THE POPULATION ECOLOGY OF JUVENILE BROWN TROUT (*Salmo trutta* L.) IN LOCH LEVEN, KINROSS, SCOTLAND

by

GABRIEL A. OMOSOLA ARAWOMO, B.Sc., M.Phil. (Ife)

Thesis submitted for the degree of

DOCTOR OF PHILOSOPHY

University of Stirling,
Stirling,
Scotland.

September, 1977

ACKNOWLEDGEMENTS

I would like to thank my supervisors: Dr. P. Tytler and Mr. J. E. Thorpe of the Freshwater Fisheries Laboratory, Pitlochry, for their advice and criticisms; Messrs. I. Irvine and A. McQueen of the Freshwater Fisheries Laboratory, Pitlochry, for their valuable field assistance; and Dr. J. M. Stewart and others in the Department of Biology, University of Stirling, for their help during the period of this study.

I would also like to thank the staff of the Institute of Terrestrial Ecology, Wetland Research Group, Edinburgh, for their co-operation and assistance; the staff of the Forth River Purification Board, Stirling, for the supply of some environmental data; the staff of the Loch Leven fisheries for their great help; and Sir David Montgomery for permission to work on the loch and for the provision of boats.

Finally I would like to thank my wife for her encouragement and patience throughout the period of this study and the Federal Government of Nigeria for the financial assistance provided.

ABSTRACT

This study on the population ecology of juvenile trout in Loch Leven included investigations on the population structure of the nursery streams; the input of juvenile trout into the loch; the distribution, the age and growth and the food of juvenile trout in the loch; and the emigration of juvenile trout from the loch into the outflowing River Leven.

The stream population structure was studied by repeated electrofishing on selected sites in the nursery streams while the input of juvenile trout into the loch was monitored by traps set on each of the major tributaries to the loch. The mean highest population density of juvenile trout in the selected stream sites was $1.103/m^2$ and this was observed from the electrofishing catches in September 1976. Three year classes of juvenile trout: I, II and III were involved in the downstream migration of juvenile trout from October 1975 to July 1976. Migration of juvenile trout into the loch was associated with increased water discharge caused by the onset of floods while increased stream water temperatures accelerated the pace of migration into the loch in the spring, reaching a peak in April.

Among the three fishing methods employed on the loch to study the distribution of juvenile trout, only gill-netting caught juvenile trout in significant numbers in the offshore areas of the loch. From gillnets set along three traverses on the loch, juvenile trout were found to be concentrated in the offshore, above the mud zone of the loch. During the summer period, gillnet captures of juvenile trout were found to increase with increasing

gillnet sets away from the shore, reaching a maximum concentration at the deepest part of each traverse. However, during the winter, juvenile trout appeared to be evenly distributed with no clear area of concentration as in the summer. Though there were few areas of overlap, juvenile trout concentrations seem to be separated from the adult trout, perch and pike populations in the loch.

Migration of juvenile trout into the loch consisted 55.9%, 37.2% and 6.9% of the first, second and third year group migrants respectively. Fast growth in Loch Leven feeder streams was responsible for the high proportion of early migrants of juvenile trout into the loch. All migrant groups showed a faster growth during their first loch year. Compared with other lochs, growth of juvenile trout in Loch Leven was relatively good and this was linked with the high productivity of the loch and the area of loch habitat relative to that of nursery stream habitat.

The main food items of juvenile trout in the loch are chironomids, crustaceans and nematodes and these are abundant in the offshore mud zone of the loch.

Emigration of juvenile trout from the loch into the outflowing River Leven extended from November to August with peaks in February and June. This occurred among all age groups of juvenile trout in the loch soon after entry into the loch from the streams or after a few months growth in the loch.

The distribution of juvenile trout in the loch is discussed in relation to food, growth, competition and predation.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

FIGURE AND PLATE CONTENTS

FIGURE AND PLATE CONTENTS (cont.)

FIGURE AND PLATE CONTENTS (cont.)

CHAPTER 1

INTRODUCTION

Trout is one of the most studied freshwater fish of the world. According to Frost and Brown (1967), more is known about the life of brown trout because a store of knowledge has been amassed for centuries by anglers and others interested in trout as a sporting fish. Notwithstanding the intensity of research carried out both in the field and laboratory on trout, there remain considerable gaps in our knowledge.

Brown trout in Scottish waters has attracted much attention because of its economic importance in the recreation industry. As more interest is generated from angling, there is even greater need for management of trout waters based on the knowledge acquired on the ecology of brown trout. Several studies have been carried out on the general biology of trout and other salmonids especially on the food, age and growth of the post juvenile stages. Management of trout in lochs has been hampered by a lack of adequate information on the biology of juvenile fish in the nursery streams and their downstream migration into lochs. Only limited studies have so far been carried out on the population biology of trout during the first few years of life after the alevin or larval stage (Le Cren, 1973).

A great deal has been published on the general biology of brown trout in Britain (Pyefinch, 1960; Frost & Brown, 1967; Mills, 1971). Many workers have concentrated on different aspects of juvenile trout in rivers (Went & Frost, 1942; Kennedy & Fitzmaurice, 1968; Le Cren, 1961, 1973; Elliott, 1967; Solomon & Templeton, 1976) while others have worked mainly on the general biology of brown trout in lakes (Allen, 1938; Frost & Smyly, 1952; Ball & Jones, 1960, 1961; Graham & Jones, 1962; Hunt & Jones, 1972). In Scotland, research into brown trout has been pursued both in the rivers and lochs by various workers (Stuart, 1953, 1957; Munro & Balmain, 1956; Munro, 1961; Campbell, 1957, 1953, 1971; Treasurer, 1976). Research on brown trout at Loch Leven has been carried out by Balmain & Shearer (1953), Munro & Balmain (1956) and Thorpe (1974a, b, c). The International Biological Programme on the ecology of Loch Leven measured major sources of production in the loch and steps were taken towards understanding the links between the trophic levels. In their summary on the IBP results, Morgan & McLusky (1974) highlighted the important gaps which need to be investigated. Among these problems are the production and feeding of young fish and especially the role of zooplankton as food for these early stages.

Thorpe (1974a, b, c) concentrated on the production biology of brown trout, Salmo trutta L., with emphasis on the adult stages from the time of recruitment to the fishery. One of the most important factors affecting the size of the population of trout in the loch is the recruitment to the stock each year. This study was designed to provide information on the population ecology of the juvenile stages of brown trout, Salmo trutta L., before recruitment into the fishable stock. Recruitment to the fishery is from a minimum fork length of 23cm, which is the lower length limit allowable for angling catch in Loch Leven. The juvenile trout referred to in this study will however include the prerecruitment stages up to a maximum fork length of 30cm. A sampling programme was therefore undertaken to include the following:

a) the river population structure and the input of juvenile trout into the loch;

b) the distribution of juvenile trout in the loch;

c) the food of juvenile trout in the loch;

d) the age and growth of juvenile trout in the loch; and

e) the emigration of juvenile trout from the loch into the outflowing River Leven.

The Environment

Loch Leven is a shallow eutrophic lake formed in a shallow depression in sand and gravel deposits which overlie great thickness of boulder clay (Smith, 1974). There are two deep holes marking the site of large detached ice blocks buried in the deposits (Kirby, 1974). The loch lies in Eastern Scotland at a latitude of 56°10' N, a longitude of 3°30' W and an altitude of 107m above sea level. It has the following morphometric data (Kirby, 1974):

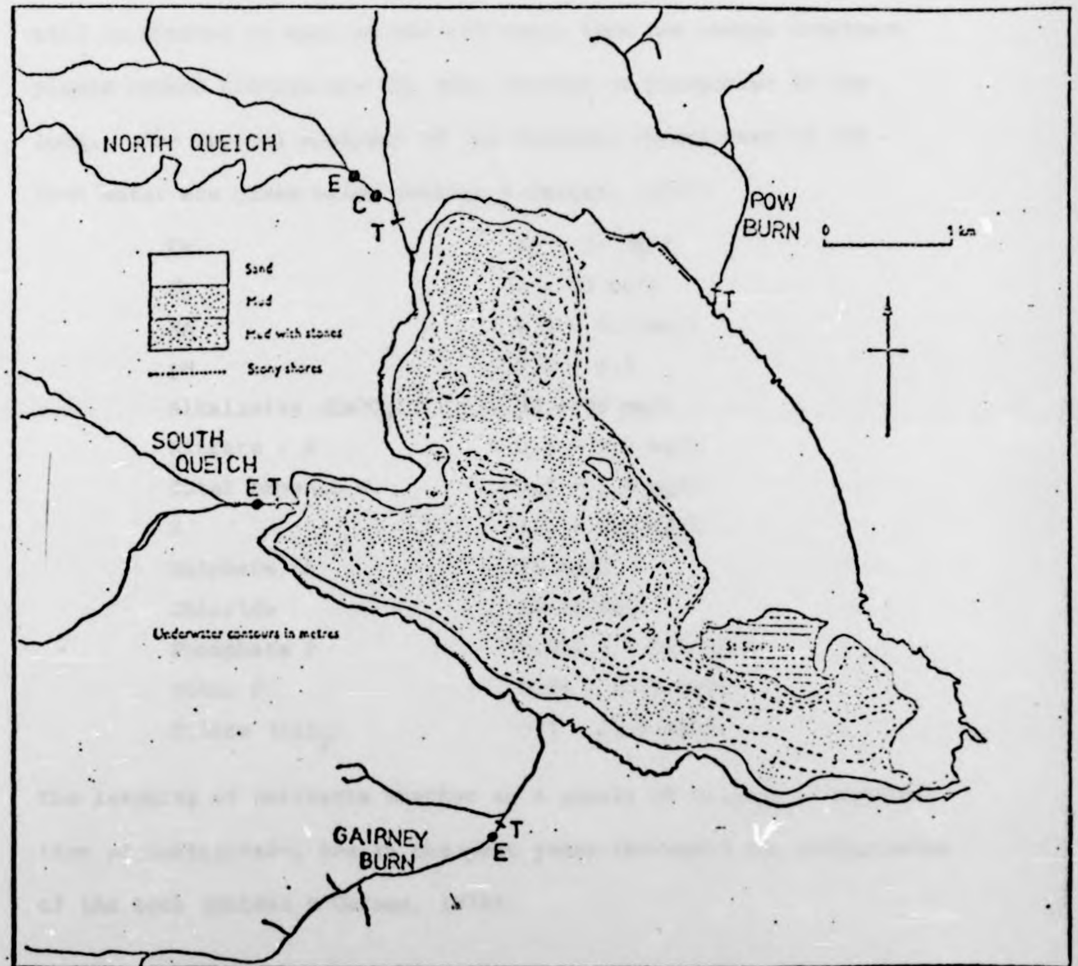
Mean depth	3.9m
Maximum depth	25.5m
Surface area	13.3km^2
Volume	52.4 $10^6 m^3$
Length	5.9km
Breadth	2.3km

The sediment on the rim is predominantly sandy with some stony shores; clay and silty muds occur in deeper water. The division between sand and mud is shown in Fig.1

FIG.1

Map of Loch Leven showing major division of loch to sand and mud zones; major tributaries to the loch, the trap sites (T) and the main (E) and control (C) electrofishing sites.

(Adapted from Smith, 1974)



NORTH QUEICH
E
C
T
POW BURN
0
1 km
T
Sand
Mud
Mud with stones
Stony shores
SOUTH QUEICH
E T
Underwater contours in metres
St Serf's Isle
GAIRNEY BURN
T
E

The catchment of the loch is drained by four major streams shown in Fig.1. Most of the land covered is used for agriculture. The nitrogeneous fertilizers used on this agricultural land appear to be the major source of nitrogen ($N-NO_3$) in the loch. The industrial wastes from the sand and gravel workings and the woollen mill in Kinross as well as the effluents from the sewage treatment plants around Kinross are the main sources of phosphorus in the loch. The typical analyses of the chemical constituent of the loch water are given below (Holden & Caines, 1974):

Ca	16 - 27 mg/l
Mg	6 - 10 mg/l
Na	5.6 - 8.2 mg/l
pH	7.2 - 9.3
Alkalinity ($CaCO_3$)	30 - 70 mg/l
Nitrate - N	< 0.1 - 1.9 mg/l
Total organic N	0.5 - 1.8 mg/l
K	1.0 - 2.9 mg/l
Sulphate ca	25 mg/l
Chloride	11-16 mg/l
Phosphate P	0.002 - 0.040 mg/l
Total P	0.04 - 0.15 mg/l
Silica (SiO_2)	0.1 - 11.0 mg/l

The leaching of nutrients whether as a result of tillage or application of fertilizers, has in the past years increased the productivity of the loch (Holden & Caines, 1974).

The climate is dominated by maritime air masses characterised by its lack of extremes: small range in temperature, rain at any time of year and by the liability to wind at any time of the year. The influence of continental high pressure air extends over Loch Leven, usually accompanied by increased temperature range and reduced wind speeds. During periods of maritime dominance the loch is well mixed and unstratified (Smith, 1974). Thermal or chemical stratification is therefore rare owing to prevailance of sufficient wind to maintain vertical circulation, except very infrequently during the spring or early summer over the deeper parts of the loch.

CHAPTER 2

THE RIVER POPULATION STRUCTURE AND INPUT OF JUVENILE TROUT INTO THE LOCH

Some studies have been made on the early life and population density of brown trout and other salmonid species in many rivers. Brown trout fry are known to be territorial in behaviour (Stuart, 1953; Kalleberg, 1958; Kennedy & Fitzmaurice, 1968; Mills, 1971; Le Cren, 1973, Mortensen, 1977). Each trout fry has been reported by Stuart (1953) to take position at least 7.5cm from its nearest neighbour. The stimulus for aggressive behaviour is reported to be visual and thus a physically more complex stream bottom with more obstruction of mutual vision for the fry can hold a larger population density (Le Cren, 1973). Mann (1971) reported that the number of fish present at any one time in a given site was governed by mortality, emigration and immigration rates. Trout fry that cannot find a territory move away, a few slightly upstream but majority downstream in search of a vacant niche (Le Cren, 1961; Frost & Brown, 1967; Mills, 1971).

Pyefinch (1960) reported that juvenile trout in a Scottish river spent one, two, three, four or more years in the nursery streams before migrating into the loch. Thorpe (1974b) observed that two length groups of juvenile trout: 0+ and 1+ were involved in the migration into Loch Leven. He identified two periods of migration of young trout into the loch, one in the autumn and the other in the spring. There has been a lot of published work on the migration of juvenile trout and salmon smolts by many workers

(Berry, 1933; White, 1939; Hoar, 1953, 1976; Solomon, 1975). Several reasons have been given to support the views that physiological, genetical or environmental factors initiate migration in salmonids. Attempts have also been made to identify the environmental factors responsible for stimulating the downstream migration of juvenile trout. High water temperatures, bright sunlight, photoperiod, lunar periodicity, rainfall, increased water discharge are some of the factors that have been suggested which influence the downstream movement of juvenile trout. The opinions expressed by the various workers have been diverse and situations appear to differ from one environment to the other. An attempt will however be made in this study to find out if environmental factors contribute to the downstream migration of juvenile trout into Loch Leven.

