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STUDIES ON THE BIOLOGY OF THE CATFISH

Ictalurus nebulosus LE SUEUR

IN THE WAIKATO REGION

A thesis

submitted in partial fulfilment

of the requirements for the Degree

of

Master of Science in Biological Sciences

at the

University of Waikato

by

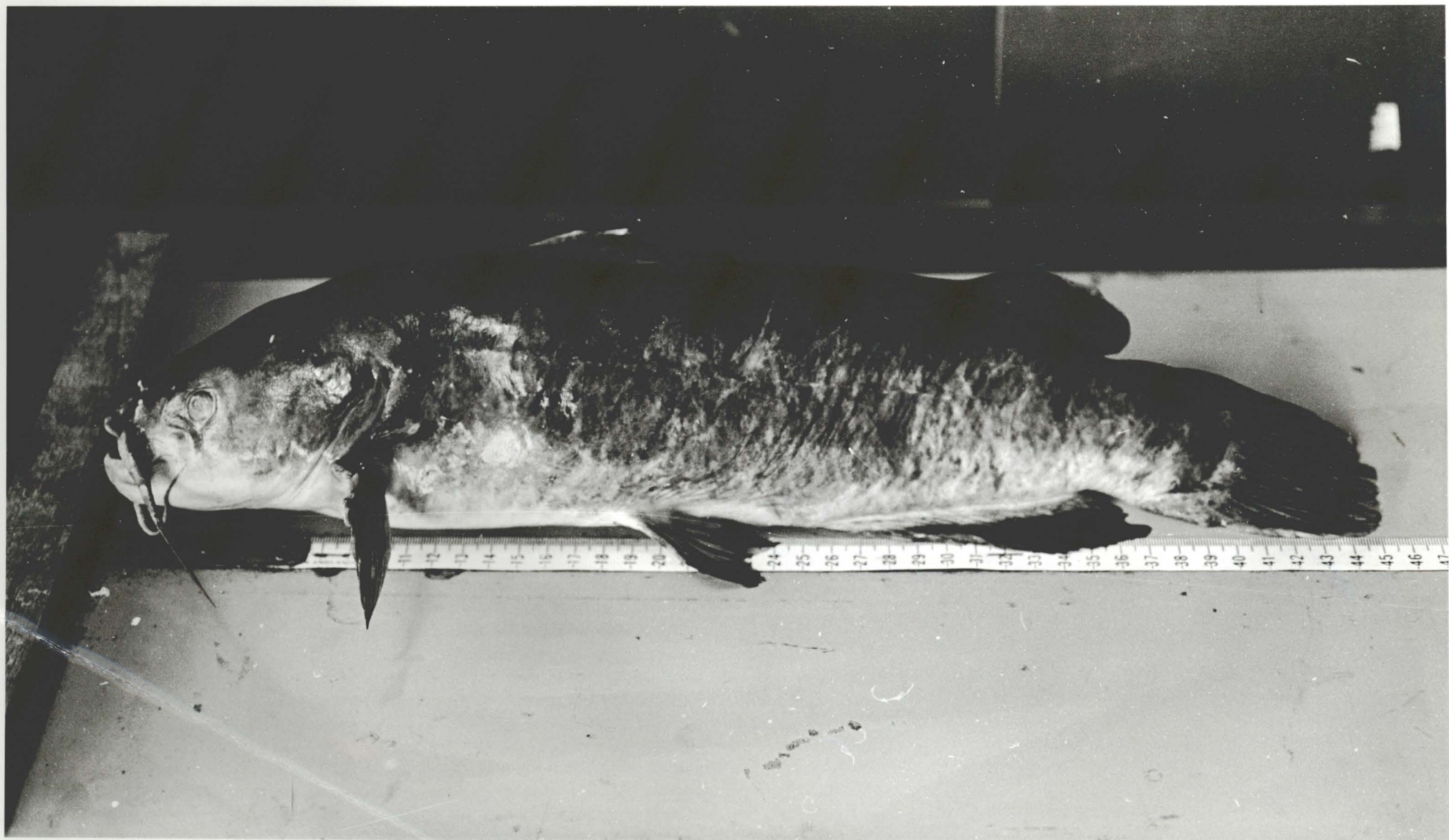
GRAHAM JAMES PATCHELL

University of Waikato

1977

" The catfish is a hideous beast,
A bottom-feeder that doth feast,
Upon unholy bait.
He's no addition to your meal;
He's rather richer than the eel
And ranker than the skate. "

Punch, circa 1900



ABSTRACT

This study investigated the age and growth, reproductive and feeding biology of the North American catfish Ictalurus nebulosus Le Sueur in the Waikato Valley of New Zealand, the changes that have occurred during acclimatisation and the extent of the differences in biology between here and other regions of the world.

Under Waikato conditions the growth rate of the catfish was much faster than is usual for the species, although the longevity of about 8 years was the same as in the northern hemisphere.

Oocyte development in the ovaries was asynchronous (Marza, 1938), with multiple spawning occurring. The duration of the spawning season was nine months, from winter to early autumn. Fecundity estimates were of a minimum of 3700 eggs laid per season.

The major foods of the catfish were chironomid larvae, oligochaete worms, molluscs and crustacea. There was no evidence of piscivorous or fish-egg eating habits as has been noted for the species overseas.

The catfish is expanding in numbers and range throughout the Waikato region because the recruitment capabilities of the population are high, with a rapid growth rate and high fecundity, and there is an apparent lack of natural predators.

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1.1 INTRODUCTION

The brown bullhead catfish Ictalurus nebulosus Le Sueur is a species which originates from fresh and brackish waters of eastern and central North America. In the late 19th and early 20th centuries this species was introduced to several countries in continental Europe and to New Zealand. The aim of this study was to investigate the biology of the catfish from the Waikato Region of New Zealand, to determine whether acclimatisation has affected the biology of the fish and to judge the extent of any differences between here and other regions of the world.

The freshwater fish fauna of New Zealand is very sparse, with only about 30 native species, of which all are either diadromous or derived from such forms (McDowall et al, 1976). Only the Galaxias spp. termed whitebait, and the two eel species Anguilla dieffenbachii and A. australis are of major commercial importance. The grey mullet, Mugil cephalus, a marine species which may spend a considerable part of its life in freshwater (Wells, 1976), also has some commercial value.

None of these native species are classified as game or sport fish, and consequently a number of exotic species have been introduced over the past 110 years, mainly by Acclimatisation Societies, to establish sport fisheries. In addition the fish fauna has been supplemented by escaped aquarium fish

which have established localised breeding populations in the wild, such as the molly Poecilia latipinna (McDowall et al, loc.cit). Most of the introduced species did not survive (Auckland Acclimatisation Society records), but a few were very successful. Of these the brown trout Salmo trutta and rainbow trout S. gairdneri have expanded in numbers to become important recreational fisheries, but others such as the goldfish Carassius auratus and the catfish Ictalurus nebulosus, although abundant in some localities, are of no commercial or major sporting interest as yet.

The catfish was introduced to New Zealand in 1878 from the United States of America by Mr T. Russell CMG, a New Zealander based in Los Angeles (Auckland Acclimatisation Society records). In total, 140 live catfish were released into St Johns Lake, Auckland, from two shipments during 1878. No catfish were reported from the lake until 1884, but in 1885 hundreds were trapped from the lake for relocation to other parts of the Auckland region and to other districts such as Wellington, which received 30 fish. It is presumably at this time that the catfish began its penetration into the Waikato region. Documentation of the distribution of the catfish from 1885 to the present day is scarce. Thompson (1922) mentioned that it was abundant in Ashburton (1919) and Lake Mahinapua (1916) as well as in Auckland, including Lake Pupuke on the

North Shore. The fish was apparently common in the Huntly district during the 1940s (P. Howard pers.comm).

I. nebulosus is today present in all the major rivers of the Waikato Valley. It has penetrated the Waipa River as far as Pirongia, the Piako River (A. Tecklenberg pers.comm), and the Waikato River to at least Taupiri (10km south of Huntly). According to Waikato eel fishermen the distribution of the fish appears to have greatly expanded over the past five years. Catfish were never caught in the Waipa River at Pirongia, nor in the Kopuka Swamp at Maramarua (north of the study area) five years ago, but they are now present in large numbers (A Tecklenberg pers.comm). Catfish also occur in many Waikato lakes, with Lakes Waikare and Waahi in the Huntly region having large populations. They have also been recorded from: Lakes Hakanoa, Ngaroto, Whangape and recently from Lake Rotoroa in Hamilton (E. Graynoth pers.comm) as well as from several small peat lakes in the Waipa River catchment. Apart from the Waikato region, the only other localities in which catfish have been located recently are Lake Pupuke in Auckland (Auckland Acclimatisation Society Report) and in Lake Mahinapua on the West Coast of the South Island (McDowall et al, 1976).

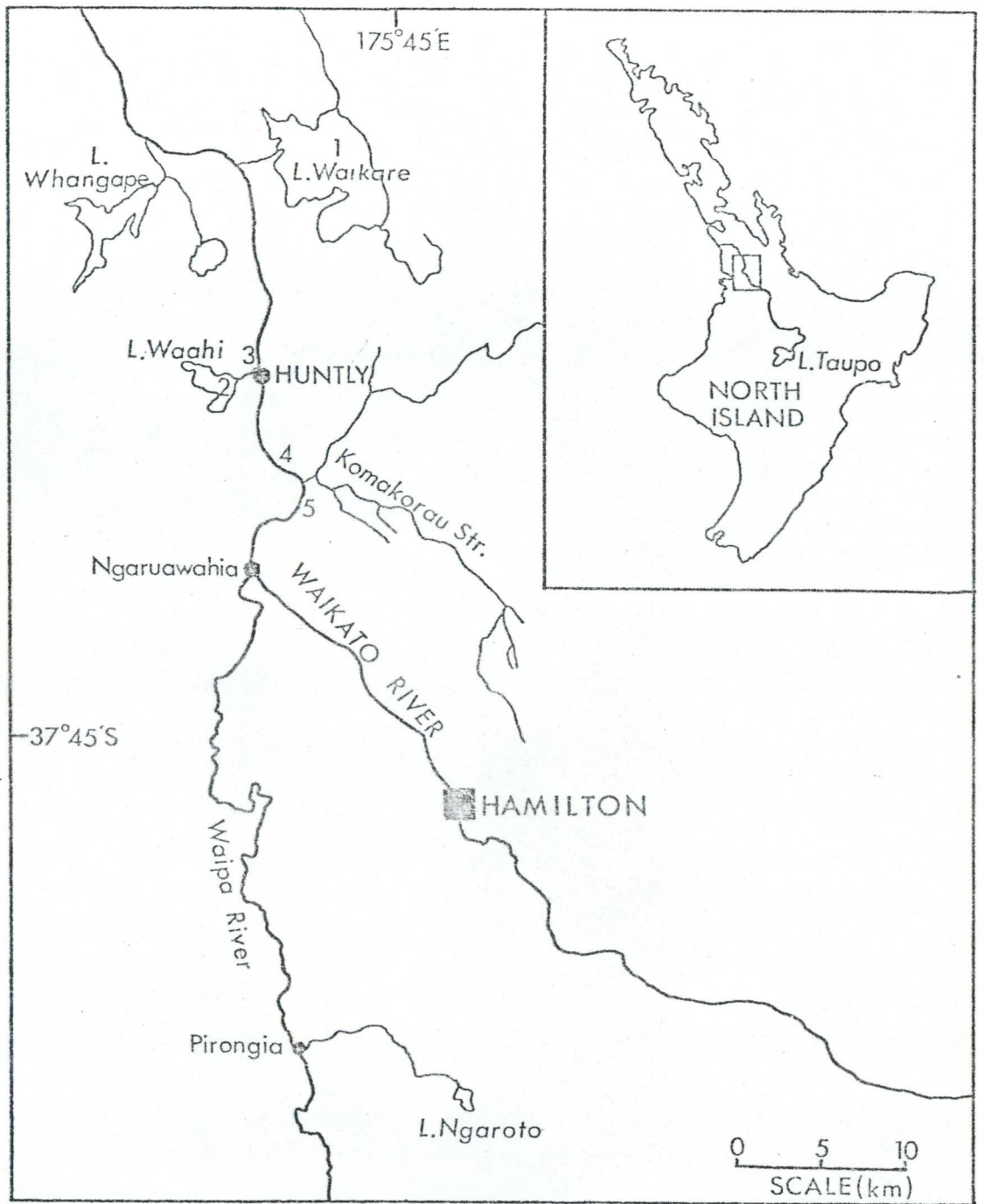


Fig 1

The Study Area

Major fishing sites numbered 1 to 5

1.2 STUDY AREA

The region of the Waikato covered in this study is shown in Fig 1. The farthest south in which fishing was carried out was in Lake Ngaroto, and in the north, Lake Waikare. Catfish are very abundant north of the study area, especially at the Waikato Heads (A. Tecklenberg pers.comm), but fishing was mainly confined to the Huntly district. In the Waikato River fish were not caught south of Taupiri (5), although fyke nets were set above and below Hamilton, up to Ngaruawahia. The Waipa River was also fished on several occasions, but without success.

THE WAIKATO RIVERS, TRIBUTARIES, AND LAKES

The two major rivers in the Waikato region are the Waikato and the Waipa. The larger Waikato River originates from Lake Taupo at the centre of the North Island and extends for 320 km, entering the sea south of the Manakau Harbour on the west coast of the North Island. The Waipa River originates northwest of Lake Taupo in the Rangitoto Ranges and joins the Waikato River at Ngaruawahia. Throughout the study area the width of the Waikato River varies from 64 to 265m, and the depth from 2.5 to 8.2m. Water velocities of up to 1.0m per sec. are attained in the lower reaches of the river around Huntly and a number of small islands occur in the river. The water is turbid with high levels of organic matter, the result of domestic and industrial sewage outfalls along

the course of the river. The river substrate is typically duning sand in the channel throughout the study area (Coffey et al, 1973), but deposition of finely divided sediments (silts/muds) occurs in zones of low flow adjacent to the riverbanks or in backwaters. Extensive macrophyte beds occur in these deposition areas, with Egeria densa being the physiognomic dominant on most soft sites in the study area. Beds of Ceratophyllum demersum and Potamogeton crispus occur also. Other macrophytes present are Glyceria maxima and Nasturtium officinale. Myriophyllum brasiliense is also abundant around Taupiri (Coffey et al, loc.cit). The banks of the river throughout the study area are covered with intermittent extensive growths of willow trees which separate the river from the surrounding pasture land.

Associated with the Waikato and Waipa rivers are a number of small dystrophic peat lakes, such as Lake Ngaroto, which have very dark coloured waters, low secchi transparencies and high primary productivities, according to preliminary investigations (Patchell, 1974, unpublished data, M.A Chapman pers.comm). Many of these lakes have resident catfish populations (M.A Chapman pers.comm).

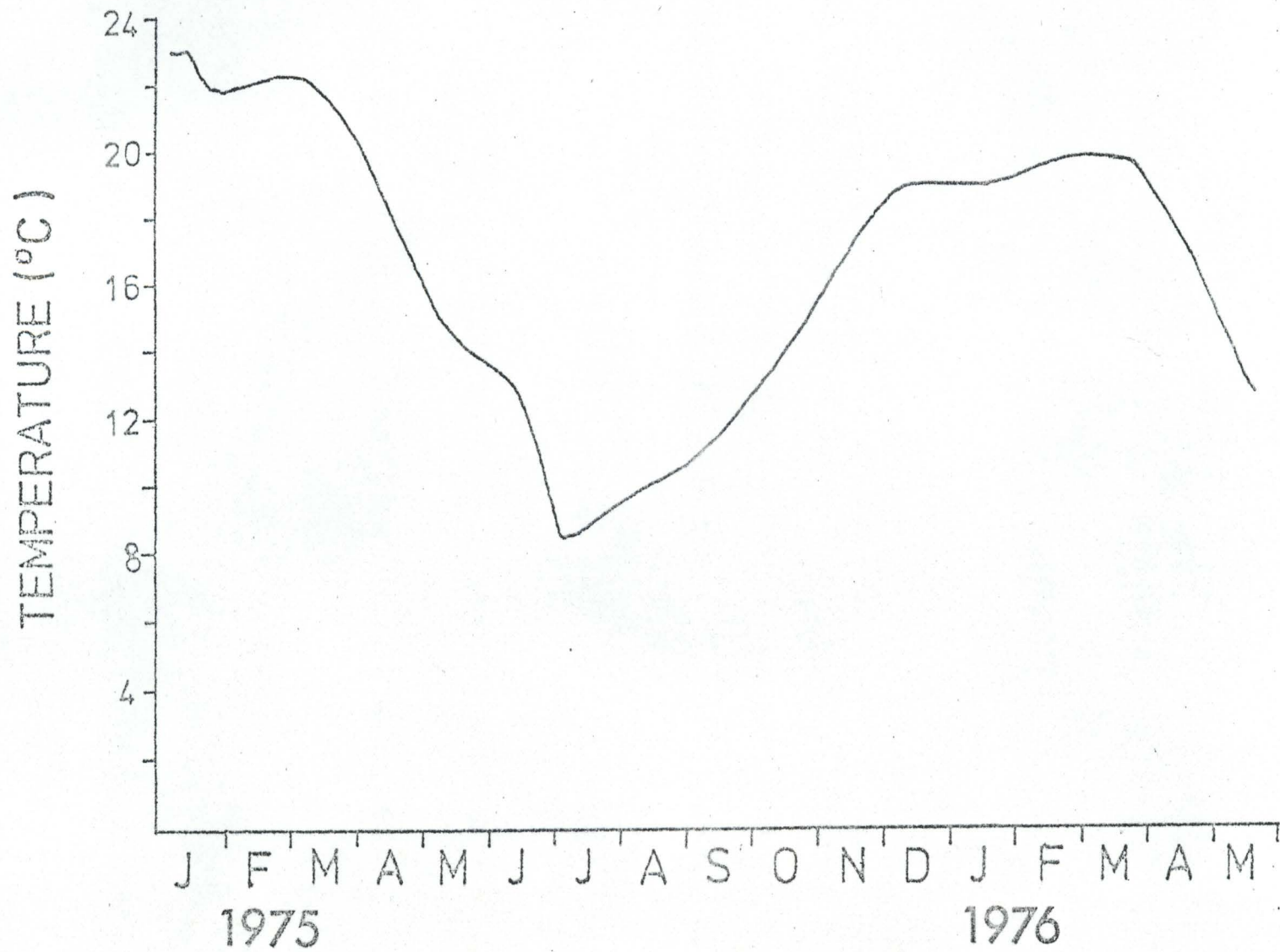
Three major lakes occur along the course of the lower Waikato River; Waahi, Whangape and Waikare. The latter is the major reservoir for the Waikato flood control scheme below the Karapiro dam, with a spillway on the western inlet from the

river, and a control gate on the northern outlet into the Whangamarino Swamp. Waikare is a shallow lake, with a maximum depth of 2m recorded by the author in a series of soundings on the eastern side of the lake. The water is the colour of brown clay, and generally few rooted macrophytes occur, except in an arm of the lake near the town of Te Kauwhata. Lake Waahi is highly eutrophic (Chapman, 1975) with extensive aquatic macrophyte growth over the whole lake. As with the Waikato River, Egeria densa is the dominant macrophyte, with beds of Elodea canadensis, Lagarosiphon major, and Potamogeton ochreatus also occurring.

Fig 2 shows mean water temperatures recorded in the Waikato River at Huntly from January 1975 to May 1976. Temperatures varied from 23°C to 9°C, but higher temperatures do occur in different environments in the area. Coffey et al (1975) recorded locally high temperatures (30°C) in the surface waters confined by dense weed beds in the river. The maximum water temperature recorded in Lake Waahi by Wells (1976) was 27.2°C, while I recorded a low of 7°C in the lake during the winter of 1975.

Fig 2

Mean monthly temperatures of the Waikato River
at the Tainui Bridge, Huntly, recorded in the
main channel (from WVA file 60/3)



PREDATORS AND PARASITES

Other fish species occurring in the Waikato River with I. nebulosus are shown in Table 1. There is no evidence as yet that any of these species significantly affect the catfish population by predation. Large longfinned eels (Anquilla dieffenbachii) of about 3-3.5 kg in weight have been known to consume large numbers of young of the year catfish, but eels of this size are now rare in the Waikato (A. Tecklenberg pers. comm). The lamprey Petromyzon marinus has been noted to attack bullhead catfish in the United States, and in Oneida Lake it was found that catfish were more susceptible to lamprey attack than any other fish (Adams, 1928), but it is not known whether or not the New Zealand lamprey Geotria australis attacks catfish. The present day distribution of the lamprey is unknown, but juveniles do occur in Lake Waikare (A. Tecklenberg pers. comm) and the species was once very common in the Waikato River (K. Wakefield pers. comm).

The black shag Phalacrocorax sulcirostris, a piscivorous bird found in large numbers on Lake Waahi, does not appear to feed on catfish. Wells (1976) noted that the black shag fed on carp (Carassius auratus) and small mullet (Mugil cephalus) but did not see any signs of catfish predation. H. Lickers (pers. comm) has observed shags catching carp in Lake Whangape but never catfish. Falla and Stokell (1945) found only eels in the stomachs of shags from Lake Waikare.

Table 1

Fish Species Found In The Waikato River And Associated
Lakes

Anquilla dieffenbachii

Anquilla australis

Retropinna retropinna

Gobiomorphous cotidianus

Galaxias argenteus

Galaxias brevipinnis

Galaxias maculatus

Mugil cephalus

Gambusia affinis

Carassius auratus

Salmo trutta

Geotria australis

The parasite fauna of the catfish in the Waikato River was studied by Lim (1974). Only three parasite species were found; the nematodes Eustron gylides, Ascarophis sp. and Heduris spirigera. Of these only E. gylides is common to both New Zealand and American catfish, and Lim concluded that the species may have been gained locally whilst the original parasite fauna was lost during acclimatisation, because the parasite was similar to one found in native New Zealand fish.

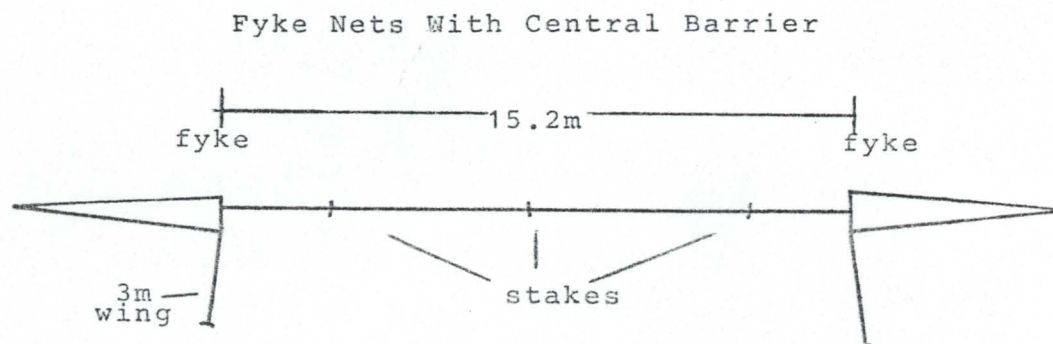
2.1 FISHING METHODS

Fishing for the catfish was carried out in the Waikato on a fortnightly basis from 22/4/75 to 25/5/76, using a variety of nets. These were usually set in the afternoon and emptied the following morning. Trapped fish were removed and placed in a 45litre plastic bin for transportation to the laboratory.

Eel fyke nets of 2.5cm mesh, with 5m leaders were generally used to trap catfish in this study. The nets were set either in slow-moving water under willow trees or in faster-moving water within 2m of the bank in locations where extensive willow growth was absent. In the slow-moving water they were set at right angles to the riverbank with the cod end out into deep water, whilst in faster-moving water they were set parallel to the bank with the cod end upstream. In the outlet stream linking Lake Waahi to the Waikato River, fyke nets were set across the stream, blocking off two thirds of it when there was little flow. When the width of the stream was increased through flooding a 6.4m extension was attached to the leader. In the shallow shoreline waters of Lakes Waikare and Waahi, a system using two fykes with leaders and wings was employed. A fyke net can only trap a maximum of 50% of the fish which may strike its leader, because the hoop

net is only at one end. The method shown in Fig 3, using a central barrier with a fyke net at each end, overcomes this deficiency.

Fig 3



Gill nets set to trap mullet also caught catfish on several occasions, but in general this method was not used because of the lack of a suitable range of mesh sizes. A 7.5m hand seine, of 2.5cm mesh, was used in Lakes Waahi, Waikare and Ngaroto, during both daytime and nighttime in the course of this study to try to catch small catfish (less than 13 cm long) which the fyke nets failed to trap. However only three large catfish were ever caught by this method, and no small catfish. Although regular sampling was attempted, on two occasions six consecutive days in the field were necessary to produce a total catch of ten and six fish respectively. The low catches were due to lack of movement by the catfish, which may have been related to factors such as lowering of the water temperature, onset of breeding and the territorial behaviour of the fish (Appendix 4). The phenomenon of

of widely fluctuating catches of catfish during a season has also been reported by some eel fishermen (A. Tecklenberg pers.comm). Catfish were also rarely caught on cloudless moonlight nights.

2.2 CATCH ANALYSIS

INITIAL EXAMINATION OF SAMPLES

Live fish brought into the laboratory were anaesthetised using a chloretone/ethanol mixture and processed as follows: Lengths were measured, to the nearest 0.1cm, from the tip of the snout to the caudal fork, on a standard measuring board (Frontispiece). All lengths quoted in this text are fork lengths (FL) unless otherwise stated.

Fish were weighed to the nearest 0.1gm on a triple beam balance.

Each fish was then cut open and the following data recorded:

- 1) Stomach fullness index
- 2) Sex
- 3) Weight of ovary to nearest 0.001gm

The stomach was removed and preserved in 4% Formalin. Ovaries were removed and preserved in Gilsons Fluid (Further details in Chapter 4).

The length weight data for each fish were stored on computer cards for analysis. Grouped length data for each location were analysed using version 5.01.330 of the SPSS statistical package (Nie et al, 1975).

RESULTS

The grouped length data for each location are shown in Fig 4, with the catch statistics in Table 2. The General data were composed of fish supplied by eel fishermen, from unknown localities, but caught by similar fyke nets.

Table 2

Catch Statistics

Site	Number caught	Kurtosis	Skewness	Range of lengths (cm)
Waikato River	45	0.392	0.627	15.4 - 37.1
Lake Waahi	126	2.99	-1.70	13.5 - 37.5
Lake Waikare	24	0.29	-0.795	13.4 - 37.5
General Data	135	0.56	0.179	12.9 - 44.5
Total	330	0.406	-0.39	12.9 - 44.5

DISCUSSION

The total catch was approximately normally distributed about a mean of 28cm, showing only a slight negative skew in the distribution, but platykurtotic. This indicates that the fyke nets used were selecting maximally for fish about 28cm long and did not catch fish below this size as efficiently. Thus, samples were not representative of the population as a

whole and this has implications for the analysis of age distribution (Chapter 3).

The catch of fish from the Waikato River showed a positive skew, with a modal group at 22 cm. Generally the fish from the river were smaller than those from the lakes and there are a number of possible reasons for this. There may have been a particularly abundant year class in the river, producing a large group with a mean length of 22cm. To establish if this were the case, sampling would have to be carried out over several years. Alternatively there may have been a tendency for young fish to move into the river from lakes and tributaries, then to return to the lakes when they were larger. If this were the case then it would explain the results from Lake Waahi where there was a very strong negative skew to the distribution and a modal group at 31cm. Fish were caught at both ends of the Waahi Outlet, indicating there was at least movement into and out of the stream. This would not be expected in Lake Waikare, where there is only inflow into the lake when the Waikato River is in flood, and outflow is through a controlled floodgate at the northern end of the lake. The Lake Waikare length distribution did approximate that of the total catch, but the sample size was unfortunately very small.

The general data was platykurtotic, with a slight positive skew. The distribution was similar to that for the total

catch and appeared to be a composite of all the catches I obtained. These general data fish were from all over the Lower Waikato region and so the effects apparent in my results were probably masked.

Numerous attempts were made to catch small fish during this study but they met with little success. In addition to my fishing, extensive seining, using the same net as myself, were carried out in Lake Waahi by Professor T. Northcote during 1976, and by Mr T. Stephens from mid-1976 to 1977. Not until February 1977 were young of the year catfish caught (4.5-6.9cm, n=11). Three young of the year were caught in Lake Ngaroto during autumn 1975 by dip netting in the reed beds around the lake shoreline. However, subsequent attempts to catch more fish by this method failed. It is unlikely that the lack of small catfish caught reflected their abundance and was probably due to their ability to evade catching by the methods used. Larval trawls using a 0.5mm mesh plankton net also failed to catch small catfish, although small Retropinna retropinna were caught.

