieve economic importance as both predators on other fish and food fish for human consumption.

The freshwater life of both New Zealand species is described in detail later.

Further information:

See under appropriate headings in section 4: Ecology of New Zealand eels in fresh water.

(d) Sexual maturity and adult spawning migration in the sea
and
(e) Little is known about this phase after the migrants reach the sea. European eels have been caught only as far as the North Sea straits. No adults have ever been taken at the spawning grounds. It can only be presumed that they die after spawning.

There is only one record of an adult New Zealand freshwater eel captured at sea (Todd 1973). This was a female long-finned eel, about 100 cm in length, which was captured in a trawl in a 113 m depth about 27 km off Cape Farewell on May 10 1971. The diameter of its eyes was about 50% greater than in non-migrant eels. The ovaries were estimated to represent about 11% of the total body weight. The largest ova measured up to 0.5 mm in diameter. The eggs and gonads were only slightly advanced in size compared to those of the long-finned migratory females caught before entering the sea. The external characteristics (size of eyes etc.) were identical to the seaward migrants.

Further information:

Bertin L. 1956 : Eels, a biological study. Cleaver-Hume Press, London. 192 pp.

Todd P.R. 1973 : First record of the freshwater eel *Anguilla dieffenbachii* Gray to be caught at sea. Journal of Fish Biology 5 : 231-2.

4. ECOLOGY OF NEW ZEALAND EELS IN FRESH WATER

(a) Glass eels

Cairns (1941) stated that the records of elver migration are incomplete. He said that elvers enter fresh water between October and December and that the first "run" of elvers each year comes to the Waikato River. Cairns also stated that as soon as pigmentation on contact with fresh water commences, the elvers take cover during the day and travel up the rivers at night. However, Cairns also observed elvers in the Waikato running freely during the daytime and during floods and freshes. Cairns (1941) gave the size of elvers entering fresh water in New Zealand at between 57 and 69 mm (no species given).

"The transparent glass eels enter the estuaries in the spring and are sometimes caught with whitebait" (Burnet 1955). Burnet recorded two old collections of glass eels, one from Styx River from September 15 1915 and one from the Waimakariri River Lagoon from September 9 1938. Both these collections were of the short-finned eels.

Castle (1963) stated that the average length of early elvers of the short-finned eel in New Zealand is about 61 mm and of the long-finned eel about 64-70 mm. Castle stated that the size of elvers is "an expression of biological-geographical conditions" as it is possible that the temperate elvers are more distant from the breeding grounds than are their tropical counterparts and this may account for their larger average size. The elvers of the short-finned eel entering the waters of New South Wales are smaller, about 53 mm on average and those in New Caledonia reach an average maximum length of only about 50 mm.

Woods (1964) gave the lengths of an unrecorded number of glass eels from the Waikato : 57 to 66 mm for short-finned eels and 59 to 71 mm for long-finned. He said that short-finned eels from a smaller sample from the Days Bay Stream, Wellington Harbour measured from 59 to 66.5 mm and weighed from 0.19 to 0.27 g (alive).

Burnet (1969d) stated that it is thought that the runs of glass eels occur when high water is about midnight during migration months (August and September). He said that the glass eels after entering fresh water become pigmented after a week or so.

The author observed glass eels at the mouths of two small streams on the Chatham Island in October.

Mr Max Burnet and his assistants electric fishing for eels in the Horokiwi Stream (top) and part of their catch (right)

Further information: No detailed published information except as quoted.

(b) Upstream migrations of juveniles

Cairns (1941) stated that as the eels approach 10 to 12 cm, large numbers of them leave the lower reaches of rivers and migrate to the upper waters in January and February. This secondary movement is a well defined migration observed in several localities in New Zealand. In the Waikato it was regular, the eels arriving at the Arapuni dam in late January from 1936 to 1939. The average size of 1,000 of these migratory eels at Hora Hora on the Waikato River was 9.8 cm, the sample consisting of 70% short-finned and 30% long-finned eels. 150 short-finned eels were on average 9.5 cm long and 150 long-finned 10.6 on average.

"On arrival up-stream the eels bury themselves in the mud under boulders and logs once more. The writer has dug out eels in great numbers from drains entering streams and rivers, one notable instance being on the Waihou, some distance below Okoroire. Here the eels were so thick in the side drains that every shovel full of mud removed revealed up to six individuals. These young eels had not long migrated up the Waihou River " (Cairns 1941).

Hardy (1950) observed the climb by elvers of a waterfall in a stream below Lake Sheppard in the headwaters of the Hurunui River (about 100 km from the sea). First elvers were observed on February 8 and the last on March 1. The total number seen was only 43 and they were no more numerous at night than in the daylight. The proportion of short-finned to long-finned eels was about 1:6, though the first short-finned was not seen until February 16. The size was about 10 cm.

Burnet (1955) summarising his observations on young eels in lowland streams near Christchurch stated : those in the "second migration" belong in the majority to a single year class (one year in freshwater).

Boud (undated) stated that in the Clutha River large numbers of young eels migrate upstream in the first four months of the year until halted by the Roxburgh Dam, which few, if any are able to pass. The size range of these eels is from 3.8 (?) to 35 cm.

Woods (1964) recorded elvers of both species down to 7 cm in length climbing the Karapiro Dam on the Waikato in February and March. He discussed at length their climbing ability, size and species composition and other factors related to the ability of eels to surmount large hydro dams and natural obstacles.

Burnet (1969d) stated that the samples of elvers collected in the Canterbury area comprised over 90% of short-finned eels, but samples from other places had larger proportion of long-finned eels. The young elvers appear to live in the lower few kilometres of the streams for one or two years, after which they move upstream to populate the entire river system. During this second upstream migration the eels, which are between 9 and 12 cm long, can be seen in large numbers at some of the hydro electric dams.

Hopkins (1970) in his study of small headwater streams of the Ruamahanga River, about 50 km from the sea and at about 150-300 m above sea level, stated that the density of eels of both species frequently reached a peak in summer (February). This was due to the influx of young eels ascending the streams then. The size of the influx was very variable between sampling stations. This irregularity was probably due to distance from the sea. No mass migration of elvers was noted, the main movement having presumably spent its force before reaching these streams.

Castle (1972) summarising the behaviour of eels in fresh water mentioned "a spring invasion of fresh waters by glass eels and an upriver movement of elvers in late summer".

Further information:

Burnet A.M.R.	1955	: A study on the ecology of the New Zealand freshwater eels. (unpublished M.Sc. thesis, Canterbury University, Christchurch). 42 pp.
Cairns D.	1941	: Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.
Woods C.S.	1964	: Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(c) Other movements in fresh water

Two main juvenile upstream migrations are described above and the spawning migration of maturing adults is described further. The main size group in the second juvenile migration includes elvers up to about 12 cm in length.

Burnet (1969d) mentioned that eels do not move much in the rivers except during the 3 or 4 migration periods. He observed some movement of immature eels, but the main downstream migrations were of pre-migrant or migrant eels. He thought that pre-migrant eels, slightly smaller than the migrant size, move down to tidal waters in preparation for maturity. The immature long-finned eels run throughout the year, but especially in December and January. The immature short-finned eels have a more restricted movement which is confined mainly to the summer.

The smallest eels of both species found by Hopkins (1970) in the upper Ruamahanga streams were about 9 cm. He found only one migratory eel during the detailed sampling carried for almost three years, but stated that some still immature adults left these streams in summer, contributing to the decline in numbers in winter and spring.

Further information:

Burnet A.M.R.	1969 b	: Migrating eels in a Canterbury River, New Zealand. N.Z. Journal of Marine and Freshwater Research 3 : 230-44.
Cairns D.	1941	: Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.
Woods C.S.	1964	: Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(d) Age determination

The growth rate of eels can be determined by the reading of otoliths (small bones from the head). Burnet (1969c) stated that the otoliths of eels around 15 cm long are easily read. For larger eels there are marked differences between the tag return data and otolith readings. The graphs constructed by Burnet show a wide disagreement with the results of Cairns (1941), who used only otoliths reading for the determination of age-growth curves. In all cases Burnet's tag data show a slower growth rate than do Cairns' otolith results, the greatest difference occuring for the long-finned eels. However, the tag data indicate the great individual variability of the growth rates and therefore it is possible that growth rates of the order obtained by Cairns occur in some areas.