Site, Materials and Methods

There are four major tributary streams which flow into the loch: North Queich, South Queich, Gairney and Pow burn as shown in Fig.1. In order to estimate the population density of juvenile trout in these streams, 50-metre stretches were demarcated on each of these streams except for Pow burn which was eliminated because of constant dredging by the farmers. An additional site was marked out as the control station in the North Queich burn. Each of these streams had peculiar characteristics as can be seen in the following description of the selected electrofishing sites (see Fig.1).

North Queich: The site had a large pool of about 1.0m deep, the bed of which was composed of big stones and had a mean width of about 6.0m. The remaining part of this stretch had water with a mean depth of 0.4m at high water and consisted of scattered stones and a coarse gravel bottom.

South Queich: This site also had a bed of coarse gravel with few scattered stones but no stable pool was formed. It had a mean width of about 4.0m and it rarely exceeded a depth of about 0.3m.

Gairney: This site was a canal-like stretch of stream with a large pool of about 0.8m in depth. It had a substratum of peat and clay and a mean width of about 5.0m. It had small bed areas of fine gravel and sand mixed with small clumps of water weeds which appeared in the shallower areas. Apart from the pool, other parts of the site rarely exceeded a depth of 0.4m.

North Queich (control): This control site was selected about 300 metres downstream of the main North Queich site and it was nearer to the loch. It was similar to the main site in that it had a pool of about 0.8m deep but had a mean width of about 4m. Sewage wastes and algae covered most of the stones and gravel substratum.

Sampling was carried out monthly on each of these main sites from September 1976 to May 1977 except for October 1976 when this was disrupted by flooded conditions. A 600-volt D.C. electric fisher, the Cybertronic Mk.12 (Marine Electrics), operated from the shore was used. Generally, on each electrofishing occasion, each section was fished in the upstream direction thrice. On the control site, however, and during earlier sampling on these main sites, only one electrofishing was done occasionally. The replicate fishing or depletion method of estimating populations was used (Leslie & Davies, 1939; Seber & Le Cren, 1967). This involved fishing a close population on a number of occasions, none of the fish being returned to the water, or if returned, marked so as to be identifiable and discounted if subsequently recaught. These sites were screened off from other parts of the stream with stop-nets while electrofishing was in progress so as to avoid any loss or addition of fish into these selected sections. The sampling was carried out on consecutive days at each of the three different streams so as to be able to compare the results on the population densities while migration from these sites was negligible. Between each successive electrofishing there was an interval of between 30 and 50 minutes in order to allow the remaining fish left in the area to recover from earlier shocks. The results from the repeated electrofishing were used to estimate the fishing efficiency of the gear.

The fish caught were anaesthetized in batches of six with 1:10,000 MS-222 SANDOZ and their fork lengths were measured to the nearest centimetre. Scale samples were removed below the dorsal fin and above the lateral line from a few larger samples of juvenile trout. The fish were then placed in wire holding-cages for recovery and then returned alive to the stream.

In order to monitor the migration of juvenile trout into the loch, a trap was installed on each of the four major inflowing streams at some distance from the loch (see Fig.1). The location of these traps depended on the suitability of the area, the nearness to the loch and accessability from the loch or the nearest road. The plan of a typical trap is shown in Fig.2a and its layout in Fig.2b. The trap was made of a rectangular wooden frame 91.4cm × 61cm × 61cm covered with wire netting of six meshes to 2.5cm and

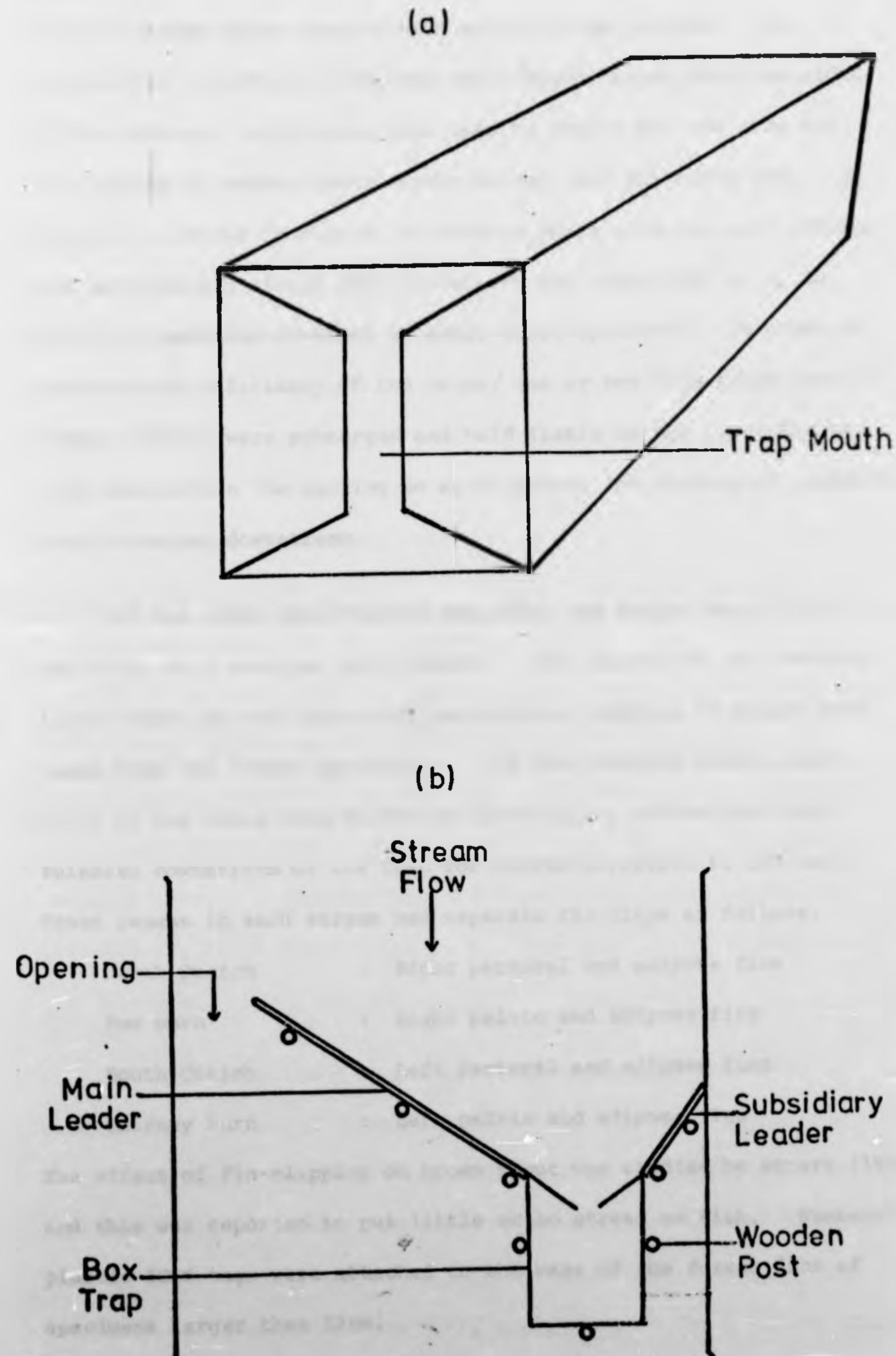
FIG.2

Stream trap for capturing juvenile trout migrating into the loch:

(a) structure of box trap;

(b) layout of trap.

grating into



had a V-shaped entrance of 6.4cm diameter. The leaders were also made of wooden frame covered with similar wire netting. The leaders had a width of 61cm. but the lengths varied with the width of the stream. Wire string was used to fasten the box trap and the leaders to wooden posts firmly driven into the river bed. An opening, as shown in Fig.2b, of about a metre wide was left between the upstream end of the main leader and the river bank so as to allow the upstream movement of adult trout spawners. In order to increase the efficiency of the traps, one or two cage traps used by Thorpe (1974b) were submerged and held firmly to the river bed by iron rods within the opening so as to reduce the chances of juvenile trout escaping downstream.

All the traps were visited regularly and during each visit, the traps were examined and cleaned. The lengths of the juvenile trout caught in the traps were measured and samples of scales were taken from the larger specimens. All the juvenile trout caught alive in the traps were marked by fin-clipping before they were released downstream of the trap for onward migration to the loch. Trout caught in each stream had separate fin clips as follows:

North Queich	:	Right pectoral and adipose fins
Pow burn	:	Right pelvic and adipose fins
South Queich	:	Left pectoral and adipose fins
Gairney burn	:	Left pelvic and adipose fins

The effect of fin-clipping on brown trout was studied by Stuart (1958) and this was reported to put little or no stress on fish. Numbered plastic ICES tags were attached to the base of the dorsal fins of specimens larger than 13cm.

RESULTS

The length-frequency histograms of the electrofishing catches are shown in Fig.3a, b, c for the three main sites on the three major streams at different months of the year. As reported by Junge & Libosvarsky (1965), Le Cren (1973) and Solomon & Templeton (1976), electrofishing gear do exhibit selection on trout fry and this was evident during this exercise where juvenile trout less than 4.0cm were not readily caught. The first juvenile trout fry measuring 2.4cm was observed in Loch Leven feeder streams by late March 1977, March 1st was therefore designated as the birthday of Loch Leven trout, assuming that the extreme cold winter of 1976/77 slightly delayed the earlier development of the fry. The length-frequency histograms in Fig.3a, b, c, show that that juvenile trout distribution was polymodal. However, as will later be seen in Chapter 4, the examination of the scales of these trout reveal three age groups. Fish within the size ranges: 4.0-8.0cm, 9.0-14.0cm, and 15.0-21cm belong to one, two and three year groups respectively. These size ranges tend to overlap because not all the fish grew at the same rate. A typical juvenile trout with slower growth only attained a size of about 6.0cm by the following March as seen in Fig.3a, b, c.

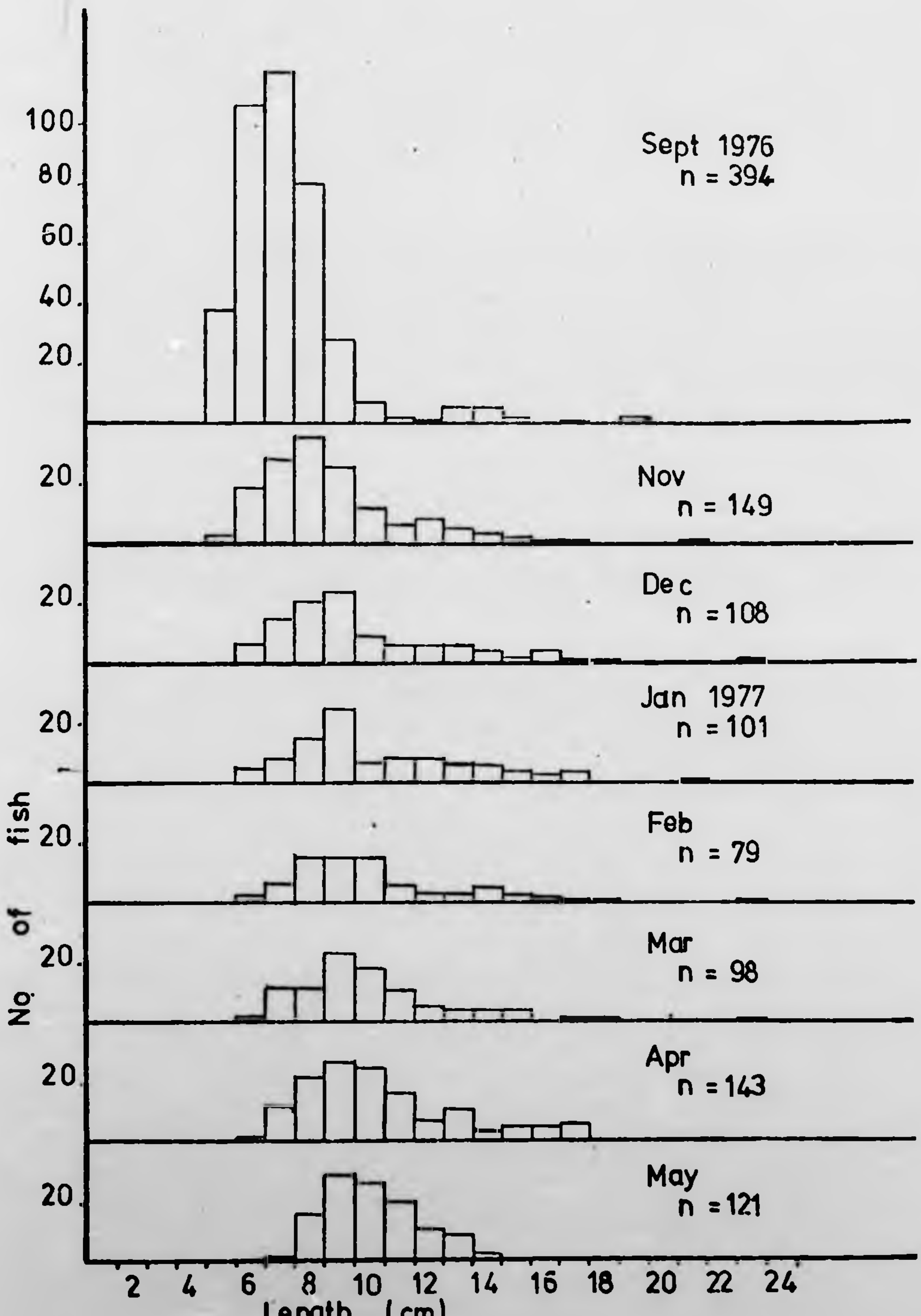
The mean efficiency of the electrofishing gear was 0.60, ranging from 0.50 to 0.73 and increasing as the turbidity of the water decreases. With this mean efficiency, it was possible to capture 94% of the total fish population in three electrofishings over an area. Using the efficiency for a particular period, it was possible to calculate the total population of the juvenile trout in an area where only one electrofishing was carried out. As seen

FIG.3a

Length frequency distribution of juvenile trout in North Queich burn.