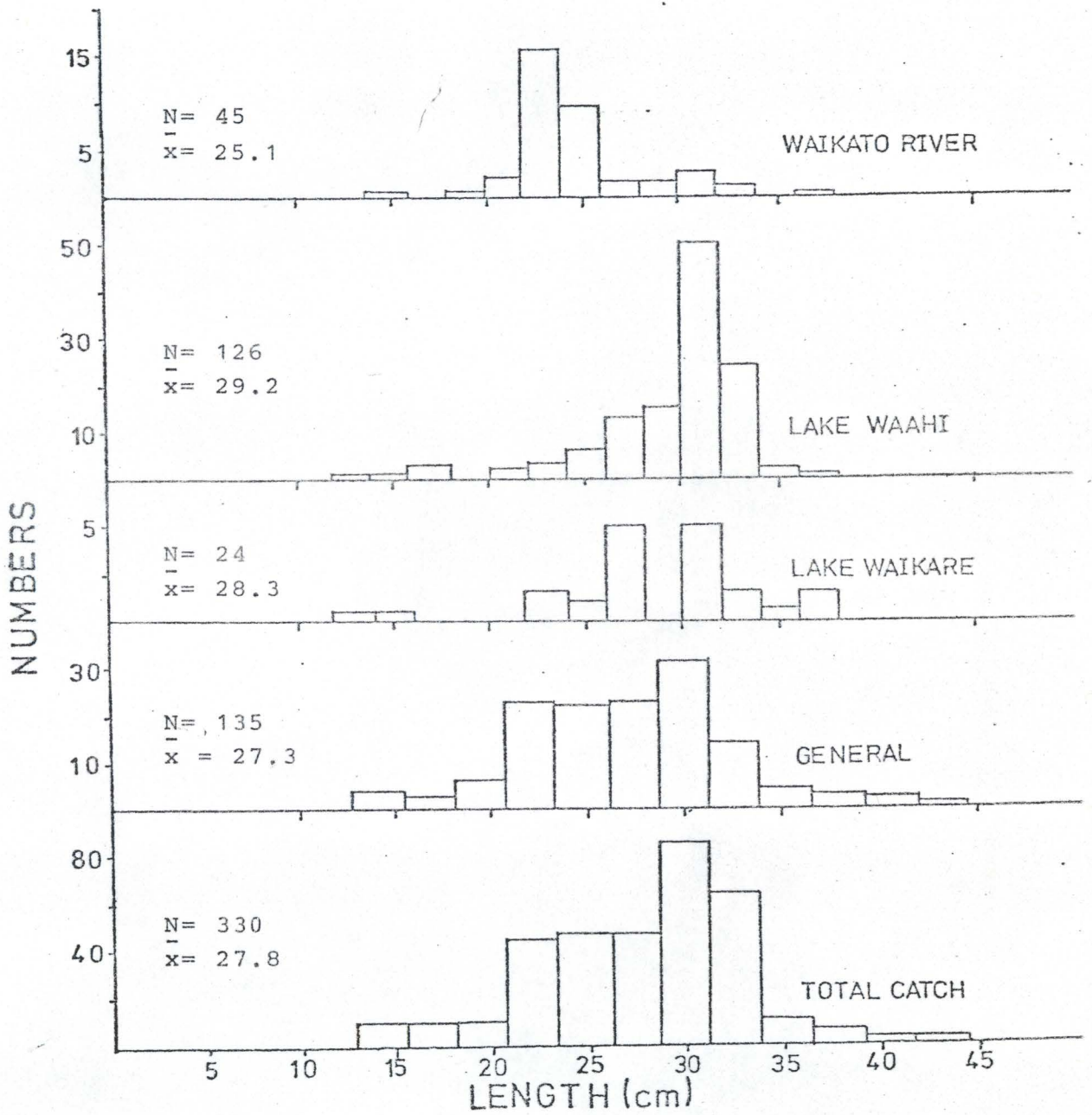


Fig 4

Length Distribution Grouped As To
Fishing Locality

3.1 INTRODUCTION

The determination of age distribution and growth rates in a population is of major importance in a study on the biology of a fish species. Information on the growth rates reveals the general condition of a fish population and this is especially important in this study because it allows comparisons to be made between the acclimatised New Zealand catfish and those from both its native and other 'exotic' habitats. The age distribution in a population provides information on the mortality rates and can give indications as to the effects fishing would have on the population. A method of reliably determining the age of a fish is also a prerequisite to any growth study.

3.2 METHODS

The problems of ageing scaleless fish such as Ictalurus nebulosus have been examined by a number of authors. Sneed (1950) used vertebrae and pectoral spines to determine age and growth in the channel catfish Ictalurus punctatus, and concluded that the growth marks occurring on these bone structures occurred annually and could be used to calculate age and growth rates accurately. Marzolf (1956) concluded that, in I. punctatus, calculated lengths based on vertebral measurements offered a better measure of growth history than

did those based on spine measurements because of the greater variability in spine data. Frank (1955) also drew the same conclusions for that species. Hensel (1966) used vertebrae to calculate age and growth of I. nebulosus in Czechoslovakia. More recently Lim (1974) used the sagittal otoliths to age I. nebulosus from the Waikato region, but unfortunately gave no validation for his technique.

In this study two methods were investigated to establish which would provide the easiest and most accurate method of age determination. The vertebral method had been used extensively to age Ictalurids overseas and showed promise as a method for ageing catfish from the Waikato.

From each fish the anterior half of the vertebral column was removed, beginning at the fused cervical vertebrae. The column was scraped clean of tissue and stored to dry in labelled envelopes at room temperature. When dry the vertebrae could easily be separated by disjuncting, and the fifth vertebra, as chosen by Appelget and Smith (1950) in their study on I. punctatus, was removed for ageing. This vertebra was selected because it was the largest apart from the first four fused cervical vertebrae. To remove any tissue adhering to the centra, each vertebra was placed in a digestive solution of 0.7% pepsin in 0.2% Hydrochloric acid for twenty-four hours at 37^oC (after Appelget and Smith, loc.cit). The cleaned vertebrae were then washed in water and placed in

glycerol for observation under a dissecting microscope, using reflected light on a black background. The number of rings present were counted and the distance between each ring was measured along the dorsal radius of the vertebra (Plate 1), to 0.05mm accuracy, using an ocular micrometer. The method of age determination used by Lim (1974) was also followed. The paired sagittal otoliths were removed from each fish by cutting off the top of the cranium and removing them from the otic cavity with fine forceps. The method of preparation of the otoliths, a modification of that used by Christiansen (1964), involved heating the otolith over a weak bunsen flame until it turned dark brown. After heating the otolith was broken and the surface of the fractures examined in glycerol, under reflected light on a black background. Growth marks showed up as dark lines across the fracture. Unfortunately, because of their small size (about 3mm diameter) the otoliths often burnt too rapidly, and growth marks did not show up. Another method often used in fisheries research is to place the whole unburnt otolith under reflected light, and to examine the opaque and transparent zones which may be apparent (Chuganova 1963). However in this case the otoliths were too dense for this to be successful.

To establish the relationship between growth in length of the fish and growth in weight of the otolith, a number of

otoliths were weighed on a microbalance to an accuracy of
+
- 0.01mg.

3.3 RESULTS

3.3 AGE ASSESSMENT

The centra of vertebrae from I. nebulosus showed a series of dark bands (Plate 1) which were thought to represent annual markings formed during a period of slow growth. These markings were similar in appearance to those found by Hensel (1966) in I. nebulosus from Czechoslovakia, and by authors studying other Ictalurids. It has been noted that the occurrence of a mark is accompanied by a change in elevation on the surface of the centrum (Marzolf, 1956 for I. punctatus, and Lewis, 1948 for I. melas), although I did not generally note this on my specimens. Ridges occurred on the centrum, but were not consistently associated with the rings. An electron microscope scan of the surface of a vertebra with five rings showed no change in elevation at the marks. To determine the nature of these vertebral rings, several approaches were followed. To determine possible variations in concentrations of elements such as Mg, Ca, Na, K, across the surface of the centrum, a multichannel analyser linked to a scanning electron microscope, set up to measure ion concentrations, was used. This method was unsuccessful because of the degree of curvature of the centrum. As the rings were only visible on the surface of the centrum,

sectioning of the vertebra to produce a flat surface would have been of little value. It was thought that a slower calcium deposition rate might be involved in the formation of these rings and consequently a method for calcium concentration determination, used by Galtsoff (1952) on tuna vertebrae, was tried. This involved staining the vertebra with the dye Alizarin Red S, which according to Hollister (1934) has a concentration specific affinity for calcium phosphate. After trials on a number of vertebrae it was found that the following treatment times for the critical stages in Galtsoff's method produced the best results: 48 hrs in 4% KOH - 48 hrs in Alizarin - 24 hrs in KOH. A vertebra before and after staining is shown in Plate 2. The regions associated with the growth rings stained much more heavily than did the rest of the vertebra, indicating that the concentration of calcium phosphate was lower in these regions. The same effect was found in a number of other stained vertebrae. It thus appeared that the presence of growth rings was associated with a greater rate of calcium deposition than the rest of the vertebra. One possible reason for this is that the slower rate of growth of the margin of the vertebra, when the ring was formed, allowed time for greater deposition of calcium in the bone matrix.

With the otolith method of age determination difficulty was encountered in achieving consistency in burning of the

Plate 1

- Upper Vertebra from a fish showing two annuli (1&2).
Measurement was along the dorsal radius A/B.
Distances from focus B to annulus 1, and from B
to annulus 2, were used to backcalculate length
at the time of formation of each annulus.
Measurement was to the inside margin of each annulus.
Distance from A to B was used to calculate the
body length/vertebral radius relationship.
- Lower Vertebra from a 3+ fish (3 annuli and growth past
the ultimate annulus)

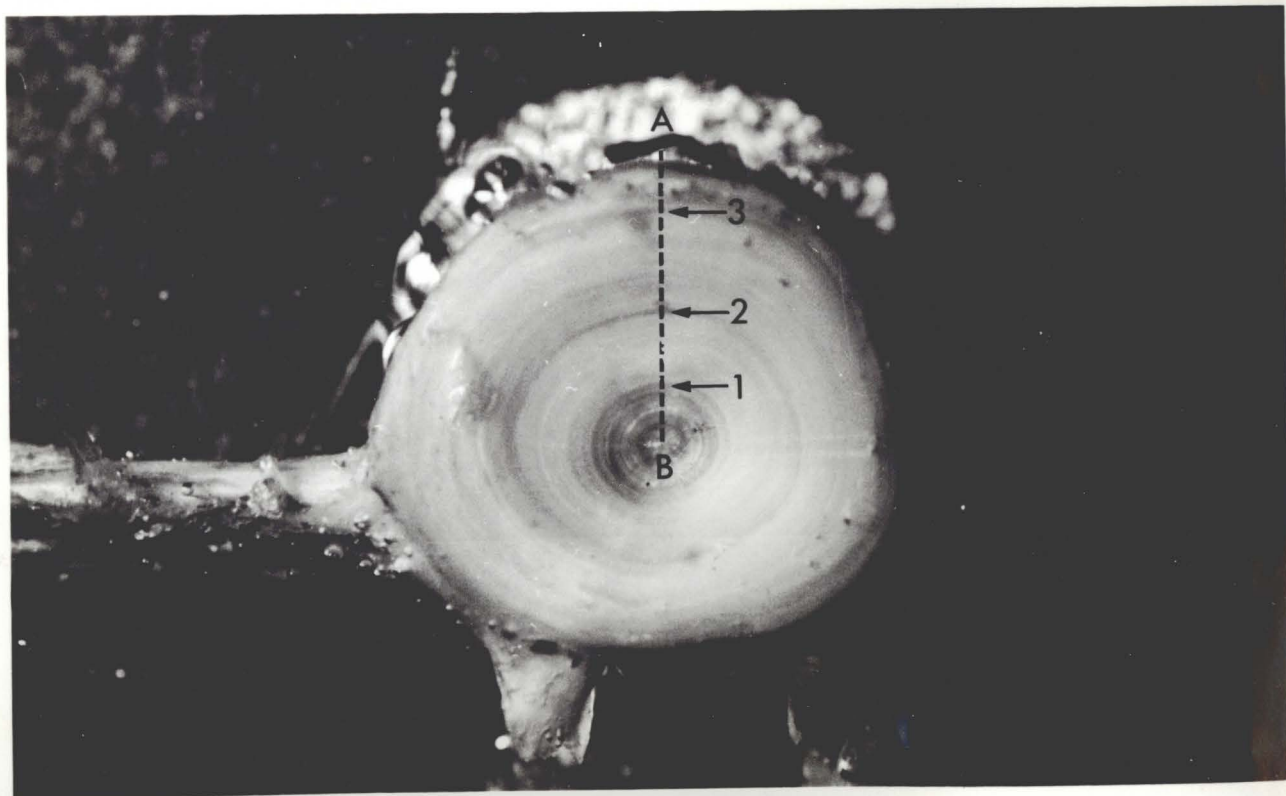
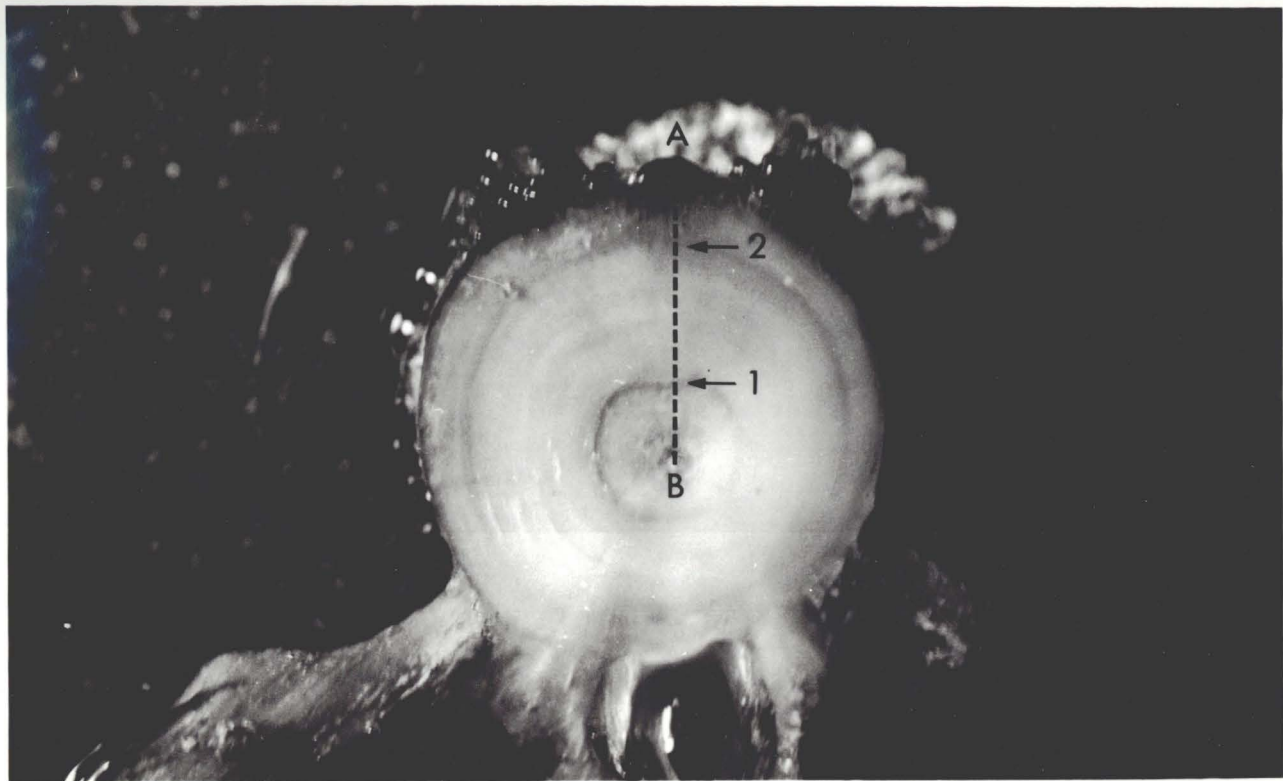
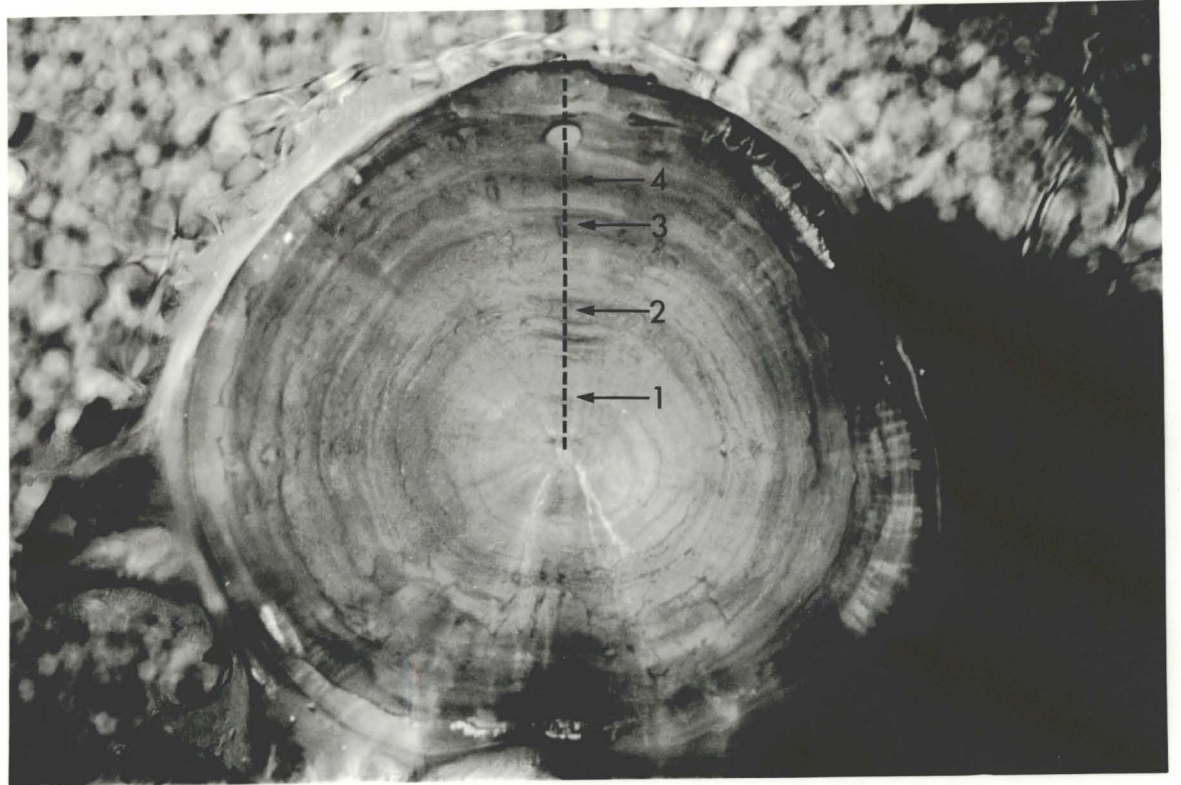
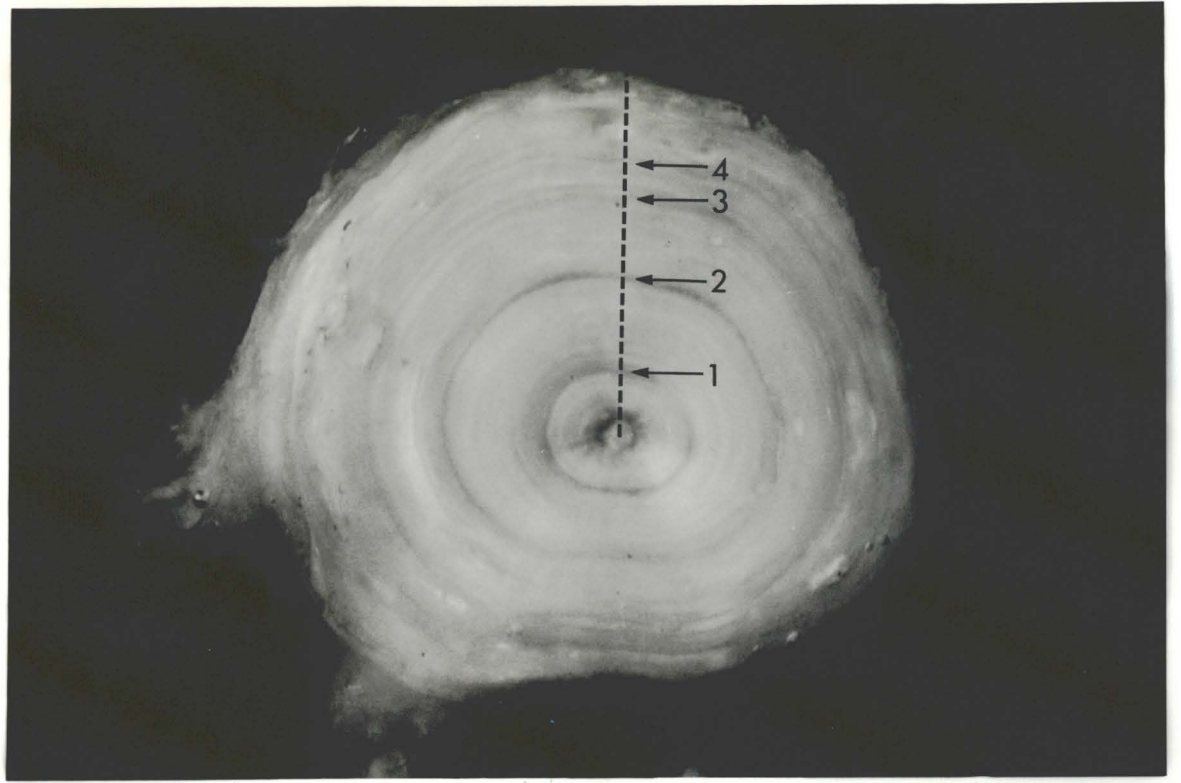


Plate 2

Vertebra from a 4+ fish, showing (upper) an untreated vertebra, and (lower) the vertebra after treatment with Alizarin Red S.



otoliths. Because of this, the method was not used continuously. In a sample of twelve fish aged successfully from otolith growth rings, the attained ages agreed with those from vertebral readings in eleven cases. 33 otolith pairs were weighed to calculate the relationship between growth in weight of the otolith and growth in length of the fish. There was no significant difference between the weights of the two otoliths from each fish ($\chi^2 = 0.171$, $df = 11$). The relationship was;

$$\log_{10} O_w = 2.3782 \log_{10} L - 2.3359 \quad (r = 0.9555, n = 33)$$

where O_w = otolith weight (mg), L = Fork length (cm), indicating increase in weight of the otolith is proportional to increase in length of the fish.

VALIDATION OF THE RINGS AS ANNULI

Although it has been established that the growth rings on the bony parts of Ictalurids are in fact annual (e.g. Appelget and Smith, 1950), it was felt necessary to verify that the rings on vertebrae of Waikato fish were also annual to justify their use in ageing.

If it could be shown that the marks form at approximately the same time each year then they can be used for age determination. To establish the pattern of ring formation, the distance between the ultimate ring (R_n) and the lip of the vertebra (R_{n+1}) was measured in 125 fish. The results are shown in Fig 5. Because only a small number of fish were caught in

July and September, the averages in these two months are linked to the preceding and following monthly means by dotted lines to emphasise their possible inaccuracy. The data includes fish of all ages except 0+. Plotting values for the 2+ fish only ($n=74$), showed a similar wide variation in the range of $R_{n+1} - R_n$ per month, but since it is the trend of the graph showing the time when the ultimate ring was closest to the margin which is important, rather than the actual values, only the graph of the sum of all ages is shown. Numbers of 1+, 3+, 4+ fish were too low to construct similar graphs.

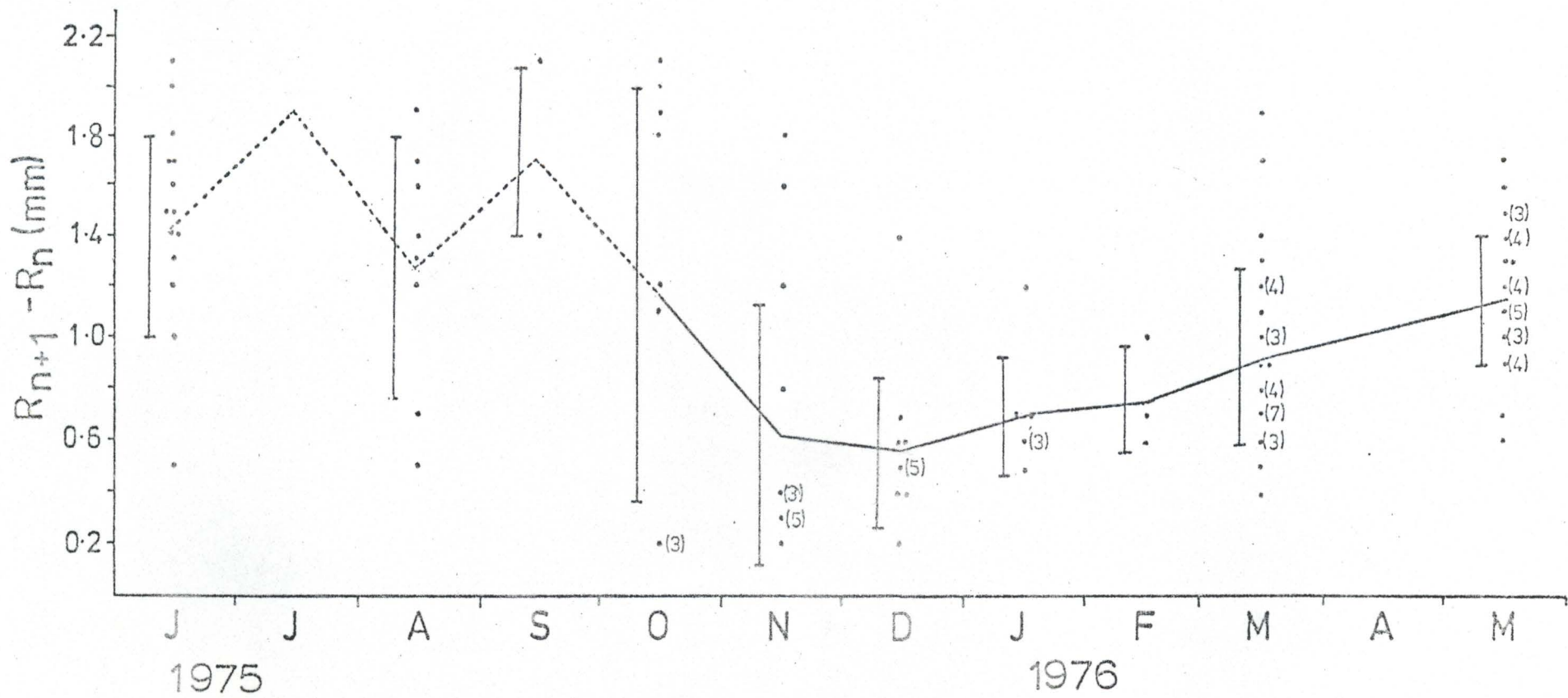
The pattern apparent was of high $R_{n+1} - R_n$ values during the winter months of June through August, followed by a rapid decrease in early spring (September/October), and a slow increase during the following summer/autumn period (January through May). These results suggested that the time of ring formation was during the winter, because in the spring there was the smallest amount of growth past a ring. No rings were ever observed closer than 0.2mm to the rim of the vertebra which suggests that the rings do not appear until there has been several months of new spring growth.

The $R_{n+1} - R_n$ values for November were widely scattered with a cluster at 0.3mm. This further supports the idea that the rings appear after extension of the margin of the vertebra, reflecting the new season's growth, and that the actual time

Fig 5

Mean monthly increase in distance from the
ultimate annulus to the margin ($R_{n+1} - R_n$)

($I = \bar{x} \pm 1 \text{ s.dev}$)



for appearance of the new ring can vary. It is possible that the formation of the rings was due to some discolouration effect in the bone matrix of the ring region associated with the high level of calcium deposition.

The above evidence indicated that the vertebral rings were laid down during a period of slow growth in the fish.

Although the time for appearance of a new ring varied, it was assumed that by the end of a season's growth the new ring would have appeared. If not, the calculated length for an age would be far too high and would stand out in an age/length analysis. This was the case for several fish, and where this occurred, other vertebra from the same fish which were checked showed the additional ring in all cases.

3.3.2 GROWTH IN LENGTH

To determine the growth in length of the catfish a backcalculation method was used (Tesch, 1971). This involved calculation of the length of the fish at the time of formation of each annulus, and thus calculation of the increment in length for each year (the annual growth rate). Two major assumptions must be made for this method; 1) the annuli must be formed regularly, either yearly or in some other predictable pattern. 2) there must be a predictable relationship between the increase in body length of the fish and the increase in size (i.e. vertebral radius) of the particular structure being used for ageing. Criterion 1

was satisfied, but the second had to be examined.

THE NATURE OF THE BODY LENGTH/VERTEBRAL RADIUS RELATIONSHIP

A scatter diagram of length of fish versus vertebral radius is shown in Fig 6. Because the relationship appeared curvilinear, several functions were examined to produce an equation which best fitted the observed values. Regression analyses were performed using the Teddybear programme (Wilson, 1976), and the results are shown in Table 3. A log/log transformation, as originally described by Monastrysky (1930) was found to best fit the observed data.

It is important to note that in studies where a curvilinear body/scale (or vertebra) regression has been described on the basis of one or two years sampling, it is possible that much of the curvilinearity may be the result of differences in the body/scale regressions of the different year classes which are used in the various segments of the all over regression (Hile, 1970). This possibility is accepted in this case, but could not be tested except by sampling over more than two years.

CALCULATION OF LENGTHS AT PREVIOUS AGES

The method used by Hile (1941) to calculate growth in the rock bass Ambloplites rupestris, where the body/scale relationship was curvilinear and best expressed by a regression line from log transformed data, was adopted in this study. Solution of the regression equation for an observed length

of fish gave an estimated or 'normal' vertebral radius. This estimated radius was divided by the actual measurement to give a correction factor which, when multiplied by the radius to each annulus, gave its corrected value. The corrected value for radius to each annulus, when substituted into the regression equation, gave the length of the fish at the time when the annulus was formed. A nomograph is usually produced to perform the above calculations in studies where backcalculation involves use of a regression equation produced from log transformed data (Monastrysky, 1930, Hile, 1941, 1970, Le Cren, 1947). In this case, however, a programme was developed (Appendix 2) to perform the computations on a PDP 11 computer.