Eels also have scales, which are very small and embedded in the skin. Cairns (1941) used them in conjunction with otoliths for age studies and found that the scales of the New Zealand eels form regularly in the seventh year of life.

Burnet (1955) concluded from foreign literature that scales are of little use for the determination of age in eels. There are many reservations about the validity of otolith reading.

Further information:

Burnet A.M.R. 1955 : A study on the ecology of the New Zealand freshwater eels. (unpublished M.Sc. thesis, Canterbury University, Christchurch). 42 pp.

Burnet A.M.R. 1969 c : The growth of the New Zealand freshwater eels in three Canterbury streams. N.Z. Journal of Marine and Freshwater Research, 3 : 376-84.

Cairns D. 1941 : Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.

(e) Age and growth in fresh water

As discussed above, glass eels of both species on entering fresh water are about 6-7 cm long and probably about one year old.

Cairns (1941) studied at length the growth age relationship, but for reasons given above, his data are suspect and only Burnet's results are summarised (Burnet 1969 c and d) as based on a completely reliable returns (individual tagging).

Typical growth rates in the Canterbury area are:

Long-finned eels : 2.5 cm/year at the length of 30 cm reducing to 1.5 cm/year at 100 cm.

Short-finned eels : 6 cm/year at the length of 20 cm reducing to 2 cm/year at 60 cm.

Burnet recaptured 2 long-finned eels which had been tagged for ten years:

Specimen No.	(1)	(2)
Length on tagging cm	109.9	36.3
Length on recapture cm	134.6	64.6
Length increase in 10 years cm	24.7	28.3

The first one of these eels weighed 4.5 kg on tagging and 9.2 kg on recapture - 4.7 kg increase in ten years.

Burnet's data (1969c) for both species show that there is no growth at all in winter in lowland Canterbury streams (May to September).

Burnet tagged eels down to 10 cm long, but returns were poor for those less than 30 cm in length, therefore otoliths were used to determine the age of small eels.

The highest growth rates recorded for the short-finned eels were 8 to 10 cm increase in length per year for those 20 to 30 cm long. The highest growth rates of largest short-finned eels, about 60-70 cm long, were up to 2.5 cm/year.

The highest annual growth rates recorded for long-finned eels were up to about 5 cm/year for eels 30-40 cm long and about 1-2 cm for larger individuals.

Burnet (1969c) drew the length-age curves up to the age of 30 years for the short-finned eels and up to the age of 60 years for long-finned. By comparison with overseas data, such life lengths for eels are quite probable. Cairns (1941) on the basis of otolith reading recorded much shorter life lengths.

Burnet (1969c) also said that overseas studies (Bertin 1956) showed that there is a relationship between growth and sex, with the female eels growing faster than the males and that his (Burnet's) study endorsed this.

Hopkins (1970) identified from histograms the youngest three age classes in one of the upper Ruamahanga streams for the samples of short-finned eels taken in February and these three age classes made up 92% of his sample. He said that the youngest year class was at least of the age 3 + years and possibly older and its mean length was 132 mm. The two subsequent identifiable classes were of 179 mm and 210 mm mean length.

For the long-finned eels, present in smaller numbers in the same stream in February, only the first two age classes were identified, which made up 62% of the sample. Their mean lengths were 129 and 170 mm. There was a much larger "tail" to the long-fin distribution than for the other species, probably containing a greater number of age groups.

The largest sizes recorded by Burnet (1969 b) in the South Branch stream near Christchurch were 81 cm long for short-finned eels and 132 cm long for long-finned eels. Woods (1964) recorded similar maximum sizes in his large samples from upper Wanganui waters. Cunningham et al. (1953) recorded an unusually large short-finned eel from Lake Waiparera in Northland, which was 102 cm long and weighed over 3.5 kg. Hobbs (1947) recorded three exceptionally large short-finned eels seen amongst many thousands in Lake Ellesmere, which were between 103 and 107 cm long and weighed up to 2.6 kg each.

The largest long-finned females in Lake Ellesmere at migration were 137 cm long and weighed over 8.5 kg. Hobbs (1948) recorded a long-finned eel from a tributary of Lake Ellesmere which weighed 14.5 kg.

In eels, the males attain a much smaller size than females, therefore, the largest specimens are all females. The largest female eels are possibly aberant, having lost their ability to mature sexually and they probably die in fresh water (Woods 1964). The largest males recorded by Woods were : long-finned 68 cm and short-finned 47.5 cm. In Lake Ellesmere, Hobbs (1947) recorded the largest males at 74 cm long-finned and 58.5 cm short-finned. Burnet (1969 b) gave the maximum sizes for migrating males in the South Branch at 74 cm long-finned and 58 cm short-finned.

Castle (1972) stated that "at migration eels are probably not less than 12-15 years old and most migrants are no doubt appreciably older".

(See Figs. 3 and 4, graphs of length/weight after Shorland and Russell (1948) p. 174).

<u>Further information</u>:

Burnet A.M.R.	1969 c	:	The growth of the New Zealand freshwater eels in three Canterbury streams. N.Z. Journal of Marine and Freshwater Research 3 : 376-84.
Cairns D.	1941	:	Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.
Hopkins C.L.	1970	:	Some aspects of the bionomics of fish in a brown trout nursery stream. Fisheries Research Bulletin 4. 38 pp.
Woods C.S.	1964	:	Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(f) <u>Sexual development and spawning migration</u>

Cairns (1942 b) described the development of gonads and stated that the sexual development was first seen at about 45 cm in long-finned eels and at 40 cm in the short-finned. Woods (1964) was able to identify reliably the sex in eels from : long-finned males 36 cm and females 37 cm and short-finned males and females 43 cm.

Cairns (1942 b) described the sex organs of eels as follows:

"The male sex organ (Fig. 12) consists of a large number of flat petal-like smooth lobes situated in a band on either side of the intestine. Within the separate lobes tubes are developed for the transference of the sperms to a common duct which passes back to open near the vent. It seems probable that the opening of the vent is used for the extrusion of the sperms, as the gut is almost completely atrophied before the eel leaves fresh water.