(n = number of fish caught)

:rout in



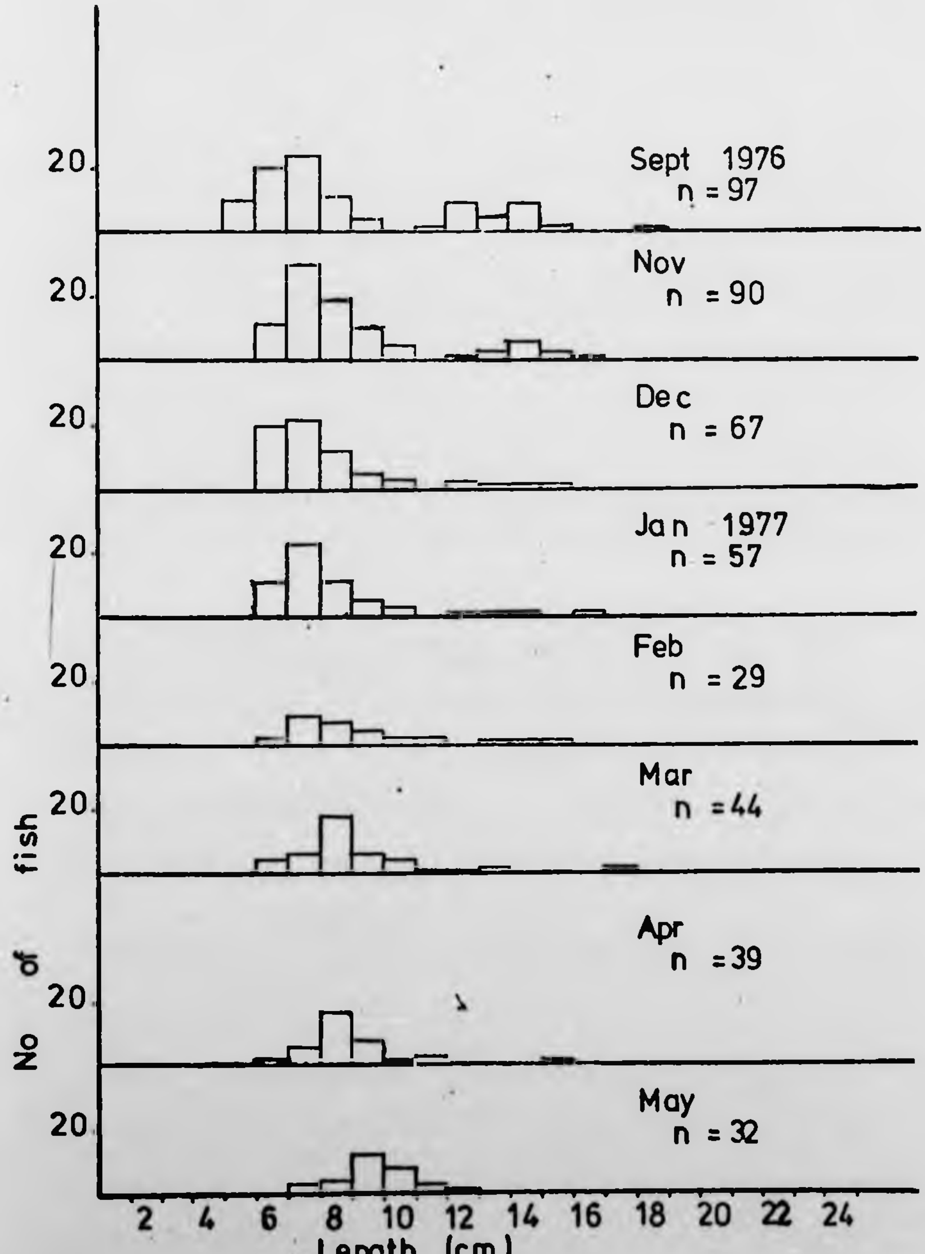
Sept 1976
n = 394
Nov
n = 149
Dec
n = 108
Jan 1977
n = 101
Feb
n = 79
Mar
n = 98
Apr
n = 143
May
n = 121
No of fish
100
80
60
40
20
2 4 6 8 10 12 14 16 18 20 22 24
Length (cm)

FIG.3b

Length frequency distribution of juvenile trout in South Queich burn.

(n = number of fish)

trout in



Sept 1976
n = 97
Nov
n = 90
Dec
n = 67
Jan 1977
n = 57
Feb
n = 29
Mar
n = 44
Apr
n = 39
May
n = 32
20
No of fish
2 4 6 8 10 12 14 16 18 20 22 24
Length (cm)

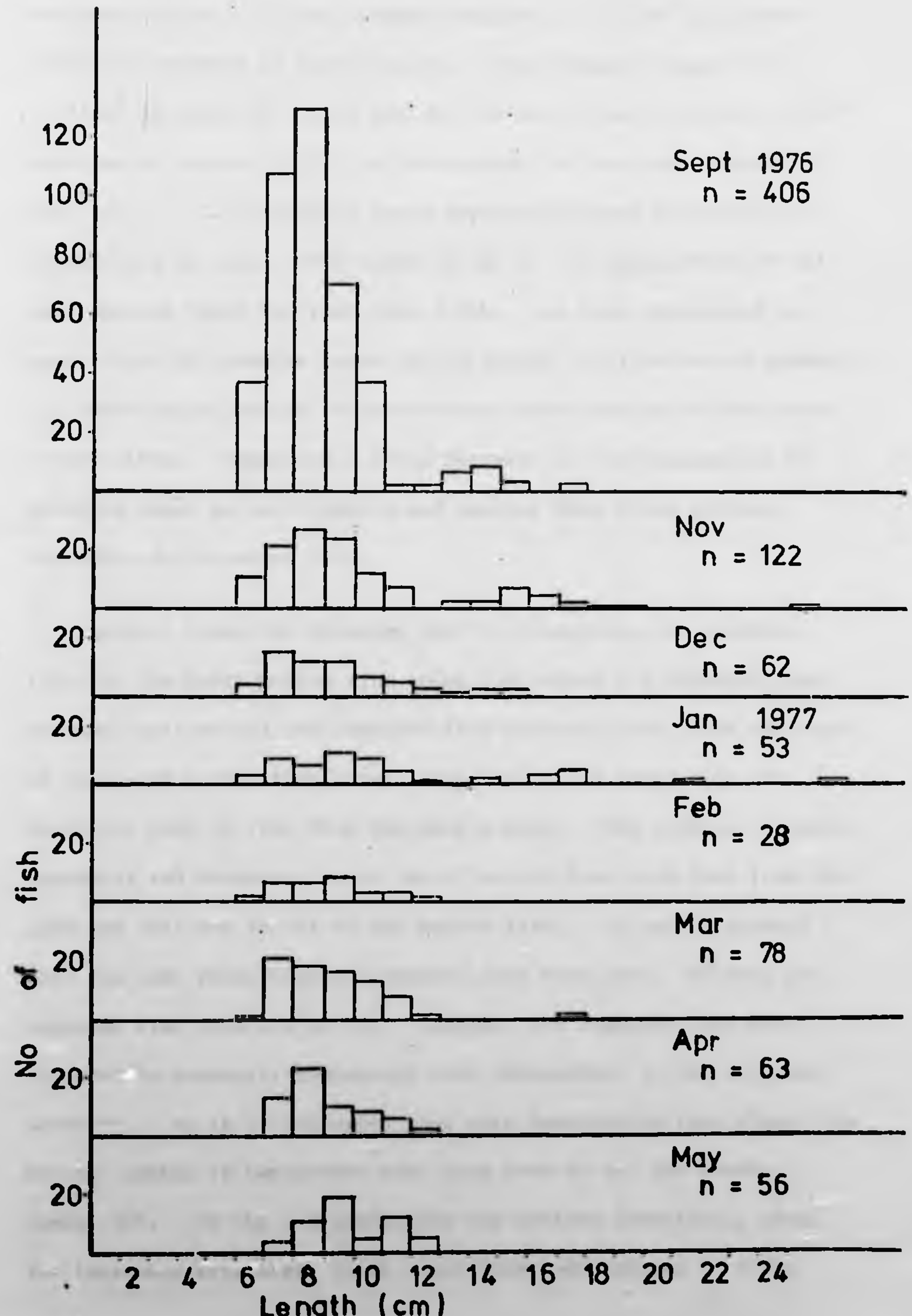
FIG.3c

Length frequency distribution of juvenile trout in

Gairney burn.

(n = number of fish caught)

trout in


Sept 1976
n = 406
Nov
n = 122
Dec
n = 62
Jan 1977
n = 53
Feb
n = 28
Mar
n = 78
Apr
n = 63
May
n = 56
120
100
80
60
40
20
No of fish
2 4 6 8 10 12 14 16 18 20 22 24
Length (cm)

in Table 1, all the sample sites supported the highest population densities of juvenile trout during the month of September 1976. Gairney burn site had the highest density of $2.430/m^2$ while the least was observed in South Queich. The highest density of $1.672/m^2$ obtained for North Queich site was higher than the $1.43/m^2$ recorded by Thorpe (1974c) as the highest for the same stream in July 1972. The relatively lower density obtained for the North Queich site in August 1976 might be due to the selectivity of the gear against trout fry less than 4.0cm. As time progressed the populations of juvenile trout at the stream sites decreased gradually but North Queich seemed to retain more trout than any of the other stream sites. There was a sharp decrease in the populations of juvenile trout in North Queich and Gairney burn sites between September and November 1976.

Table 2 shows the movement and the interchange of juvenile trout at the North Queich site among the marked and unmarked fish. Assuming that marked and unmarked fish behaved alike, then the rate of change of marked fish gives a measure of the emigration and mortality rate of fish from the sample area. For example, between September and November, 66 of the 87 marked fish were lost from the area and this was 78.16% of the marked fish. It may be assumed that the same proportion of unmarked fish were lost, reducing the unmarked fish from 331 to 72. However, 141 unmarked fish were recorded in November, indicating that immigration to the area had occurred. As it is not known when this immigration took place, the minimal number of immigrants must have been 69 and the maximum number 308. If the 308 immigrants had arrived immediately after the September estimates, these would have been reduced to 69 by

TABLE 1 - The Calculated Total Numbers and the Population Densities of Juvenile Trout at the Electrofishing sites on the Loch Leven Feeder Streams

Date	North Queich		North Queich (control)		South Queich		Gairney	
	Calculated total catch	Density no/m^2	Calculated total catch	Density no/m^2	Calculated total catch	Density no/m^2	Calculated total catch	Density no/m^2
April 1976	96	0.384					138	0.552
May	65	0.260					122	0.488
June	48	0.192					112	0.448
August	223	0.892						
September	418	1.672	187	0.935	102	0.680	486	2.430
November	160	0.533			95	0.475	135	0.540
December	116	0.387			75	0.375	67	0.268
January 1977	110	0.367	76	0.380	64	0.320	60	0.240
February	88	0.293			31	0.155	32	0.128
March	102	0.340	70	0.350	47	0.235	85	0.340
April	150	0.500	102	0.510	41	0.205	69	0.276
May	128	0.427			34	0.170	58	0.232

TABLE 2 - The Movement and Interchange of Juvenile Trout at the North Queich Site

	Calculated Total Catch	No. of juvenile trout marked	Calculated total marked recapture	* Rate of Change % marked fish	% unmarked fish
August 1976	223	126			
September	418		87	- 30.95	+ 241.24
November	160		19	- 78.16	- 57.40
December	116		12	- 36.84	- 26.24
January 1977	110		7	- 41.67	- 0.96
February	88		6	- 14.29	- 20.39
March	102		4	- 33.33	+ 19.51
April	150		2	- 50.00	+ 51.02
May	128		0	-100.00	- 13.51

* Positive (+) rate of change of juvenile trout indicates higher immigration while negative (-) rate of change indicates higher emigration and mortality of juvenile trout in the site.

1

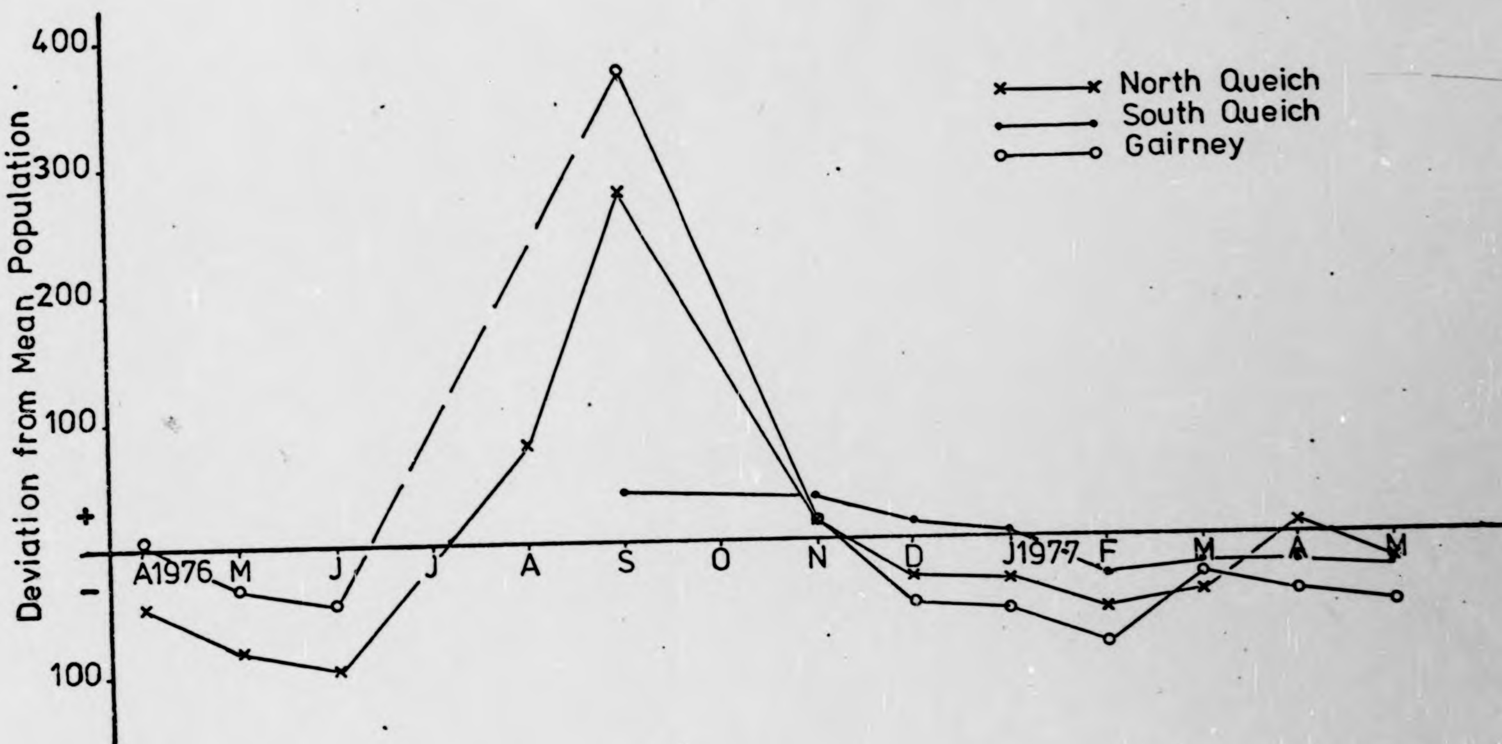
November. It therefore seems as if immigration to the area was a gradual process. Only between January and February was the loss of unmarked fish greater than would have been expected from that of the marked fish but the difference is small, and also based on very few marked fish. It is therefore probable that little if any emigration occurred between the January and February 1977 estimates. As shown in Table 1, the population density at the North Queich control site was higher than that of the North Queich main site, indicating that more juvenile trout had been displaced downstream between September and January from the main site. As also seen in Table 2, there was more immigration of juvenile trout than emigration and mortality among the unmarked fish between March and April. With a few marked fish left at the sample area between March and May, the high rate of emigration and mortality among the marked fish cannot be adequately compared with that of the unmarked fish. It is however evident that a higher emigration and mortality rate in May followed the high immigration rates of March and April among the unmarked juvenile trout in the sample site.