Controversy exists in the early literature as to the correct interpretation of the body/scale regression for computing body length in fish (Whitney and Carlander, 1956). It was decided that in this case a geometric mean regression (GM) (Ricker, 1973) was the appropriate relationship to use. This is because the measurement variation is negligible compared with the inherent natural variability in both vertebral radius and body length. Neither can adequately be termed the ' independent variable ' and since the back-calculation method involved prediction of fish length from vertebral radius and vice versa, this functional regression was employed. The programme for calculation of the GM

regression is shown in Appendix 2.

Because there was no significant difference between the slopes and intercepts for male and female regressions, at the 2.5% level, the data was pooled and a GM regression calculated for length of fish on vertebral radius where:

$$\ln L = \ln 2.50089 + 0.844864 \ln V$$

(L = length(cm), V = vertebral radius(mm), std.dev= 0.01726)

Table 3

Functions Examined For Best Fit Of
Body Length/Vertebral Radius Data

Untransformed data

Linear regression $L = 7.1615 + 7.5272 V$

The regression accounted for 87.8% of the variation

$F = 1066.5$ $P = 0.000000$

2nd Degree Polynomial $L = 0.836 + 14.0308 V - 1.3867 V^2$

The regression accounted for 93.2% of the variation

$F = 1010.9$ $P = 0.000000$

3rd Degree Polynomial $L = -2.3077 + 20.775V - 4.766V^2 + 0.47V^3$

The regression accounted for 94.1% of the variation

$F = 775.3$ $P = 0.000000$

Transformed data

$\ln L = \ln 2.5224 + 0.8187 \ln V$

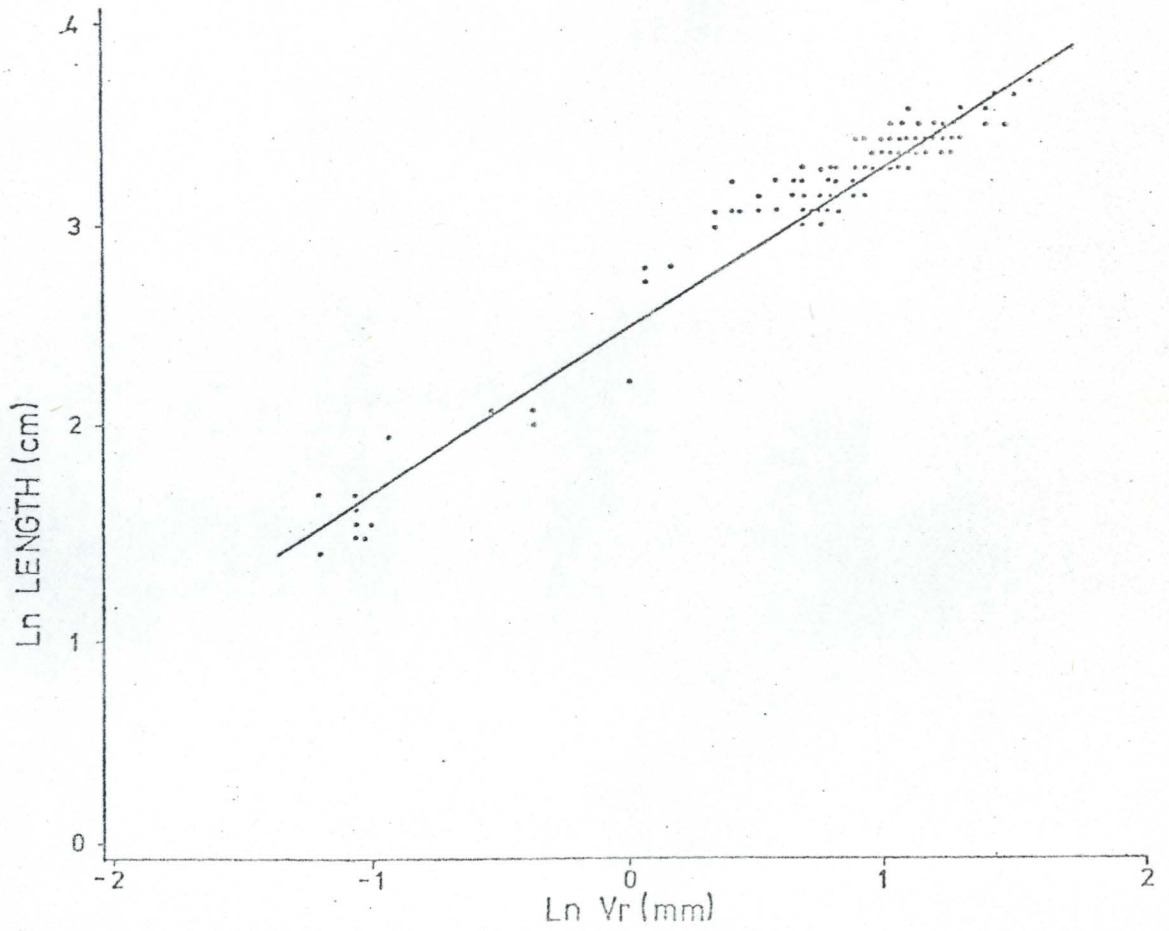
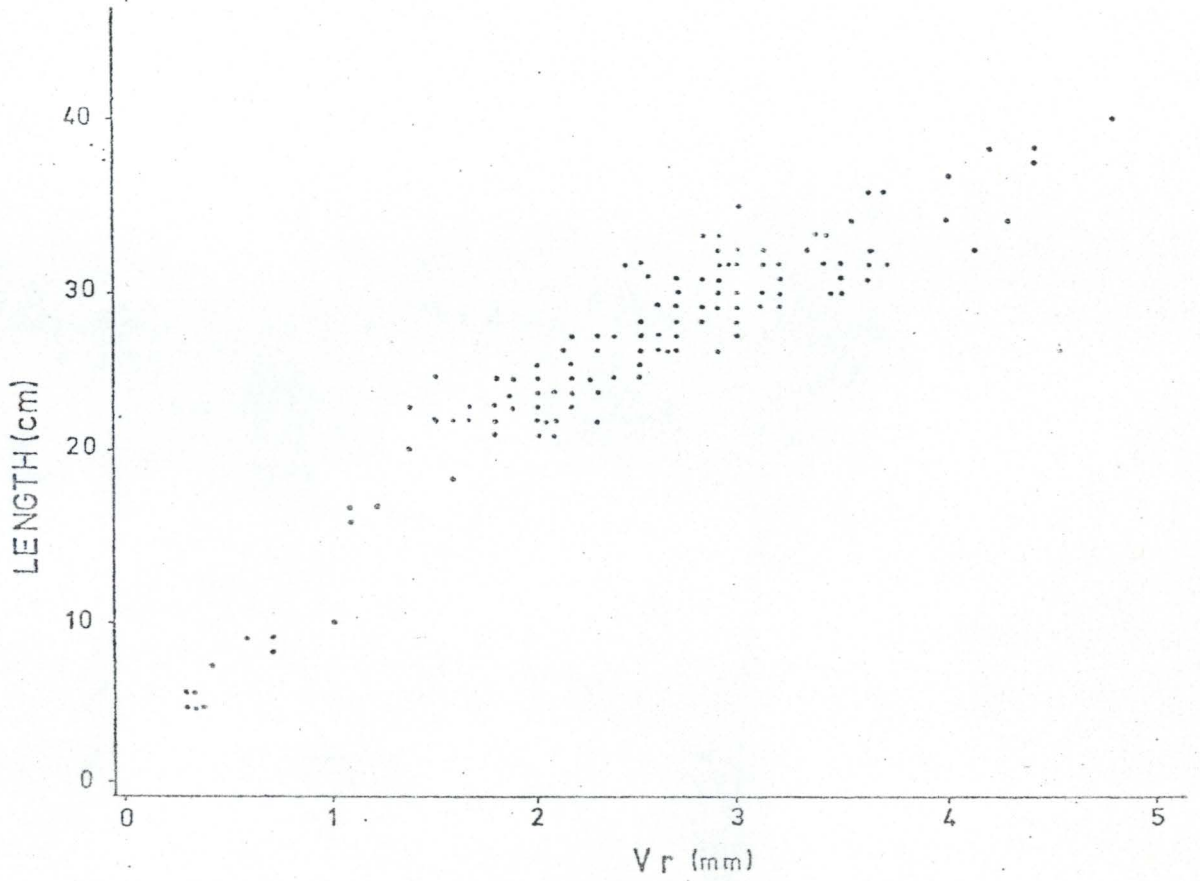
The regression accounted for 94.05% of the variation

$F = 2339.9$ $P = 0.000000$

$L =$ length in cm, $V =$ vertebral radius in mm

Fig 6

Relationship between fish body length and vertebral
radius (n = 150)



3.4 AGE ANALYSIS

POPULATION AGE STRUCTURE

The fish caught in this study were classified into age groups such that fish in their first growing season were designated as 0+, fish which had completed a full year's growth and were in their second season as 1+, et cetera. The ages of fish caught during the sampling period ranged from 0+ to 4+, but one 5+ and a 7+ fish were taken at other times. An analysis of the numbers of fish in each age class caught in the fyke nets is shown in Fig 7. The 0+ class is omitted since only two specimens from this class were caught in this way. The greatest percentage of the population was in the 2+ year class, which may reflect an exceptional year class in 1973-74. It is also possible that, because the fyke net was selective against fish below 28cm in length, much of the effect was due to selection against the size range in which the 1+ fish occurred (mean length 24.4cm) and that the net was only catching the larger specimens of this age group.

LENGTH FREQUENCY ANALYSIS

The length frequency data for all the fish caught in the Waikato district was analysed using the STATUS matrix interpretative programme (Turner and Rogers, 1974). Data for January through March 1975 were supplied by Mr G. Coates. The results are shown in Fig 8. A number of modes were

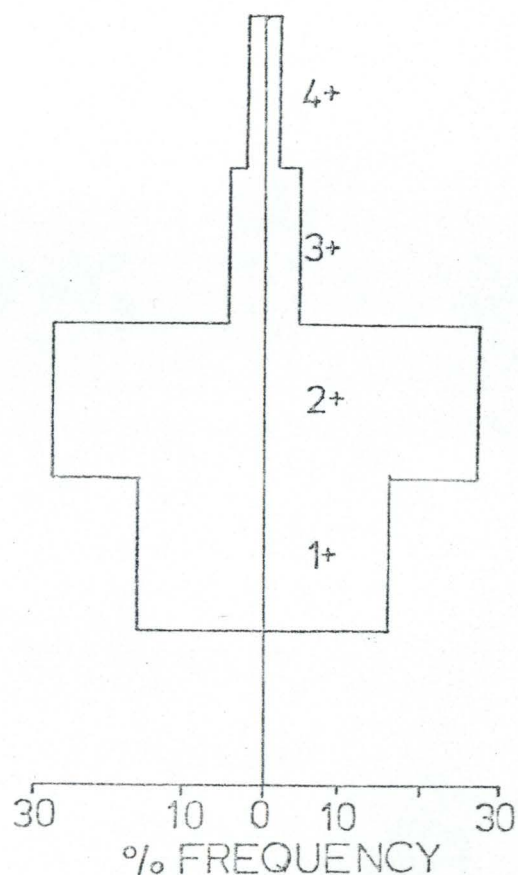


Fig 7

Age Class Distribution

(n = 137)

apparent in the length distribution, but statistical analysis of the data by a method such as that of Tanaka (1962) to determine age classes, was not attempted for several reasons. Backcalculations showed that lengths at each age varied over a wide range and that there was considerable overlap between age groups. Therefore statistical separation of the length distribution into quasi-age groups was not justifiable. In

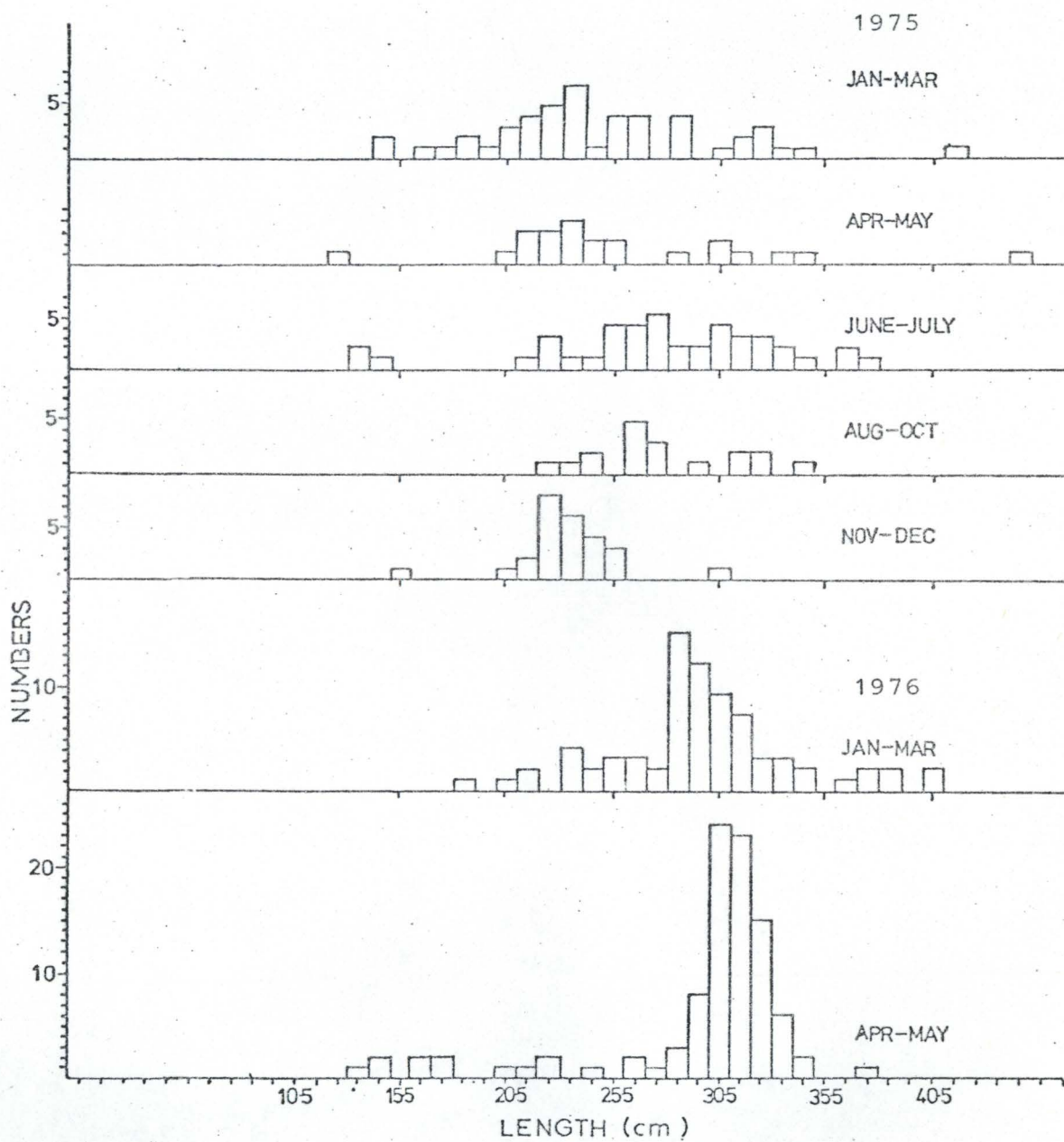


Fig 8

Length Frequency Analysis

addition, the length frequency method of determination of age classes (Peterson method) assumes a short distinct spawning season, but in Waikato conditions this was not so. In fact multiple spawning occurred.

COMPARATIVE LONGEVITY AND SIZE BETWEEN
WAIKATO AND OVERSEAS FISH

The maximum age/ length recorded for catfish in the Waikato was 7+/45.5cm (1630gm). Hensel (1966) found the maximum age of I. nebulosus in Czechoslovakia to be 6+, but the total length (TL) was only 26.4cm (25.2 - 28.0). Emig (1966) gave the maximum age recorded in Lake Tenmile, Oregon, USA, as 6+ and the length as 29.0cm (TL). Scott and Crossman (1973) quoted a length of 26.7 cm (TL) at 5 yrs for fish in Little Lake Butte des Mortes, Wisconsin, USA. Carlander (1953) quoted a maximum length of 53.2cm (TL) in Florida, USA, but did not give the age.

It appears that the maximum ages attained by Waikato catfish were similar to those recorded in the northern hemisphere, but the length at maximum age was far greater in my fish, which indicates a much faster growth rate.

3.5 GROWTH

3.5.1 LENGTH/WEIGHT RELATIONSHIP

The relationship between length and weight was computed using the programme shown in Appendix 2. The geometric mean regression should be used in this case, for similar reasons for its use in interpreting the body length/ vertebral radius relationship i.e any variation in both parameters was due to natural variability. The functional regression was of the standard form $W = aL^b$ (Tesch, 1971), and is shown in Fig 9. There was no significant difference at the 10% level between slopes and intercepts of the separate regressions for each sex.

Growth in weight of the catfish was found to be proportional to the cube of increase in length of the fish i.e $b = 3.06$, a relationship which is found in many fish species (Tesch, loc.cit), and indicates that the catfish grows isometrically. The symmetry of growth for the Waikato fish is similar to that established for the species in the USA:

$$\log W = -5.166 + 3.125 \log FL \text{ (Smith, 1939)}$$

$$\log W = -5.061 + 3.065 \log TL \text{ (Priegel, 1966)}$$

$$\ln W = -4.486 + 3.060 \ln FL \text{ (Waikato)}$$

CONDITION FACTORS

The condition factor (K), an index of the ' relative robustness ' of a fish, is often used as a measure of the condition of a fish (Tesch, loc.cit). K is calculated as

Fig 9.

Length/Weight Relationship

Geometric Mean Regression

$$\ln W = -4.486 + 3.060 \ln FL$$

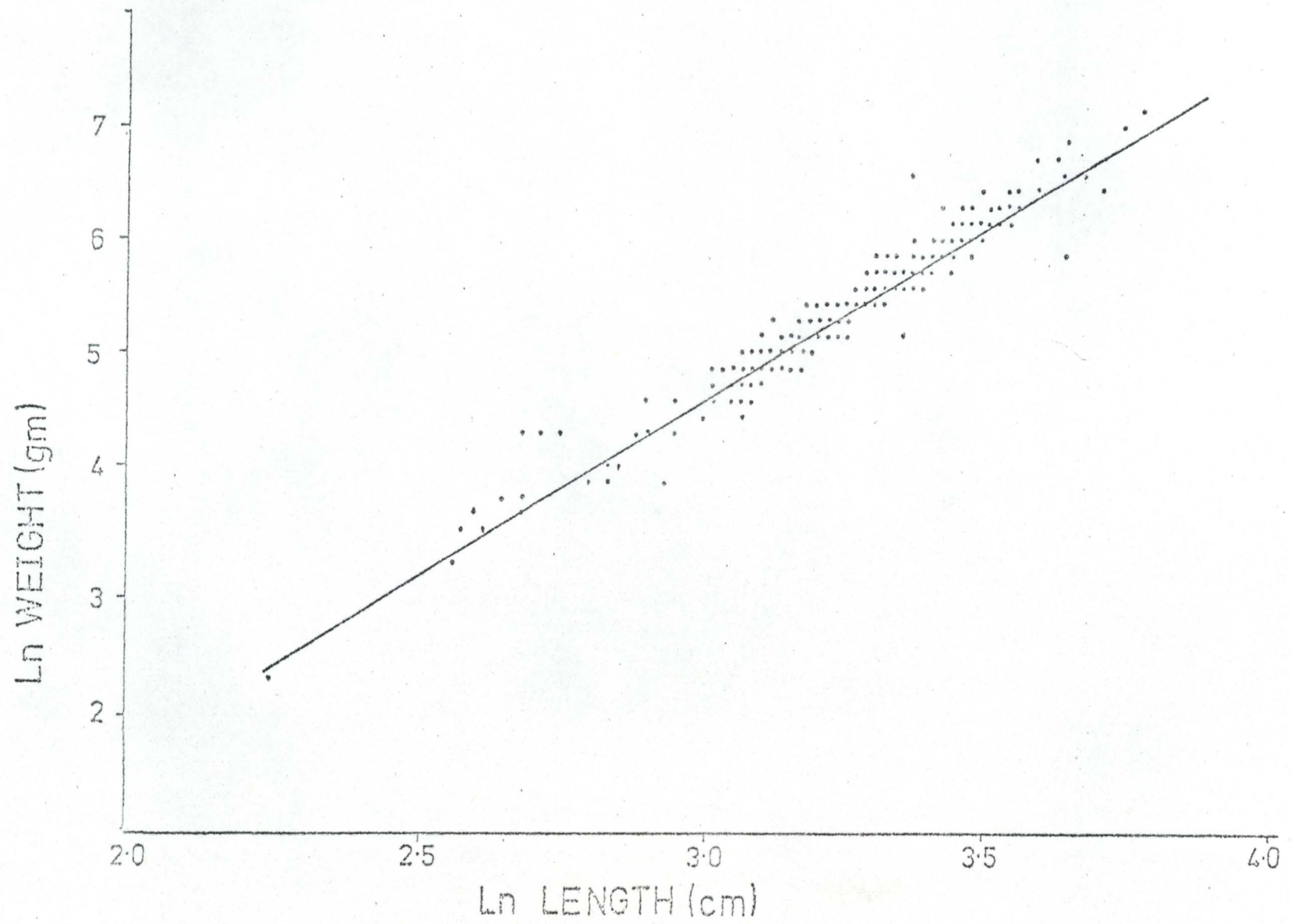
Predictive Regression

$$\ln W = -4.147 + 2.958 \ln FL$$

The regression accounted for 95.3% of the variation

$$F = 6743.4 \quad P = 0.000000$$

(n = 330, W = weight in grams, FL = length in cm)



$$K = \frac{W (10^2)}{L^3}$$

where W = weight (gm)

L = length (cm)

If the exponent in the length weight relationship is 3 i.e growth is isometric, then comparison of K values between fish reflects individual variability (Tesch, 1971). Fig 10 shows the mean monthly values calculated for K.

The apparent pattern was a decrease in condition through autumn/early winter (February through May), followed by a rise during winter to a peak at a K value of about 1.6 during the summer.

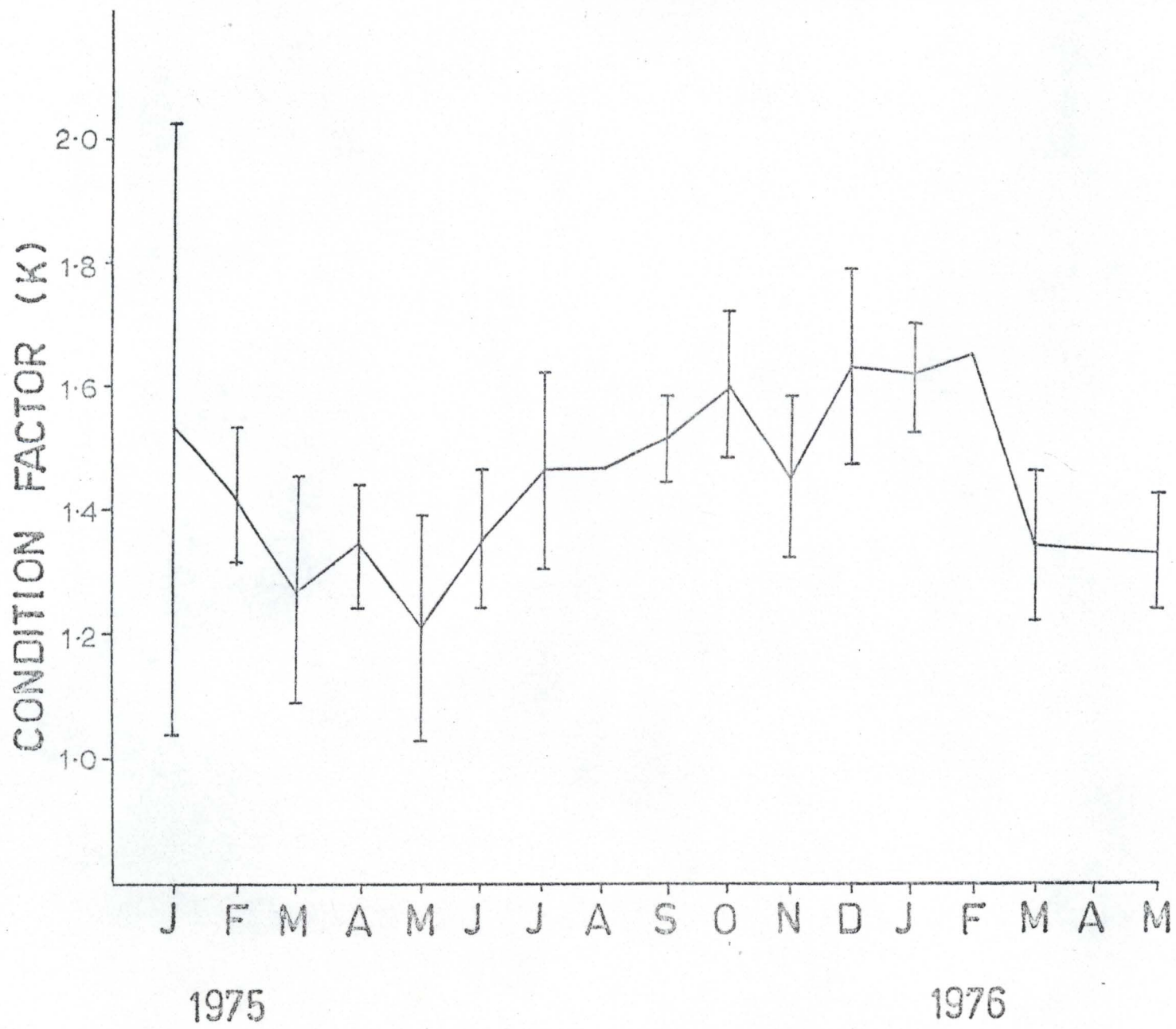
The relationship $K = W/L^3$ can be rewritten as $W = KL^3$, which is analogous to the length/weight relationship $W = aL^b$.

Since it was established in this study that ' b ' was approximately equal to 3, any variation in ' a ' during the year can be attributed to the fluctuations in K already established. Thus it follows that the intercept ' a ' for the length/weight regression line varies throughout the year, but the slope of the line remains constant at $b=3.06$, and that the ' a ' value established in this study is a mean value for the sampling period.

Fig 10

Monthly Condition Factors

($I = \bar{x} \pm 1 \text{ s.d}$)



3.5.2 BACKCALCULATED GROWTH IN LENGTH

Mean lengths at the end of each year of life are shown in Table 4. There was no difference in mean lengths between the sexes at the 5% level of significance. It is apparent that Lee's phenomenon of decreasing length at the first annulus in older fish (Tesch, 1971) has occurred in this study. The average length at age 1 from backcalculation for 1+ fish was considerably higher than for 2+ fish. Ricker (1975) suggested three reasons for this phenomenon:

- 1) Technical - use of incorrect body/scale relationship.
- 2) Biased or nonrepresentative sampling, and catching the larger fish in a year class.
- 3) Selective mortality - where mortality rate among the larger fish of an age group is different from that among the smaller.