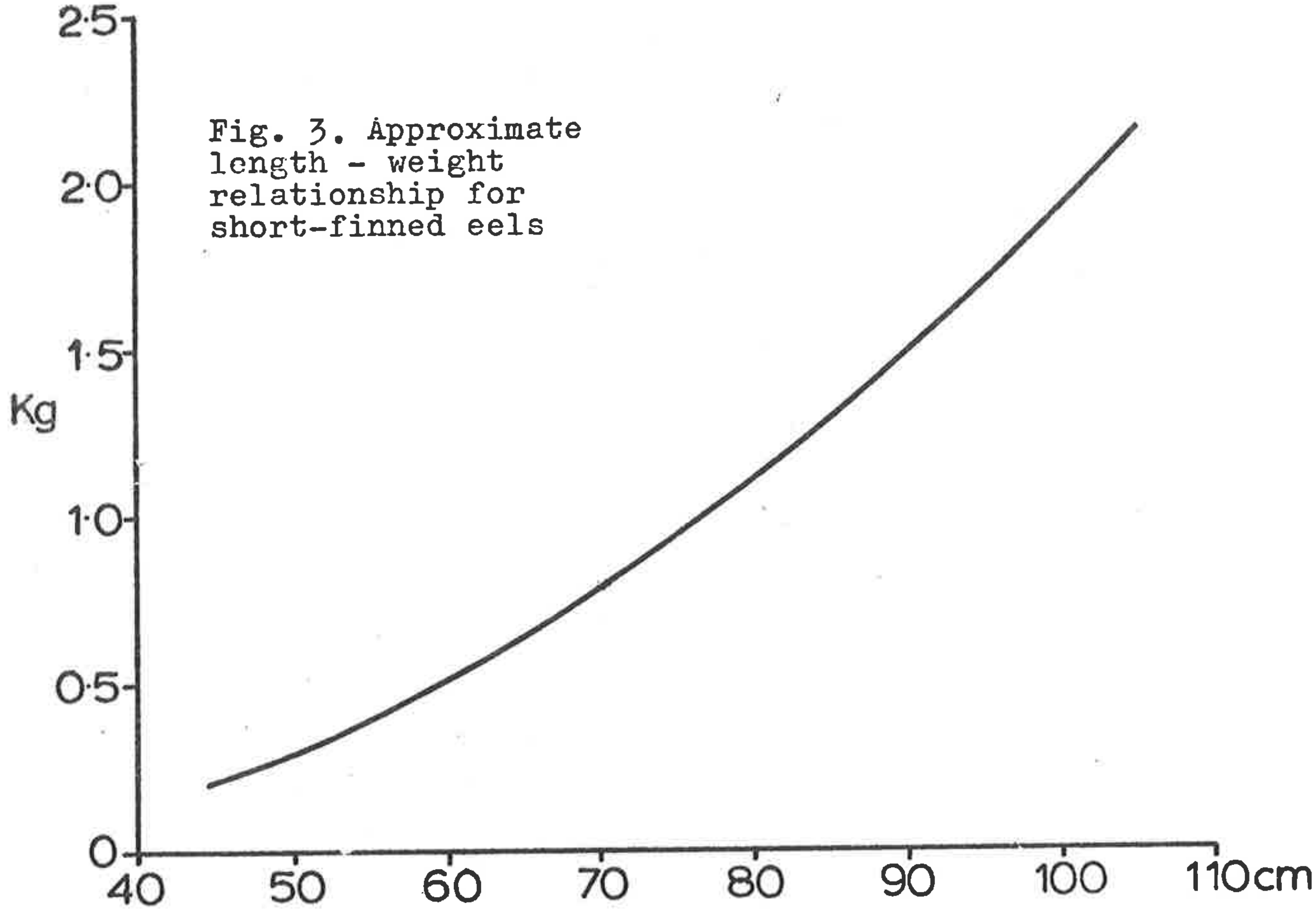


Fig. 3. Approximate length - weight relationship for short-finned eels

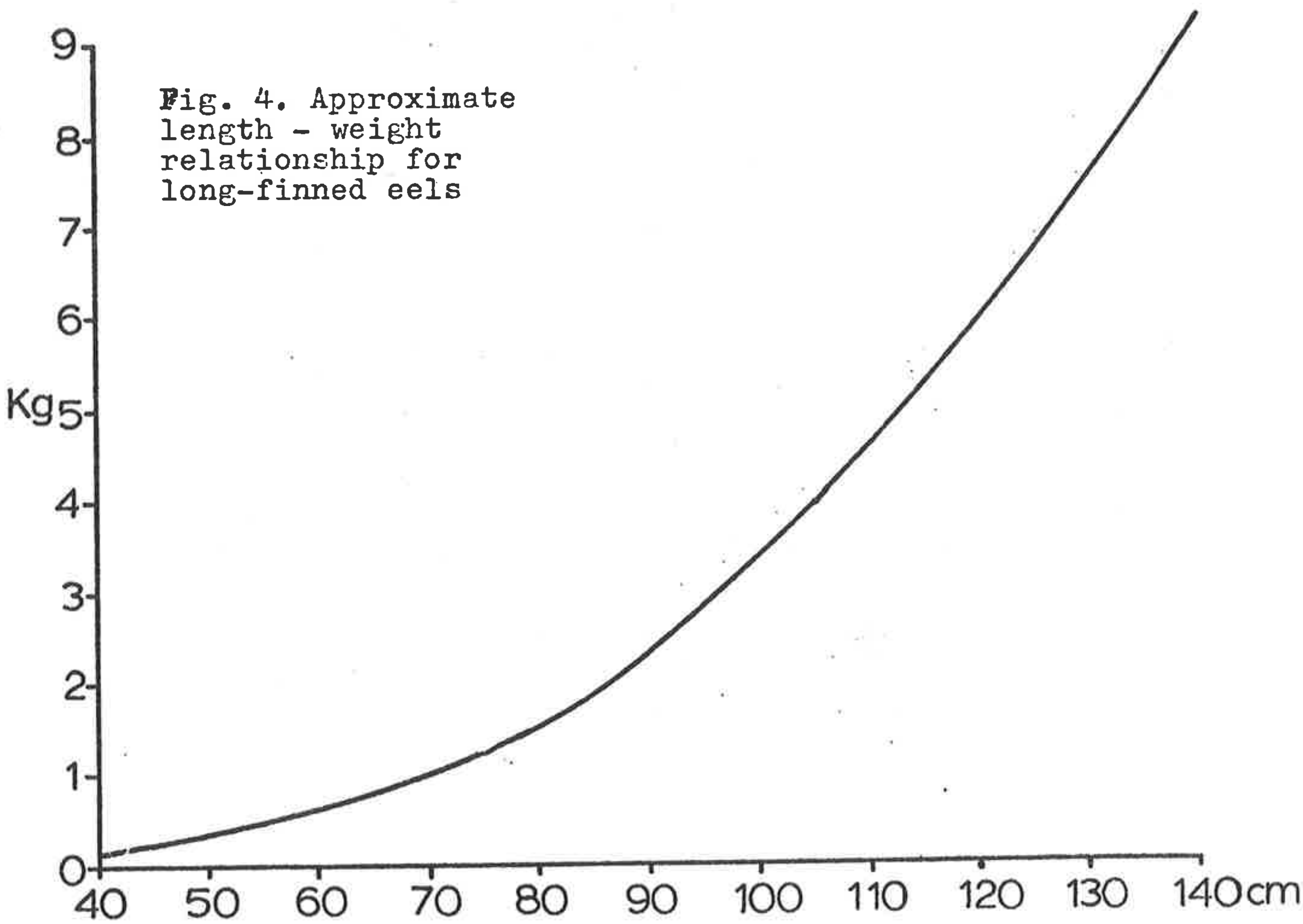


Fig. 4. Approximate length - weight relationship for long-finned eels

The female sex organ (Fig. 13) is situated in the body cavity in a position similar to that of the male gonad. When immature it is a delicate pinkish band on either side of the gut, one edge of which is attached to the body wall and one end free. As maturity approaches, the bands widen and become creamy-yellow in colour. When the maximum development in fresh water is attained they are a yolk-yellow and in the form of an extensively convoluted frill. (The outer edge of the ovary is much longer than the inner attached edge.) The eggs (ova) are situated on the lamellae on the outer side of the ovary and may number up to four or five million. They are probably liberated in the body cavity and passed out of the vent. The ova may be seen by the aid of a magnifying glass (X 10) in some of the well-developed eels.