Figure 4 shows the deviations from the mean sample populations plotted against time. The stream populations were above the mean mainly in the summer months as the young of the year were being recruited into the population. As the stream populations decreased between September and November 1976, this fell below the mean in North Queich and Gairney burns except for South Queich where the juvenile trout population remained above the mean until January 1977.

Only limited trapping of migrant juvenile trout was possible

FIG.4

Deviations from mean populations of juvenile trout in Loch Leven feeder streams as obtained from the sample sites.



le trout in

the

because of the following reasons:

(a) regular clogging of the traps with vegetation, sewage and factory wastes which led to a frequent diversion of the river course and the death of some migrants in the South Queich trap;

(b) broken traps due to spates from excessive rains and as such traps were not in operation during the floods;

(c) external interference with the traps by human intruders and occasional dredging of the Pow burn by the farmers.

Some information was however obtained on the migration and the size range of juvenile trout migrants from the trap catches. The monthly and the overall length frequency distribution of juvenile trout migrants caught in the traps are shown in Fig.5 and Fig.6 respectively. The monthly pattern of migration of juvenile trout on the basis of the trap catches can be seen in Fig.7. The downstream migration of juvenile trout extended from October to July in the 1975/76 season. From the examination of scales of the migrating juvenile trout, three year classes: I+, II+ and III+ age groups were revealed.

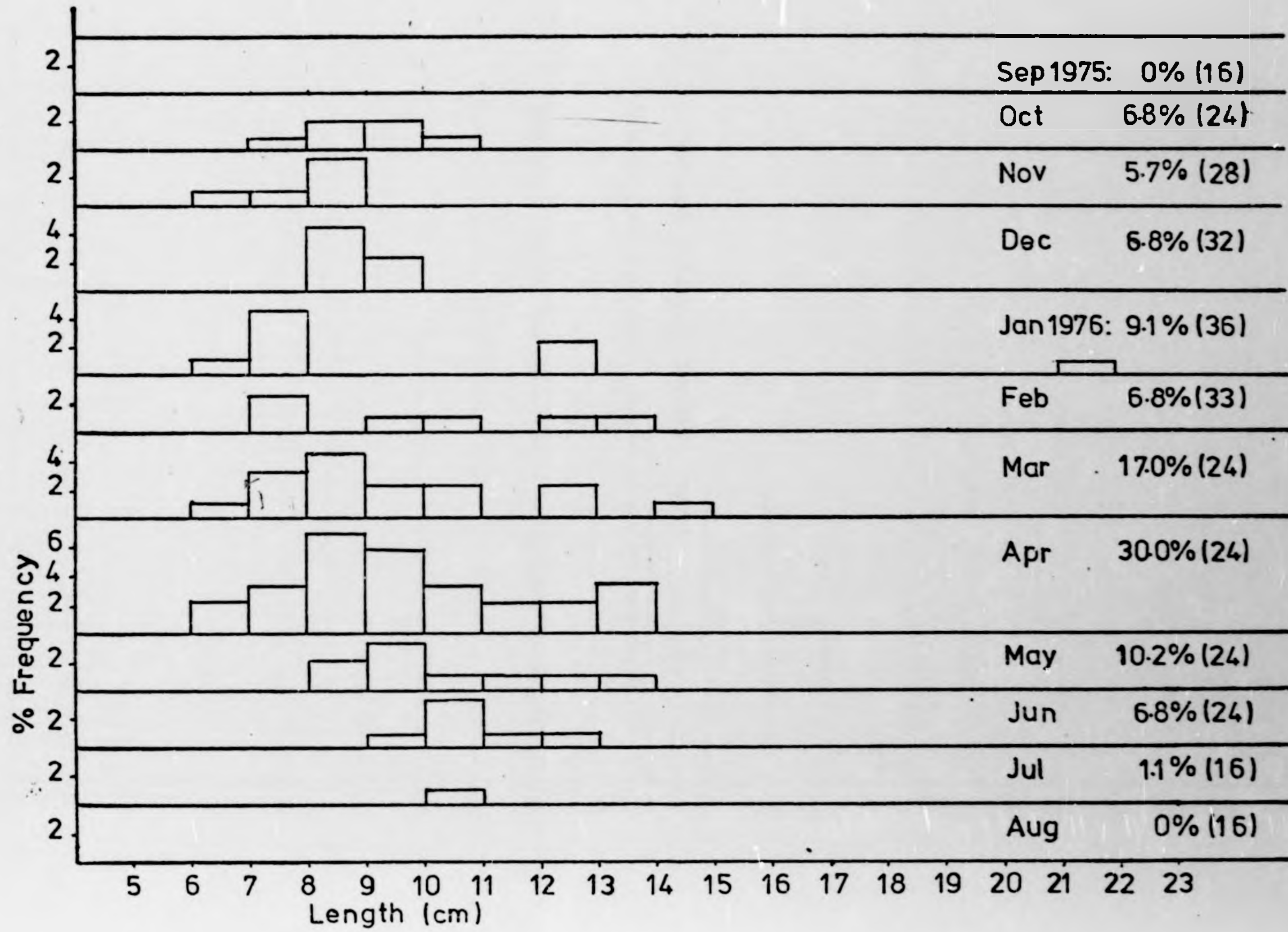
Other fish species caught in the downstream migrating traps were perch, minnow, stickleback, stone-loach and brook lamprey. There was an instance when about 500 perch fry were caught in the Gairney burn trap in a day.

It would appear from the trap data alone (Fig.5 and 6) that there was a peak period of migration in April. Early trout migrants were of the small size range (6-9cm) while the late migrants had larger size juvenile trout (up to 21cm). This pattern

FIG.5

Monthly length frequency distribution of trap-caught downstream migrating juvenile trout.

(Figures in brackets indicate the number of trap sets)

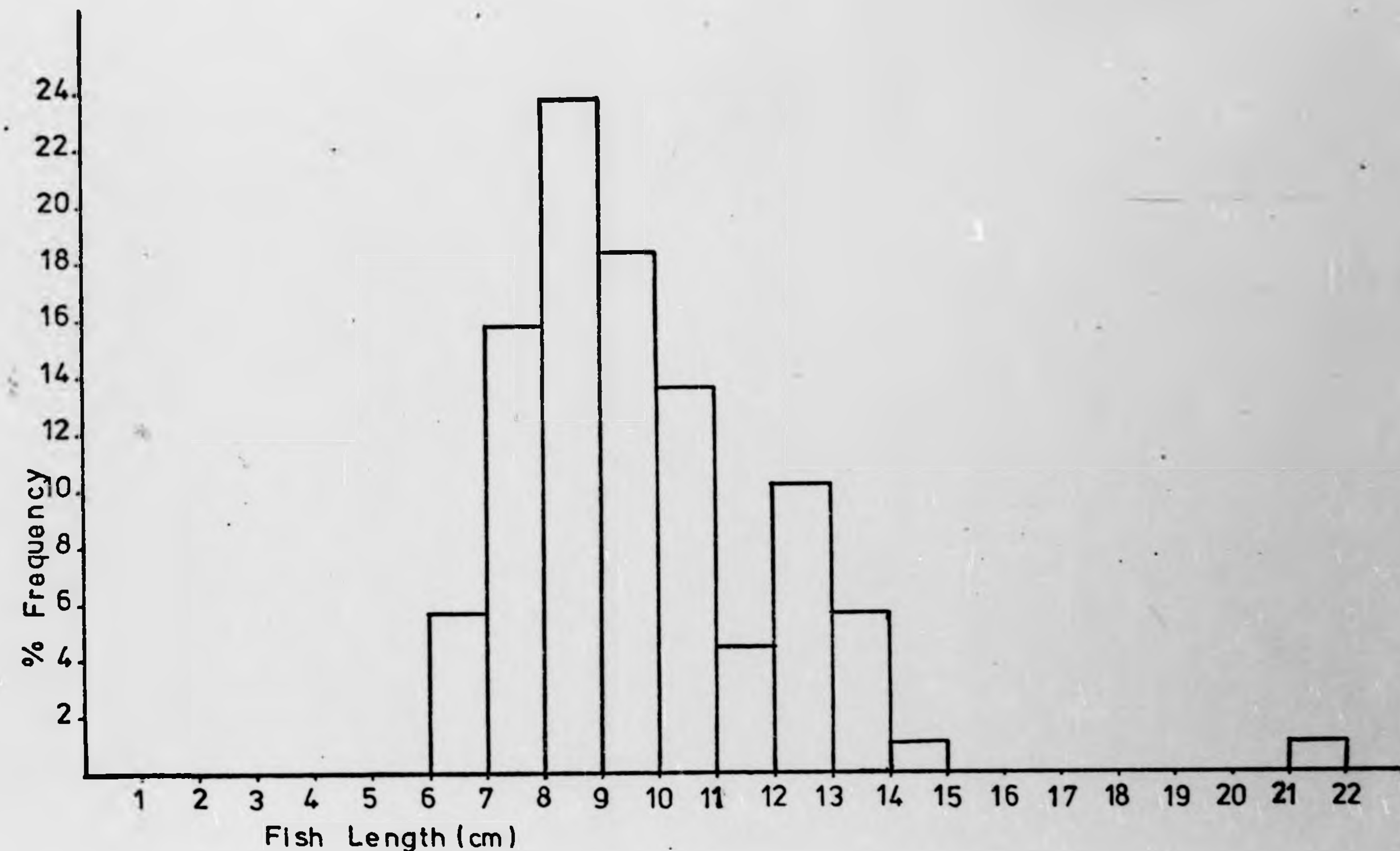


caught

ap sets)

FIG.6

Length frequency distribution of total trap-caught downstream migrating juvenile trout.



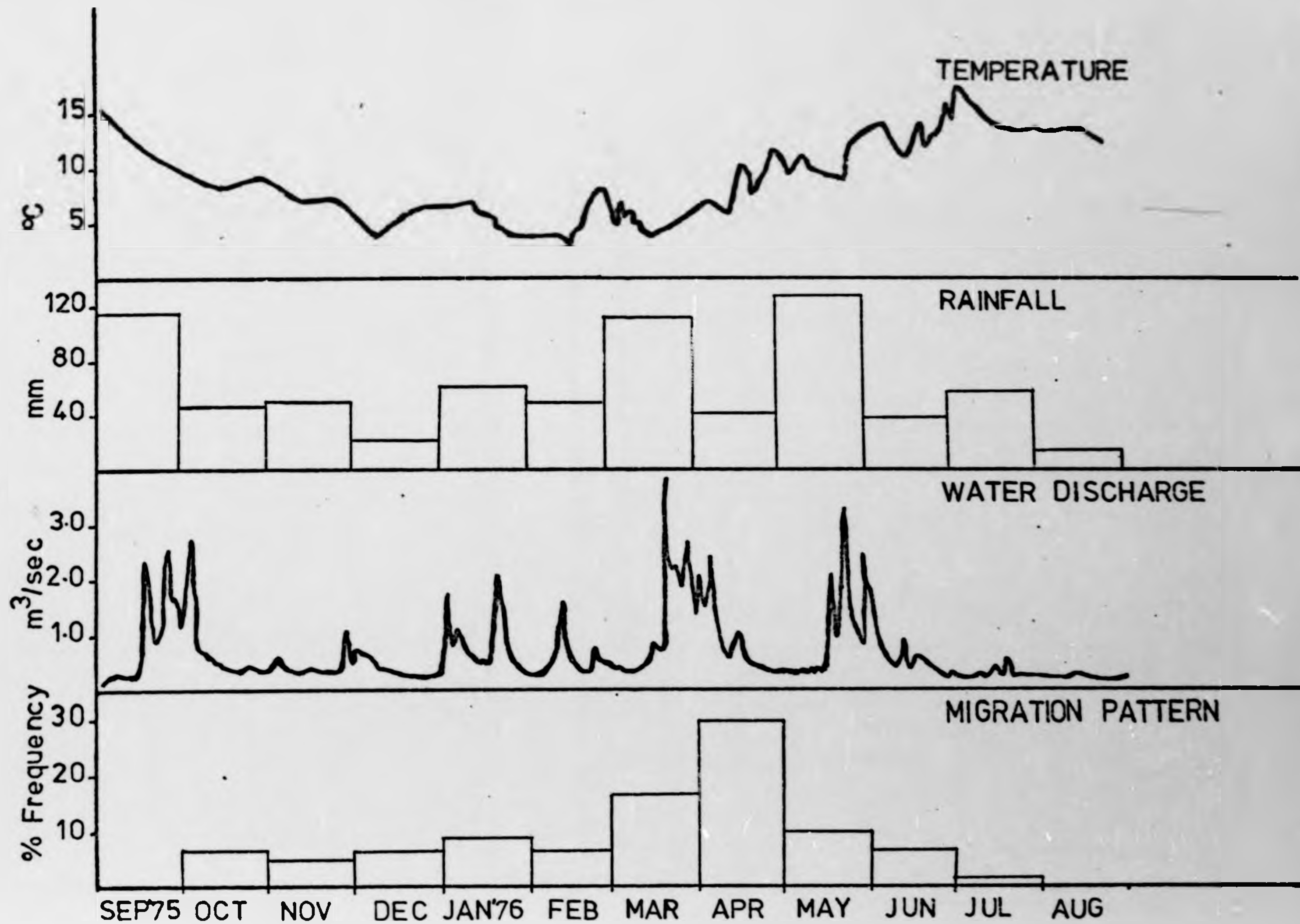
% Frequency
2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22. 24.
Fish Length (cm)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

was similar to that obtained in the river population structure where there was an early decrease in the small size trout (4-9cm) between September and November and later more of the larger size trout (above 12cm) disappeared from the stream population after January. The sharp drop in the stream population of the juvenile trout between September and November was not however reflected in the trap catches.

The pattern of trout migration from the trap catches and the total monthly river population of juvenile trout in the streams are compared with corresponding changes in stream temperatures, rainfall at Loch Leven area and the stream discharge as measured on the South Queich burn in Fig. 7 and Fig.8 respectively. It was evident from Fig.8 that the decrease in the stream population of juvenile trout coincided with the onset of floods caused by heavy rainfall and with an increase in the stream water discharge. This period also coincided with the onset of migration of juvenile trout as shown in Fig.7. Though the trap efficiency was low, the sharp drop in the stream trout population which was not reflected in the trap catches of juvenile trout migrants suggests that the decrease was not due to migration into the loch. Brown trout is territorial and as such a stretch of water will only hold a certain number of trout (Kennedy & Fitzmaurice, 1968). As also reported by Le Cren (1961), Frost & Brown (1967) and Mills (1971), trout fry that cannot find a territory move away, and a few go a little way upstream but the majority emigrate downstream in search of a vacant niche. As observed by Kelleberg (1958), the depth of water and the rate of flow were important for fry dispersal. It might therefore be that the sharp drop in the stream site population of

FIG.7

The pattern of juvenile trout migration in relation to stream temperature, rainfall and water discharge.