In this study it was apparent that situation 2) was responsible for Lee's phenomenon. It was established that the fyke nets were selective. The sampling was biased so that mainly the larger fish in the 1+ age class were caught. Thus selection was for the faster-growing fish of this age class, which is consequently reflected in the high mean calculated length at age 1

The growth rate of the catfish, i.e increment in length per year, is shown in Fig 11. At the end of the first year of life catfish have attained a mean length of 8.0cm. The

Age group	N	Av. length at capture	Length at end of each year			
			1	2	3	4
0+	13	6.96				
1+	46	24.4	10.0 $\bar{\pm} 2.3$			
2+	74	28.4	7.9 $\bar{\pm} 1.9$	20.9 $\bar{\pm} 3.1$		
3+	12	32.8	7.3 $\bar{\pm} 1.8$	17.0 $\bar{\pm} 2.8$	26.3 $\bar{\pm} 3.4$	
4+	5	37.6	6.8 $\bar{\pm} 1.1$	18.0 $\bar{\pm} 2.3$	28.2 $\bar{\pm} 2.4$	33.7 $\bar{\pm} 2.8$
Average length at end of each year			8.0	18.6	27.3	33.7
Average increment in length per year			8.0	10.6	8.7	6.4

Table 4

Backcalculated Lengths At Previous Ages

(length = $\bar{x} \pm 1 \text{ s.d}$)

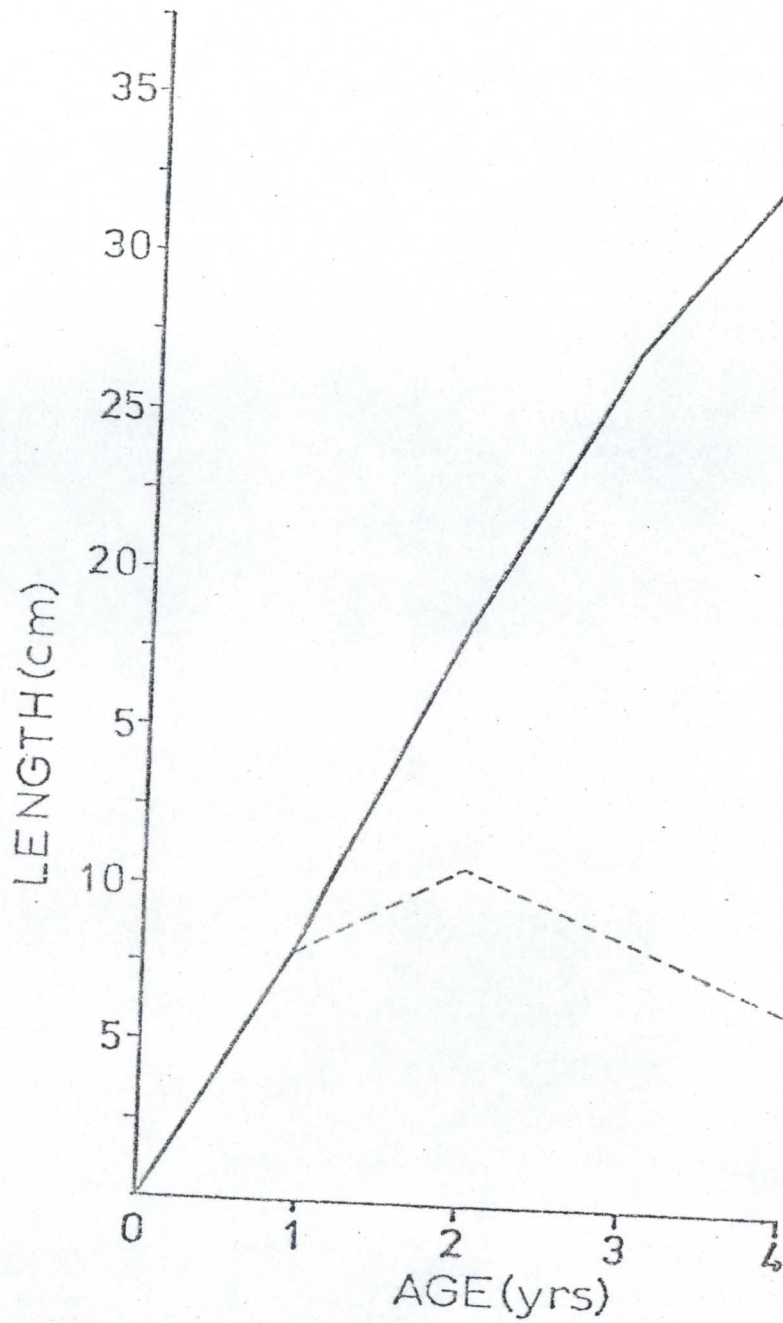


Fig 11

Growth In Length

Annual increment in length (broken line)

Length at end of each year (solid line)

range in lengths was from 4.4 to 15.3 cm and it is possible that this wide variation was due to differing growth rates between fish in each year, but was more probably due to the long spawning season of the fish (Chapter 4). A fish spawned at the beginning of the growing season will have a much longer period of growth before the following winter than will a fish spawned late in the season.

At the end of their second year , the fish have attained a mean length of 18.6 cm, an increment of 10.6 cm. This apparently indicates a faster growth rate than in the first year, but since the first year would not be a complete year, the figures are not comparable.

In the third year of life the growth rate slows to 8.7 cm and at the end of the year the mean length is 27.3 cm. Since increase in weight is proportional to the cube of length it is probable that, at this size, fish are increasing more in body mass than in length.

During the fourth year the growth rate declines further to 6.4cm per year. Since the maximum length found was 45.5cm for a 7+ fish, it is probable that the growth rate declines even more after the fourth year of life and that the growth in weight is even greater.

It was apparent in this study that the ultimate annulus on each vertebra did not appear until well into the following growing season in many cases. This caused difficulties in accurate ageing of the fish, because a fish with a large

$R_{n+1} - R_n$ value caught in December, with only one growth ring, was not a 1+ but a 2+ fish. By taking a common date such as September 1 for the change of age this problem would have been overcome, but this was not adequate for backcalculation purposes. It was accepted that in the backcalculation results each age group could contain fish of different ages, but that this would not make the calculated length at each annulus any different.

GROWTH IN LENGTH

A Walford graph of length at age $t+1$ versus length at age t was plotted for the average length at the end of each year using data produced from backcalculation. The length at age 1 was taken from the mean of the lengths at end of year 1 for 2+, 3+, 4+, fish, with 1+ fish being omitted because of the fishing size selection in this age class. Because of the short life of the species, only three points could be plotted (Fig 12) and thus the results from this analysis are only approximate. From the slope of the line ($k = 0.728$) and the ordinate intercept (13.5cm), L or the maximum length attainable by the fish, was calculated as 49.7 cm from the formula:

$$L(1-k) = \text{the ordinate intercept (Ricker, 1975)}$$

This value is compatible with the maximum length attained in this study (45.5 cm) and the maximum length quoted by Mansueti and Hardy (1967) of 50.8cm. The results suggested

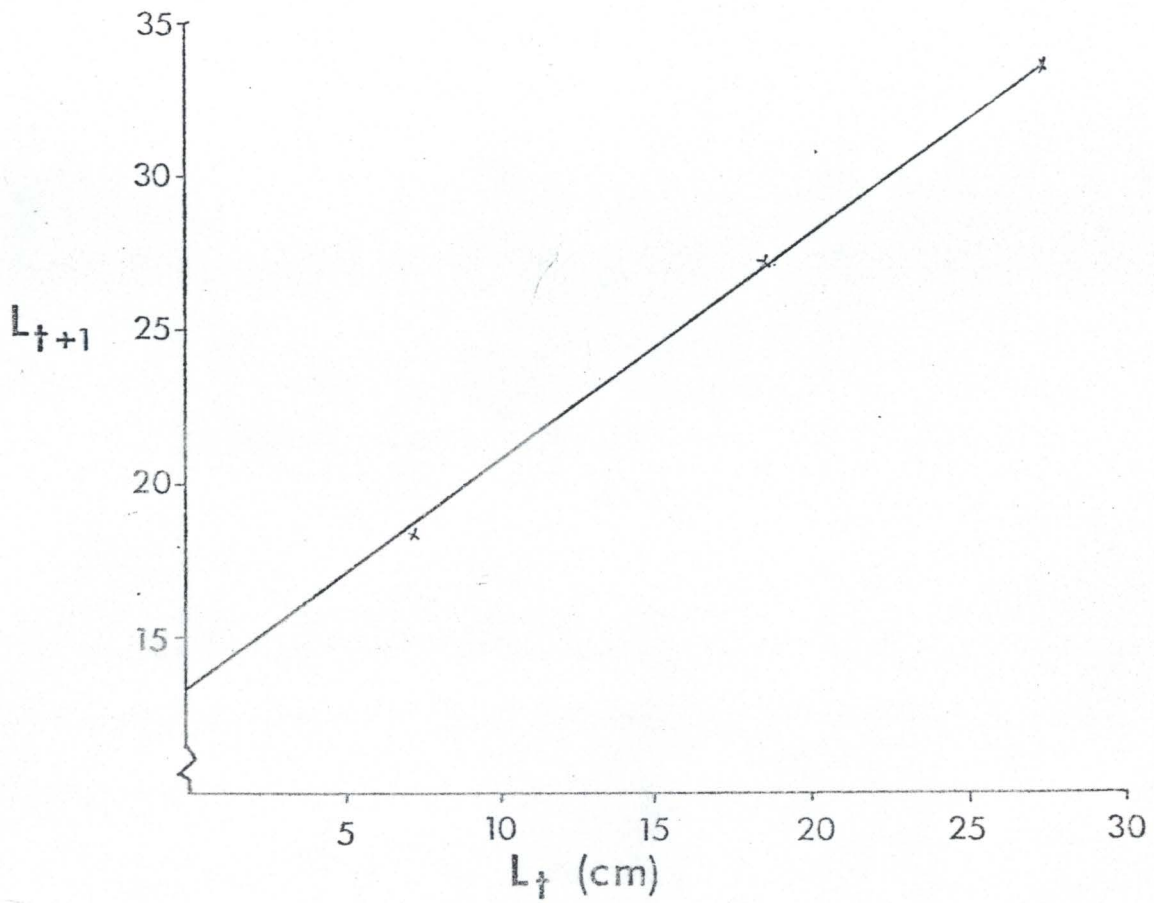


Fig 12

Walford Plot Of Growth

that the growth of the fish could be described by the Von Bertalanffy growth equation, but it was thought there was insufficient data to warrant attempting this.

GROWTH IN WEIGHT

The mean population instantaneous growth rate (G_x) can be obtained by comparing the mean length of the surviving fish at successive ages (from Table 4) and multiplying the natural log of the differences. between ages by the length/weight relationship exponent ' b '. The mean instantaneous individual growth rate (G) is calculated as the differences between the natural logarithms of the lengths of each fish at the previous two annuli, multiplied by ' b '. The mean of these individual growth rates gives the instantaneous growth rate in weight for each year (as per Ricker, 1975)

Population growth			Mean Individual growth	
Age interval (yrs)	Length interval (cm)	G_x	Length interval (cm)	G
1-2			7.9 - 20.9	3.0173
2-3	20.9-26.3	0.7033	17.0 - 26.3	1.4812
3-4	26.3-33.7	0.7587	28.2 - 33.7	0.5022

Fishing in this study was selective for at least fish of age 1 and so no G_x value was calculated for the 1-2 year age interval.

The mean instantaneous individual growth rate for fish from the 1-2 year age interval was twice that for the 2-3 year age interval, indicating a much faster growth rate. During

the third year of life the growth rate dropped markedly to one third that of the previous year.

The population instantaneous growth rate was considerably different from the mean individual growth rate. If more of the larger sized fish in a year class die than smaller fish, then the mean length of the population sampled would be less than might be expected. Because of this, the mean instantaneous individual growth rate provides a better estimate of true growth rates (Ricker, 1975). If more large fish do die then G_x will be much smaller than the corresponding G . This was apparent for the 2-3 age interval but because of the small sample size ($n = 13$) it cannot be reliably said that the mortality was greater.

3.5.3 COMPARATIVE GROWTH RATES

The mean increment in length during the first year of life was 8.0cm for Waikato fish. Raney and Webster (1939) found a mean total length increment of 7.7cm (maximum of 10.2cm) for fish in Lake Cayuga, New York, USA. Carlander (1953) cited the length increase in Czechoslovakia (from backcalculation) as 8.1 cm, and from two studies in the USA, 9.1 and 14.7 cm. Emig (1966) quoted a length increase of 7.6 cm for fish in Oregon, USA. Although the growth rates for the first year appear similar between the countries, the mean value for Waikato fish was diminished because of the long duration of the spawning season, and it was inferred that the spawning season was short and definite in the above references. This same effect would be shown at all ages for the Waikato fish.

By the end of the second year the Waikato fish have reached a mean length of 18.6cm, which is similar to those recorded in the USA (18.0, 20.3, 20.8), but markedly greater than those from Czechoslovakia (11.9, 12.4) (Carlander, loc.cit). During the third year of life the rate of growth for the Waikato fish is still very high (8.7 cm) and the fish attain a mean length of 27.3cm. It is during this year that the growth rate begins to differ from northern hemisphere fish. In Czechoslovakia the fish reaches only 16.0 cm TL (4.1 cm), and in the USA, 23.9, 25.9, 25.6 (3.6, 7.9, 4.8).

In the fourth year of life the increment in length is still greater in the Waikato fish (6.4 cm) compared with fish from the USA (5.3, 1.3 cm) and Czechoslovakia (4.1 cm). Fig 13 summarizes the growth rates determined by back-calculation of lengths at previous ages from different localities. The calculations for USA fish were on a direct proportion basis from spine measurement data. I cannot comment on the validity of the results, as the original papers were not available. However it was established in this study that backcalculation on a direct proportion basis, when in fact the body length/vertebral radius relationship is curvilinear, results in an overestimation of calculated length at each age.

It thus appears that the growth rate is similar, on available evidence, to that of USA fish in the first two years and is much faster in the following years and that the growth rate of fish in Czechoslovakia is much slower.

This faster growth rate of an exotic fish in New Zealand when compared with that in European countries has also been noted for the perch Perca fluviatilis in Lake Rotoroa, Hamilton (E. Graynoth, pers.comm). This suggests that the conditions found in many of the Waikato lakes are favourable to rapid fish growth.

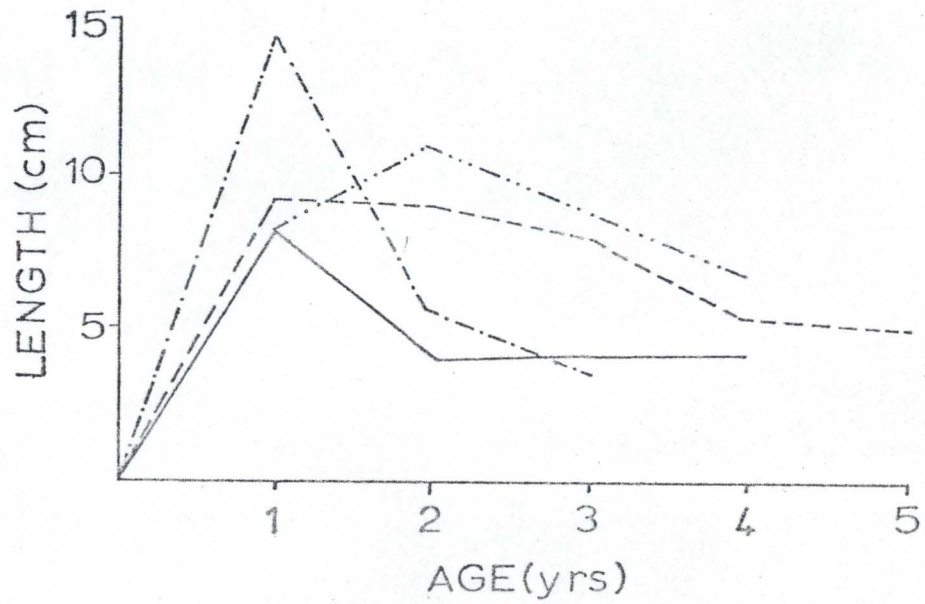


Fig 13

Comparative Growth Rates

- New Zealand
- USA (Carlander, 1953)
- USA (" ")
- Czechoslovakia (" ")

4.1 INTRODUCTION

Aspects of the reproductive biology of the catfish Ictalurus nebulosus have been studied in detail in the USA, and a resume of the breeding and brood habits of the species is given in Appendix 3.

Determination of the type and length of spawning season in a fish is important to age and growth studies, and a knowledge of fecundity as it relates to recruitment is necessary for management considerations. Although most evidence from the USA suggests a short, late spring/early summer, spawning season for the catfish (Mansueti and Hardy, 1967), and it has been suggested that multiple spawning may occur (Breder, 1935) and initial observations on the gonads of my catfish suggested that the latter was so in the Waikato.

4.2 METHODS

From ovarian weights, the gonadosomatic ratio (GI) was calculated as an index of gonad maturity. The formula used was:

$$GI (\%) = \frac{\text{Gonad Weight}}{\text{Somatic Weight}} \times 100$$

where Somatic weight = Wet weight of fish - Gonad weight

A GI of less than 1% was considered to indicate a state of low maturity and ovaries in this category (established by

visual inspection) were not removed from the fish.

After weighing, the ovaries were split longitudinally, turned inside out, and placed in a jar with Gilson's Fluid preservative (Simpson, 1951). They were shaken vigorously and left to harden. Periodic shaking helped to loosen the eggs from the ovarian tissue. After at least four months, the eggs were washed. Owing to the large size range of eggs in some ovaries, the most effective cleaning method was to use a double filter system (Plate 3), through which the eggs were washed with cold water. After all the minute fragments of ovarian tissue had been removed, eggs were washed from both filters into beakers for measurement and counting. Each sample was made up to 500 ml in volume and subsamples were taken with a Stempel pipette (Plate 3) of 4.4 ml volume. After inverting the sample twenty times to randomly distribute the eggs, a subsample was taken and placed in a squared perspex plankton-counting tray. The eggs were counted and measured to the nearest 0.05 mm under a stereoscopic dissecting microscope, using an ocular micrometer. Because of the lack of symmetry in the eggs due to preservation, diameters were measured at random, rather than the maximum axis of each egg. De Jong (1939) said that in a frequency histogram of ova diameters produced by this method, the differences between modal groups appear less obvious than they are in reality.

Egg counts were corrected to give total numbers per 0.01 mm

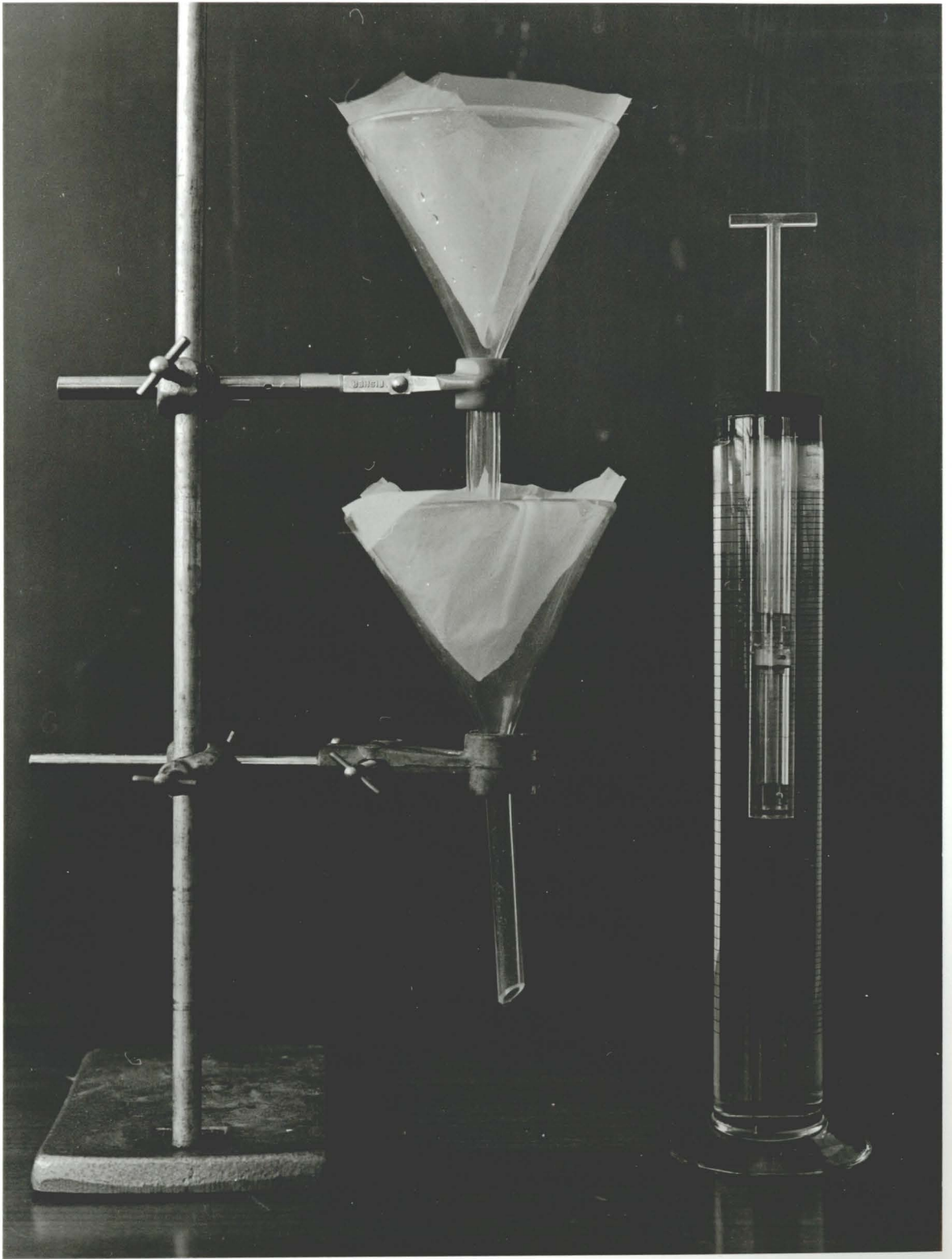
size class for each fish. Replicate counts showed a coefficient of variation of 7.4% between subsamples. Comparison between a total count of eggs for one sample (1100) and the number estimated from subsampling (1250) showed an error of 8.8%. Bagenal (1957) found a coefficient of variation of 10.05% in egg counts for the long rough dab. Simpson (1951) had a coefficient of variation of 9.57% in his study on plaice.

It was found that there was little variation in the weight or overall size of the testes between fish compared with that found between ovaries and because of this they were only occasionally removed. The testes of Ictalurids are lobate rather than compact, solid appearing glands as is usual in warmwater fish (Sneed and Clemens, 1963).

Sections were prepared from ovaries which had been fixed in Bouin's Fluid. The fixed gonads were washed in running tap water for 24 hrs to remove the Bouin's Fluid. Ovaries with small oocytes were cleared in xylol/chloroform, and embedded in paraffin wax in the normal manner. Ovaries with large heavily-yolked oocytes were cleared in Cedarwood oil. 10 micron sections were cut, stained in Ehrlich's Haematoxylin and counter stained in eosin. Duplicate sections were stained in Heidenhain's haematoxylin. It was found that sections stained in Heidenhain's gave much clearer photographs than did those stained with haematoxylin and eosin.

Plate 3

Egg cleaning apparatus, with 0.5 mm mesh filter
in the top funnel, 0.09 mm mesh in lower funnel.
Stempel pipette in 500 ml cylinder, showing the
sampling position.



4.3 GENERAL REPRODUCTIVE BIOLOGY

AGE AND SIZE AT MATURITY

No consistent external differences between the sexes were apparent in I. nebulosus, but the sexes could be differentiated by the gonad present in fish longer than 9.0 cm. In young of the year catfish (about 5.0 cm long) the gonads consisted of undifferentiated orange coloured tissue lying close to the vertebral column. The ovaries of a fish 13.0 cm long and in its second year of life, contained predominantly 0.1 - 0.2 mm diameter oocytes (95%), but some ova were up to 0.6 mm in diameter. The smallest sized fish with almost mature ova was 22.1 cm long, with a gonadosomatic index of 13.8%. The oldest fish found in the Waikato (7+) (Frontispiece) had no apparent gonads.

The female catfish first begins to develop secondary oocytes at a length of 13.0 cm and age 1+. Menzel (1945) reported the length at maturity for I. nebulosus in Virginia, USA, as being 15.2 - 18.0 cm, and it appears as though the size at first maturity is similar between the Waikato catfish and those from its native habitat. Menzel however does not quote the age at sexual maturity. Scott and Crossman (1973) said sexual maturity is attained by age 3 and a length of 20.3 cm.

SEX RATIO

The sex ratio for a total was found to be 52.6% females to 47.4% males. A Chi-square test showed no significant

difference from a ratio of 1:1 ($P = 0.4$). This relationship was as expected, because I. nebulosus is a nest building species (Breder, 1935).

4.4 SPAWNING SEASON

Although I. nebulosus is known to be a nest building species (Breder, 1935), no nests were ever located in the study area. This was because of the dense rooted macrophyte communities, which prevented any direct observations on the fish to determine spawning season.

Another method which may be used to establish the spawning season is by calculation of the percentage of ' running ripe ' fish per month. Fish which had large, fully yolked ova present were caught at intervals, but none in the ' running ripe ' condition were found. One possible reason is that ripe fish may have shed their gametes while held in the net overnight, but it is more likely that a fish in which spawning was imminent, would restrict its movements to the near vicinity of the nest and consequently would not be caught in a fyke net. In some species of fish the final stage of vitellogenesis is very rapid. Yamamoto and Yoshioka (1964) showed that in the freshwater fish Oryzias latipes, oocytes at the tertiary yolk stage (0.6 mm diameter) develop into the ripe stage (1.3 mm) over about half a day. The same may be true for the catfish, but an intensive study would be necessary to prove this. It has been established that catfish spawn during the day (Stranahan, 1910, Breder, loc.cit) and because my fishing took place at night time, there could have been sufficient time for rapid egg maturation which would ensure that no running ripe fish were caught.

4.4.1 SEASONAL REPRODUCTIVE CYCLE

Changes in ovarian weights through the year, represented by the gonadosomatic index (GI) have often been used to illustrate gonad development in fish studies. This index illustrates the seasonal state of maturity of a fish, and a graph of the annual variations of GI in a population is often used to estimate the type and length of spawning season (Yamamoto and Yoshioka, 1964).

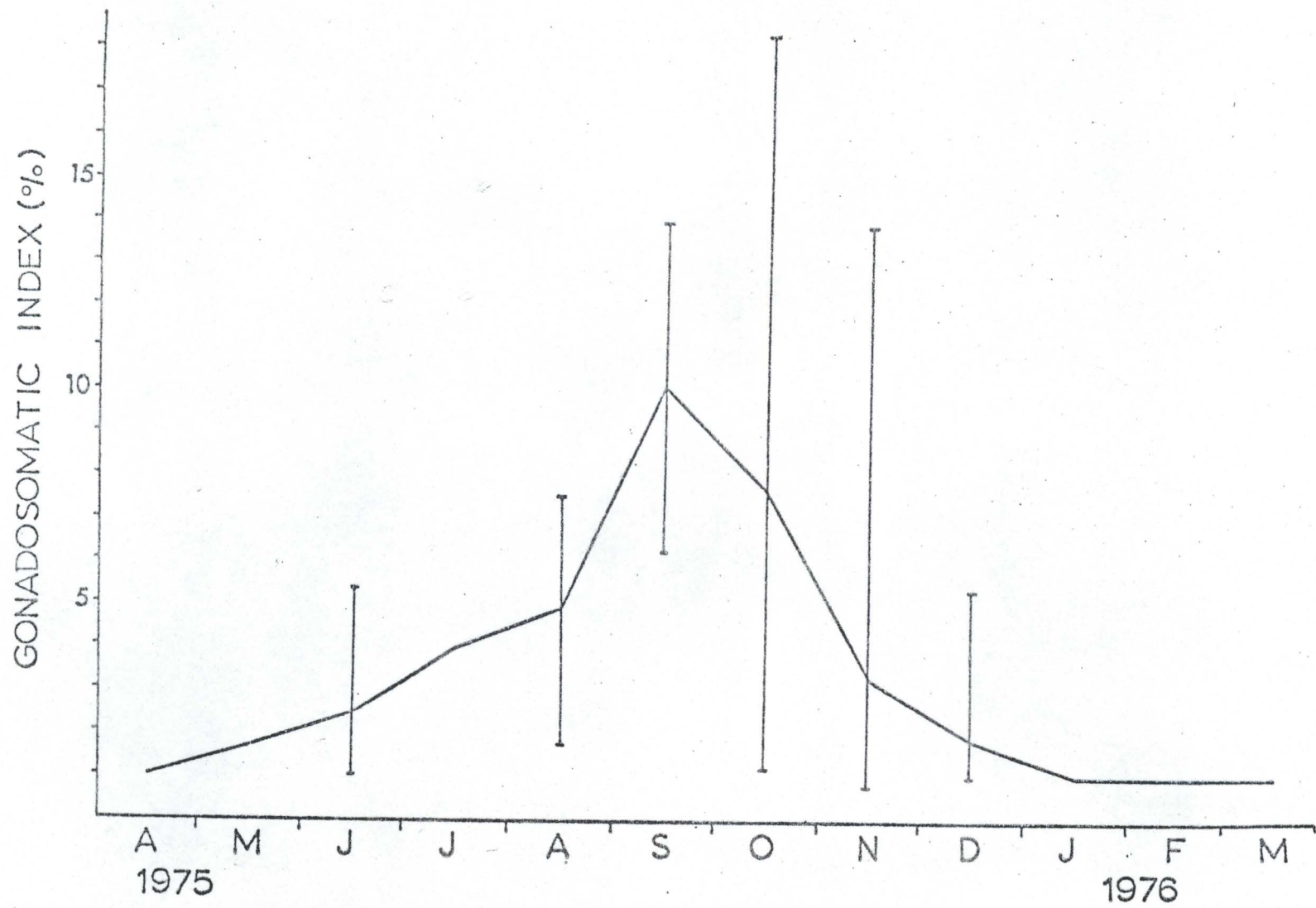
The annual GI measurements for the catfish are shown in Fig 14. The mean GI value increased during the early winter months (June through August) to reach a peak in September, after which the mean value began to drop, indicating the commencement of spawning. The rapid increase in mean GI which occurred after August corresponded to a general increase in water temperatures for the region at the same time (Fig 2), which suggests that the onset of maturation may be temperature dependent, a point which is clarified in the discussion of ova maturation. After spawning there was a gradual decline in the mean GI until February when all female fish had a GI of approximately 1.0%.

From the above evidence it was inferred that the duration of the spawning season was approximately four months, from September to December.