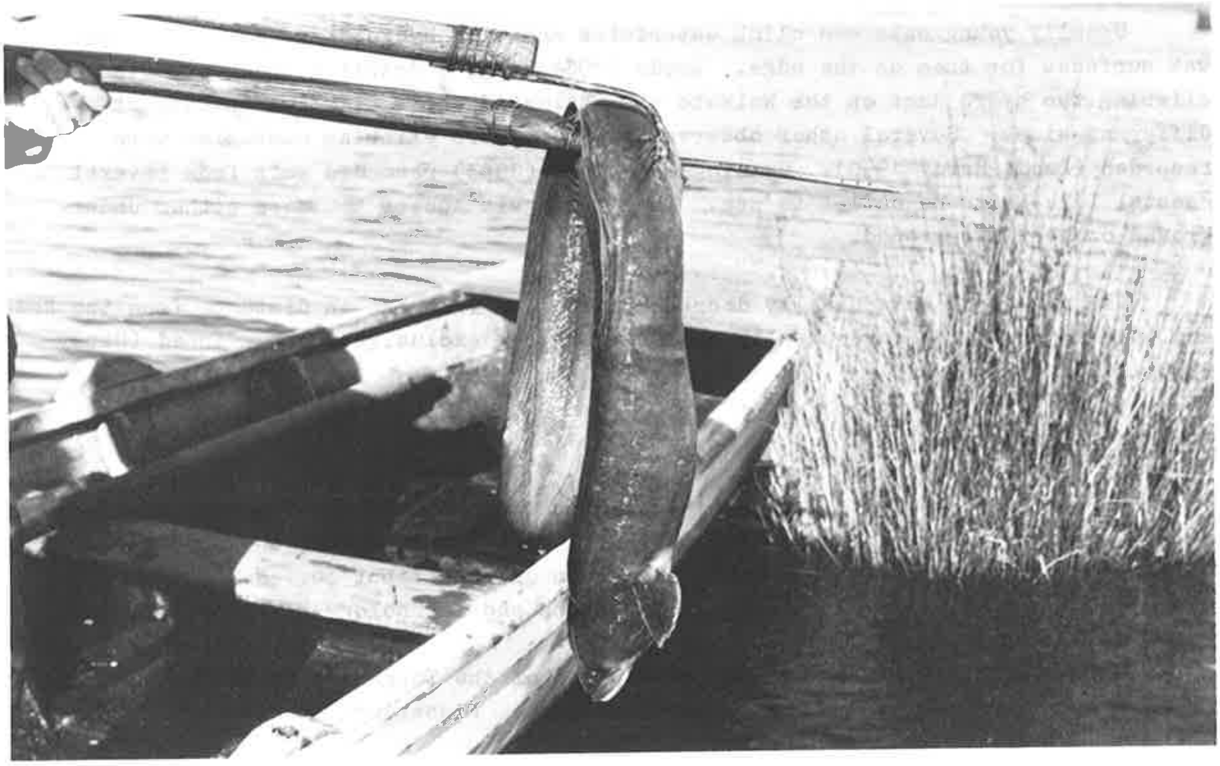
The sex organ of the male eel is fully developed (as far as the freshwater life is concerned) at about 55 cm to 65 cm in the case of the long-finned eel and 45 cm to 50 cm in the case of the short-finned eel. The female of the long-finned eel reaches the same stage at about 85 cm to 95 cm, but odd individuals remain sterile for many years and are known to the Maori as kokopu-tuna (large eel). The female of the short-finned eel is fully developed (see above) at 75 cm to 85 cm - the largest specimen taken by the writer in two years and a half of sampling was 92.5 cm long".

The subject of eel sexuality is complex (Bertin 1956) and overseas studies link the development of the sex organs with environment. Cairns (1942 b) described the apparent change in sex from male to female in eels between 45 cm and 60 cm sampled in the Horokiwi Stream near Wellington. It appears that eels below a certain size (age ?), if transported from one body of water to another with different characteristics, can change their sex. Various eel populations have different sex composition (Burnet 1969 c, Woods 1964). Early workers (Cairns) thought that the male eels live only in brackish waters, but the later work of Burnet and Woods disproved this. Woods (1964) found males generally much more numerous than females in the upper tributaries of the Wanganui River. It is not known if the sex change can still occur at a larger size, once the sex organ has started developing, or even during spawning migration (Woods 1964).

Burnet (1969 b) studied the downstream migration of eels in a lowland stream near Christchurch, situated 18 km from the sea. These migrations showed a seasonal and lunar periodicity, and the larger runs were also influenced by rainfall, water volume, or the passage of a depression. Seasonal peaks were marked for mature eels of both species.

"From October to April, the seasonal sequence for the runs of mature eels was: A. dieffenbachii males, A. dieffenbachii females, A. australis males and females. Hobbs (1947) studied the seaward migration of New Zealand eels at the outlet of Lake Ellesmere into the sea. The sequence there, from March to June, was : A. australis males and females, A. dieffenbachii males and then females of this species. This is a reversal of the sequence observed at the South Branch trap, with the dates all later, especially for A. dieffenbachii. The date of migration into the sea may be expected to be later than the dates of migration from upstream areas. Possibly, there is a longer lapse between the stimulus to migrate downstream and the stimulus to migrate to sea in A. dieffenbachii because this species is generally found further inland than A. australis. Conversely, because A. australis is usually found in streams near the coast, it probably does not take as long to move down stream; there may be only a short time between the stimulus to move downstream and the stimulus to move into the sea. Such a difference between the two species could explain the reversal in times between the South Branch trap results and Hobbs's Lake Ellesmere records".

Well known tame eels at Takaka, South Island, coming to be fed (National Publicity Studios)



A5 kg eel caught in Lake Ellesmere (National Publicity Studios, June 1948)

The mean sizes of the mature eels caught at the South Branch trap were all 4-5 cm less than those recorded by Hobbs (1947) at Lake Ellesmere, except that female A. dieffenbachii were slightly larger (in the South Branch long-finned males average size was 59.1 cm, females 120.8 cm and short-finned males 43.4 cm, females 64.1 cm). However, the South Branch sample is too small to make accurate comparisons. The generally smaller size of eels in the South Branch is associated with a slower growth rate.

Cairns (1941) stated that he observed in the adult migration runs, the large female long-finned eels, up to 180 cm in length "which have been delayed in development for a period of years".

Further information:

Burnet A.M.R.	1969 b	:	Migrating eels in a Canterbury River, New Zealand. N.Z. Journal of Marine and Freshwater Research 3 : 230-44.
Hobbs D.F.	1947	:	Migrating eels in Lake Ellesmere. Proceedings N.Z. Science Congress 1947 : 228-32.

(g) Distribution

Both species are present throughout New Zealand including the Chatham Islands. The only areas where eels are completely absent are those to which they cannot gain access in their migration from the sea.

The most notable area where eels are absent is the central North Island including Lake Taupo and Rotorua Lakes. The eels are blocked from entering this area by long stretches of very fast water in rocky gorges (Cairns 1941).

Usually young eels can climb waterfalls and also hydro-dams, provided there are wet surfaces for them on the edge. Woods (1964) made a detailed study of eels climbing the hydro dams on the Waikato and estimated their climbing ability at different sizes. Several other observations of elvers climbing obstacles were recorded (Boud, Hardy 1950). Cunningham et al. (1953) recorded eels from several coastal lakes with no outlet to sea. They must gain access to these either underground or over wet ground.

The number of eels usually decreases with the increase in distance from the sea and upland populations are usually predominantly or exclusively long-finned (Hardy 1950, Woods 1964).

Further information:

Cairns D.	1941	:	Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.
Woods C.S.	1964	:	Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(h) Habitats

Cairns (1941) collected and examined 25,000 non-migratory eels from many localities in New Zealand. He described his collection as follows:

"Eleven thousand eels were taken from the Hedgehope River and its tributaries in Southland. These were all long-finned females. The Hedgehope River is a tributary of the Oreti (or New) River. In the estuarine waters of the Oreti the short-finned female eel was taken along with the long-finned female eel. At a collecting station situated where the tidal influence ceases to affect the river-flow, 98 eels were taken. Of these, 97 were long-finned female eels and 1 a short-finned eel. Above this point all samples consisted of long-finned female eels. This was also true for the Waimatuku Creek, the Aparima River, and the Waiau River. The Waituna Lagoon contained both long and short-finned male and female eels.

In the Kakanui River in Otago the short-finned female eel was taken only as far as the tidal influence affects the flow of the river. This was also true of the Waimakariri River and the Rakaia River in Canterbury. Lakes Ellesmere and Forsyth, However, contained both sexes of both species, and in these lakes the short-finned female was in the majority.

In the North Island the rivers of the Wellington Province were extensively trapped. The Hutt River, Otaki River, Waikanae River, Ruamahanga River, Tauherenikau River, and many others of the fast-flowing, shingle-bottomed rivers have the short-finned eel only in the lower reaches, which are, as a rule, deep and slow-flowing. In the Wanganui and the Manawatu Rivers the writer found that the short-finned eel penetrated well inland. In the Wanganui River it is not found very far above Pipiriki, and in the Manawatu River not far above Palmerston North. The lake-controlled Waikato River has short-finned eels inhabiting the same water as long-finned eels. Only the females of the two species, however, travel upstream. In the Waipa River, which is deep and sluggish for a considerable distance upstream (above its confluence with the Waikato River at Ngaruawahia), there is a big population of short-finned female eels. This river receives the waters of a number of small lakes. An interesting fact was noted during sampling of this river. A small tributary, the Kaniwhanawhana Stream, joins the main Waipa at Karamu. This stream comes from steeper country to the west, and about half a mile from the main river no short-finned female eels were obtained, although these eels were obtained many miles farther up the Waipa River. This change in population seemed to be correlated with the change in type of the stream to a fast-flowing boulder-strewn mountain water. The population of eels in this habitat was entirely long-finned. In the Waihou River the short-finned female eels are to be found some distance above Te Aroha, but upstream from here the population is almost entirely long-finned females. Long-finned female eels are also found in the Kaueranga and Waitewhata tributaries.