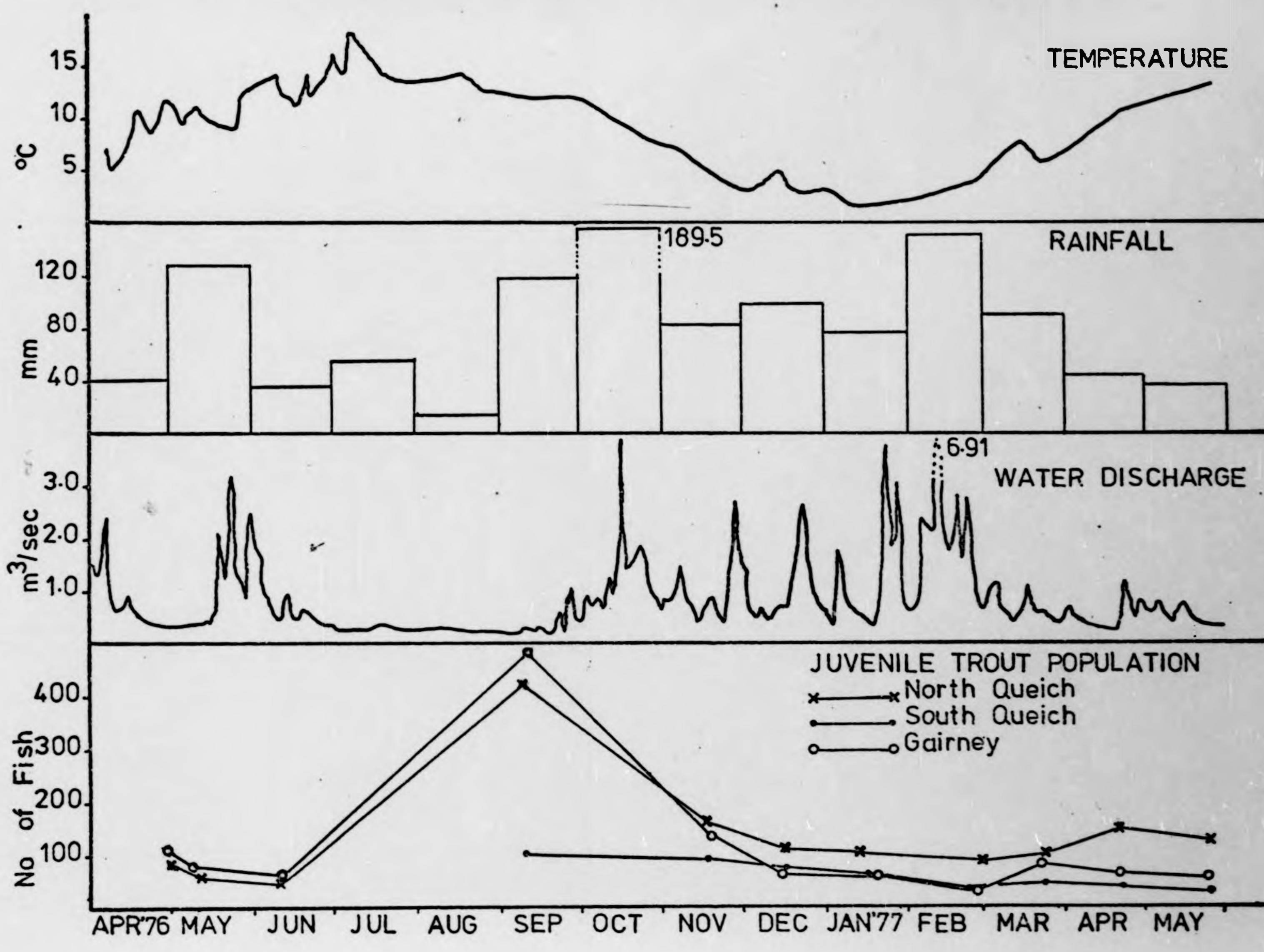


lation to

rge.

FIG.8

Juvenile trout stream site population in relation to temperature, rainfall and water discharge.


TEMPERATURE
°C
15.
10.
5.
RAINFALL
mm
120.
80.
40.
189·5
WATER DISCHARGE
m^3/sec
3·0.
2·0.
1·0.
6·91
JUVENILE TROUT POPULATION
North Queich
South Queich
Gairney
No of Fish
400.
300.
200.
100.
APR'76 MAY JUN JUL AUG SEP OCT NOV DEC JAN'77 FEB MAR APR MAY

tion to

juvenile trout between September and November was due to a displacement downstream following the increased water flow from the nursery areas to suitable areas downstream.

The peak of the migration of juvenile trout as seen in Fig.7 appears to be related to the onset of higher temperatures. The effect of increased stream temperatures on the populations of the juvenile trout at the main sites can also be seen in Fig.8. The slight increase in the juvenile trout population at the stream sites during March-April 1977 seems to coincide with the increase in the stream water temperatures. This indicates that there was an increase in the immigration of juvenile trout to these sites. Evidence of high immigration rates of juvenile trout to the North Queich site during this period can be seen in Table 2 while the high emigration and mortality of juvenile trout from the site was proceeding simultaneously. These show that increased stream water temperatures stimulate high activity in juvenile trout in the streams, leading to a fast immigration and emigration of juvenile trout and hence increased migration of juvenile trout into the loch.

Discussion

Among the tributaries of Loch Leven, North Queich and Gairney burns appear to support a higher population density of juvenile trout than South Queich. This might be due to the nature of these stream sites which gave enough cover for the young trout. As reported by Le Cren (1973) that a complex stream bottom was responsible for a stream holding a high population density, the relatively higher population density in North Queich site by May might be due to the nature of the site.

Le Cren (1973) reported a mid-summer population density of $5.8/m^2$ in a northern England stream and that in situations where the fry populations were as high as $8.5/m^2$, mortality was high. Le Cren (1961) and Mills (1971) also reported that the survival rate of the young stages of salmonids in the streams increase as their density is decreased. The relatively low population densities observed at the electrofishing sites in the Loch Leven nursery streams may enhance their survival.

The age structure of the stream juvenile trout at Loch Leven tributaries seems to justify the three age groups: I+, II+ and III+ trout migrating into the loch. It is therefore doubtful if there are trout living permanently in these streams. Campbell (1957) reported that the majority of young trout spend two years in the nursery streams of northern Scotland before migrating into the highland lochs while in Loch Tummel which is quite larger, most juvenile trout spend three or four years in the streams. The situation in Loch Leven feeder streams shows that good breeding facilities are available and the low population densities may promote good growth.

The factors responsible for initiating a migratory urge in stream juvenile trout have been widely discussed. Migration in salmonids is size dependent (Hoar, 1976). Hoar (1953) also suggested that the migratory urge is hormonal. However this urge seems to be triggered by some environmental factors. Berry (1933) related migration with the incidence of flood conditions while White (1939) related this to a rise in temperature.

Volovik (1967) suggested that illumination, transparency and discharge rate of water influenced migration. Migration of trout and salmon have also been associated with increased flows and turbidity and large migration was related with higher temperatures by Solomon (1975). Pemberton (1976) also associated the descent of young trout with rises in river levels. The migration of brook trout, Salvelinus fontinalis, in a Michigan stream has also been reported by Manion (1977) to occur after floods in autumn and with rising water temperatures of about 10°C in the spring. This appears to be closely related with the situation in Loch Leven where the onset of floods coupled with increased water discharge seem to influence the downstream migration of juvenile trout into the loch. Increased stream water temperatures too seem to accelerate the pace of migration of juvenile trout into the loch. Photoperiod may play a part, through the agency of endocrine control, in preparing trout for migration but environmental factors such as water flow and temperature rise may initiate the actual movement.

CHAPTER 3

THE DISTRIBUTION OF JUVENILE TROUT IN THE LOCH

Introduction

Although much has been published on brown trout in many water bodies, relatively little quantitative information is available on their distribution in lochs. The distribution of fish may be governed by many factors including: the nature of the bottom, water depth, temperature, light intensity, dissolved gases, pollutants, sexual development, predators, competitors, food and social response. Northcote (1967) remarked that many freshwater fish exhibit rather extensive movements in lakes both vertically as well as horizontally and on a diel cycle as well as seasonally. Such movements may have considerable effect on the feeding, growth, survival or other characteristics of importance to the fish production.

Allen (1938) reported that trout in Lake Windermere lived in deep water away from the shore as well as along the littoral region and that there were probably considerable seasonal variations in the proportions of trout populations which inhabited the two environments. His observations were based on seine net catches in the shallow part of the lake where he estimated that 50% and 25% of the littoral region trout population were in their third and fourth years respectively. Ball & Jones (1960) also reported that trout were scarce in the littoral region of Llyn Tegid during the summer but increasingly abundant during the winter. In Loch Leven however, Thorpe (1974b) observed that juvenile trout on entry into the loch dispersed all over the loch and that sizes between 20 and 30cm occurred offshore throughout the year but moved inshore on reaching a size of about 30cm. Further details on the distribution patterns of juvenile trout is expected in this study.

Materials and Methods

Between October 1974 and December 1976, the distribution of juvenile trout in the loch was studied by the following fishing methods:

Seining: A 107m beach seine net with a bag of 7m deep and 2.5cm mesh was set on 30.4m warps so that it could sweep an area of 3050m^2 at each time it was operated. The beach seine could reach a distance of 57m out from the shore and as such only fish in the inshore area of the loch were caught. This net was used at favourable shore-line areas of the loch but only three sites: X, Y and Z marked on Fig.9 were found to be suitable sites for juvenile trout at certain periods of the year. The use of the beach seine depended on suitable weather conditions and the availability of at least four people to operate it, hence its operation was limited. As seen in Table 3, this method was not suitable for catching juvenile trout in large numbers.

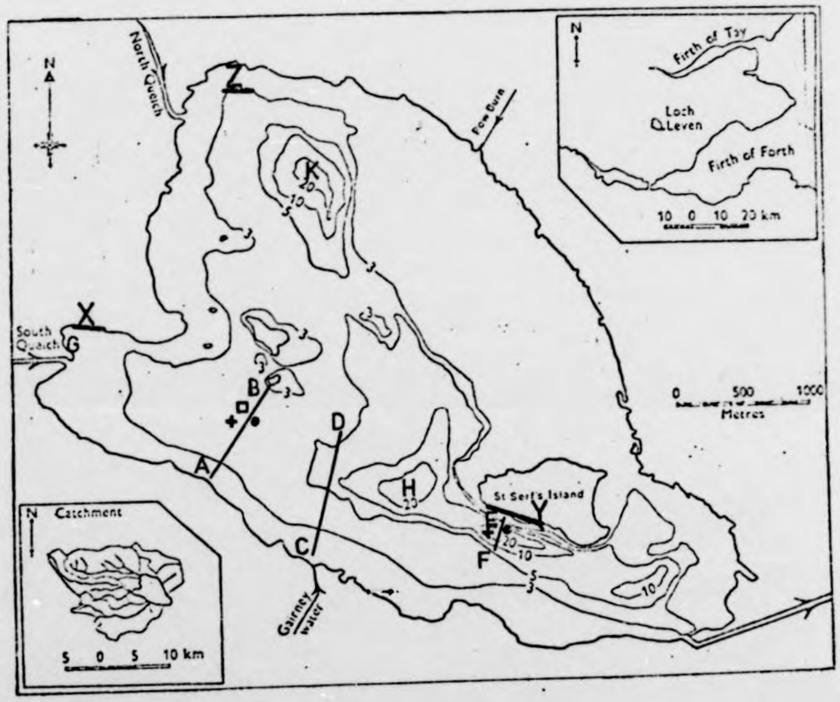
Trawling: An otter-trawl with a lead-line of 7.6m and a cod-end mesh of 2.5cm was towed behind a 6.5m catamaran to sample the offshore area of the loch. This exercise was carried out extensively over various sections of the loch from the harbour to the North and South deeps as well as the sluice area. It was also found not suitable for catching juvenile trout as seen in Table 3.

Gillnetting: Gillnet operation on the loch posed some initial difficulties because for a major part of year year; between April and October, the anglers usually fish daily on the loch

FIG.9

Map of Loch Leven showing depth contours in metres, sampling traverses (A-B, C-D, E-F), beach seining sites (X, Y, Z) and recapture sites.

Adapted from Morgan (1974)



G - Harbour
H - South Deep
K - North Deep
✚ - Recaptures from South Queich
◻ - Recaptures from North Queich
● - Recaptures from Gairney
Depth contours in metres

between 10.00 and 23.30 hours. The Loch Leven estate authorities too were reluctant to allow gillnetting on the loch because of the fear that the post-recruitment stages of the loch trout would be indiscriminately killed. However, with the assurance that only small size mesh nets would be used, limited operation of gillnets was approved to be set late at night and removed before the arrival of the anglers the following day.

Both monofilament and multifilament gillnets of mixed meshes: 1.9cm, 2.5cm, 3.2cm, 3.8cm, 4.5cm, 5.0cm, 6.0cm and 6.3cm of 70 or 80 metre lengths and average depth of two metres were used. During the summer period, between June and September, these nets were set between midnight and 1.30 hours and removed the next day between 9.00 and 12.00 hours, depending on the number of fish caught. However, during the winter season, between October and December, the gillnets were set earlier between 14.00 and 16.00 hours because of the shorter days and poor weather conditions and removed around 10.00 hours the next day. These gillnets were operated generally once a week depending on the prevailing weather conditions except occasionally twice a week during the summer period.

The gillnets were set at different sites on the loch parallel or perpendicular to the shore. When the juvenile trout populations were located, attempts were made to define these positions. Gillnets were therefore set along traverses A-B, C-D and E-F shown in Fig.9 and at each occasion, both the distance of gillnet sets from the shore and the depths were recorded.

Gillnets were also set in circular and semi-circular forms on isolated areas in the loch during the day while the surrounded area was disturbed with the aim of driving the fish into the nets. This exercise did not however prove successful in catching juvenile trout.

The gillnet sets generally followed the contours of the loch bed but vertical gillnets were set a few times, hanging from the loch surface through the water column to the loch bottom. The vertical gillnet sets did not catch any trout except for one juvenile perch.

When the downstream migration traps were in operation, all the trap-caught juvenile trout were marked and released downstream of the trap for onward migration into the loch. Similarly all the electrofished juvenile trout were marked and also released below the traps for onward migration into the loch. A total of 1079 juvenile trout were marked and released. It was intended to use the recaptures of these in the loch to show the dispersal pattern of juvenile trout on entry into the loch.