The descending region of the graph extends over three months, and this has been suggested to be characteristic of multiple

Fig 14

Annual Maturity Indices

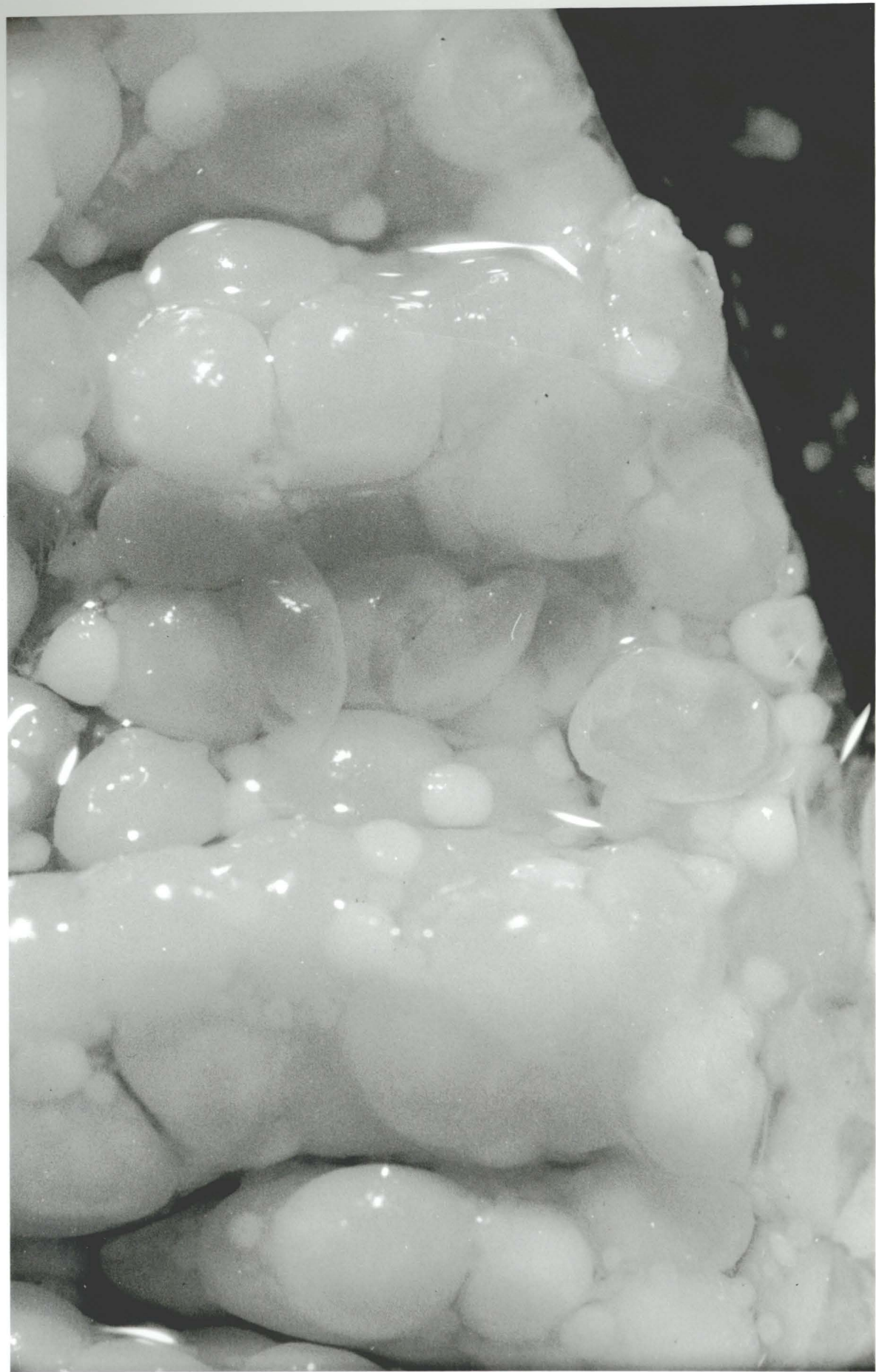


spawning fish. Yamamoto and Yoshioka (1964) showed that the curve of GI of Liopsetta obscura, a fish which spawns only once per year, falls abruptly after the commencement of spawning, from a GI of 28% to 1.5% in one month. However in the goldfish Carassius auratus, which spawns several times per season, Yamamoto and Yamazaki (1961) found a slow rate of descent of the GI curve after reaching its maximum value. The same type of curve has been found in other multiple spawners such as Scomber japonicus (Tateishi et al, 1957), and the Medaka Oryzias latipes (Yamamoto and Yoshioka, loc. cit).

The wide range of GI values through the months October/ November indicates that although the apparent peak of spawning was in September, fish were still maturing as late as November. This indicates a wide range in gonad maturation rates in the Waikato fish, which also suggests multiple spawning.

Plate 4

Ovary from a 32.2 cm fish, with a GI of
18.1%, caught on 8/10/75. The largest
ova were 3.0mm diameter



4.4.2 OVA MATURATION

INTRODUCTION

Hickling and Rutenberg (1936) suggested that measurement of the diameters of ova from ovaries well advanced towards spawning may give evidence of the duration of spawning. From the general egg stock, of small yolkless transparent eggs, a quota is withdrawn each year, to be matured and eventually spawned, and a new batch of oocytes, which have developed beneath the surface of the ovigerous lamellae, is added to the general stock. If the spawning season is short and definite, the eggs withdrawn will be in a single batch clearly distinguishable, at least in the late maturation stages, from the parent egg stock. When the season is long and indefinite, withdrawal of eggs from the general egg stock will be a continuous process and no sharp separation between the maturing and general stock will occur. A cursory examination of catfish ovaries showed that two, possibly three, size groups of ova were present (Plate 4), which suggested that the spawning season might be long and indefinite, with multiple spawning occurring.

OOGENESIS

A histological study of oocyte maturation in the catfish showed five developmental stages:

1) Oogonia

These cells, of about 5 microns diameter, appeared in

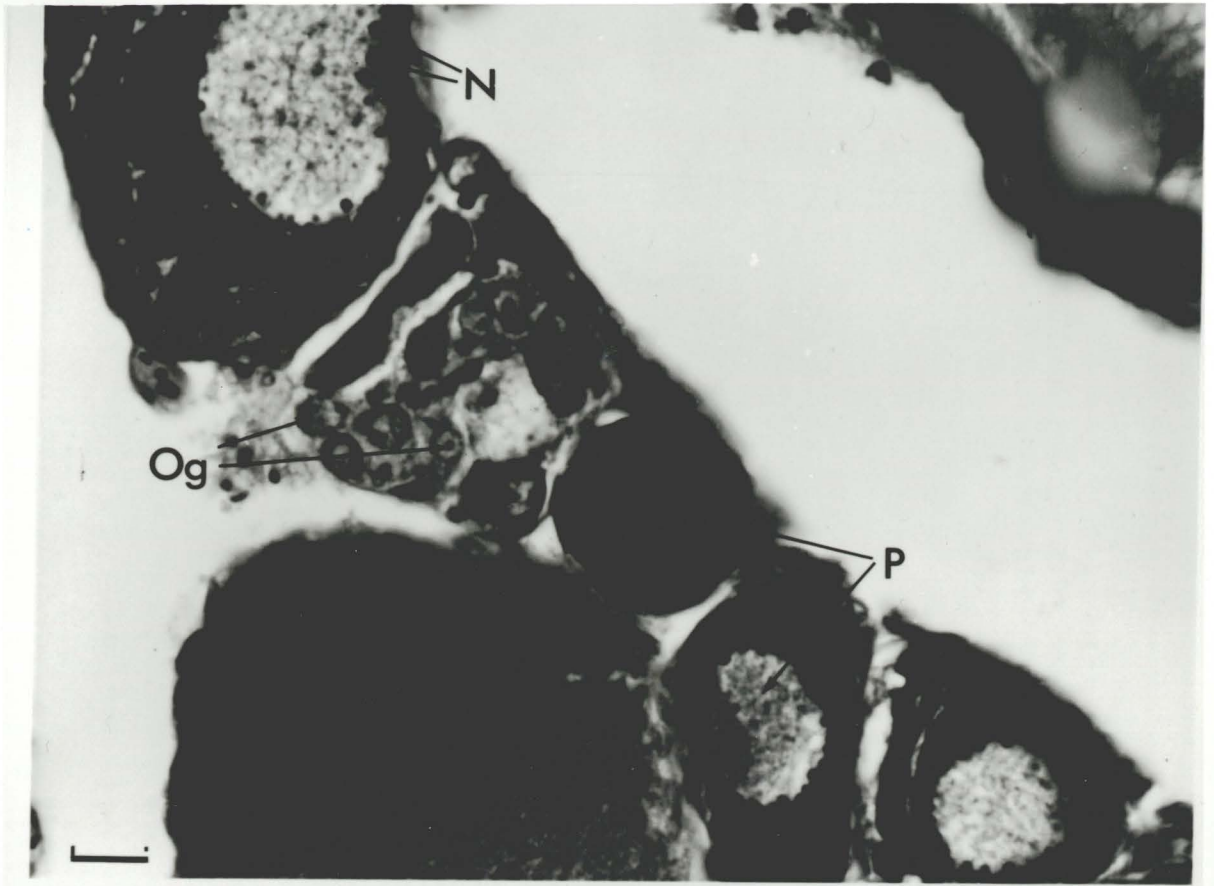
Plate 5

A Transverse section of an ovary showing
developing oogonia (Og), primary oocytes
(P), and nucleoli (N).

Scale = 20 microns Heidenhain's haemotoxylin

B Transverse section of an ovary showing the
stages of vacuolation (V) of secondary oocytes
from the point of first appearance of vacuoles
(stages 1, 2, 3).

Scale = 60 microns Heidenhain's haemotoxylin



'oogonial nests ' scattered around the ovary (Plate 5A). They were apparent in fish caught in late summer but not in a recently spawned fish caught in spring, and it appears that the catfish follows the pattern found in many teleosts (e.g Mystus tengara, Guraya et al, 1975) with the oogonia (the new season's stock) only developing towards the end of a spawning season.

2) Primary Oocyte

The size of these developing oocytes ranges from 0.04 to 0.2 mm in diameter. The nucleus is large and the cytoplasm stains deeply with haematoxylin. A number of nucleoli (10-25) are arranged around the periphery of the nucleus (Plate 5A). When ovaries were preserved in Gilson's Fluid, a large number of small oocytes less than 0.1 mm diameter were apparent in many fish. These oocytes had a white nuclear region, about half the total diameter, and a milky cytoplasm surrounding it. They were very different from the oocytes larger than 0.1 mm, which were completely white. Because of their number, it was thought that, rather than being artifacts, they were small primary oocytes which had been affected by treatment in Gilson's Fluid because of some feature of their cytoplasm. Because the egg samples were filtered through a 0.09 mm mesh it is probable that most of the smaller oocytes of this type were lost. In the ova diameter frequency analysis these oocytes were grouped under a

category called preprimary oocytes.

Secondary Oocytes

3) Vacuolation

Vacuoles, which increase in size and number as the oocyte develops (Plate 5B), first appear in the periphery of the cytoplasm of oocytes of a minimum size of about 0.2 mm in diameter (in sectioned material).

4) Vitellogenesis

This process first occurs in oocytes of about 0.6 mm diameter, when yolk droplets appear associated with the vacuoles. These droplets stain deeply with haemotoxylin. As vitellogenesis continues, the oocytes become so heavily yolked that they are very difficult to embed in paraffin wax. Plate 6A shows a heavily yolked oocyte and Plate 6 the details of the membranes surrounding a vitellogenic egg. An important feature here is the size of the granulosa cells which are thick and well developed. In teleosts such as Cheilodactylus macropterus with free floating eggs, the granulosa consists of flattened follicle cells (Tong and Vooren, 1973). The reason for the better development of the follicle cells in the catfish is probably because the eggs are adhesive rather than planktonic.

5) Mature Eggs

Mature eggs were identified from the samples preserved in Gilson's Fluid, and were in the size range 2.5 - 3.2 mm in diameter.

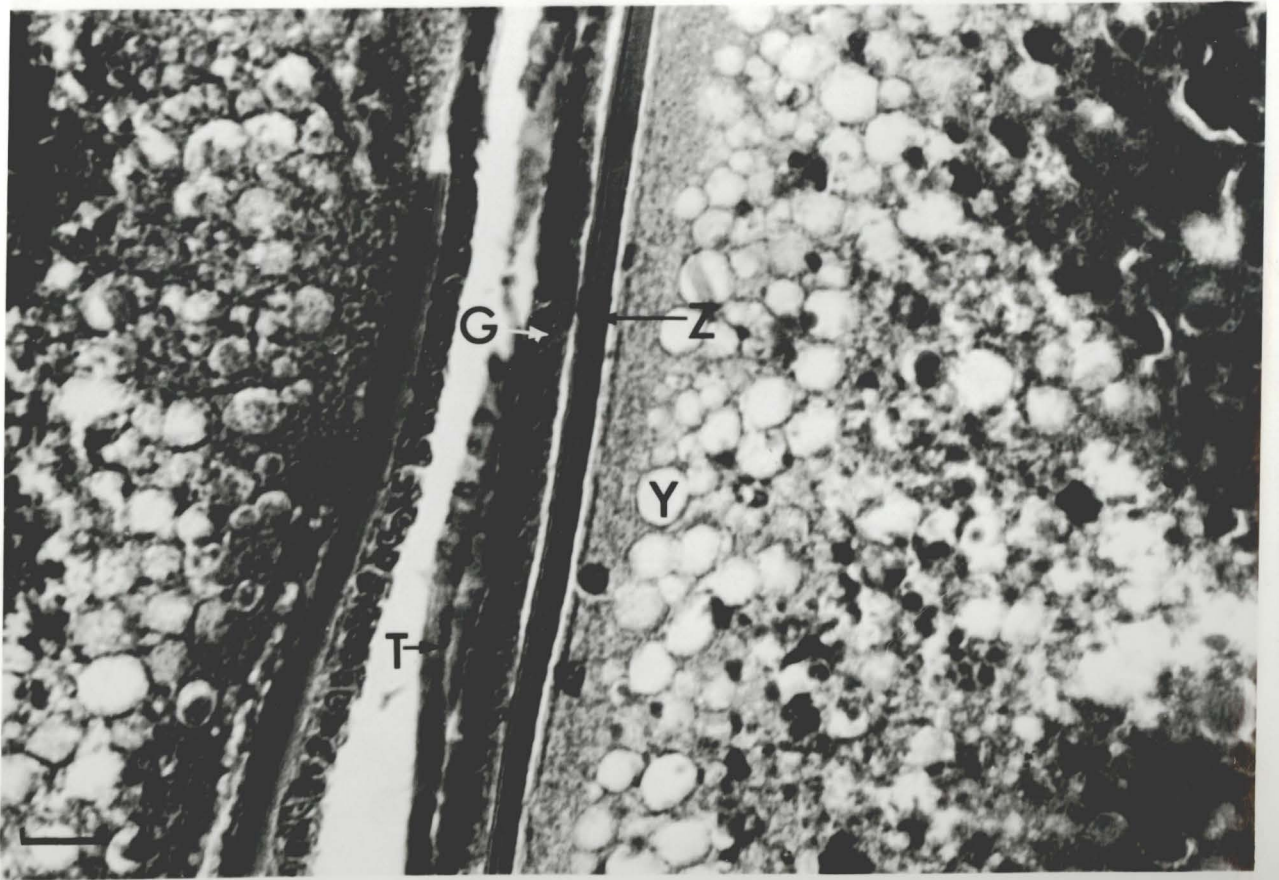
Plate 6

A Transverse section of an ovary showing a heavily yolked secondary oocyte of 1.0 mm diameter.

Scale = 770 microns Haemotoxylin and eosin

B Detail of an egg showing the theca (T), zona radiata (Z), and yolk globules (Y).

Scale = 20 microns Haemotoxylin and eosin



RESULTS

The results from the gonadosomatic index study suggested that the onset of spawning was controlled extrinsically by temperature. However, if the triggering of ovary maturation was extrinsic, then the ovaries of similar sized fish, collected in the same sample would be expected to be at approximately the same stage of maturity. The ova diameter frequency distributions in a sample of seven 2+ fish are shown in Fig 15. It is apparent that there was wide variation between the fish, which suggests that the onset of maturation is not controlled extrinsically by a single factor. It is more likely to be decided by several factors such as the individual's internal readiness and availability of spawning sites as well as the overriding influences of temperature and photoperiod. Guraya et al (1975) concluded that the interaction of these factors controlled the onset of maturation in the Indian catfish Mystus tengara.

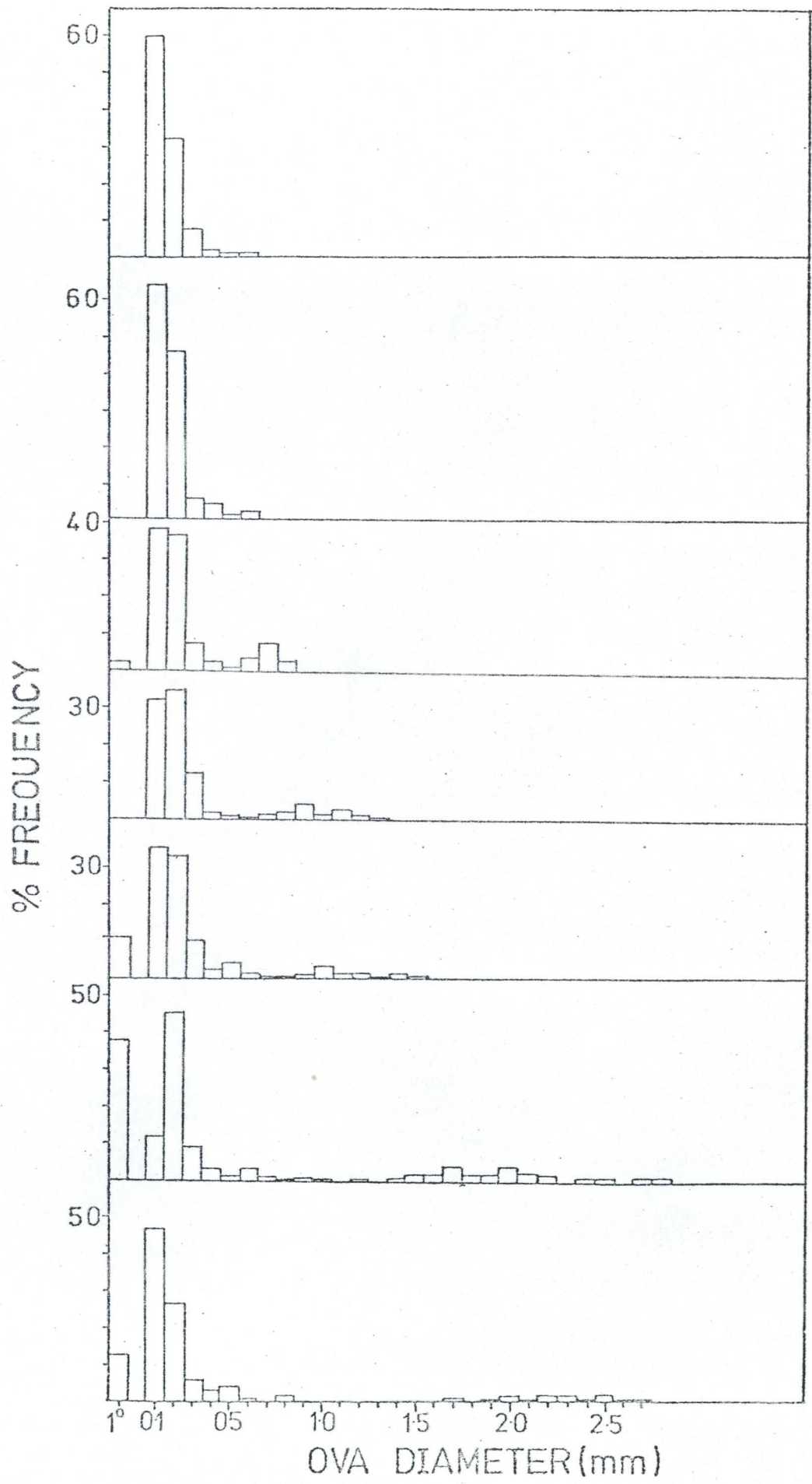
Since there was such wide individual variation, no chronological arrangement of ova diameter data to show ova maturation could be made. The results have been grouped into six stages, using the criteria shown in Table 5, and according to the location of the largest mode in the ova diameter frequency distribution for each fish. This type of classification has been used by Clark (1934) and Saigal (1967) with multiple spawning fish in preference to the International Maturity Scale of Hjort (1911) and the scale of Nikolskii

Fig 15

Ova diameter measurements for seven

2+ fish (caught on 6/11/75).

Mean length = 23.0 cm (22.1-23.9)



(1963). The cut-off point for each stage was arbitrary and does not reflect the continuous process occurring in the ovaries. Figures 16 - 21 show the maturation of ova from ovaries of fish caught between April 1975 and May 1976. Fish with a gonadosomatic index of less than 1.0% (stage I) were not usually removed for analysis.

Table 5 Ovary Stages

Stage	Characteristics
I (immature)	Predominance of immature ova 0.1-0.2 mm in diameter (primary oocytes). Macroscopically few eggs distinguishable to naked eye. Ovary turgid, GI less than 1.0%. No preprimary oocytes present.
II (maturing)	Two categories of ova present, large primary oocyte class and small group of secondary oocytes greater than 0.03 mm diameter. At the beginning of this stage, eggs just visible to naked eye, ovary turgid and 40% length of body cavity, GI from 1.0-1.5%. At end of stage, ova up to 1.0mm diameter and yolky, GI greater than 1.7%, preprimary oocytes first apparent.
III (maturing)	Ovaries occupy up to 70% length of body cavity eggs golden coloured. Continuous distribution of ova from 0.1-1.5 mm in diameter at end of stage, with three modal groups apparent. Pre primary oocytes present in large numbers, GI up to 6.0%.
IV (mature)	Ovaries occupy up to 90% of body cavity, eggs yellow coloured. Discontinuous distribution of ova, with ultimate modal group separate from main body of 2 ^o oocytes. GI from 6.0-18.0%. At end of stage, ultimate modal group at mean size of 3.0mm and mature.
V (partially spent)	Ovaries flaccid compared with stages I-IV. GI from 1.0-2.5%. Two modal groups, with largest of 1200-1500 ova.
VI (recovering spent)	Primary oocytes predominate. GI less than 1.0%. Differentiated from stage I by flaccidness of ovary.

Figs 16-21

Ova diameter histograms from fish
caught between April 1975 and May
1976, showing ovarian stages I - VI