The Kaituna River, fed from Lakes Rotorua and Rotoiti and the hot-spring country, seems an ideal environment for the short-finned female eel. It penetrates well upstream, co-existing with the long-finned female eel."

Burnet (1969 d) summarised the habitat requirements and distribution of both species as follows:

Short-finned eels prefer the more stable streams, and lagoons and lakes. The juveniles do penetrate to the headwaters of our rivers, but do not remain unless they find a lake, a pond, or a stable stream.

The long-finned eels are found in almost all areas, and there are only a few localities where I have found only short-finned eels.

It is difficult to generalise on quantities, but I think that the long-finned eel is the most widely spread, and most abundant of our two eels, but the short-finned eel is found in more localised areas resulting in higher local concentrations.

Such distribution seems to be related to temperature tolerance and Woods (1964) discussed this relationship in more detail.

No upland eel populations have been studied in detail, but it appears that beyond about 100 km from the sea or less the short-finned eels become quite rare. Streams studied by Hopkins (1970) about 50 km from sea, contained about twice the number of short-finned eels compared to long-finned. The streams studied by Woods (1964) further inland contained mainly long-finned eels.

Many lowland lakes (Cunningham et al. 1953) contain both species in varying proportions although short-finned eels tend to be predominant. Pukepuke lagoon in the Manawatu contains only short-finned eels except an odd specimen, according to the recent studies (Castle 1972). The species composition of migrants in Lake Ellesmere according to Hobbs (1947) was over 20 short-finned to one long-finned. Burnet (1969 c) gave the percentage by species in a Lake Ellesmere tributary as 69% short-finned and 31% long-finned. Of two lowland tributaries of the Waimakariri also studied by Burnet, one contained 80% long-finned eels and the other only 47%. Burnet (1952 b) showed the large difference in population by species in two lowland streams near Wellington. In the Horokiwi Stream short-finned eels comprised between 11 and 88% of the eel population at various distances from the sea, in the Wainuiomata River in most places sampled short-finned eels comprised only 1-4% and in only one place 21%. In these two short lowland streams short-finned eels penetrate right up to headwaters, in the Wainuiomata the headwater sample actually had the largest percentage of short-finned eels (21%).

Hardy (1950) was able to trap only long-finned eels in the lakes at the headwaters of the Hurunui, but he saw elvers of both species climbing the waterfalls below these lakes.

Very little is known about eel populations in upland lakes. Hardy (1950) caught long-finned eels in Lake Taylor down to the depth of 36 m.

<u>Further information:</u>

Cairns D. 1941 : Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.

Commercial eeling on Lake Ellesmere in June 1948 with long spears (day) and jag (night) - National Publicity Studios

Burnet A.M.R. 1952 b : Studies on the ecology of the New Zealand freshwater eels. 1. The design and use of an electric fishing machine. Australian Journal of Marine and Freshwater Research 3 : 111-25.

Burnet A.M.R. 1955 : A study on the ecology of the New Zealand freshwater eels. (unpublished M.Sc. thesis, Canterbury University, Christchurch). 42 pp.

Woods C.S. 1964 : Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(i) Feeding

Eels feed mainly at night and throughout the year, except at periods when the temperature becomes low. Burnet (1969 d) commented as follows: While winter temperatures slow down and in some cases stop the feeding altogether, I have found no evidence that eels hibernate. Eels are just as easily caught by electric fishing in the winter and swim almost as actively as in summer. Woods (1964) stated that 6°C is normally the lowest temperature for feeding.

Cairns (1941) cited evidence that few eels feed in winter, and said that no difference was observed in the reaction of the two species or the sexes to the cold temperatures of the winter period.

Cairns (1942 a) examined stomachs of 9 643 eels and found 6 092 of them empty. He suggested that:

"Eels feed spasmodically, often taking large amounts of food and then resting in hiding while this is digested. Spasmodic feeding and slow growth may be correlated with the large populations of eels which our streams can support. The writer conducted various small-scale experiments on the rate of digestion in the eel. Eels were fed various items of food in pools where they could be later recaptured. In the case of the larger types of food such as crayfish, bully, cicadas, freshwater shrimp, and others, it was possible to identify the food in the diverticulum for thirty-six hours after ingestion. In some cases this could be extended for a longer period. Smaller types of food could still be identified after twenty-four hours in the gut. Food such as caddis and may-fly larvae, dipterous larvae, and others falls in this category."

Burnet (1952 a) and Hopkins (1965, 1970) similarly found a large percentage of the eel stomachs empty.

Cairns (1942 a) who studied the largest number of eel stomachs, as mentioned above, subdivided his material into several length categories. He found only invertebrates in the eels below 40 cm long. In long-finned eels between 40 and 75 cm he found that about 3% contained trout and about 10% other fish. Of the short-finned eels in the same size category none contained trout and about 30% contained other fish (mainly bullies). The trout taken by this size group were fry or fingerlings.

Long-finned eels above 75 cm long examined by Cairns contained trout in 25% of the individuals and other fish in nearly 20%. No trout were found in short-finned eels of this category and about 10% contained other fish. Cairns's data suggest that larger long-finned eels prey fairly heavily on trout and that larger short-finned eels also prey on fish, but not trout.

Cairns (1950) summarised his study of the food of eels as follows:

Both long and short-finned eels in the first group (up to 40 cm long) were found to live on much the same diet consisting of the following organisms (principal genera only given): Crustacea (Water fleas); Paracalliope; Daphnia; Oligochaetes (Worms); Lumbricus; Ephemeroptera (May-fly larvae); Ameletus; Deleatidium; Atalophlebia; Trichoptera (Caddis-fly larvae); Pycnocentria; Olinga; Hydropsyche; also a small number of Molluscs and Coleoptera larvae. The habitat occupied by eels in this group (in a semi-subterrenian existence, seldom if ever, feeding in open water) is quite clearly reflected in the food consumed.

The next group 41 to 75 cm are more diverse feeders in open water. Principal items in the diet of the long-finned eels are as follows: Ephemeroptera (May-fly larvae); Trichoptera (Caddis-fly larvae); Mollusca (Freshwater snail and mussel); Oligochaeta (Worms). Subsidiary groups identified and of some importance included: Diptera (two-winged flies); Crustacea (Crayfish, crab and shrimp); Fish (various including bully, inanga, Retropinna or smelt and trout); Coleoptera (Beetle larvae and adults).

In this group the short-finned eels consumed very much the same types of food, but the order of preference shows a distinct change and no Ephemeroptera are recorded. The principal items in order of preference are as follows: Mollusca; Oligochaeta; Diptera; Crustacea; Trichoptera.

Main genera noted were: Ephemeroptera (except in short-finned samples); Ameletus; Deleatidium; Ameletopsis; Coloburiscus; Trichoptera; Olinga; Pycnocentria; Hydropsyche; Hydrobiosis; Crustacea; Paranephrops; Xiphocaris; Daphnia; Boeckella; Mollusca; Potamopyrgus; Isidora; Myxas; Diptera; Chironomus; Austrosimulum; Calliphora; Bombylius; Oligochaeta; Lumbricus; Coleoptera; Odontria; Pyronota.

In the largest size group of eels 76 cm and over, the very diverse nature of the diet is again notable. The preference for certain types of food changes again. The order for the long-finned eel is as follows: Salmonidae and other fish; Crustacea; Mollusca; Ephemeroptera; Trichoptera; Coleoptera; Oligochaeta; miscellaneous groups.

For the short-finned eel quite a different pattern is observed. Trichoptera take preference followed by Mollusca, Oligochaeta and Crustacea.

Food habits alter, however, with the season of the year and the habitat of the eel. Detailed samples have been recorded (Cairns 1942 a) illustrating the food of eels in many different environments in New Zealand.