The division between sand and mud, shown in Fig.1 was used to classify the juvenile trout in the loch into inshore and offshore catches. Along the traverse E-F where the shore is stony, the inshore zone was taken as 57m from the shore, which was the distance reached by the beach seine from the shore.

All sampling carried out on the loch in the period April - September and October - March were grouped into summer and winter seasons respectively.

Results

Juvenile trout catches obtained by the three sampling methods used in the loch are shown in Table 3. Gillnetting proved to be

TABLE 3

The Efficiency of Sampling Juvenile Trout in the Loch with Trawling, Seining and Gillnetting

Sampling Method	No. of Trials	No. of Juvenile Trout Caught	Average Catch per Effort
Trawling	6	8	1
Seining	23	50	2
Gillnetting	44	970	22

most efficient in catching juvenile trout in the loch. Though gillnetting fished over a longer period of time, it has the advantage of being operated both inshore and offshore in the loch. Gill-netting has been reported by many workers to be highly selective. However, with a wide range of small-mesh gillnets used in this study, the extent of selectivity of the gillnets on the juvenile trout may not be great. The smallest size of juvenile trout caught in a gillnet size of 3.8cm in the loch was 10.3cm in July. Back-calculations of growth from the scales show that the fish entered the loch at a size of 8.7cm.

The results obtained in Table 3 can be used to determine the distribution of juvenile trout in habitats where they were operated. The beach seine was operated in the inshore area of the loch. Among the three favourable areas where the beach seines were used, juvenile trout appeared in the catches at station X only during the winter season but the other two stations were productive at most times of the year. These other two stations: Y and Z are those where the beach seine could stretch over a water depth of three metres or more when operated. The smallest size of juvenile trout caught by beach seining was 11.0cm in June. Back-calculations of growth on the scales show that the fish entered the loch at a size of 7.1cm. This indicates that the beach seine could fish as efficiently as the gillnets. The low catches of juvenile trout obtained by beach seining was an indication that the fish were not present in large numbers within its operational area. Gillnetting seems to be more successful because of its advantage in being operated offshore and at greater depths. The poor catches from offshore trawling might however be due to the inefficiency of the gear to sample adequately. Since the trawl was operated at a low speed, there were great chances of fish escaping capture.

By operating the gillnets perpendicular to the shore, it was possible to obtain the fish distributions at various distances from the shore. The results of these are shown in Fig.10 a, b, c and Fig.11 for the summer and winter periods respectively along the different traverses taken on the loch. The results obtained for the gillnet set at varying depths are also shown in Fig.12 for the summer period. Along the traverses A-B, C-D and E-F, it was evident that the number of juvenile trout caught increased as the gillnets were set further away from the shore and at greater depths during the summer period. Similarly, the numbers of juvenile trout seem to increase with the depth of gillnet set but this increase in number was not directly proportional to the absolute depth. The inefficiency of the vertical gillnet sets probably due to the short width (3m) casts a shadow on the true depth distribution of juvenile trout in the loch. However, these juvenile trout concentrations

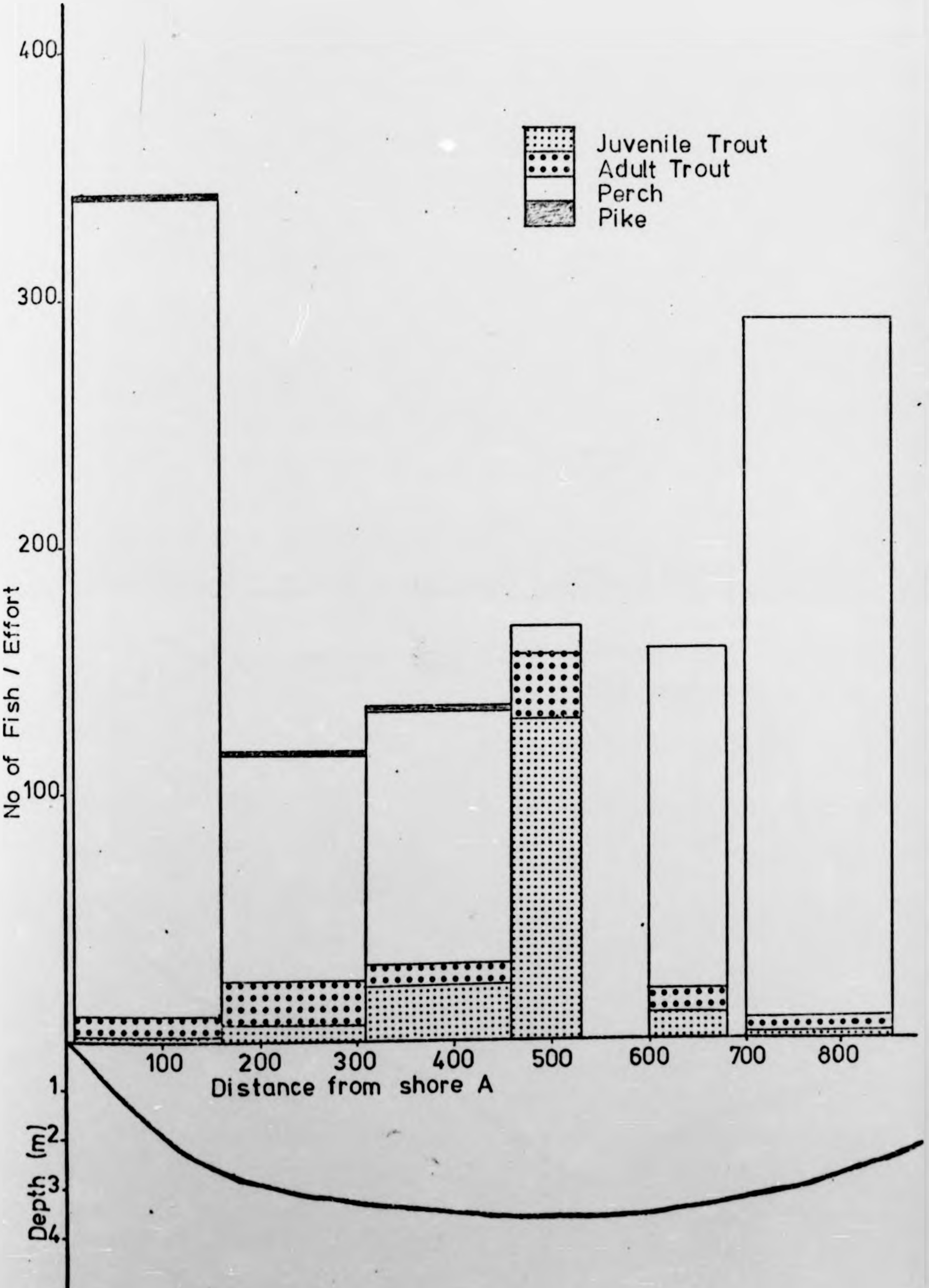
FIG.10a

Fish distribution along traverse A-B between June and September 1976.

FIG.10a

Fish distribution along traverse A-B between June and September 1976.

June and

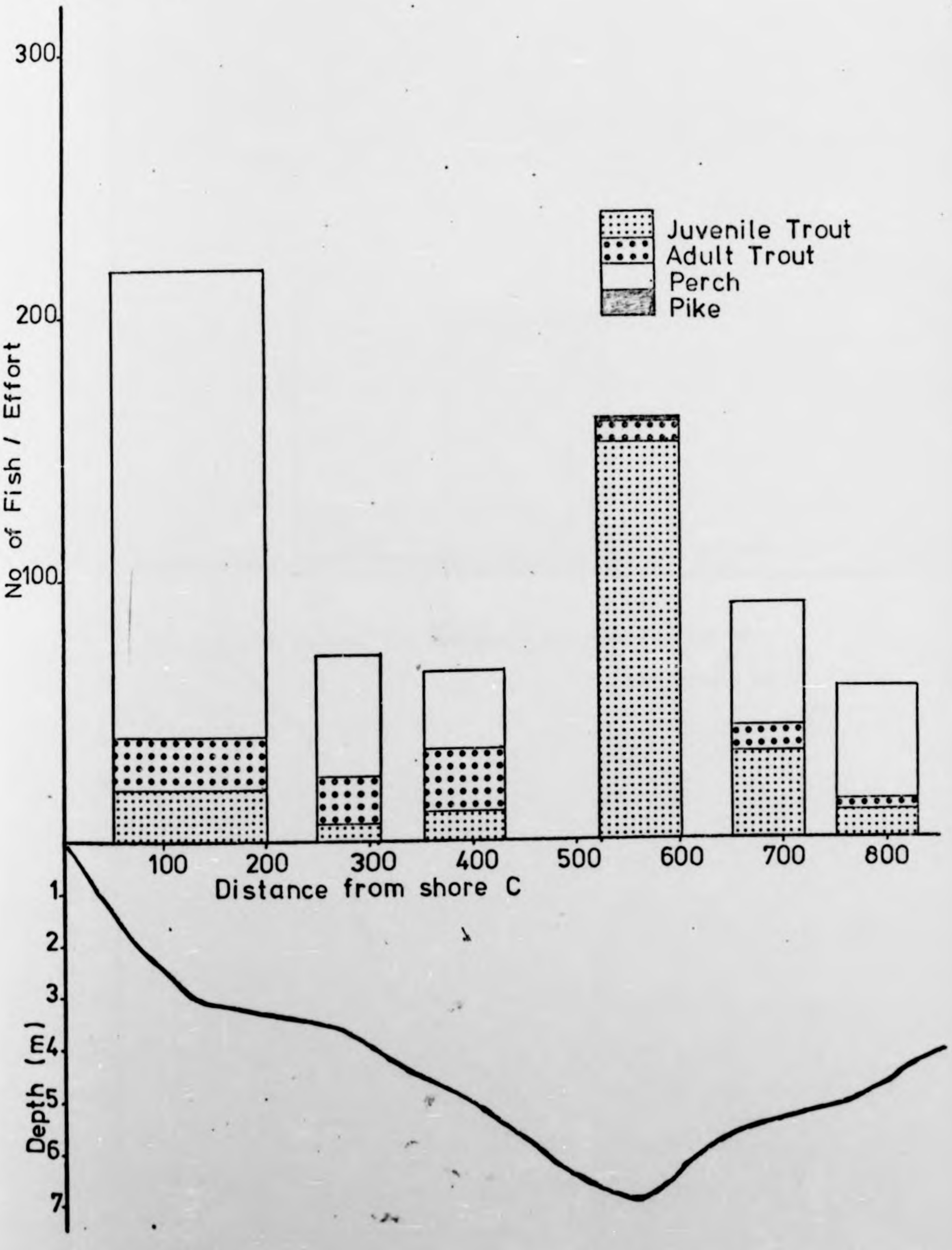


Juvenile Trout
Adult Trout
Perch
Pike
No of Fish / Effort
400
300
200
100
100
200
300
400
500
600
700
800
Distance from shore A
Depth (m)
1
2
3
4

FIG.10b

Fish distribution along traverse C-D between June and September 1976.

June and

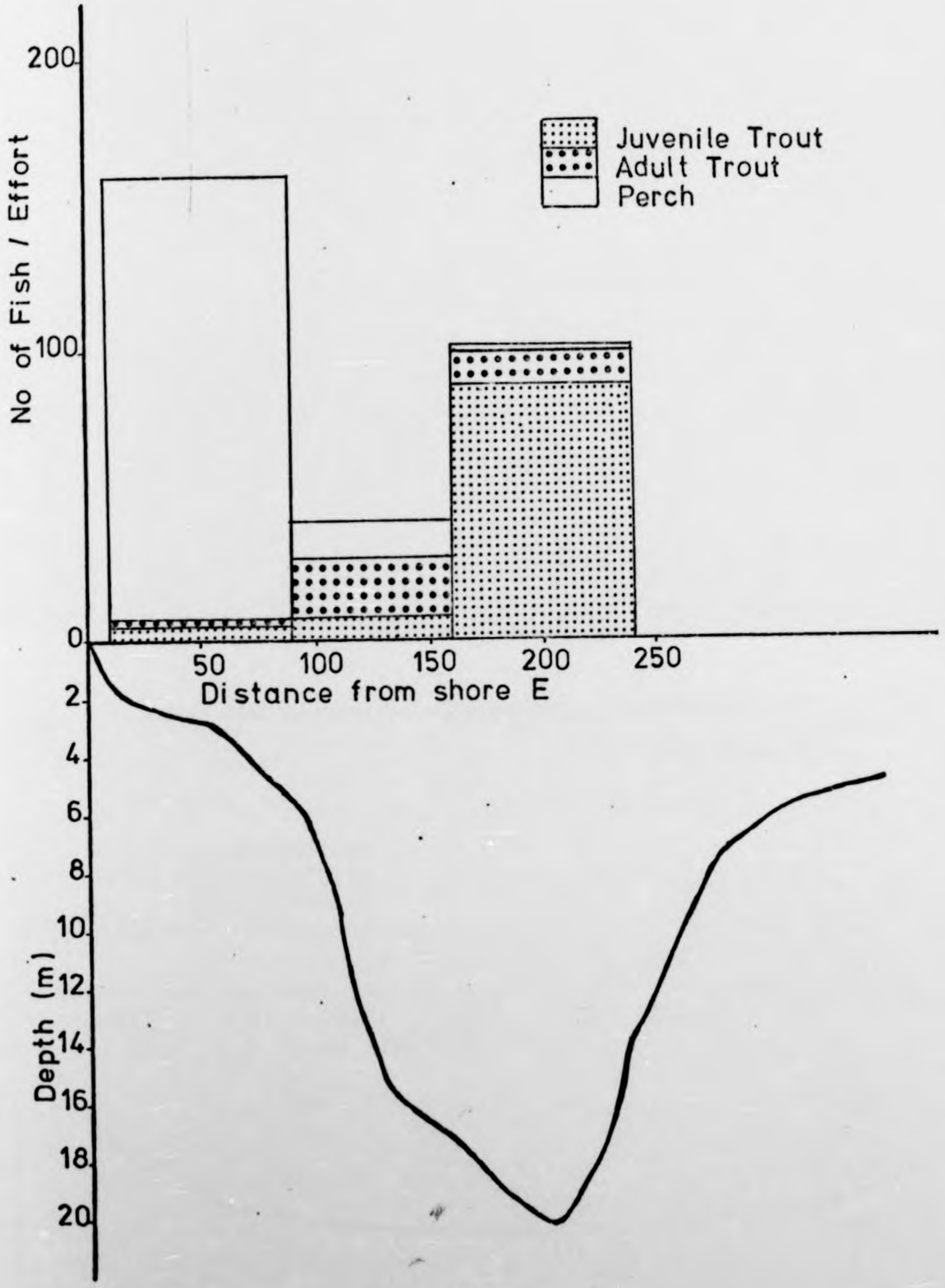


300
200
100
No of Fish / Effort
Juvenile Trout
Adult Trout
Perch
Pike
100
200
300
400
500
600
700
800
Distance from shore C
1
2
3
4
5
6
7
Depth (m)

FIG.10c

Fish distribution along traverse E-F between June and September 1976.