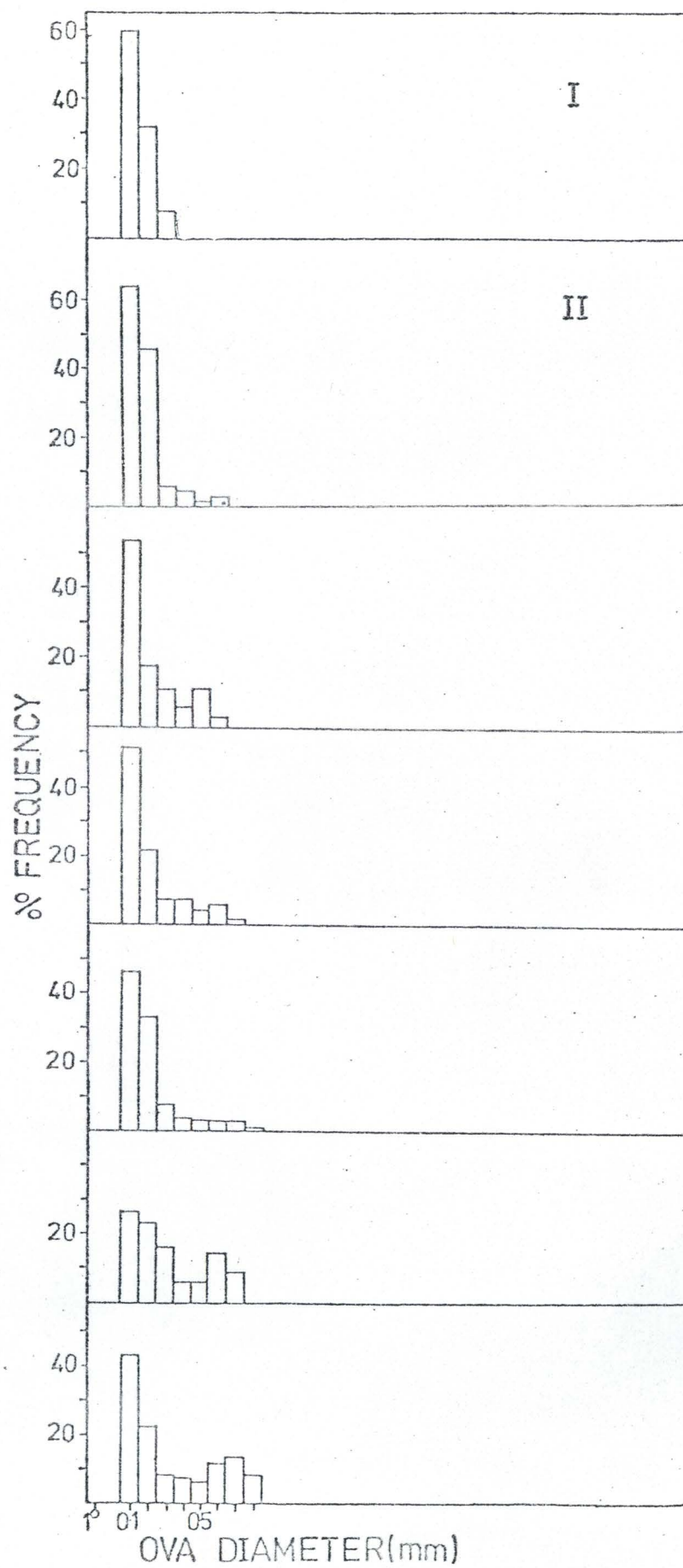


Fig 16

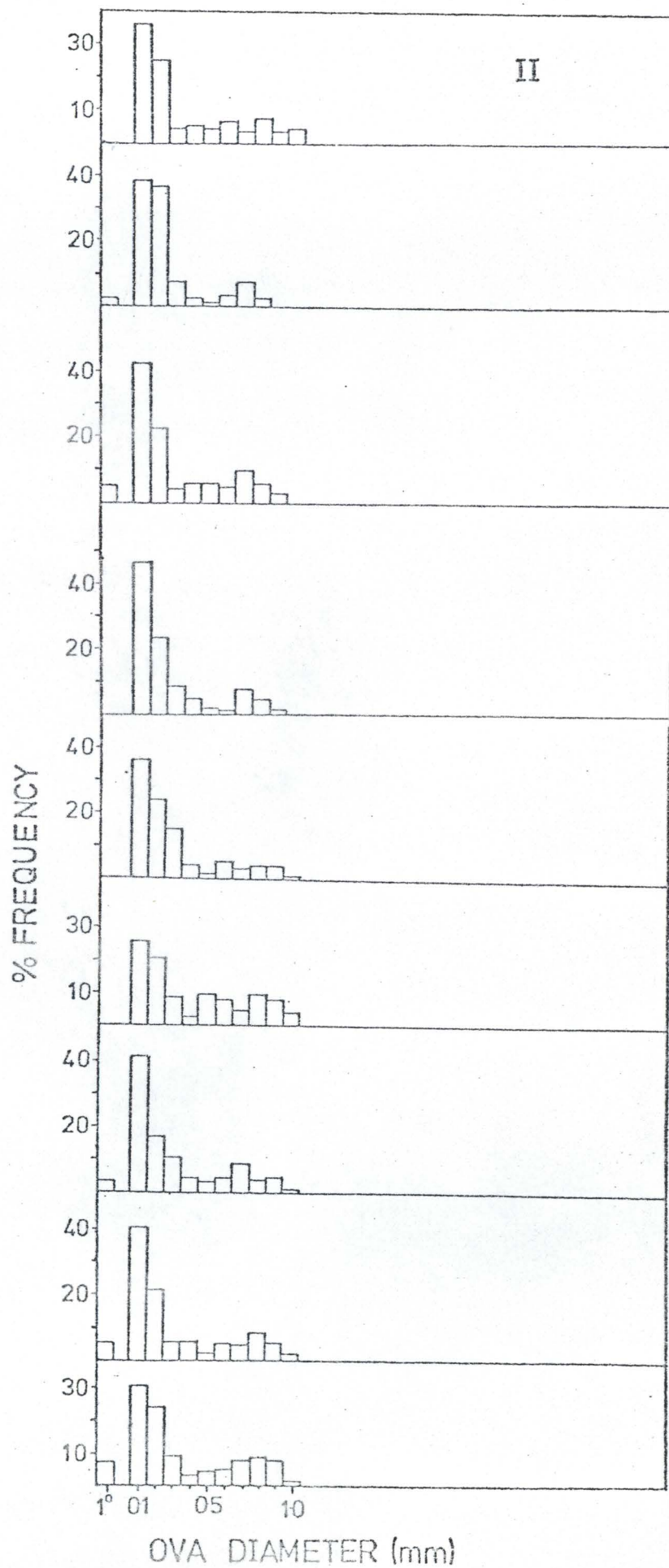


Fig 17

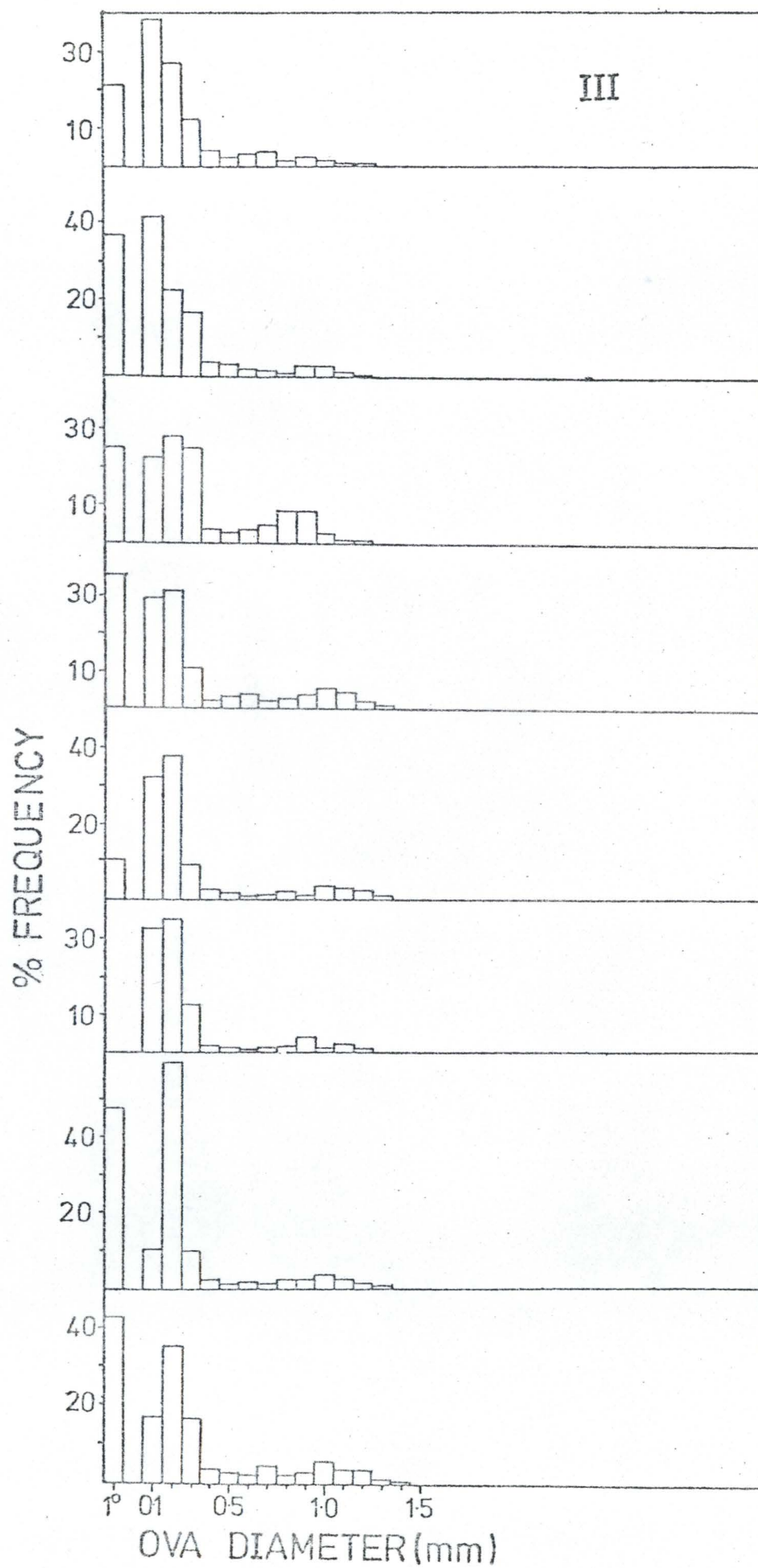


Fig 18

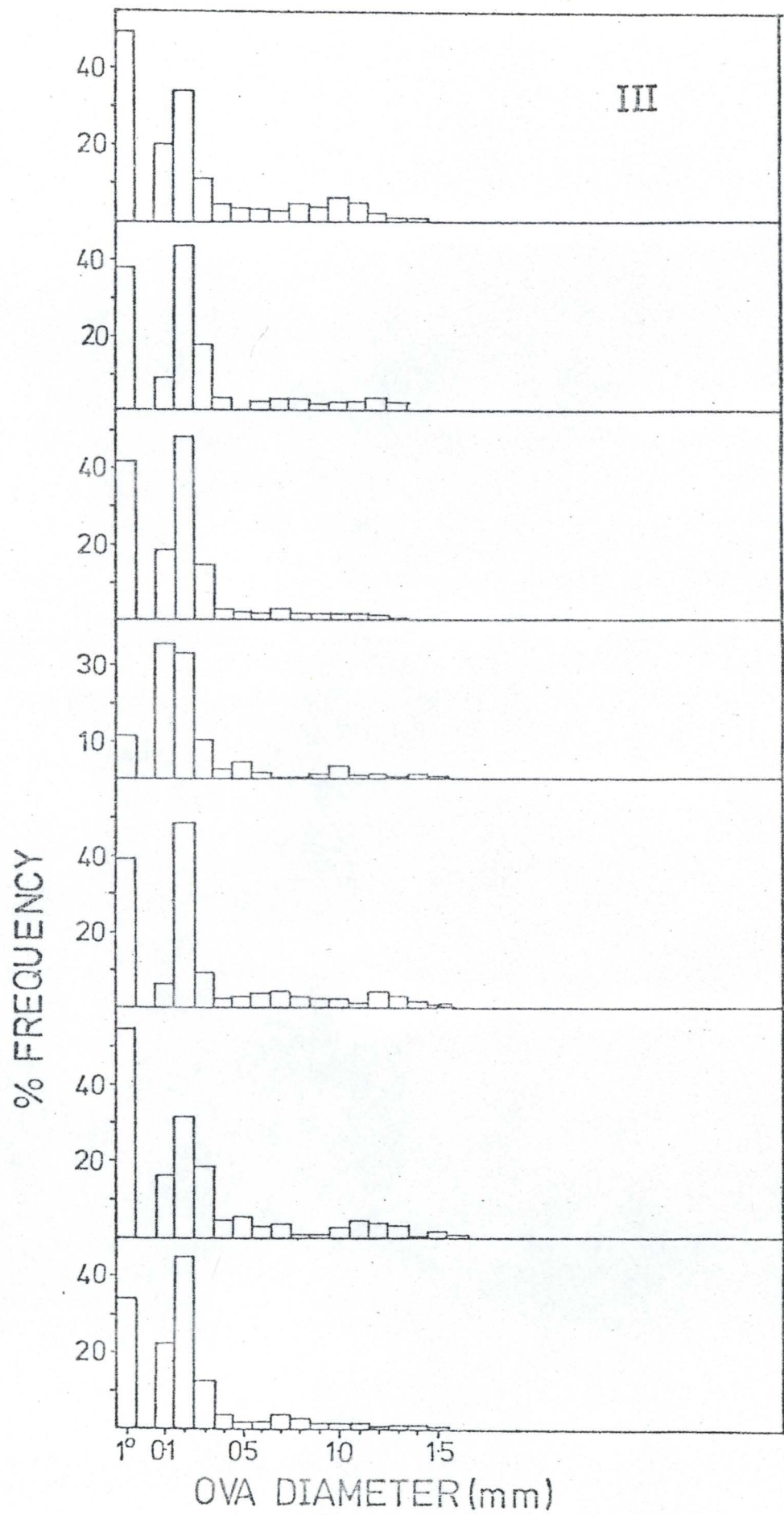


Fig 19

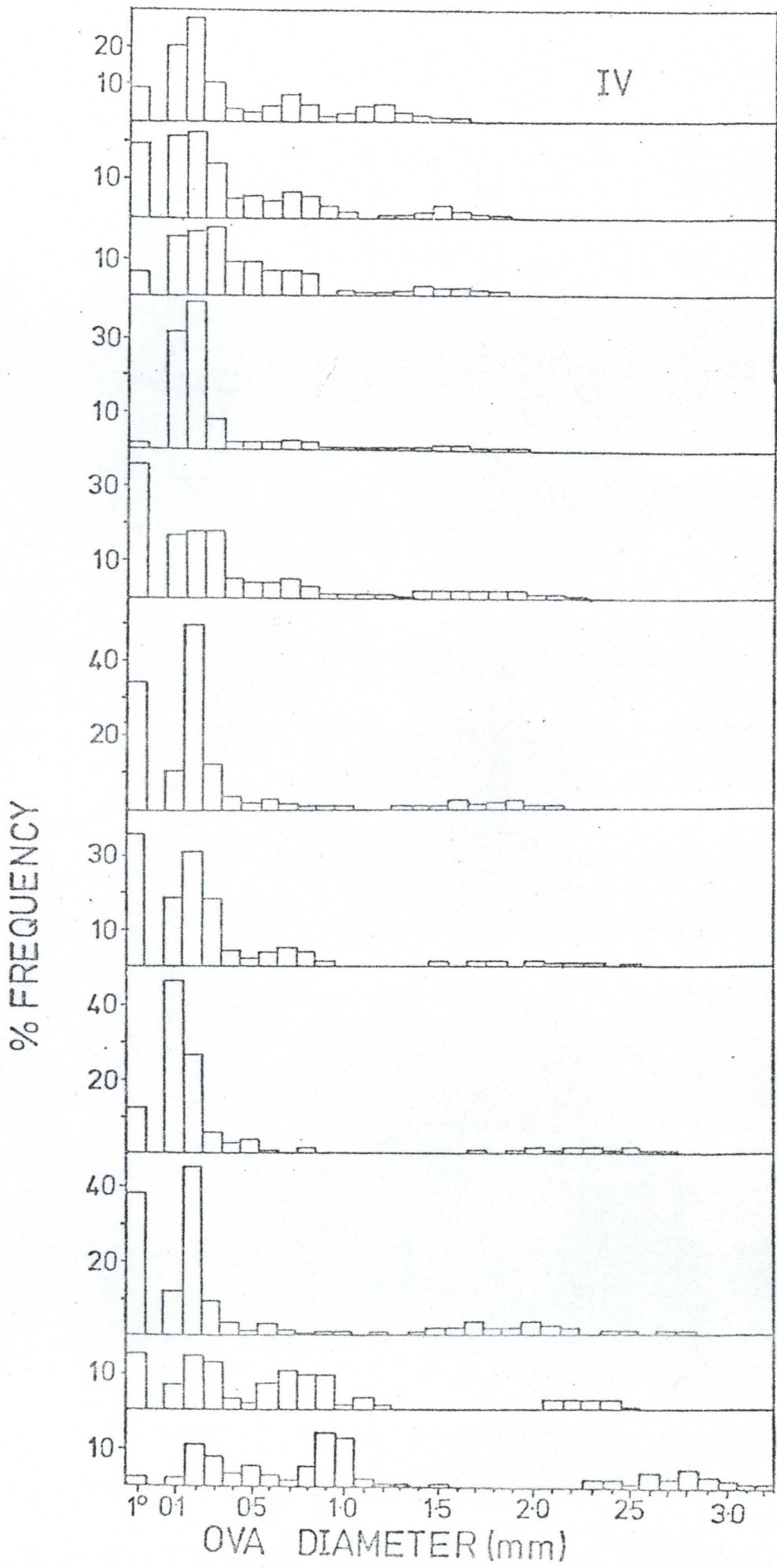


Fig 20

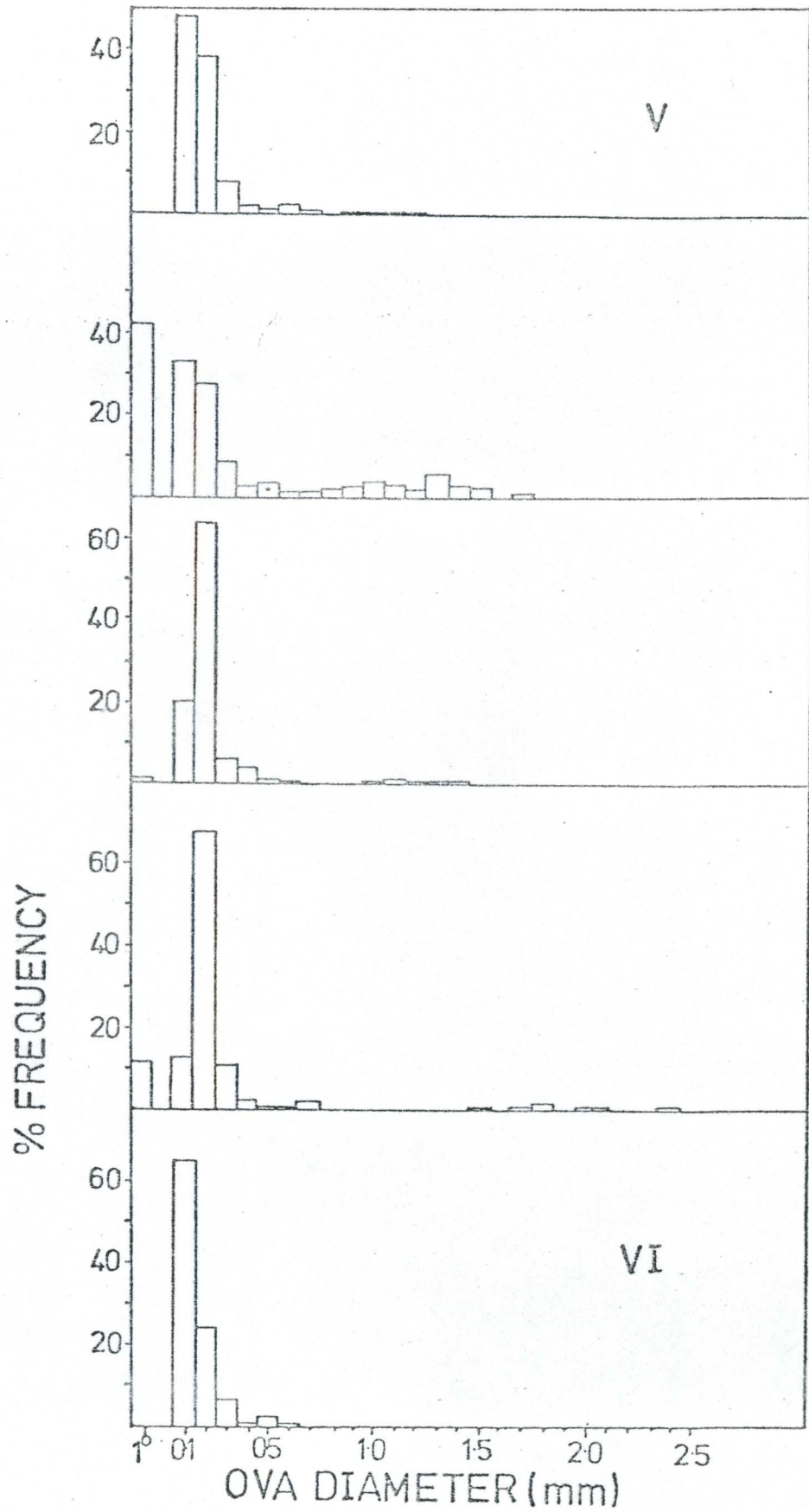


Fig 21

No secondary, nor preprimary, oocytes were apparent in the stage I ovaries examined (Fig 16). The lack of these oocytes, and the large numbers of oocytes in the 0.1-0.2 mm size class, suggested that this was the general egg stock of primary oocytes which would provide the eggs for the coming years spawnings.

As development progresses into stage II (Figs 16&17), the ova increase in size, become vacuolated, and the percentage frequency of ova in the general egg stock begins to decrease. At the end of this stage there is a continuous range of ova sizes from 0.1 to 1.0 mm, with vitellogenesis occurring in the larger oocytes and preprimary oocytes begin to appear. This apparent lag in production of preprimary oocytes was probably due to the effect of using a 0.09 mm filter. If the production of oogonia was a discrete process rather than continuous, then this would show up as a discontinuous distribution of primary oocyte sizes, as has occurred. The general egg stock seems to be diminishing in size as ova are removed from it, but with no apparent input from preprimary oocytes during most of this stage, until some of the larger oocytes have reached 1.0 mm in diameter. According to Hickling and Rutenberg (1936) this pattern is indicative of a long and indefinite spawning season because the withdrawal of eggs from the general stock is continuous, and no sharp separation between the general and maturing stocks occurs. Bagenal (1967) stated that " In some cyprinids

the eggs mature slowly and the spawning season is prolonged. In such cases all of the maturing eggs are not of the same size and do not differ markedly from the recruitment stock. A size frequency diagram of egg diameters in the ovaries would exhibit a number of modes, and a sharp distinction between the recruitment stock and the maturing eggs would be difficult to make ". Such a pattern is apparent in this stage and becomes even more evident in stage III.

In stage III (Figs 18&19) the number of preprimary oocytes increases and accounts for up to 50% of the total number of oocytes. As the mean diameter of the ultimate modal group increases, the percentage of primary oocytes (1^o and general stock) fluctuates, suggesting that even during this stage primary oocytes are becoming vacuolated. At the end of this stage ova of all sizes from 0.1 to 1.6 mm in diameter occur, with three modal groups present at; 0.2, 0.5, 1.5 mm diameter (separated by Cassie's, 1954, length frequency analysis method).

In stage IV (Fig 20) the ultimate modal group eggs have become very yolky and in preserved material are golden in colour compared with the penultimate group of ova which are white. The ova diameter distribution becomes discontinuous as these large ova reach maturity, suggesting that they develop in size at a much faster rate than do the other secondary oocytes. The last ovary shown in the stage IV series has an ultimate modal group of ova from 2.3 - 3.2 mm

in diameter, which were considered to be fully mature.

Menzel (1945) found the eggs of sexually mature bullheads to be 2.0 - 2.5 mm in diameter, but Armstrong and Child (1962) indicated a size at maturity of 3.0 mm. Bachmann (1914) indicated a size difference of 1.0 mm between the eggs in different nests.

Stage V (Fig 21) is composed of fish which appeared to have already spawned at least once. The ovaries were up to 50% of the length of the body cavity but were flaccid. Ova from these fish were in two major size groups, the largest with a mean diameter of 1.7 mm.

The size range of ova from a stage VI fish (Fig 21) was similar to that in a stage II fish but the ovary was flaccid compared to the latter. It was thought that the ovary was in this state because the ovary walls had insufficient time to shrink after being subjected to the large ova of stages IV and V. It was probable that the ovary was in this condition for a very short time, since only one was ever found.

DISCUSSION

The polymodal distribution of ova in almost mature ovaries strongly suggested that as the ultimate modal group of ova was matured and was spawned, the preceding (penultimate) group also matured to be spawned later in the season. Other investigators since Hickling and Rutenberg (1936) have found the same patterns of ova maturation in

fish and concluded that it indicated multiple spawning (e.g Clark, 1934, Saigal, 1973). All investigators have found it necessary to show that the penultimate group of ova does not represent eggs that will be spawned in succeeding seasons , or does not comprise eggs that will never ripen but will degenerate and be resorbed at the end of the season. If only one batch of ova is spawned per year, then a relatively constant ratio between the number of maturing and mature ova would be expected. However it was found that the ratio in fish with stage IV ovaries ranged from 1:10 to 1:5. Examination of stage V ovaries provided further evidence for the spawning of the penultimate modal group of a stage IV fish. These stage V fish were presumed to have spawned earlier in the season because of the flaccidness of the ovary. Ovaries of this type were first seen in December but most occurred in February. The ultimate modal group in these ovaries contained only about 1500 ova, approximately half the number in the ultimate modal groups of stage IV fish, even though they were in several cases much larger fish. It was concluded that these were not residual eggs being resorbed since they did not break down in Gilsons Fluid in which, according to Macer (1976), atretic eggs would. Sections of stage V ovaries showed large vitellogenic ova present with no signs of mass atresia, although occasional resorbing eggs were apparent (Plate 7B).

The stage V ovary from a fish caught in December had a large

number of empty follicles present (Plate 7 A) which indicated that the fish had previously spawned, and also had many vitellogenic oocytes present. In the stage V ovaries taken in February there were only occasional remnants of empty follicles present. The vitellogenic oocytes in these February fish were larger than those in the December fish which suggests that if the follicles remain in the ovary for a long time, then the speed of vitellogenesis is slow. The actual time for which empty follicles remain in the ovaries varies between fish species. Yamamoto and Yamazaki (1961) found that the follicles existed for a long time in the goldfish Carassius auratus, but Yamamoto and Yoshioka (1964) found they disappear within three days in the Medaka Oryzias latipes. It appears that the rate of disappearance of the follicles is closely linked with the rate of vitellogenesis, which is very rapid in the Medaka.

The evidence outlined above suggests that multiple spawning occurs in I. nebulosus but gives no indication of the periodicity involved. Clark (1934) found that the oocyte maturation rate was slow in the Californian sardine. If the rate of maturation is similarly slow in the catfish then the pattern would be as follows:

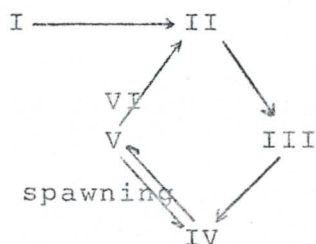


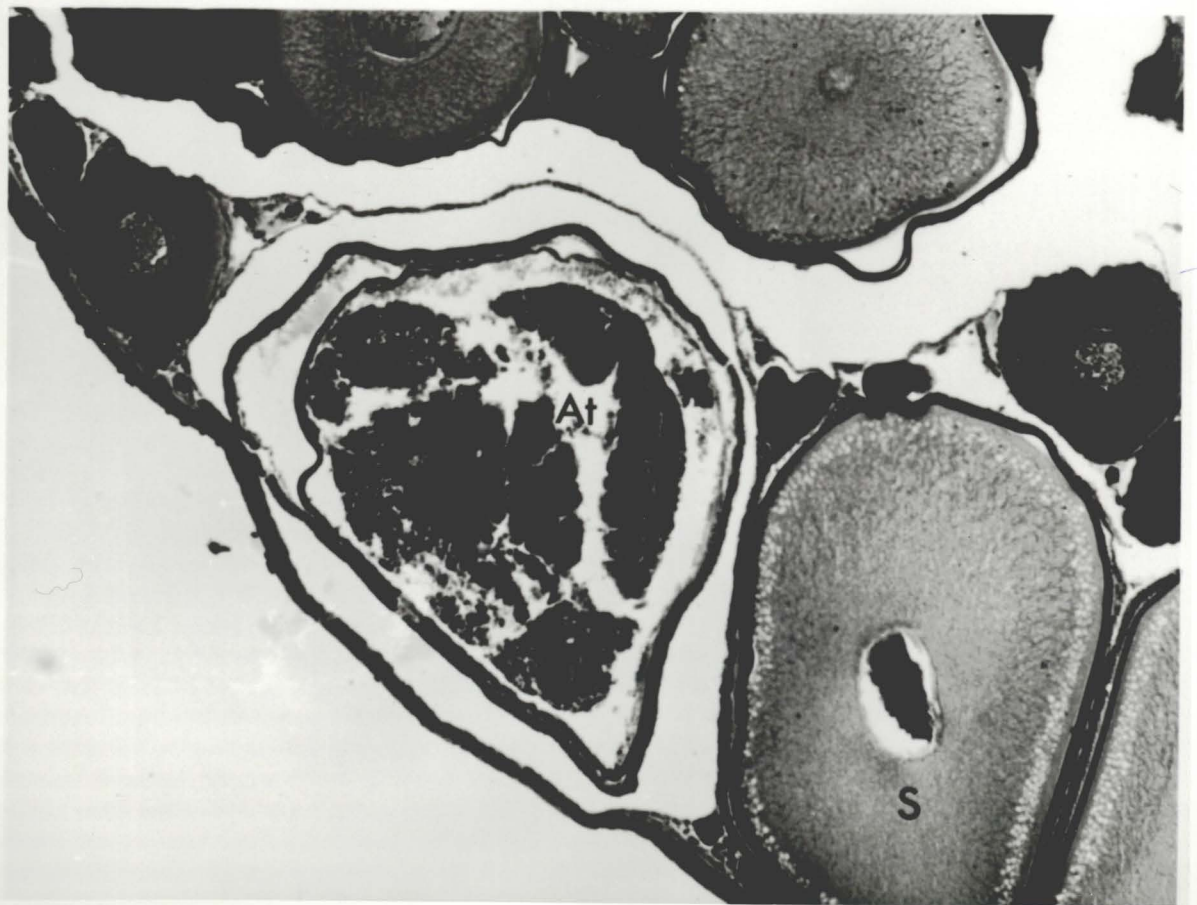
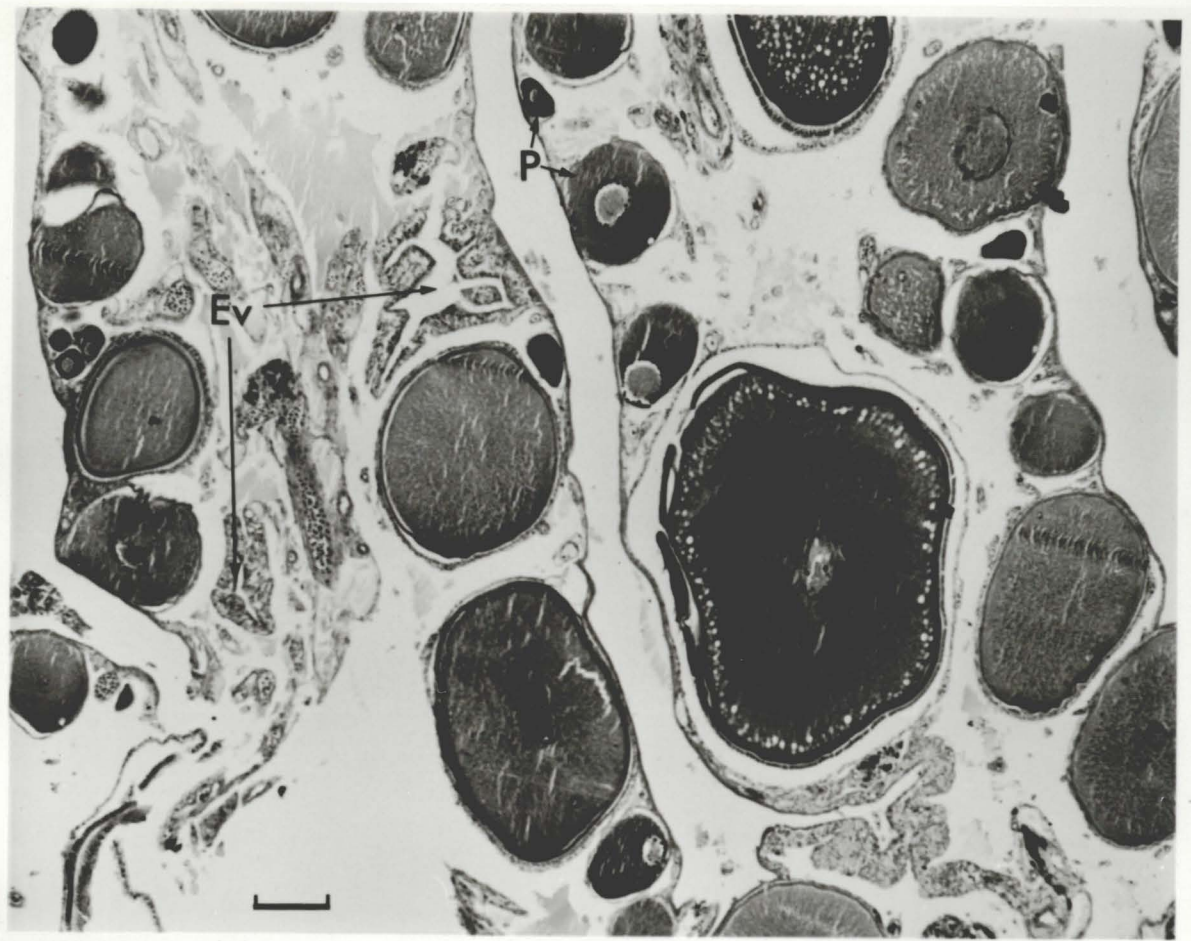
Plate 7

A Transverse section of an ovary from a stage V fish caught in December, showing evacuated follicles (Ev), primary oocytes (P), and vacuolated secondary oocytes (S)

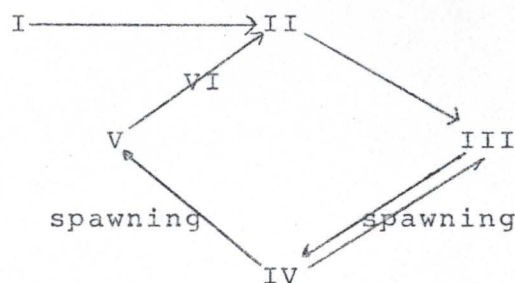
Scale = 200 microns Heidenhain's haemotoxylin

B Transverse section of Stage V ovary showing atresia (At), and secondary oocytes (S) with a dark band of yolk forming near the vacuoles.

Scale = 150 microns Heidenhain's haemotoxylin



As a fish spawned it would pass from stage IV to V then whilst the next modal group matured, the fish would pass back into stage IV. When the last batch of ova for the season had been spawned, the fish would then pass into stage II, a resting phase, where the number of primary oocytes was built up for the following season. It is also possible that the period of maturation between stages III and IV is very short rather than a long process as portrayed by the scheme above. The final stages of the process of vitellogenesis may be very rapid and most of the increase in size of the late maturing oocytes may be due to water uptake. With such a rapid maturation process the pattern would be:



In this situation the time spent in stage IV and V would be brief, with the major part of the cycle being spent in stages II and III.

Irrespective of the speed of the final stages of vitellogenesis in the ultimate modal group of ova, it would be probable that the interval between spawning of successive batches of ova would be equal to the length of time from spawning to the point where the school of young guarded by the parents breaks

down (approximately 3 weeks, Breder, 1935). The minimum time at least would have to be 6 - 9 days because it has been established (Armstrong and Child, 1962) that during the post-spawning period the eggs must be continually aerated by the parents for them to be viable (Appendix 3). The burden placed on the parents i.e continually aerating the eggs and caring for the developing young, would probably be too great for any less than three weeks ^{between} batches to occur.