Burnet (1952 a) demonstrated heavy predation on trout by eels in two stable streams with weed bottom and little predation in four rivers with open shingle beds. He said that it may be that in the weed the eel has a much better chance to capture trout. In the four open rivers, the largest percentage of eels with trout in their stomachs was 2.4% and the number of trout per eel was one. In the two weedy streams the percentage of eels with trout was 18.9 and 46.5% and the number of trout per eel was 2.4 and 2.1. In these two streams no eels below 70 cm contained trout and the percentage of stomachs containing trout increased with size, 71.4% of eels in the size group 100-110 cm containing trout. The trout found by Burnet in eel stomachs during this study were up to 16 cm long, with mean length 9 cm.

Where freshwater crayfish were available, they formed a fairly important part in eel diet. In the shingle-bed streams examined, 75% of the stomach contents was made up by Trichoptera and Ephemeroptera larvae (Burnet 1952 a).

Hopkins (1965) examined stomach contents of 13 eels of both species from small streams near Wellington and found the diet of both species to be similar. He stated:

"It appears that Deleatidium larvae make up the bulk of the diet and that greater use of Mollusca and cased caddises (in this instance members of the Sericostomatidae) is made than by P. breviceps and S. trutta. Surprisingly, no fish were found in the food. However, Cairns (1942) is of the opinion that eels of less than 600 mm length rarely take fish since, until they exceed this size, the gape is too small. In the present instance only one eel exceeded 600 mm.

A great deal of vegetable matter was ingested by the eels, an indication that most of their feeding was carried out under the stream banks where such detritus tends to settle out in the slower water. Volumetric measurements of stomach contents showed that there was sometimes more ingested plant material than animal matter."

Burnet (1969 a) stated that eels in the South Branch had no definite first preference, such as trout there, whose most important item on the diet was the sandy-cased caddis Pychocentria. The order of importance of food organisms for eels was : Polycentropidae (caddis), Physastra (snails), Pychocentria (most important item of trout diet) and Deleatidium (mayfly). Eels of both species in this study contained only 19 fish i.e. about 0.15% of all animals found in their stomachs.

Burnet (1969 d) stated that the feeding of the eel is generalised and as with most fish there is a tendency to use the item which is most readily available in the environment. The smaller eels feed on the stream invertebrates and as they increase in size their preferences change. The larger eels over 30 cm are more inclined to feed on other fish, carrion or any other animals available.

Hopkins (1970) stated that there appears to be little difference in the diets of the two species of eel. In his sample of 117 eels of both species, bullies occurred in the stomach contents of 2% and eels and trout 1% each. The percentage of fish in the diet by number of animals was below 1%, but by weight trout comprised 14% of the food and bullies 4%. 18 large eels examined by Hopkins contained one bully and one eel.

Further information:

Burnet A.M.R.	1952 a	:	Studies on the ecology of the New Zealand long-finned eel, Anguilla dieffenbachii Gray. Australian Journal of Marine and Freshwater Research 3 : 32 - 63.
Cairns D.	1942 (a)	:	Part II of Cairns 1941 - Food and inter-relationships with trout. N.Z. Journal of Science and Technology 23 : 132-48.
Hopkins C.L.	1970	:	Some aspects of the bionomics of fish in a brown trout nursery stream. Fisheries Research Bulletin 4. 38 pp.

(j) Hibernation

Cairns (1941 and 1950) included a section on hibernation in his papers and cited evidence that "eels of most New Zealand waters hibernate". He stated that he removed eels in winter from deep mud and sand, but they were absent from such areas in summer.

Burnet (1969 d) stated that he found no evidence for eel hibernation in winter, although their feeding slows and may stop in low temperatures. Hopkins (1970) mentioned "comatose eels" and the fact that in general fewer eels were caught in June than at any other time of the year.

Further information:

Cairns D.	1941	:	Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.
Hopkins C.L.	1970	:	Some aspects of the bionomics of fish in a brown trout nursery stream. Fisheries Research Bulletin 4. 38 pp.

(k) Composition of eel stocks

(i) By species

The composition of stocks by species is discussed above in section (h). In most places in New Zealand one can expect to find both species in varying proportions. At distances from the sea of about 100 km and more, most eels are long-finned. In some lowland lakes and lagoons some populations are almost exclusively short-finned.

Burnet (1955) showed the relative abundance of both species in several streams in North Canterbury. He said that short-finned eels generally prefer more stable streams or lakes.

(ii) By sex

This is discussed above in section (f). Recent workers (Burnet 1969 b, Woods 1964) showed that males were predominant in the areas they studied. Hobbs (1947) found the females greatly predominant in both species amongst the migrants in Lake Ellesmere.

(iii) By size

The size of migrants is discussed in section (f). Several authors showed the composition of stocks by size : Hardy (1950) in upper Hurunui lakes, Burnet (1952 a) in several wide-spread populations of long-finned eels, Burnet (1952 b) in streams near Wellington, Burnet (1955) in some streams in North Canterbury, Woods (1964) in the central North Island, Burnet (1969 b) in the South Branch near Christchurch, Hopkins (1970) in streams in the Wairarapa.

The direct comparison of these samples is very difficult because they were taken using various techniques (mainly traps and electric fishing), at different times of the year and in various conditions, which affected the efficiency of sampling.

Further information:

In all references listed above.

(l) Density of populations

Hobbs (1947) estimated the total number of migrants present in Lake Ellesmere at about 1 million with a total weight of over 500 metric tons (99% short-finned eels).

Burnet (1952 b) gave estimated densities derived from electric fishing sampling at between about 45 and 1 000 kg/hectare in three North Island streams. The average densities for two streams sampled at several points in summer were 315 kg/ha for the Wainuiomata River and 520 kg/ha for the Horokiwi Stream.

Woods (1964) estimated the total number of eels in the upper Wanganui area at between 5 000 and 17 500 at densities from 6 to 188 per 1 000 sq metres of water surface area (0.008 to 0.188 eels / m^2).

Burnet (1969 c) gave the density of populations of both species at between 130 kg/hectare and 254 kg/hectare in three Canterbury streams.

Hopkins (1971) gave the number of eels of both species per square metre in the small streams he studied in the range from 0.08 to 0.26 in one stream at different dates and from 0.81 to 1.74 eels/metre^2 in another stream. The biomass data for the same samples from the two streams was from 8.2 to 19.8 g/m^2 (82-198 kg/ha) in one stream and from 36.2 to 130.2 g/m^2 (362-1302 kg/ha) in the other. The annual production of eels in these streams was estimated at 10 g/m^2 and 59 g/m^2.

Commercial spearing of eels in Lake Ellesmere in June 1948 and packing the catch for transport to canning factory (National Publicity Studios)

Castle (1972) quoted Matsui (1969) that eel stocks in New Zealand have an average density of about 450 kg/hectare of permanent fresh water. However, there is undoubtedly a marked variation in the quantity of eels in our waters from very high abundance in lowland lakes to very low abundance in most fast-flowing streams. Castle said that an estimate recently made by him for the dune lakes on the west coast of the southern part of the North Island is at least 1120 kg/hectare.

The above data combined suggest that Matsui's figure of about 450 kg/hectare average density may be a fairly good general guide line.

Further information:

Burnet A.M.R. 1952 b : Studies on the ecology of the New Zealand freshwater eels. 1. The design and use of an electric fishing machine. Australian Journal of Marine and Freshwater Research 3 :111-25.

Burnet A.M.R. 1969 c : The growth of the New Zealand freshwater eels in three Canterbury streams. N.Z. Journal of Marine and Freshwater Research. 3 : 376-84.

Castle P.H.J. 1972 : A biologist's appraisal : prospects for the New Zealand freshwater eel industry. Commercial Fishing 11 (10) : 13-5.

Hobbs D.F. 1947 : Migrating eels in Lake Ellesmere. Proceedings N.Z. Science Congress 1947 : 228-32.

Hopkins C.L. 1971 : Production of fish in two small streams in the North Island of New Zealand. N.Z. Journal of Marine and Freshwater Research 5 : 280-90.

Woods C.S. 1964 : Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

(m) Repopulation of harvested areas

Cairns (1942 b) described the eel destruction campaign in Southland in which nearly 12 000 eels weighing over 12 000 kg were killed. Most eels from the streams fished were removed, but long term effects were not recorded.