June and

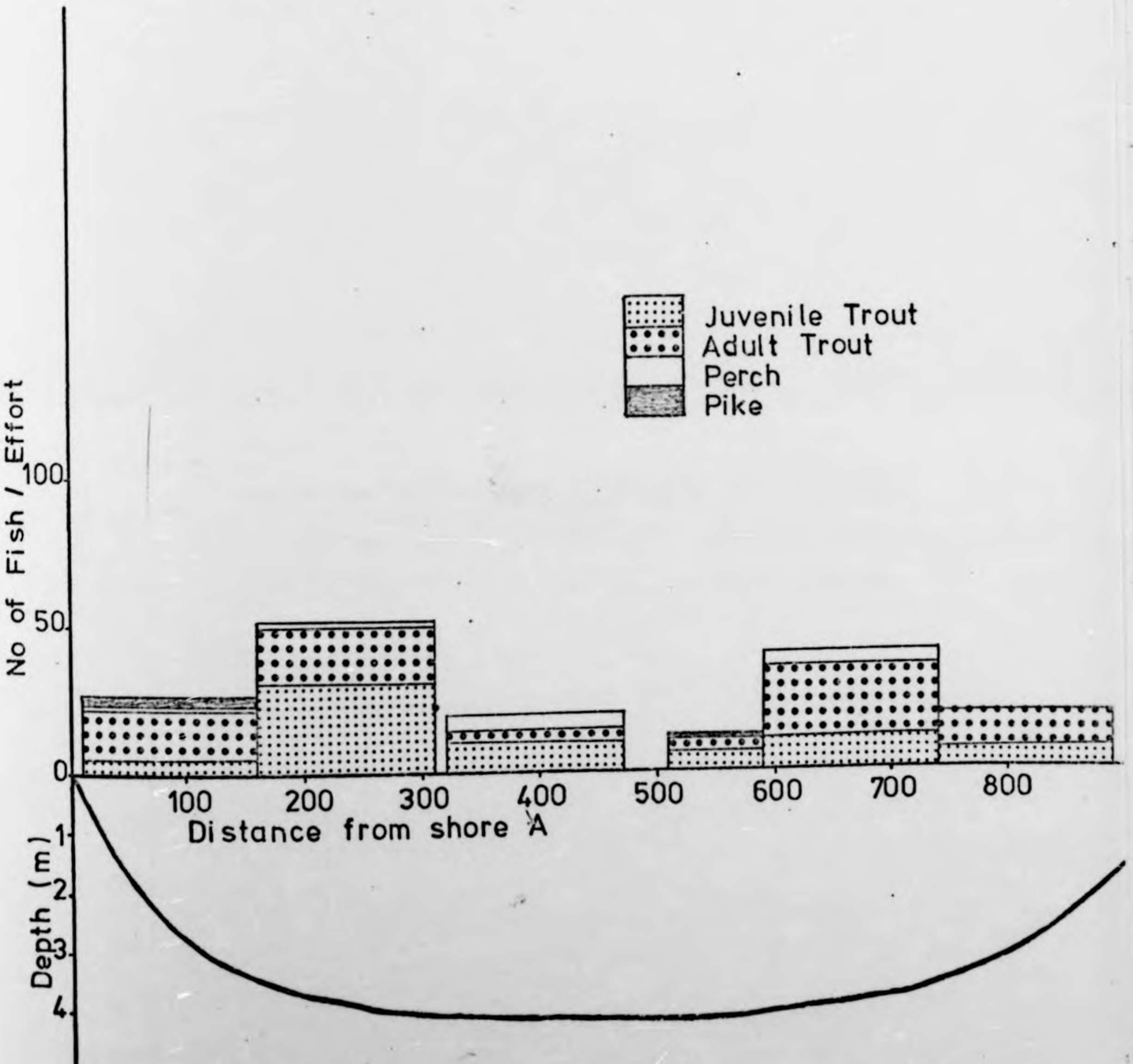


Juvenile Trout
Adult Trout
Perch
No of Fish / Effort
200
100
0
50
100
150
200
250
Distance from shore E
Depth (m)
2
4
6
8
10
12
14
16
18
20

FIG.11

Fish distribution along traverse A-B between October and December 1976.

October and



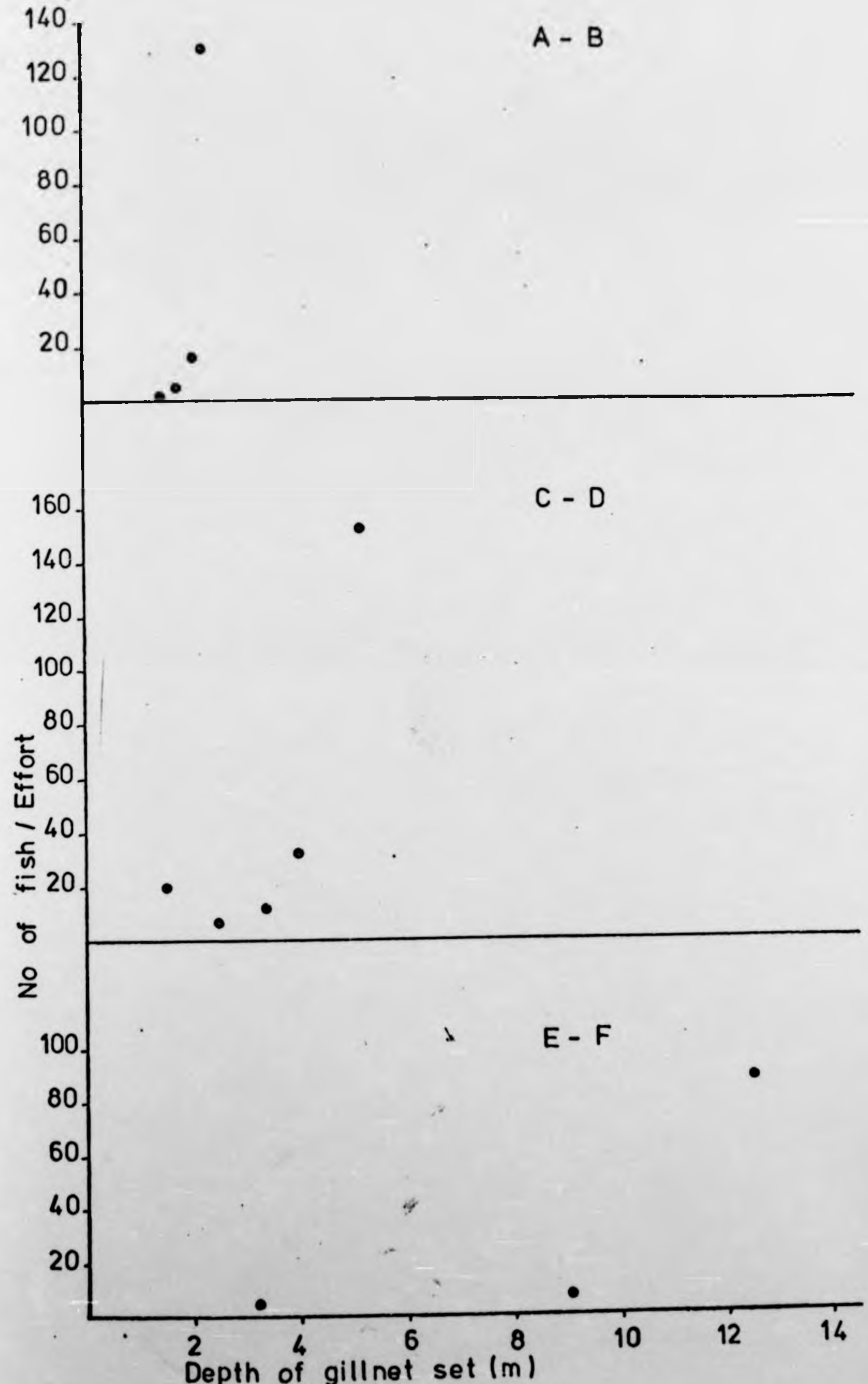
Juvenile Trout
Adult Trout
Perch
Pike
No of Fish / Effort
100
50
0
100
200
300
400
500
600
700
800
Distance from shore A
Depth (m)
1
2
3
4

FIG.12

Juvenile trout distribution with depth of gillnet set along traverses: A-B, C-D, E-F between June and September 1976.

llnet set

and



had depth preferences of between 2.5 and 13 metres. It is also evident from Fig.10 a, b, c, that juvenile trout were mainly concentrated offshore over the deepest part of each traverse. The juvenile trout concentrations account for 75.1%, 65.2% and 87.1% of the total number caught along each of traverses A-B, C-D and E-F respectively. The pattern of distribution of juvenile trout during the winter period was entirely different from the summer situation as seen in Fig.11. Juvenile trout appear to be more evenly distributed with no clear area of concentration as in the summer.

When gillnet catches of juvenile trout along the traverses on the loch are divided into inshore and offshore zones as shown in Table 4, it was found that an average of 96.4% of the summer

TABLE 4

Summer Distribution of Juvenile Trout Between the Inshore (Sand) and Offshore (Mud) Zones in Loch Leven

*Location	Total No. Caught	%Inshore	% Offshore
Traverse A-B	173	0.6	99.4
Traverse C-D	233	6.9	93.1
Traverse E-F	101	2.0	98.0
Mean	169	3.6	96.4

* Locations correspond to those marked on Fig.3.1

caught juvenile trout were concentrated above the offshore mud zone of the loch. Though juvenile trout along traverse A-B were evenly distributed during the winter period, the offshore mud zone still accounted for 94% of the total number caught. These results indicate that the offshore mud zone is a favourable area for juvenile trout in the loch. Only 3.6% and 6.0% of the total number of juvenile trout caught during the summer and winter periods respectively were in the inshore area of the loch.

The length frequency distribution histograms of the juvenile trout concentrations which appear in Fig.10 a, b, c, are shown in Fig.13. The size range of fish caught are similar though caught at different areas of the loch. When selected samples of trout from these concentrations were examined for age, they were found to be made up of I+, II+ and III+ age groups and most of them were in their first and second loch years.

As shown in Fig.10a, b, c, gillnet catches along the traverses also include adult trout (above 30cm), perch and pike. The adult trout caught in this study were those hooked by their teeth to the nets since the gillnet meshes used were meant to select against adult trout. The juvenile trout concentrations seem to live separated from the adult trout concentrations. Adult trout were more evenly distributed along the traverses and between the juvenile trout populations and other fish. The relationship between the distribution of perch and juvenile trout was quite distinct. It was obvious from Fig.10a, b, c, that perch concentrations live separated from the juvenile trout concentrations though there were areas where a few of both fish species overlap. As juvenile trout populations increase with increasing distance from the shore, perch populations decrease.

Adult trout seem to be concentrated more towards the inshore area of the loch during the winter as seen in Fig.11. Perch populations too appear to have disappeared from the gillnet catches in winter. Pike which only appeared one at a time during the summer

FIG.13

Length frequency distributions of juvenile trout concentrations caught along traverses: A-B, C-D and E-F.

trout concen-

and E-F.

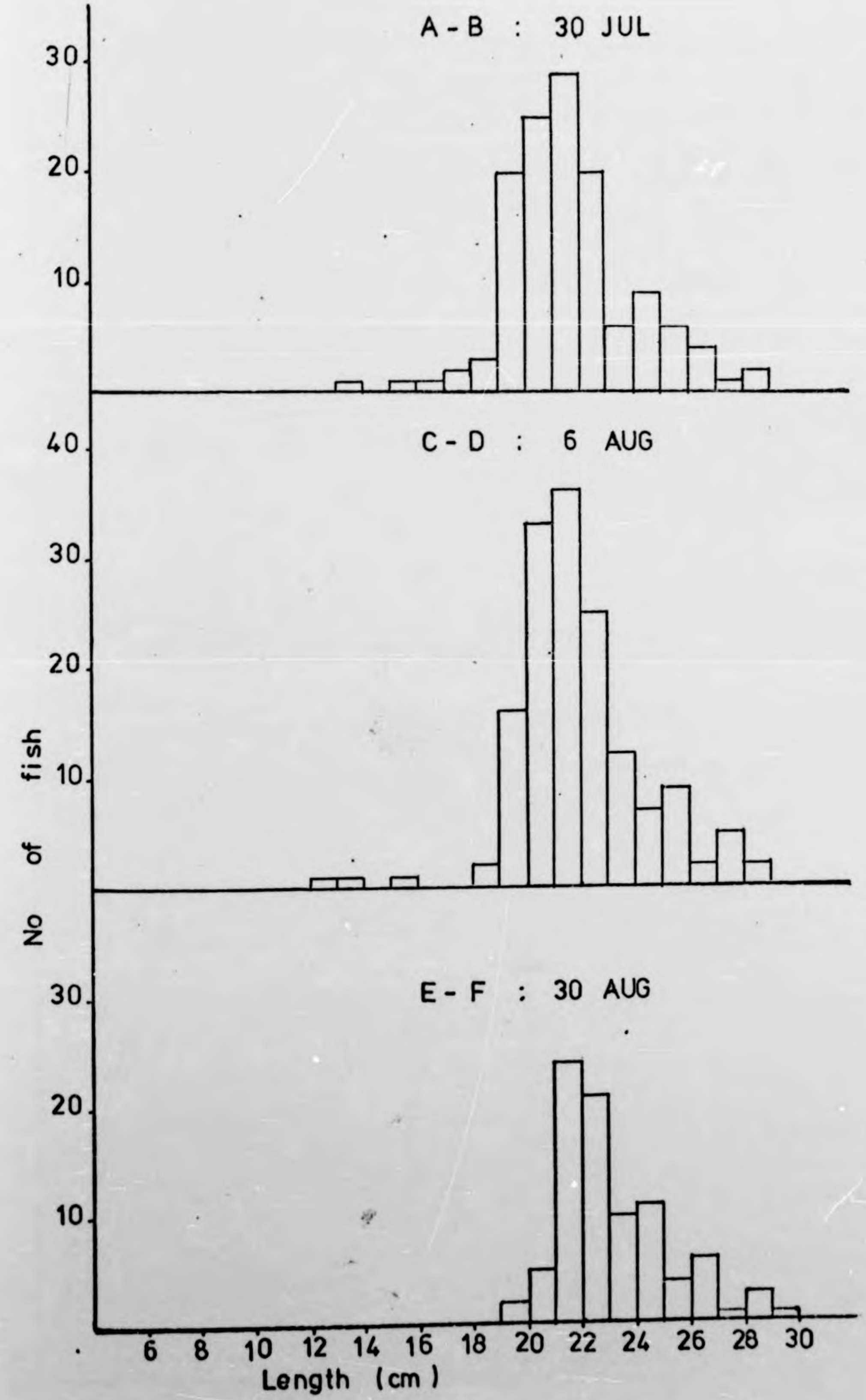
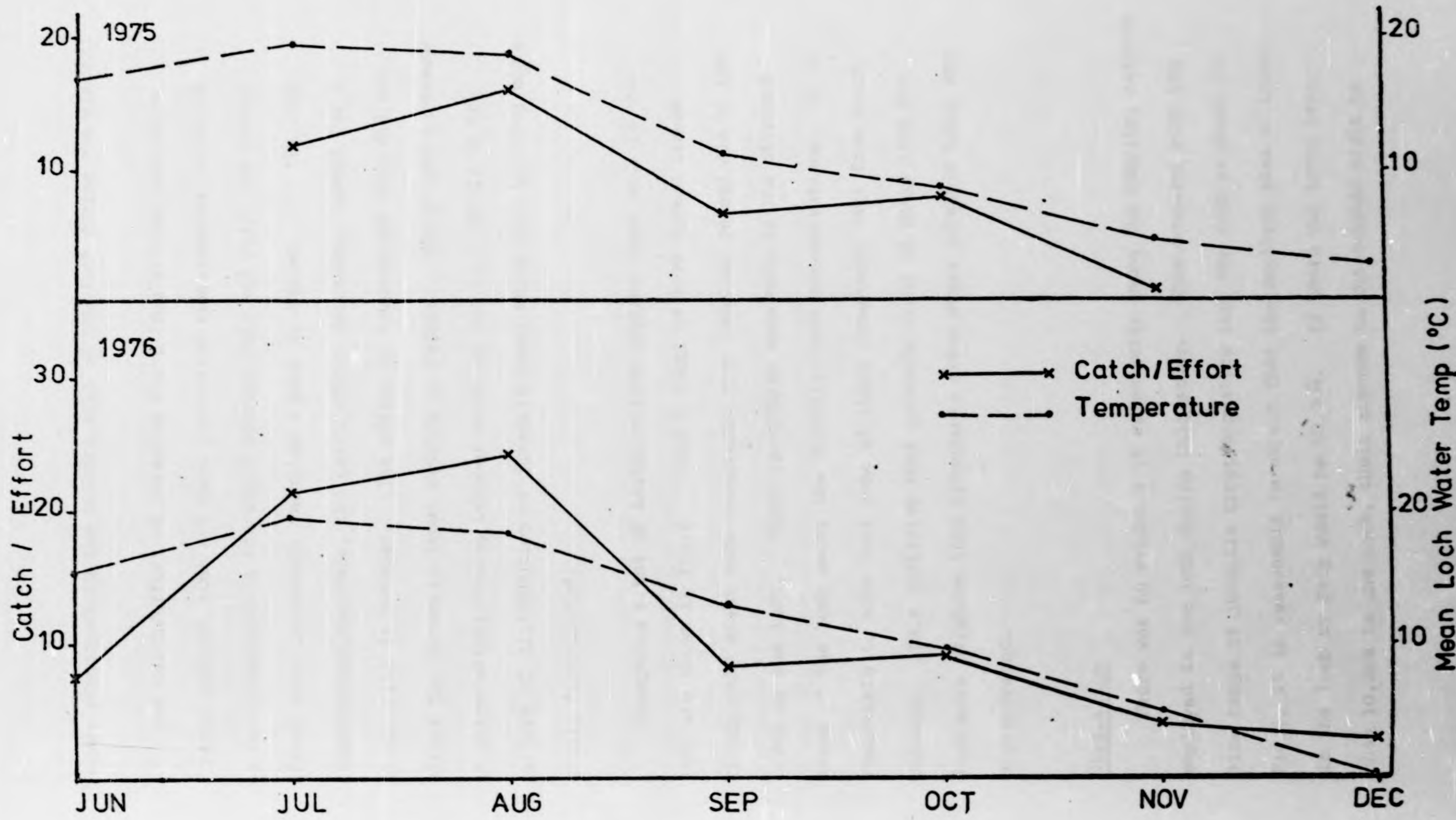