The duration of the spawning season can be estimated by the time between the first appearance of stage IV fish and the time when the last stage V fish was caught. The first stage IV fish, with ova of up to 1.8 mm in diameter, were found in June 1975 (Table 6) but a fully mature fish was not caught until August. It is impossible to determine how close the June fish were to spawning because the speed of the final stages of vitellogenesis is not known. It can only be surmised that the beginning of the spawning season for the catfish is, at the earliest, late June. The last stage V fish was caught in late February, indicating a late February /March close to the season. This nine month spawning season is much longer than was suggested by the gonadosomatic index study which shows that analysis of ova maturation, rather than changes in gonad weight, is a more reliable indicator of duration of spawning season. However it is unlikely that individual females were spawning right through this period. To precisely determine the length of the spawning season, a

Table 6

Monthly Variation In Ovarian Stages Of Fish

	Numbers of fish/stage/month*				
	II	III	IV	V	VI
April	2				
May	3				
June	10	4	4		
July		1			
August	1	1	1		
September			2		
October	1		4		
November	3	1	2	1	
December	1	1		1	1
January	4		1	1	
February			1		
March					
April	1				
May	3	10			

* includes fish staged only by gonadosomatic index.

detailed histomorphological study of ovarian changes through the year would be necessary (as done by Yamamoto and Yamazaki, 1961).

Further evidence for a long spawning season is provided by the wide range of calculated lengths from the age and growth study, where fish at age 1 varied in length from 5.4 to 14.6 cm. Although some variation may be expected due to different growth rates, the wide range found is best explained by a long season.

Marza (1938) suggested three categories of oocyte maturation and since then a number of authors have followed this system (e.g Guraya et al, 1973, Yamamoto and Yoshioka, 1964). The categories are:

- a) Total synchronism - where all the oocytes develop synchronously in the ovary, as in Onchorynchus masou (Yamamoto et al, 1959)
- b) Partial synchronism - where two groups of oocytes can be distinguished, indicating spawning once per year, with a short and definite season as in herrings (Hickling and Rutenberg, 1936)
- c) Asynchronism - where several batches of oocytes in different stages are present, indicating a long spawning season and several spawnings within the season, as in sardines (Clark, 1934).

The polymodal frequency distribution of oocytes in a mature ovary of Ictalurus nebulosus indicates that the species

belongs to this third category. The fact that the intermediate batches of ova do not appear to degenerate but are spawned, indicates the catfish is capable of multiple spawnings in a season. The results do not reveal the exact number occurring but suggest a minimum of two.

4.5 FECUNDITY

Fecundity is here defined as the total number of secondary oocytes present in the ovaries prior to the first spawning of the season.

The relationship between egg numbers (N) and length of fish is shown in Fig 22. A natural log transformation was made on the data, as suggested by Bagenal (1966), to stabilise the variance along the regression line. The relationship was of the form $y = ax^b$ where $b = 2.375$. Thus the numbers of eggs increased with the length of a fish. It is not valid, however, to say that the calculated egg numbers equalled the number of eggs to be spawned in a season because it was apparent that primary oocytes were developing into secondary oocytes continuously through the year.

However, an indication of the number of eggs which may be spawned in a season can be gained by determination of the number of yolked oocytes in stage IV and V fish (Table 7). On the assumption that there was a minimum number of two spawnings in a season, summation of the numbers of ova in the ultimate modal groups of stage IV and V fish will give a minimum number of eggs to be spawned in a season. The possible range was from 3522 (2499 + 1023) to 7443 (6137 + 1306) depending on the size of fish. If, in addition, the penultimate group from stage IV is also released, then the number spawned could be up to 17,000.

Berg (1949) estimated that I. nebulosus in the USSR spawn

Fig 22

Egg Numbers Versus Length

$$\ln N = \ln 12.93 + 2.375 \ln L$$

The regression accounted for 52.3% of the variation

$$F = 40.56 \quad P = 0.000000$$

N = Number of secondary oocytes

L = Length of fish

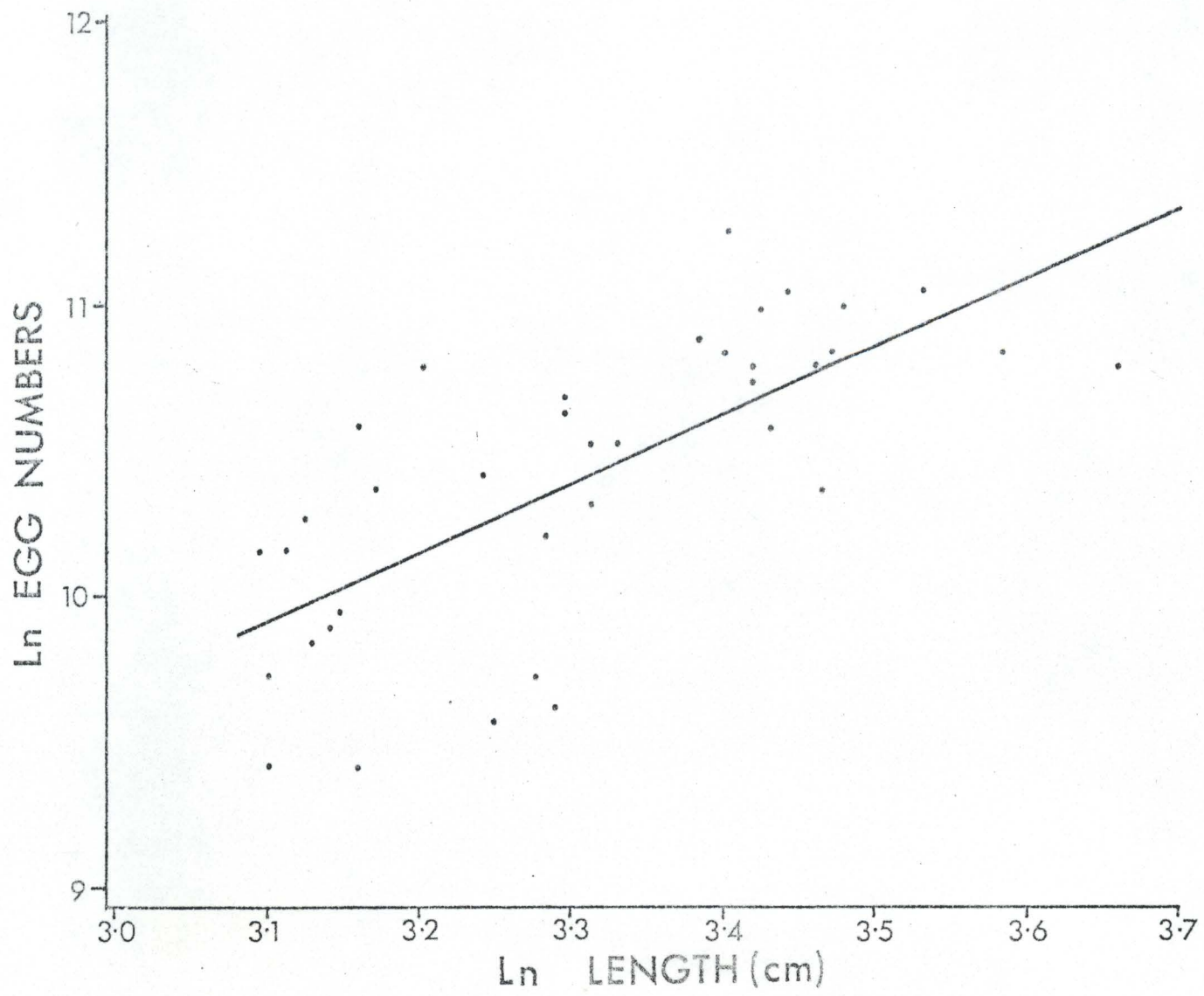


Table 7

Oocyte Numbers In Stage IV And V Fish

	Length of fish (cm)	Number oocytes in ultimate group	Number oocytes in penultimate group
	36.0	6010	indistinct
	32.2	3864	6024
	32.0	2499	3522
IV	27.9	2954	7726
	27.4	3863	9431
	26.9	2500	8066
	26.8	2885	6476
	23.6	6137	5663
	22.1	2499	3522
	37.1	1306	
	29.3	1023	
V	23.5	1250	
	25.1	1250	

2000-3000 eggs per year which is considerably less than the minimum number of eggs indicated in this study.

The total number of secondary oocytes in catfish ovaries prior to spawning varied from 12,159 to 76,021 for fish from 22.1 to 36.0 cm long, which is considerably higher than the 2000-13,800 (Mansueti and Hardy, 1967) and 6000-13,000 (Eddy and Surber, 1943) recorded for the bullhead in the United States.

These figures indicate that the possible fecundity and the probable number of eggs laid per season was considerably higher in the catfish from the Waikato region compared with the northern hemisphere.

Chapter 5 FEEDING BIOLOGY

5.1 METHODS

Stomachs were removed from catfish caught between April 1975 and May 1976. Each stomach was allotted a value for fullness according to the visual estimation classification of Ball (1961).

Visual estimation	Points
Distended	10
Full	8
3/4 Full	6
1/2 Full	4
1/4 Full	2
Trace	1
Empty	0

Stomach contents were then removed and preserved in 4% Formalin for later analysis.

FOOD ANALYSIS

The total settled volume of the contents of each stomach was determined using a measuring cylinder as shown in Plate 8. Stomach contents were sorted under a binocular dissecting microscope and analysed according to the following three methods:

1) Numerical analysis

In a stomach sample a count was made of all the individuals of each food item, which was identified to species level where possible. Numbers of Chironomidae were

ascertained by counting the number of head capsules present. This was necessary because, generally, digestion initially separated the head from the rest of the body.

2) Volumetric analysis

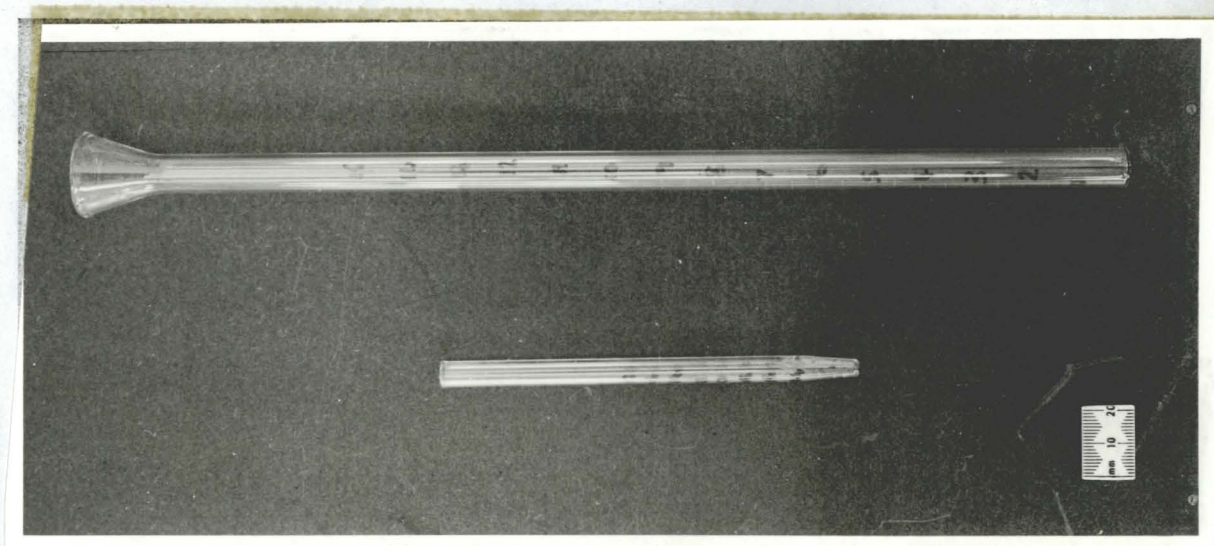
The total volume of each species (or taxa) in a sample was measured using the cylinders shown in Plate 8. The total settled volume was measured rather than the volume of water displaced (as is usual in volumetric analysis) because of the difficulty in handling samples with large amounts of detritus present.

3) Frequency of occurrence

The number of fish stomachs in which each food species occurred was calculated, the results being expressed as a percentage of the total number of food containing stomachs, to give the relative frequency of occurrence.

Plate 8

Measuring Cylinders



5.2 RESULTS

Of 141 fish stomachs checked between April 1975 and May 1976, 46 (30%) were found to contain food. This low percentage of food containing stomachs was due to the fishing methods used in this study, where the nets were set at night when catfish are most active, being nocturnal predators. A fish caught early on in the night would have little food present in the stomach when the nets were uplifted the following morning, presuming the previous night's meal had already been digested. Fish caught after several hours feeding would have had up to 12 hrs to digest any food in their stomachs before they were examined and only those fish caught late at night would have full stomachs when examined. On a number of occasions fyke nets contained a large number of eels, making conditions very crowded, and in such circumstances it was possible that some catfish regurgitated their stomach contents. Regurgitation sometimes occurred during transportation to the laboratory, often a trip of 50 kilometres or more. This could have been prevented by killing the fish immediately after trapping, but catfish, upon death, exude mucous from skin chemoreceptors (Appendix 4), making them very messy to handle in the laboratory.

Detritus, consisting of macrophyte and unidentifiable organic debris, constituted a large proportion of the total stomach contents of most fish. The presence of this material caused problems in analysis and it was important to establish

whether or not it was a significant food item. Observations on catfish feeding in aquaria showed that when a suitable food item was encountered, the fish would open its mouth and suck in both the food item and any debris that was surrounding it. Sometimes the catfish would expel the debris, at other times it would not. Analysis of the stomach contents of two fish kept in an aquarium showed considerable amounts of organic debris present.

In the stomach samples it appeared that the amount of detritus was related to the particular locality in which the fish was caught. Below are shown the percentages of volumes of detritus and animal material for the three localities studied.

	Volumes (%)	
	Animal	Detritus
Lake Waikare	66.3	33.7
Waikato River	61.1	38.9
Lake Waahi	31.9	68.1

A t test showed a significant difference between the volumes of detritus in the Waikato River and Lake Waahi ($t = 2.672$, $P < 0.02$, $df = 32$) but none between the river and Lake Waikare. These results reflected the conditions in the lakes and river. The greatest percentage of detritus was found in Lake Waahi fish and a substantial portion of this material was partially decomposed macrophyte detritus. Lake Waahi during the summer months becomes almost unnavigable by boat due to the extensive growth of macrophytes, which break

down ' in situ ' to leave an extensive layer of detritus on the lake bed. Lake Waikare on the other hand has few macrophytes present, the detritus in the stomachs of fish from this lake being a white material, of unknown origin, rather than plant detritus. Waikato River fish had both macrophytic material and filamentous algae present, but much less of the former than in Lake Waahi fish. This was as expected since, although submergent and emergent macrophyte communities are present in the river, thus creating ' in situ ' detritus, this material is less stable, being susceptible to flushing out by variations in river water velocities.

The two major food items of the catfish were detritus dwelling species of Chironomids and Oligochaete worms. It was thus concluded that the detritus was taken up accidentally and was not a primary food source, but that some nutrition could be gained from the associated bacterial flora. Cable (1928) studying the food of the bullhead in South Dakota, USA, found that where both animal and plant foods were available, the fish took the animal and rejected the plant material. In only three out of the eleven lakes studied was plant material an important constituent , forming 23.5, 37.1 and 45 % of the diet. Although concluding that the plant material was not taken by accident and was digested, she found that though the quantity of animal material was proportionately greater than plant material in the stomach, the reverse was true in the intestine. Other authors studying

the diet of bullheads make no mention of significant amounts of plant material (e.g Raney and Webster, 1939, Turner, 1966).

One fish from Lake Ngaroto was found to have significant amounts of filamentous algae (Oscillatoria sp, Spirogyra sp, Oedogonium sp) in its digestive system. Gunn (1966) found that algae often represented more than 60% of the diet of I. nebulosus in the Ottawa River, Canada, and Gunn et al (1977) found that the bullhead was capable of metabolising C_{14} from Spirogyra sp and Anabaena flos-aquae. It was concluded from this that although generally algae were not a significant food item in the Waikato, catfish do sometimes feed on them and are capable of metabolising algae.

The mean index of fullness results are shown in Table 8. At the 1% level there was a significant difference between the means for Lake Waikare and Lake Waahi fish ($t = 3.078$, $df = 24$) and at the 5% level a significant difference between Lake Waikare and the Waikato River ($t = 2.1599$, $df = 24$). These results reflect the levels of detritus found in the stomachs of fish from each area, with the high indices being recorded in the Waikato River and Lake Waahi fish because of ingestion of large volumes of detritus with the animal food.

Table 8

Mean Indices Of Fullness

	Mean	Range	Number of fish
Lake Waikare	4.4	1 - 10	10
Lake Waahi	8.13	2 - 10	16
Waikato River	7.13	2 - 10	16

LAKE WAAHI

The stomach contents from Lake Waahi fish are shown in Table 9. Numerically the most abundant food organisms were aquatic oligochaetes. These were not identified because the setae which are generally used to identify the species had been digested off the bodies. The chironomid Polypedilum pavidus was second in abundance numerically, six times as abundant as the other chironomid Chironomus zealandicus. These three most abundant taxa numerically also rank in the same order and proportion in the volumetric analysis, and the relative closeness of the two sets of results indicates that in this case there is no apparent bias in either method. The results from one stomach sample have been omitted, since it contained 103 terrestrial oligochaetes (14 ml) which would have seriously biased the overall results. Examination of the frequency of occurrence of different items in the diet showed that chironomids were taken more frequently than oligochaetes.

Food Species	Numbers of organisms		Volume of organisms		Frequency occurrence	
	Actual	%	Actual	%	Actual	%
Oligochaete sp	1870	61.66	12.55	10.97	6	38
<u>Chironomus zealandicus</u> l.	161	5.31	1.96	1.71	8	50
<u>C. zealandicus</u> p.	8	0.26	0.08	0.07	5	31
<u>Polypedilum pavidus</u> l.	888	29.28	4.73	4.13	4	25
<u>P. pavidus</u> p.	2	0.07	0.02	0/02	1	6
<u>Tanetarsus</u> a.	1	0.03	0.01	0.01	1	6
Chironomid sp. a.	1	0.03	0.01	0.01	1	6
<u>Sigara arguta</u>	5	0.17	0.25	0.22	3	19
Hymenopteran, terrestrial	1	0.03	0.04	0.04	1	6
Diplopoda sp	1	0.03	0.5	0.44	1	6
<u>Paraleptamphopus</u> sp	1	0.03	0.02	0.02	1	6
<u>Porcelio scaber</u>	1	0.03	0.1	0.09	1	6
Amphipoda , terrestrial	86	2.84	2.8	2.5	2	13
<u>Simocephalus vetulus</u>	3	0.1	+	+	1	6
<u>Bosmina meridionalis</u>	1	0.03	+	+	1	6
<u>Keratella vulga</u>	1	0.03	+	+	1	6
Cyclopoid nauplius	1	0.03	+	+	1	6
Unidentified eggs	1	0.03	+	+	1	6
Detritus			91.31	79.83	14	89

l = larvae p = pupae a = adult
+ denotes volume too small to be measured

Table 9.

Stomach Contents Of 16 Fish From Lake Waahi

(average FL = 27.6 cm)

Of the other insect species found, only the backswimmer Sigara arguta was of any major importance, occurring in 19% of the stomachs examined.

Crustacea were of minor importance in the stomachs examined.

One young of the year catfish (4.0 cm long) contained in its stomach; a cladoceran, a rotifer, and a cyclopoid nauplius as well as 98 Polypedilum pavidus larvae. The planktonic crustacean Simocephalus vetulus occurred in 19% of the stomachs but was insignificant in volume. Terrestrial amphipods, presumably washed into the lake, occurred in two specimens and constituted 2.5% of the total volume, ranking third in importance volumetrically behind C. zealandicus. Only one egg, of 1.5 mm diameter and which showed signs of development, was found in a stomach. This egg was too small to be a trout egg and too large to be attributed to any other fish in the lake such as Carassius auratus.

WAIKATO RIVER

The analysis of stomach contents from Waikato River fish is shown in Table 10. Numerically, and by volume, the chironomid Chironomus zealandicus was by far the most abundant food organism and it occurred in 94% of the stomachs examined.

Bivalves (Sphaeriidae) and oligochaete worms were both regularly found in the stomachs, with the former being slightly more important in volume.

Food Species	Numbers of organisms		Volume of organisms		Percentage occurrence	
	Actual	%	Actual	%	Actual	%
Oligocheete sp	840	11.8	1.99	2.18	10	62
<u>Chironomus zealandicus</u> l.	5872	82.52	32.07	35.17	15	94
<u>C. zealandicus</u> p.	135	1.9	2.38	2.61	12	75
<u>Syncricotopus</u> (WII) sp l.	1	0.01	+	+	1	6
<u>Austrolestes colenisonis</u> l.	1	0.01	0.04	0.04	1	6
<u>Paratya curvirostris</u>	6	0.08	3.0	3.29	5	32
<u>Tenagomysis chiltoni</u>	1	0.01	0.02	0.02	1	6
<u>Paraleptamphopus</u> sp	18	0.25	0.19	0.21	7	44
<u>Porcelio scaber</u>	1	0.01	0.1	0.11	1	6
<u>Herpetocypris pascheri</u>	12	0.17	0.03	0.03	5	32
<u>Simocephalus vetulus</u>	1	0.01	+	+	1	6
Sphaeriidae	95	1.35	2.62	2.87	9	56
<u>Potamopyrgus antipodarum</u>	111	1.56	1.36	1.49	6	38
<u>Physa acuta</u>	4	0.05	0.05	0.05	2	13
<u>Gyraulus corinna</u>	1	0.01	0.01	0.01	1	6
Planarian	1	0.01	+	+	1	6
Nematode sp	10	0.14	+	+	5	31
Unidentified eggs	6	0.08	+	+	3	19
Detritus			47.34	51.9	15	94

l= larvae p = pupae

Table 10

Stomach Contents Of 16 Fish From The Waikato River

(average FL = 23.8 cm)

The freshwater shrimp Paratya curvirostris was also an important food species, occurring in fewer stomachs than bivalves or oligochaetes but being more important in total volume. Another mollusc Potamopyrgus antipodarum also occurred in significant amounts, being the fifth most abundant species.

Two crustacean species, the ostracod Herpetocypris pascheri and the amphipod Paraleptamphopus sp. appeared regularly in the stomachs but were too few in number and small in volume to be considered important food items.

Unidentified eggs, of similar size to those found in a Waahi fish, occurred in river fish also.

LAKE WAIKARE

The results from stomach analyses of Lake Waikare fish are shown in Table 11. Chironomus zealandicus was by far the most abundant food species. Two crustacean species, Paraleptamphopus sp. and the mysid shrimp Tenagomysis chiltoni were also important with T. chiltoni occurring in as many stomachs as C. zealandicus. Oligochaetes were of minor importance in these fish with a volume of only 0.43% of the total. One catfish was found to contain the remains of another small unidentifiable fish which was the only one ever found in the stomach of a catfish. Animal tissue of unknown origin was also found in the same stomach.

Food Species	Numbers of organisms		Volume of organisms		Percentage occurrence	
	Actual	%	Actual	%	Actual	%
Oligochaete sp	57	3.0	0.15	0.43	3	30
<u>Chironomus zealandicus</u> l.	1702	89.58	14.25	40.81	7	70
<u>C. zealandicus</u> p.	23	1.21	0.6	1.72	6	60
<u>Polypedilum pavidus</u> l.	8	0.42	0.02	0.57	2	20
<u>Sigara arguta</u>	1	0.05	0.05	0.14	1	10
<u>Tenagomysis chiltoni</u>	26	1.37	1.03	2.95	7	70
<u>Paraleptamhopus</u> sp	82	4.32	1.26	3.44	4	40
Fish remains	1	0.05	0.2	0.57	1	10
Animal tissue	-	-	0.2	0.57	1	10
Detritus	-	-	17.22	49.3	8	80

l = larvae

p = pupae

Table 11

Stomach Contents Of 10 Fish From Lake Waikare
(average FL = 29.2 cm)

5.3 DISCUSSION

Although the number of catfish stomachs analysed was low, the results did show some significant trends. The data were separated into the three localities because of the marked differences which appeared in the diets. Thus, although only ten fish were collected from Lake Waikare, the absence of molluscs and the abundance of large crustacea made them distinctive.

The three main food species of the Lake Waahi fish, Polypedilum pavidus, Chironomus zealandicus and oligochaete worms, are burrowing organisms found in the top five centimetres of the detrital bed of the lake (M.A Chapman, pers. comm). Preliminary studies on the benthos of Lake Waahi suggest that P. pavidus is more abundant than C. zealandicus and that both species are concentrated around the fringes of the lake. Two core samples from the lake contained 1 oligochaete per 10 cc and 4.4 cc of detritus respectively, and 1 chironomid per 7.4 and 2.8 cc of detritus. These figures may not be representative of the lake as a whole, of course, but if taken at face value, and compared with the ratio of 1 chironomid and 2 oligochaetes per 0.087 cc of detritus in catfish stomachs, it would appear that the fish are selectively removing organisms from the detritus. One young of the year catfish had 98 P. pavidus larvae in its stomach, with very little detritus (0.02 cc detritus against 0.18 cc of chironomids), which suggests that small catfish

can catch large numbers of chironomids without ingesting large quantities of detritus. It may be more economical of energy for large catfish not to be too selective in expelling detritus. Nikolskii (1963) cited the case of young pike feeding on planktonic crustaceans, where very soon the amount of energy expended on the capture of crustaceans begins to exceed their calorific value and the pike begins to feed on fish. If the pike is retained on planktonic crustaceans, it gradually ceases to grow. By inference this provides a reason why the Waikato fish did not feed on planktonic crustacea to any degree, nor fish. The growth rate of the catfish is so rapid that plankton and fish do not provide a nutritious enough food supply. The net gain of energy from feeding (i.e the energy value of the food minus the energy expended in capture or digestion) is not high enough when compared to the energy gained from feeding on benthic organisms. Turner (1966) found the white catfish I. catus, did not significantly feed on fish in the San Joaquin Delta, California, USA, but cited Stevens (1959) who found in South Carolina, 64.4% of the larger catfish preyed on other fish. The growth rate of the former fish was much faster after two years of life than the latter, which Turner suggested was due to the amount of fish in the diet.

Although the feeding of I. nebulosus has been likened to the action of a vacuum cleaner (Keast and Webb, 1966), it would thus seem to be a rather selective and efficient vacuum

cleaner. No attempt was made to see if any size selection for chironomids had occurred because the catfish is not a visual feeder.

Although the percentage volume of terrestrial amphipods in the diet was comparatively high, they were not considered to be an important food feature of the catfish diet because they occurred in only two stomachs. Their significance lies in their indication of the opportunistic predation of the catfish as does the presence of the terrestrial slater Porcelio scaber, the diplopod and the terrestrial hymenoptera..

In the stomachs of the river fish, C. zealandicus was by far the most abundant food species. No data are available on the abundance of this chironomid in the region of the river north of Taupiri where the fish were caught, but Boubée (1977) found that in the stretch of river around Hamilton, C. zealandicus is the second most abundant chironomid after the weed-dwelling orthoclad chironomid Syncricotopus (W II) sp. No Polypedilum pavidus larvae were found in the river fish stomachs which probably reflects their scarcity compared with in Lake Waahi.

The importance of oligochaetes to fish in the river is apparently much less than it is to fish in Waahi. Although the percentage occurrence of oligochaetes was high the volume was low, suggesting that their overall abundance is lower than in Waahi, and thus it would appear that the low water

flow zone of the river is less suitable for oligochaetes than the littoral zone of Lake Waahi.

Molluscs appear to play an important role in the nutrition of river fish but were lacking in Waahi fish stomachs. Two species of ' pea mussel ' (Sphaeriidae) are commonly found in the river, Pisidium aucklandica and Sphaerium novae-zelandiae (Boubée, 1977) but they are externally very similar in appearance and difficult to distinguish. Thus these molluscs were grouped as Sphaeriidae where they occurred. In some stomachs these bivalves were found in different stages of digestion, from soft transparent decalcified shells to hard undigested shells , and it is possible that they are held in the stomach over several feedings. Consequently the results may overestimate their importance. The gastropod Potamopyrgus antipodarum occurred in large numbers in the river fish. Although usually found grazing on macrophytes, this snail is also often found feeding in large numbers in detritus beds. A brief study on the benthos of the Waikato River, including the region of the river at Taupiri, showed that P. antipodarum was co-dominant with oligochaete worms, chironomid larvae, nematode worms and Mussels (Pisidium, Sphaerium, Hyridella) (Coffey et al, 1975). The browsing gastropod Physa acuta and Gyraulus corinna also appeared in the diet, but in low numbers, which seems to reflect their abundance and distribution in the river (Coffey et al, loc.cit).

Of the several crustacean species which appeared in the diet regularly, the true shrimp Paratya curvirostris was particularly abundant. This species is very common in the river and, although retiring to the weed beds during the day, actively feeds on the detritus during the night (D. Nash, pers.comm). The size of the organism and the regularity with which it was taken suggests that it may be a valuable food source for the catfish.

The amphipod Paraleptamphopus sp, although occurring in a number of stomachs, was of minor importance, with low numbers and low total volume. The same is true for the ostracod Herpetocypris pascheri, a species normally found in bottom deposits in the littoral zone of lakes, or in swamps, rather than in rivers, because of its reduced swimming setae (Chapman and Lewis, 1976). Its presence in the diet indicates the fish has been feeding in areas of slow-moving or stagnant water.