Burnet (1969 d) summarised the result of his experimental eel removal from a stream near Christchurch as follows:

"I have indicated that the growth rate of eels is slow in streams: especially so in those areas where there are large numbers of eels. All the indications are that a fished out area would be very slow to recover. We removed most of the eels (over 3 000) from 1.6 km length of stream, in one of our experiments. This was done 10 years ago, and I have found no evidence of a significant repopulation. There has been replacement of the smaller eels, and this could be measured.

In general eels do not move much in the rivers except during the 3 or 4 migration periods. In almost all cases the tagged eels were recaptured within a few hundred metres of the point of release - even in the case of those recaptured after 10 years."

Reports from industry sources indicate that some areas fished out by commercial fishermen three or four years ago are still uneconomic to fish.

(n) Effects of commercial fishing on stocks

Castle (1972) discussed at length the implications of commercial fishing:

"An intensive fishing effort in some areas of New Zealand, notably rivers and lakes close to processing factories, has accompanied the rapid development of this fishery. This has resulted in stocks being considerably reduced in these areas. Even so, there has not been a fall-off in landings because unexploited stocks in new areas have been brought into production. It seems likely that at least for a time this trend will continue, but that fishermen will need to go further afield to maintain high returns."

Further, he said that current commercial production of eels is "the product of many years growth rather than that of an annual increment. Although Cairns suggested that the potential sustainable production for the whole of New Zealand from the wild stock could be 5000-10,000 tons per annum these figures should, for the moment, be treated with utmost caution. The situation could be likened to the drawing on one's capital as opposed to receiving annual interest."

Castle (1972) also discussed the commercial fishing pressure as related to the life cycle of the eels and suggested possible management and conservation measures.

Further information:

Castle P.H.J. 1972 : A biologist's appraisal : prospects for the New Zealand freshwater eel industry. Commercial Fishing 11 (10) : 13-5.

(o) Eel-trout relationship

For many years until recently eels were not utilised except by Maoris to a small extent. Therefore, interest in them was centred around their relationship with trout and the damage they may do to trout fisheries.

Hobbs (1948) and other earlier workers advocated destruction or exclusion of eels, at least from trout nursery streams.

The studies of eel feeding habits (see section (i)) showed that larger eels (mostly long-finned) do indeed include trout in their diet. Probably even more important in most streams, however, is that trout and eels compete to a large extent for the same food, the bottom living water insects.

Recent work by Burnet and Hopkins showed that the relationship between eels and trout is complex. Destruction of eels may increase trout numbers, but not necessarily increase the return to the angler or the quality of trout.

Burnet (1968) removed most eels from a 1.6 km long section of stream (see also section (m)), where originally eels exceeded trout both in number and by weight. He concluded that eel control resulted in a marked increase in the trout population number with a consequent increase in density and an associated decrease in growth rate. As the growth rate of the trout decreased, their condition declined from good to poor. The study extended for three years before eel removal and four years after removal.

Burnet (1968) also discussed a wider application of eel removal and stated that in open shingle streams with good spawning, eel removal may cause little change in the trout population.

Burnet (1969 a) stated that the two main items of the eel diet in his experimental stream near Christchurch were not important to the trout. The diets of these species (eels and trout) showed similarities, but also considerable differences. Also, there was evidence that eels and trout feed in different areas: eels in the weed beds, which have a numerousand diverse invertebrate fauna and trout on the fauna of the gravels.

Hopkins (1970) showed that bullies, trout and eels in trout nursery streams in the foothills in the Wairarapa relied mainly on mayflies as a source of food. However, he concluded that there is little material competition for food among those species despite the general similarity of their diet. He considered that competition for space between the trout themselves is more important in limiting the trout population numbers.

Further information:

Burnet A.M.R.	1968	:	A study of the relationships between brown trout and eels in a New Zealand stream. Fisheries Technical Report 26. 49 pp.
Burnet A.M.R.	1969 a	:	A study of the inter-relation between eels and trout, the invertebrate fauna and the feeding habits of the fish. Fisheries Technical Report 36. 23 pp.
Cairns D.	1942 a	:	Part II of Cairns 1941 - Food and inter-relationships with trout. N.Z. Journal of Science and Technology 23 : 132-48.
Cairns D.	1942 b	:	Part III of Cairns 1941 - Development of sex. Campaign of eel destruction. N.Z. Journal of Science and Technology 23 : 173-8.
Hobbs D.F.	1948	:	Trout fisheries in New Zealand : their development and management. Fisheries Bulletin 9. 175 pp.
Hopkins C.L.	1970	:	Some aspects of the bionomics of fish in a brown trout nursery stream. Fisheries Research Bulletin 4. 38 pp.

(p) Eel parasites and diseases in New Zealand

A list of parasites of New Zealand fishes (Hewitt and Hine 1972) includes nine internal parasites found in short-finned eels and seventeen internal parasites found in long-finned eels. None of these parasites are known to have caused serious sickness or death of eels.

The most serious diseases causing mass mortalities of eels in Europe have not been recorded in New Zealand (M. Hine, pers. comm.), but this does not exclude the possibility that they may be present.

Dr M. Hine (Fisheries Research Division, Ministry of Agriculture and Fisheries, P.O. Box 19062, Wellington) has recorded some diseases in New Zealand eels which could be potentially dangerous in crowded conditions.

Any disease in eels should be communicated immediately to Dr Hine and specimens retained for his examination.

Further information:

Hewitt G.C. and Hine P.M.	1972	:	Checklist of parasites of New Zealand fishes and of their hosts. N.Z. Journal of Marine and Freshwater Research 6 : 69-114.

From Dr Hine personally.

APPENDIX 1

Current research on eels in New Zealand

Information on eel diseases and parasites is being collected and analysed by Dr M. Hine of the Fisheries Research Division, Wellington (see section (p)).

Three biological studies are currently undertaken at the Zoology Department of the Victoria University of Wellington:

(1) Dr P.H.J. Castle, Senior Lecturer is conducting a study of an eel population in a coastal lagoon, which he outlined as follows (Castle 1972):

"In early 1972 a long-term population study of the short-finned eel was begun by the author at Pukepuke Lagoon, Manawatu. This 8 hectare body of water has not been fished commercially although neighbouring lakes have received considerable attention from fishermen during the past two years.

The Pukepuke study is designed primarily to determine the role of eels in the ecology of the lagoon, but it is hoped incidentally to establish the annual productivity of eels in such a lowland lake, which must be regarded as a typical one for this area. At the same time studies will be made of a comparable lake system in which there has been relatively heavy fishing pressure, in order to determine the rate of growth and regeneration of the stock under such conditions. The above research will hopefully provide guidelines for setting fishing intensities and the advisable rate of annual draw-off from this important resource in New Zealand."

The other two studies are done as Ph.D projects by two scientists from the Ministry of Agriculture and Fisheries.

(2) Mr D.J. Jellyman (pers. comm.) outlined his study, entitled "Aspects of the biology of New Zealand freshwater eels" as follows:

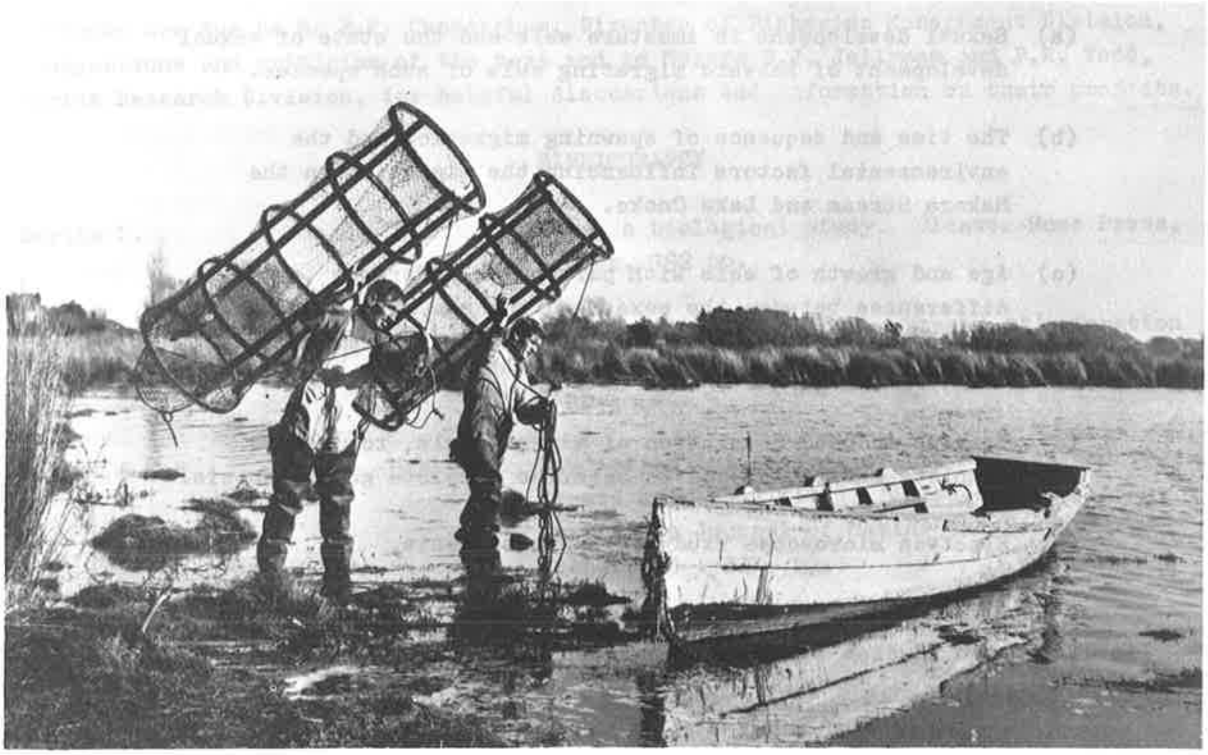
(a) Invasion of fresh water by glass eels - times, environmental influences, size range, species proportion, vertebral counts.

(b) Upstream migration of glass eels - environmental influences, species proportion, habitat preferences.

(c) Elvers (adolescent eels) - summer migrations, species proportion, sizes, habitat preferences.

(d) Age and growth - age determination technique including scales and scale formation and development, ages (by otoliths) of small eels for selected areas, length/weight relationship.

(e) Experimental growth - introductory experiments on elvers of both species at varying temperatures and varying feeding rates.



Eeling with baited traps around Lake Ellesmere in June 1948
(National Publicity Studios)

(3) Mr P.R. Todd (pers. comm.) outlined his study, entitled "Reproductive biology of New Zealand freshwater eels" as follows:

(a) Sexual development in immature eels and the state of sexual development of seaward migrating eels of each species.

(b) The time and sequence of spawning migration and the environmental factors influencing the migration in the Makara Stream and Lake Onoke.

(c) Age and growth of eels with particular reference to growth differences between the sexes and the age at migration. Comparison of length-weight relationship between migrant and non-migrant eels.

(d) Hormone induced maturation of migrant eels, to observe complete maturation and to describe complete gametogenesis.

(e) Electron microscope study of spermiogenesis.

The latter two studies should be completed early in 1974.

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BIBLIOGRAPHY

Bertin L. 1956 : Eels, a biological study. Cleaver-Hume Press, London. 192 pp.

* Boud R. (Undated) : An investigation of the upstream eel migration at the Roxburgh Dam. Investigation Report 23. 2 pp.

** Burnet A.M.R. 1952 a : Studies on the ecology of the New Zealand long-finned eel, Anguilla dieffenbachii Gray. Australian Journal of Marine and Freshwater Research 3 : 32 - 63.

** ——— 1952 b : Studies on the ecology of the New Zealand fresh-water eels.
1. The design and use of an electric fishing machine. Australian Journal of Marine and Freshwater Research 3 : 111-25.

——— 1955 : A study on the ecology of the New Zealand fresh-water eels. (unpublished M.Sc. thesis, Canterbury University, Christchurch). 42 pp.

* ——— 1968 : A study of the relationships between brown trout and eels in a New Zealand stream. Fisheries Technical Report 26. 49 pp.

* ——— 1969 a : A study of the inter-relation between eels and trout, the invertebrate fauna and the feeding habits of the fish. Fisheries Technical Report 36. 23 pp.

* ——— 1969 b : Migrating eels in a Canterbury river, New Zealand. N.Z. Journal of Marine and Fresh-water Research 3 : 230-44.

* ——— 1969 c : The growth of the New Zealand freshwater eels in three Canterbury streams. N.Z. Journal of Marine and Freshwater Research. 3 : 376-84.

——— 1969 d : New Zealand freshwater eels in Report on Eel Seminar. Fishing Industry Board.

Cairns D. 1941 : Life history of the two species of New Zealand freshwater eel. Part I - Taxonomy, age and growth, migration and distribution. N.Z. Journal of Science and Technology 23 : 53-72.

________ 1942 a : As above Part II - Food and inter-relationships with trout. N.Z. Journal of Science and Technology 23 : 132-48.

________ 1942 b : As above Part III - Development of sex. Campaign of eel destruction. N.Z. Journal of Science and Technology 23 : 173-8.

________ 1950 : New Zealand freshwater eels. Tuatara 3 : 43-52.

Castle P.H.J. 1963 : Anguillid leptocephali in the southwest Pacific. Zoology Publication from Victoria University of Wellington 33 . 14 pp.

________ 1969 : Early life history and general distribution of eels <u>in</u> Report on Eel Seminar. Fishing Industry Board.

________ 1972 : A biologist's appraisal : prospects for the New Zealand freshwater eel industry. Commercial Fishing 11 (10) : 13-5.

**Cunningham B.T. et. al.1953 : A survey of the western coastal dune lakes of the North Island, New Zealand. Australian Journal of Marine and Freshwater Research 4: 343-86.

Eales J.G. 1968 : The eel fisheries of eastern Canada. Fisheries Research Board of Canada. Bulletin 166. 79 pp.

Griffin L.T. 1936 : Revision of the eels of New Zealand. Transactions of the Royal Society of New Zealand 66: 12-26.

Hardy C.J. 1950 : Summary of a report on eel trapping and observations at Lakes Taylor and Sheppard <u>in</u> North Canterbury Acclimatisation Society eighty-sixth Annual Report : 24-6.

**Hewitt G.C. and Hine P.M. 1972 : Checklist of parasites of New Zealand fishes and of their hosts. N.Z. Journal of Marine and Freshwater Research 6 : 69-114.

**Hobbs D.F. 1947 : Migrating eels in Lake Ellesmere. Proceedings N.Z. Science Congress 1947 : 228-32.

** ________ 1948 : Trout fisheries in New Zealand : their development and management. Fisheries Bulletin 9. 175 pp.

**Hopkins C.L. 1965 : Feeding relationships in a mixed population of freshwater fish. N.Z. Journal of Science 8 : 149-57.

** Hopkins C.L. 1970 : Some aspects of the bionomics of fish in a brown trout nursery stream. Fisheries Research Bulletin 4. 38 pp.

** ———— 1971 : Production of fish in two small streams in the North Island of New Zealand. N.Z. Journal of Marine and Freshwater Research 5 : 280-90.

** McDowall R.M. 1964 : A bibliography of the indigenous freshwater fishes of New Zealand. Transactions of the Royal Society of New Zealand, Zoology 5 : 1-38.

Matsui I. 1969 : Prospects for eel cultivation in New Zealand. Fishing Industry Board, Wellington. 16 pp.

Schmidt J. 1928 : The freshwater eels of New Zealand. Transactions and Proceedings of the New Zealand Institute 58 : 379-88.

** Shorland F.B. and Russell J. 1948 : Observations on the oil content of New Zealand freshwater eels. N.Z. Journal of Science and Technology 29 : 164-200.

** Todd P.R. 1973 : First record of the freshwater eel *Anguilla dieffenbachii* Gray to be caught at sea. Journal of Fish Biology 5 : 231-2.

* Woods C.S. 1964 : Fisheries aspects of the Tongariro Power Development Project. Fisheries Technical Report 10. 214 pp.

* Available from Fisheries Management Division, Ministry of Agriculture and Fisheries.

** Available from Fisheries Research Division, Ministry of Agriculture and Fisheries.

All other publications listed are available for study in the Fisheries Research Division Library, 327 Willis Street, Wellington.