The diet of the fish from Lake Waikare was much less diverse than in the other two areas. This result may be due to the fact that all the Waikare fish were caught on one day, but may also be indicative of overall low species diversity in the lake. As yet no faunal survey of the lake has been undertaken.

By far the most abundant species in these fish was the chironomid C. zealandicus. The large volume of the species

compared with the volume of detritus suggests that the chironomids are more abundant in Waikare than in the other two areas studied. Few P.pavidus larvae were found compared with C. zelandicus, the opposite pattern to that found in Waahi, which may indicate that each species favours different conditions.

The amphipod Paraleptamphopus sp and the mysid shrimp Tenagomysis chiltoni were present in greater abundance than in fish from either the river or Lake Waahi and this again reflects their comparative abundance.

In Lake Waikare the only evidence of predation on smaller fish was found. The backbone and some flesh of a small fish, along with chironomids, several amphipods and shrimps, and some non-piscine animal tissue, occurred in one stomach. It is not known if the catfish took this small fish alive or picked up the partially decomposed remains whilst browsing through the bottom deposits.

5.4 THE DIET OF WAIKATO CATFISH IN COMPARISON TO NORTHERN HEMISPHERE CATFISH

The pooled results of stomach analyses are shown in Table 12. Detritus comprised a large proportion of the material found but it was not considered to be of major importance. The species composition of the diet varied according to the locality, but generally Chironomid larvae were by far the most abundant organisms. The only other insect species of importance, mainly in small catfish, was the water boatman Sigara arguta. Aquatic oligochaetes were the second most important food source, followed by bottom dwelling crustaceans such as Paratya curvirostris. There were mainly two types of molluscs fed upon; Sphaeriidae and Potamopyrgus antipodarum. A number of terrestrial organisms occurred in the diet, showing the fish is apt to consume any organism of suitable size upon which it comes. This allochthonous input may be very important to the species.

The diet of the catfish as reported by overseas authors differs in a number of respects from that of the Waikato fish. Scott and Crossman (1973) stated " the adults are truly omnivorous in that their food is composed of; offal, waste, molluscs, immature insects, terrestrial insects, leeches, crustaceans (crayfish and plankton) , algae, plant material, fishes and fish eggs " .

Keast and Webb (1966) gave the following results from a

study of the feeding of the catfish in Lake Opinicon in Canada:

30-60 mm TL Chironomid larvae (50%), Cladocera (60%), Ostracoda, Amphipoda, Hemiptera, and small Ephemeroptera
70-120 mm TL Same as for smaller fish but Cladocera replaced by increased amounts of Hemiptera, Ostracoda, and newly hatched fish fry.

120-240 mm TL Chironomid larvae (80%), Mollusca (40%), Ostracoda (30%), small crayfish (20%) and Amphipoda (16%).

Raney and Webster (1939) found the diet of young catfish in Cayuga Lake, New York, USA, consisted of mainly dipteran larvae (chironomids) (24.3%), Cladocerans (25%), Ostracoda (20.5%), Copepoda (4.3%), Isopoda (6.7%), and Amphipoda (2.4%). The rest of the diet consisted of small amounts of Ephemeroptera, Odonata, Trichoptera, Hemiptera, Coleoptera, fish eggs and remains.

Cable (1928) investigated the food of bullheads in the USA and found the major organisms to be Chironomus (36%), Cladocera (12.5%), Amphipoda (4.6%), Damsel fly nymphs (4.8%), Cyclops viridis (Copepoda) (6.3%), as well as some bivalves, snails and beetle larvae.

Frank (1955) studying the food of the bullhead in Czechoslovakia found that juveniles (TL 33-53 mm) took predominantly crustacea, especially the littoral/benthic cladoceran Chydorus, and copepods. With increasing size the main food

Food Species	Frequency occurrence	Numbers		Volume(cc)	
		total	%	total	%
Oligochaete sp	43	2767	22.96	14.69	6.11
<u>Austrolestes colenisonis</u>	2	1	0.01	0.04	0.02
Diplopoda sp	2	1	0.01	0.5	0.21
Hymenopteran, terrestrial	2	1	0.01	0.04	0.02
<u>Porcelio scaber</u>	4	2	0.02	0.2	0.08
<u>Sigara arguta</u>	10	6	0.05	0.3	0.12
<u>Chironomus zealandicus</u> l.	72	7735	64.2	48.58	70.19
<u>C. zealandicus</u> p.	56	116	1.38	3.06	1.27
<u>Polypedilum pavidus</u> l.	15	896	7.43	4.75	1.97
<u>P. pavidus</u> p.	2	2	0.02	0.02	0.01
<u>Tanetarsus</u> sp a.	2	1	0.01	0.01	+
Chironomid sp a.	2	1	0.01	0.01	+
<u>Syncricotopus(WII)</u> sp l.	2	1	0.01	+	+
<u>Paratya curvirostris</u>	10	6	0.05	3.0	1.25
<u>Tenagomysis chiltoni</u>	25	27	0.22	1.05	0.44
<u>Paraleptamphopus</u> sp	30	101	0.84	1.41	0.59
Amphipoda, terrestrial	4	86	0.71	2.8	1.16
<u>Simocephalus vetulus</u>	8	4	0.03	+	+
<u>Herpetocypris pascheri</u>	10	12	0.09	0.03	0.01
<u>Keratella vulga</u>	2	1	0.01	+	+
<u>Bomina meridionalis</u>	2	1	0.01	+	+
Cyclopoid nauplius	2	1	0.01	+	+
Sphaeriidae	19	95	0.8	2.62	1.09
<u>Potamopyrgus antipodarum</u>	12	111	0.92	1.36	0.57
<u>Physa acuta</u>	4	4	0.03	0.06	0.03
<u>Gyraulus corinna</u>	2	1	0.01	0.01	+
Eggs	15	7	0.06	+	+
Fish remains	2	1	0.01	0.2	0.01
Nematode sp	14	10	0.08	+	+
Detritus	87	-	-	155.8	64.8

l = larvae p = pupae a = adult

Table 12

The Diet Of Waikato Catfish

source became chironomid species (Chironomus and Endochironomus), and molluscs (Gyraulus albus and Pisidium). The largest fish (135-320 mm) consumed small fish (33-62 mm SL) of the species Gobio gobio, Rutilus rutilus, Scandinus erythrophthalmus, Blicca bjorka, and Rhodeussericceus. Moore (1972) found that fish comprised 88% of the diet of large catfish (21.5-26.5 cm) in the semi-dystrophic Lockhart Pond, Ontario, Canada, and suggested this piscivorous habit was due to high population densities.

The pattern of catfish in the northern hemisphere is to feed on Chironomid larvae and littoral/benthic crustacea, and as the fish becomes larger, molluscs, larger crustacea, and fish become more important, especially when fry are available. The feeding habits of small catfish in the Waikato are not known clearly, although one young of the year was found to have consumed a large quantity of chironomid larvae. The feeding habits of the larger catfish are similar to the northern hemisphere fish in that they rely heavily on chironomids, molluscs and larger crustacea. But the Waikato catfish do not appear to prey on fish to any extent, which may be because the eutrophic and dystrophic waters in which the catfish lives here may have such abundant benthos that there is no necessity to pursue such highly mobile prey as fish. Observations on catfish in aquaria have shown that they will take small fish such as the mosquito fish Gambusia affinis under high density conditions and can exist quite

successfully on this diet. But no catfish was found to consume G. affinis in Lake Waahi where the latter species is present in large numbers.

Scott and Crossman (1973) were the only authors to mention catfish predation on oligochaetes (worms) and it would appear they are much more important in the diet of fish from the Waikato than in the northern hemisphere fish.

Catfish are said to regularly consume fish eggs in the northern hemisphere (Atkinson, 1931). Although some eggs were found in Waikato fish stomachs, these could not be attributed to any other fish species.

Waikato catfish were found to ingest large volumes of detritus, a feature not apparent in the overseas studies. Other authors do not state whether the presence of detritus was ignored or not so no comparisons can be made.

Chapter 6 CONCLUDING DISCUSSION

In this study it was established that there have been a number of marked changes in the biology of the catfish Ictalurus nebulosus since its introduction into Lake St John in 1878.

One major change has been in the growth rate of the fish. Although the longevity of the species was the same, the length at maximum age was far greater than that recorded in the fish's native habitat in most cases. The growth in length over the first four years of life (8.0, 10.6, 8.7, 6.4 cm), determined from backcalculation, was greater than that recorded in the USA, and much greater than that recorded for the fish in Czechoslovakia (the only country into which the species has been introduced from where growth data is available). There are no published G values (instantaneous growth) for the species and so no comparisons could be made in this respect. No differences in the symmetry of growth for the species (isometric, $w = al^3$) between New Zealand and overseas were apparent.

The development of ova in females was asynchronous (Marza, 1938) and there was strong evidence for multiple spawning. A short distinct spawning season is usual for the species in its native habitat (Scott and Crossman, 1973), although multiple spawning has been suggested as possible (Breder, 1935). It was difficult to obtain accurate estimates of

fecundity because of the multiple spawning. However a reliable estimate of a minimum of 3,700 eggs laid per season was indicated, a figure which was greater than that recorded for the species overseas (Berg, 1949).

The major food of the catfish was Chironomidae and Oligochaetes although the fish appeared to follow the pattern overseas of being omnivorous. Considerable amounts of detritus were found in the stomachs, a phenomenon which has not been reported overseas. It was concluded that the detritus was of minor importance to the fish. There was no evidence of predation on eggs of other species nor of piscivorous feeding habits.

It is apparent, from reports by eel fishermen, that the distribution of the catfish is expanding in the Waikato. Reasons for this apparent rapid increase can be seen in the combination of several factors indicated in this study. The recruitment capabilities of the population appeared to be very high. With the rapid growth rate, maturation of the fish occurred at an early age and thus the replacement time of the spawning stock was short. The actual spawning life of an adult appeared to be in the order of 4-5 years. The size and turnover time of the reproductive group of the population, coupled with the multiple spawning capabilities and high potential fecundity indicate that the fish is capable of rapidly increasing in numbers if there are no natural checks on the intrinsic rate of natural increase (r) of the

population. One such check may have been, in earlier years, competition with eels (Anguilla spp.). As yet there is no direct evidence of competition between the catfish and eels, but, as pointed out Johannes and Larkin (1961), there does not need to be any direct evidence of niche competition for two species to significantly affect each other. Over the past few years catches of eels have decreased in the Waikato, probably as a result of overfishing (A. Tecklenberg, pers. comm). The expansion in numbers of catfish may be directly correlated with this reduction in numbers of eels because the two phenomena appear to have occurred at approximately the same time.

One mechanism that may be controlling the localised numbers of catfish, but not their spread, is that of density dependent spacing through territoriality. It has been established that I. nebulosus is at times a highly aggressive territorial fish (Todd, 1971). In a habitat such as Lake Waahi, there is probably only a limited number of suitable territories. Fish that do not possess these cannot form pair bonds, and thus it is logical to assume that the eggs produced by single females will never be fertilised, or if they are, they will not be properly aerated (Appendix 3) and thus will not be viable. Secondary oocytes may not even develop in such individuals and this may explain why fish with a low maturity index (GI less than 1.0%) occurred all year round in the lake. Such density dependent population regulatory mechanisms have been

described for many species (Wynne-Edwards, 1962), and it is quite possible that such a mechanism exists in the catfish, a species with well developed social behaviours and social pheromones (see Appendix 4). Todd (1971) goes so far as to suggest that " the bullhead may represent a pinnacle in the evolution of the chemical senses in fishes ". With such a phenomenon of density dependent regulation there is usually a pool of freely moving, often gregarious, individuals, or ' floaters ' (Manuwal, 1974). I observed the gregarious behaviour of non-territorial individuals in aquaria. It is these floaters in the population that may have resulted in the ' runs ' of catfish noted in the Waikato by some eel fishermen, and they may also be responsible for the rapid expansion of the fish in recent years. Population numbers may have built up to such levels that Lake Waahi is saturated, as far as territories are concerned, and migrations are occurring. Some support for this may be drawn from the fact that the majority of fish caught in the river were 1+ fish and those caught in Lake Waahi were 3+. The younger fish may move out of the lake into new areas. Emig (1966) cited a study in which bullheads in Folsom Lake, USA, moved an average of 1.7 miles before they were recaptured, and the longest distance travelled was 16.2 miles. A tagging programme in the Waikato (see Appendix 5) would be invaluable in exploring these possibilities further. An investigation into the size of territories and the effects of removal of a

pair from their territory (as done on the striped parrotfish Scarus croicensis by Buckman and Ogden, 1973), would provide evidence as to the presence of floaters in the population.

A thermal power station, of 1000mW generating capacity, is at present being built beside the Waikato River at Huntly, and it is planned to use water from the river as a coolant. Little is known at present of the effects the thermal effluent will have on fish populations in the river. I suspect that some major changes will occur for at least one species, Ictalurus nebulosus.

It has been shown (Alabaster, 1962) that most coarse fish are attracted by heated discharge water of 26^oC. Coutant (1970) reported the attraction and concentration of bullheads at generating stations in the USA. Marcy (1969) described the accumulation of fish around the heated discharge from the Connecticut Yankee Atomic Power Company station on the Connecticut River, USA (discharge approximately 853 cfs cooling water, 12.5^oC above ambient, at full capacity). Massengill (1973) studied the feeding habits and condition factors (K) of bullheads overwintering in the discharge canal from that power station and found that these fish were in a much poorer condition than those from a control area some 8 km downstream. He found that the fish Notropis hudsonis was the major food item of the adult catfish, compared with chironomid larvae for the control fish. Of

major significance was the finding that the immature bullheads in the effluent fed mainly on eel elvers (Anguilla rostrata) and in one month these constituted 98% of the total weight of food consumed.

Moore (1972) found that the bullhead was piscivorous under high density conditions. It is suspected that the introduction of a thermal effluent into the river at Huntly would cause large congregations of bullheads, as well as other fish. Such aggregations could have a serious effect on upstream migration of eel elvers (Anguilla dieffenbachii and A. australis), as well as other native fish species.

Little work on the feeding biology of native species in the Waikato has been done as yet. However a study is at present under way on the feeding habits of the native species Retropinna retropinna and Gobiomorphus cotidianus, and preliminary results show both species feed on the chironomid Polypedilum pavidus in Lake Waahi (T. Stephens, pers.comm), indicating there is some food competition between the catfish and native species.

The introduction of a species into an environment where there are supposedly unexploited niches is a practice which has been widespread in the past, especially in countries such as New Zealand. It is doubtful whether there is any sound ecological basis for such a practice. Bump (1951) pointed out that a species " cannot succeed in a new habitat without

causing some changes in plant and animal associations already established ". Magnuson (1976) concluded that the net effect of introductions of new fish species into a lake has been " to increase the intensity of species interactions and produce local extinctions ".

Ictalurus nebulosus was a popular species for introductions to European countries during the late 19th and early 20th centuries (Schindler, 1957). These introductions were condemned by many authors, but there is no critical analysis of the effects of the fish on native faunas in the literature (Vooren, 1972). This study has described the major changes in the biology of the catfish which have occurred since its introduction some 100 yrs ago and it is hoped this will provide a basis for further work on the effects of this species on the native fauna, and provoke further research into the biology of introduced species and the ecological consequences of their introductions.

APPENDICES

APPENDIX 1

DESCRIPTION OF THE SPECIES

The species of catfish was identified by the following criteria which differentiate Ictalurus nebulosus from other similar members of the genus with which it may be confused, I. melas and I. natalis.

1) The pronounced serrations on the posterior edge of the pectoral spines in I. nebulosus (much smaller serrations in I. natalis, and barbs weak or absent in I. melas) (Scott and Crossman, 1973).

2) Fin ray numbers D VII, P₁ IX, A XX, P₂ VIII

Scott and Crossman (loc.cit) gave the fin ray numbers for Ictalurids as follows:

I. nebulosus D VII, P₁ (VIII-XX), A (XVIII-XXI), P₂ VIII

I. melas D (VI-VII), P₁ IX, A (XV-IXX), P₂ VIII

I. natalis D VII, P₁ (VII-VIII), A (XXII-XXV), P₂ VIII

3) Dark brown upper and lower barbels in I. nebulosus compared with grey to yellow upper, and yellow to white lower, barbels in I. natalis.

SYSTEMATICS

Super Order	OSTARIOPHYSEI
Order	CYPRINIFORMES
Sub-order	SILUROIDEI
Family	ICTALURIDAE
Genus	<u>Ictalurus</u>
Species	<u>nebulosus</u>

ETYMOLOGY

Ictalurus - fish cat nebulosus - clouded

COMMON NAMES

Brown bullhead, horned pout, bull pout

NOMENCLATURE

Pimelodus nebulosus - Le Sueur, 1819 (Type locality, Delaware
River at Philadelphia)

Silurus felis, Silurus (Pimelodus) coenosus, Silurus
(Pimelodus) nigrescens, Pimelodus vulgaris, Pimelodus felis
Pimelodus catus, Pimelodus atrarius, Amiurus nebulosus,
Amiurus vulgaris, Amiurus catus, Ameiurus lacustris,
Ameiurus vulgaris, Ameiurus nebulosus, Ictalurus nebulosus
nebulosus (Taylor, 1954)

DISTRIBUTION

Native to fresh waters and rarely brackish waters of
eastern and central North America. Introduced to California
(USA), Germany, Canada, France, Switzerland, USSR,
Czechoslovakia, New Zealand.

APPENDIX 2

Programmes for calculation of

- A) Predictive and geometric mean regressions
- B) Lengths at previous ages (Nomograph calculation)

```

10 REM PROGRAM FOR PREDICTIVE AND FUNCTIONAL REGRESSIONS
30 LET X1=0\LET X2=0\LET Y1=0\LET Y2=0\LET N=0\LET C1=0
35 PRINT "INPUT FILE "\INPUT Z$
40 OPEN Z$ AS FILE #1
50 REM READ A CASE
70 INPUT #1:AS
80 LET X=VAL(SEGS(AS,4,5))
90 LET X=X/10
95 LET X=LOG(X)
100 LET Y=VAL(SEGS(AS,4,5))
110 LET Y=Y/10
115 LET Y=LOG(Y)
120 GOSUB 1000
130 IF END #1 GO TO 200
135 GO TO 70
200 REM CALCULATION OF Y ON X
210 REM I.E LENGTH ON VERTEBRAL RADIUS
220 LET M1=X1/N
230 LET M2=Y1/N
240 LET B=(C1-N*M1*M2)/(X2-N*M1*M1)
250 LET A=M2-B*M1
260 LET D=(C1-N*M1*M2)/(Y2-N*M2*M2)
270 LET C=M1-D*M2
280 LET S3=((Y2-N*M2*M2)-B*(C1-N*M2*M1))/(N-2)
290 LET V=SQR((Y2-N*M2*M2)/(X2-N*M1*M1))
300 LET U=M2-V*M1
310 REM VARIANCES OF SLOPE
320 LET V1=S3/(X2-N*M1*M1)
330 LET V2=S3/(Y2-N*M2*M2)
400 REM OUTPUT
410 PRINT " X=LOG(VERTEBRAL RADIUS)"
420 PRINT "X=LOG(LENGTH)"
430 PRINT
440 PRINT "PREDICTIVE Y ON X"
450 PRINT "Y=";A;
452 IF B<0 GO TO 454
453 PRINT "+";
454 PRINT B;"X"
460 PRINT "STD DEV B=";SQR(V1)
470 PRINT
480 PRINT "PREDICTIVE X ON Y"
490 PRINT "X=";C;
492 IF D<0 THEN GO TO 494
493 PRINT "+";
494 PRINT D;"Y"
500 PRINT "STD DEV D=";SQR(V2)
510 PRINT
520 PRINT "GM FUNCTIONAL REGRESSION Y ON X"
530 PRINT "Y=";U;
532 IF V<0 GO TO 534
533 PRINT "+";
534 PRINT V;"X"
540 PRINT "STD DEV V=";SQR(V1)
550 STOP
1000 REM ACCUMULATION SUBROUTINE
1010 LET X1=X1+X
1020 LET X2=X2+X*X
1030 LET Y1=Y1+Y
1040 LET Y2=Y2+Y*Y
1050 LET C1=C1+X*Y
1060 LET N=N+1
1070 RETURN

```

B

```
10 OPEN "GPAT01.DAT" AS FILE #1
20 PRINT
21 INPUT #1:Z5
22 IF VAL(SEGS(Z5,6,7))=0 THEN 21
25 IF END #1 THEN 500
30 LET Y=VAL(SEGS(Z5,1,3))\LET Y=Y/10
32 LET Y=LOG(Y)
35 LET V1=VAL(SEGS(Z5,4,5))\LET V1=V1/10
37 LET V2=VAL(SEGS(Z5,6,7))\LET V3=VAL(SEGS(Z5,8,9))
38 LET V4=VAL(SEGS(Z5,10,11))\LET V5=VAL(SEGS(Z5,12,13))
39 LET V2=V2/10\LET V3=V3/10\LET V4=V4/10\LET V5=V5/10
40 LET X=(Y-2.50039)/.844864
42 LET X=EXP(X)
43 LET K=X/V1
45 LET L=K*V2\LET L=LOG(L)
46 GOSUB 100
48 PRINT EXP(Y),C,
50 IF V3=0 THEN 20
55 LET L=K*V3\LET L=LOG(L)
60 GOSUB 100
65 PRINT C,
70 IF V4=0 THEN 20
75 LET L=K*V4\LET L=LOG(L)
80 GOSUB 100
90 PRINT C,
92 IF V5=0 THEN 20
96 LET L=K*V5\LET L=LOG(L)
97 GOSUB 100
98 PRINT C,
99 GO TO 20
100 LET C=2.50039+.844864*L
102 LET C=EXP(C)
105 RETURN
500 STOP
```

APPENDIX 3

Reproductive Biology

The breeding and brood habits of Ictalurus nebulosus have been extensively studied in the USA (Eycleshymer, 1901, Breder, 1935, 1939). The fish is a nest building species, and typically the pair construct a shallow nest in mud, sand, or among the roots of aquatic macrophytes. According to Stranahan (1910) and Breder (1935) spawning takes place during the daytime within the nest cavity. The fish settle over the nest, bodies in contact but facing in opposite directions, and spawning occurs. Breder (1935) stated that bullheads go through the spawning motions a number of times until the female is empty of her eggs. Fowler (1917) stated that I. nebulosus may lay as many as 500 eggs per motion. The eggs are constantly attended, especially by the male, being lain upon by either, or both of the parents, violently agitated by being beaten with the ventral fins, or taken into the mouth and ejected violently. The eggs are adhesive, about 3 mm in diameter with a soft gelatinous covering, and they hatch in 6-9 days (at 20^oC), when the embryo is 6 mm long (Armstrong and Child, 1962). The young cannot swim at this point because of the size of the yolk sac, but after several days (6-16, Mansueti and Hardy, 1967) they begin to swim and feed actively. The young fish are shepherded around by the parents in a dense school (Stranahan, loc.cit), apparently kept together by visual stimuli (Breder, 1935)

until about 5.0 cm in length when the school breaks down
and the individuals disperse.

APPENDIX 4

The Physiology Of Ictalurus nebulosus

I. nebulosus has four pairs of barbels, two nasal which point upwards, four mandibular pointing downwards and usually being dragged over the bottom over which the fish is moving, and two maxillary barbels pointing ventrolaterally from the corners of the mouth. Within each barbel is a thin flexible rod of cartilage, running throughout its length, which is attached at its base via a ' joint ' to the head thus permitting movement of the barbel as a ' feeler '. Catfish do not use their visual system when catching food but localise it by direct contact. The barbels have exquisite tactile sensitivity and, projecting radially out from the head, enable the fish to scan a much larger volume of water for food than it could without them. Accurate seizing of food requires that precise sensory information reaches the central nervous system as to its location. Glide units with small receptive fields can signal the radial distance from the head along a given barbel. Simultaneously input from position units indicates the degree of displacement of the barbel from resting position (Biedenbach, 1971).

It has been established that the bullhead is more active at night and during overcast days and that in the turbid waters the fish occupies, light intensities by day must often fall below the level for photopic vision. The retina of the eye, although possessing rods and cones, has poorly

developed neural layers compared with pelagic fish (Arnott et al, 1974).

In addition to its barbels, I. nebulosus has highly developed senses of taste and smell which are important in food finding. Its nose is said to be almost as keen as that of the eel, and its entire body is covered with thousands of taste buds which have been likened to the oral mucosa of terrestrial organisms (Biedenbach, 1973). Studies by Todd (1971) have shown that it is not the sense of smell which leads bullheads to food, but rather their taste buds. Blinded bullheads, deprived of their olfactory receptors, were able to swim directly to a food source in still water. But when the taste buds on one side of the body were destroyed by surgery, the fish had difficulty in finding the food and was only able to do so by constantly looping to the uninjured side.

The catfish also has electroreceptors called ' small pit organs ' (Dijkgraaf, 1968). Peters and Buwalda (1972) studied the electroreceptive system in I. nebulosus to try and gain a better understanding of its biological significance. They found that, from the responses of a fish in a horizontal electric field, the ability of directional electric sensitivity seemed very probable. Results showed that all electric potential differences with frequency components of from 0.03 to 25 Hz and in the order of magnitude of 10^{-4} uA/mm² can be perceived by a stationary fish, and moreover, swimming fish

can detect DC fields. Stationary electric fields from 1 to 10 mV are present in the habitat of the catfish, which corresponds to current densities of 10^{-4} uA/mm² in water with a specific resistance of about 50 ohm/m. These fields are apparently constant, strongly localised and dependent on the depth of water and structure of the bottom. Roth (1972) found the small pit organs were most sensitive to changing electrical fields in the water, sometimes arising from moving objects.

In addition to the small pit organs, the catfish has other sense organs of the lateral line system distributed over the head and trunk; the canal organs and large pit organs. These two are mechanosensitive, particularly to water displacements resulting from objects moving at a distance (Dijkgraaf, 1968). In addition the large pit organs seem sensitive to certain cations (Katsuki et al, 1970).

Todd (1971) studied the use of pheromones in social communication in catfish and concluded that the highly evolved sense of smell is used in communication, whilst the well developed chemosensory taste buds are used in food procuring. He said the chemical language is probably complex, communicating information about the individual's species, status, sex, age or size, reproductive state, individual characteristics, and perhaps even family communication.

In a natural environment bullheads often form a dense community composed of hundreds of individuals, that is based not on a

a hierarchy or collection of territories, but on close togetherness, with the members swimming freely and peacefully throughout the pond that houses the community. Todd reproduced this community in the laboratory by placing a large number of newly caught bullheads in one tank. The members then spent most of their time resting in close contact with one another in a kind of 'love in'. This phenomenon was also seen in my tanks, where a group of newly caught bullheads, when placed in an aquarium (2.13m x 0.3m x 0.46m) spent most of their time cruising up and down the tank in a closely packed group. Todd also found that if water in which one of these 'love ins' had taken place was introduced into tanks where two territorial and highly aggressive bullheads were kept, the aggressive behaviour was slowly extinguished, which indicated the presence of pheromones.

APPENDIX 5

Notes

The major problem faced during this study was how to obtain sufficient numbers of fish for analysis. For future reference, the problems encountered, possible solutions, and general aspects relevant to studies on fish in the Waikato are discussed below.

The lack of sufficient numbers of fyke nets and of a suitable range of different mesh sizes of gill nets, made adequate representative sampling impossible. Because fyke nets rely on fish movement over an area, this method is not ideally suited to a study on a fish exhibiting territoriality. This behaviour, especially if the defended area is also a feeding area, restricts the movements of a fish considerably. A much more suitable method would be to use a long distance of wide ranging mesh sizes of gill nets. When spread out over a lake, these nets can sample a wide area, and can catch fish even when movement is very localised. The catch rate for these nets would be far greater than for fyke nets generally.

Other fishing methods which could have some uses are electro-fishing (for which the operator must undertake a special course) and explosive fishing. The latter method, using dynamite, is advantageous in that it can produce a representative sample in a short time. However it is not desirable from an ecological point of view because of the general

damage the shock may cause.

One suggested method for obtaining adequate samples of fish was to collect them from the eel fishermen who fish in the Waikato. However, most eel fishermen are loathe to handle catfish due to the risk of infection from the poisonous spines on the fish. Because of this, eel processing firms approached during this study were unable to provide any regular samples.

A fish-tagging programme to estimate abundance and mortality rates was contemplated during this study, but the manpower requirements proved too great. My catches were too small, and fish caught by eel fishermen were often injured to such a degree that their growth rates, if not their survival, would be seriously impaired if they were released. McGammon and Seeley (1961) undertook a tagging programme on Ictalurids in Clear Lake, California, USA, and achieved a 5.6% return rate of tags for I. nebulosus. The type used was a disc dangler, and Pelgen (1954) outlined the method of attachment used. I obtained similar tags to those used in that study from Spinwell Products, Christchurch, in 1975. If such tags are used in the Waikato, they must be marked with the Auckland Acclimatisation District identification letter ' C '.

In this study, nets were set from 3m aluminium dinghys, which were found to be of adequate size for working in most of the Waikato Lakes. No difficulty was encountered in

setting or retrieving gill nets from these boats. However, Lake Waikare is not suitable for fishing with gill nets from this type of boat. The lake is large, shallow, and very exposed to the west, the predominant wind direction. A short sharp chop can occur quickly on the lake, making it very dangerous for small, heavily laden dinghys. When fishing was carried out on this lake during the study, it was with the assistance of the Waikato Valley Authority jet boat.

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