FIG.14

Seasonal variation in gillnetting catch/effort of juvenile trout.



1975
1976
Catch/Effort
Temperature
Catch / Effort
Mean Loch Water Temp (°C)
JUN
JUL
AUG
SEP
OCT
NOV
DEC
10
20
30

became prominent in the inshore area of the loch during the winter.

The catch/effort of juvenile trout from gillnet sets were plotted against time and mean loch water temperatures in Fig.14. As the temperatures increased between June and July, the catch/effort also increased, reaching a peak in August. As the loch temperatures decrease, the catch/effort decreases, except for a slight rise in October. The effect of temperature drop did not affect the juvenile trout catches in August. The slight increase in catch/effort during October might be due to a change in the pattern of distribution of juvenile trout which were becoming more evenly distributed.

Recapture sites of marked stream migrant trout made in the loch are shown in Fig.9. From a total of 1079 marked stream trout, only eight were recaptured when sampling ceased due to ice cover on the loch. These recaptures were made in the offshore areas of the loch among the juvenile trout concentrations. It is remarkable to note that none of these recaptures came from beach seining. This indicates that juvenile trout on entry into the loch move offshore into favourable areas where juvenile trout are concentrated.

Discussion

There was no evidence of selectivity among the sampling methods employed in the loch during this study. When compared with the size range of juvenile trout migrating into the loch as shown in Fig.6, it is reasonable to expect that the smallest size of trout in the loch by July would be 10.3cm. If there was trout less than 10.3cm in the loch, their absence in the catches might be due to limited sampling or the fish not being susceptible to capture. However, the smallest sizes of juvenile trout caught in the loch appear to be similar to those in Lake Windermere where Allen (1938) reported that only few trout under about 12cm were caught.

The apparent absence of juvenile trout in the inshore areas of the loch seems not to be peculiar to Loch Leven alone. Allen (1938) reported that few juvenile trout were present in the littoral of Lake Windermere. It therefore appears that juvenile trout migrants into the loch, move offshore as reported by Thorpe (1974b) until they reach a size of about 30cm. This fact is further supported by the recaptures of marked stream trout in the offshore areas of the loch. The limited and restricted sampling carried out on the loch might be the reason for the low recaptures. The trend of recaptures however support the earlier report by Thorpe (1974b) that juvenile trout on entry into the loch disperse all over the loch though within the offshore areas.

Seasonal variation in the proportions of trout occupying the shallow and the deep water have been reported by Allen (1938) and Ball & Jones (1960). A similar situation was reported for adult trout in Loch Leven by Thorpe (1974b) and the findings on adult trout in this study confirmed the seasonal changes. Juvenile trout in this study have also been found to exhibit seasonal variations in their distributions. However this did not amount to a complete movement of juvenile trout populations from the offshore to inshore region. Though no concentrations of juvenile trout were found during the winter season, they still preferred the offshore mud zone. Perch populations completely disappeared from the inshore zone and only a few of them were found scattered in the midwaters over the loch. As reported by Allen (1935) and Thorpe (1974c), perch populations inhabit deeper waters during the winter and they were found to live at depths between 18 and 27m in Lake Windermere. This might therefore account for the disappearance of perch populations in the catches during the winter. The fact that swimming activity may drop in winter may reduce gillnet capture but this would definitely affect the trout populations too. Though the catches of juvenile trout were low in winter, the proportions of perch to trout fell drastically during the winter, with a more severe effect on perch.

Many factors have been suggested to influence seasonal changes in the distribution of fishes. As far as juvenile trout populations of Loch Leven are concerned, loch temperature variations seem to influence changes in their distribution pattern and also affect their susceptibility to catch. Changes in the distribution pattern of other fish might also affect the distribution of juvenile trout. Perch populations which were dominant in the inshore zone of the loch during the summer disappeared during the winter period. Since juvenile trout populations appear to live separated from the perch populations, the disappearance of the juvenile trout concentrations from the deeper offshore areas of the loch might be a social response to perch populations which presumably inhabit the deeper parts of the loch in winter. Adult trout too were found to live separated from the juvenile trout concentrations. Brown (1957) reported that among trout populations from fry to old fish, the very presence of a larger individual depressed the growth of smaller individuals. This apparent separation of juvenile trout from their adults might be a social response to avoid inhibition to their growth.

Seasonal changes in activity patterns of trout have been shown by Muller (1969). Crepuscular activity in trout have also been demonstrated by Holliday et al (1974) and this was related to their need to search for food. The true depth distribution of juvenile trout in the loch cannot therefore be clearly defined due to their variable activity. Most of the juvenile trout caught in this study was by gillnetting and they are suspected to have been caught early in the morning since many of the fish appeared fresh and lively when the nets were being examined. It is most likely that the juvenile trout were caught in the morning when moving in search of their food. This time appears to coincide with the peak of activity at dawn as reported by Holliday et al (1974). The food of juvenile trout in the loch can be said to play a part in their distribution.

Ball & Jones (1962) reported that only a few trout live at the bottom of Llyn Tegid at a depth of 18 metres when gillnets were set at the bottom. Attempts were made to sample the deeps during this study but the nets were lost due to bad weather conditions on the loch. It is most likely that juvenile trout populations in Loch Leven live in the midwaters and move towards the loch bottom or towards the loch surface during feeding periods.

Pike did not occur in large numbers during the summer catches but the few caught during the winter suggests that they were concentrated in the inshore areas of the loch. Juvenile trout concentrations live far away from the inshore areas of the loch where pike are most abundant. Though pike could move into the offshore areas of the loch, the separation of the juvenile trout from the pike might be a means of avoiding the pike.

CHAPTER 4

THE AGE AND GROWTH OF JUVENILE BROWN TROUT IN THE LOCH

Introduction

The age and growth of brown trout has attracted much attention from various workers all over the world. In Britain a lot of research has been carried out on the age and growth of brown trout in many water bodies (Allen, 1938; Swynnerton & Worthington, 1939; Frost, 1950; Frost & Smyly, 1952; Campbell, 1957, 1961, 1963; Ball & Jones, 1960; Munro, 1961; Graham & Jones, 1962; Hunt & Jones, 1972). The growth of trout in Scotland has been studied by many workers but the recent work carried out by Campbell (1971) on 24 highland lochs and Treasurer (1976) on a coastal dune lake gave details on the growth in different habitats.

As the exploitation of brown trout continues all over the world, there is an increasing demand for more information concerning the age and growth of trout in relation to their environment. Reference has been made about the growth of brown trout in Loch Leven by Worthington (1939, in Litt). This study is therefore carried out to complement the earlier work done and to supply further details on the age and growth of juvenile trout before they are recruited into the Loch Leven fishery.

Materials and Methods

Between October 1974 and December 1976, Loch Leven was sampled at different times of the year by seining, trawling and gillnetting as described in Chapter 3. Juvenile trout were caught by electrofishing in the four major tributaries to the loch. Traps were also used to catch the downstream migrants in the streams and emigrants from the loch at the sluice gate.

Juvenile trout specimens caught in the loch and the streams were anaesthetized on the spot. Measurements were made of each specimen to the nearest millimetre from the tip of the snout to the tail fork using a measuring board and weighed to the nearest gram on a weighing balance. Scale samples were removed from selected fish samples by scraping the body surface with a blunt knife. The scales were always taken from a small area on the left side just in front of the dorsal fin and above the lateral line. In the laboratory, most of the scales were cleaned in 10% ammonia. These scales were preserved in small envelopes on which measurements were written for later identification.

The scale method is usually favoured for the determination of the age and growth of trout. For examination, six scales or more from each fish sample were mounted and pressed between two pieces of thin celluloid strips using a metal roller and thus leaving permanent impressions of the scales for age and growth studies. Only scales with perfect centres were selected for reading.

For age determination, the annuli were identified and counted. These were read on a magnified built-in screen of a scale reader on the assumption that the number of completed bands of winter rings equalled the age of the fish in completed years. The year of life of trout is reckoned from the time of hatching. As explained in Chapter 2, March 1st was chosen as the date in which most of Loch Leven trout hatch. For all calculations in this study, the length of trout fry at birth is taken as 2.4cm as was also suggested by Frost & Brown (1967).

Loch Leven trout hatch in the feeder streams and then migrate into the loch (Balmain & Shearer, 1953; Thorpe, 1974b). They migrate during the winter and the spring/early summer as mentioned in Chapter 2. The period: October to July can be referred to as the migrating season. Each trout can be placed in a migrant group according to the age at which it migrated. All the trout which migrated during the winter or spring/summer after the completion of their first growing season of life are 1-migrants. Similarly, trout which migrated on the completion of their second and third growing seasons of life are 2- and 3-migrants respectively. A group of fish of the same age are termed age group. During their first year of life, trout belong to the 0+ age group and in their second and third years of life I+ and II+ respectively.

For growth determination, the distance of the annuli from the centre of the scale is measured and also the total length of the scale from the centre to the edge. The logarithms of the total scale lengths are plotted against the logarithms of the fish lengths and then a regression line was drawn through these points by the method of least squares. The slope of this line represents the regression coefficient. From the straight line, the fish lengths for different scale lengths are back-calculated.

The annual growth rates are expressed as the percentage increase per annum or the specific growth rate (G) defined as follows:

$$G = \frac{\log_e L_2 - \log_e L_1}{T_2 - T_1} \times 100\%$$

where L_2 and L_1 are the lengths at times T_2 and T_1 respectively.

In fishes, the length-weight relationship can usually be adequately represented by the equation:

$$W = a L^b$$

where a is a constant and b is an exponent. It is convenient to plot the logarithms of weights against the logarithms of lengths and from this the equation of the regression line can be calculated from the transformed expression:

$$\log W = \log a + b (\log L) .$$

The regression coefficient is b, while log a is the intercept of the line with the y-axis.

Results

(a) Scale structure and time of annulus formation

An examination of the loch fish scale shows an oval centre followed by widely spaced rings and then closely spaced rings. The wide and narrow circuli laid down on the scales correspond roughly with the spring-summer and autumn-winter periods respectively. The wide circuli on the fish scales appear to be laid down between March and September while the narrow circuli are laid down between October and February (see Plate 1).

The width of the circulus is an index of the rate at which fish is growing when the circulus is formed. An examination of the circuli at the end of the scale should show whether the fish was making slow or rapid growth at the time it was caught. The scales of all juvenile trout examined in this study showed rapid growth during the period May to August as evidenced by the wide circuli laid down. In some fish however this band of wide circuli is often interrupted by one heavy irregular line (see Plate 2). This indicates that the fish made no growth in winter and hence no narrow circulus was laid down. In most fish scales, the main growing period is during the period March to September. Hence 0+ fish migrating to the loch between October and July are termed 1- migrants, having spent the growing season in the stream and migrating during the winter-spring when there is little or no growth.

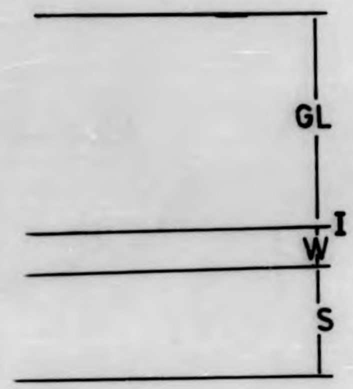
The scales of all juvenile trout caught in the loch showed a sudden well-marked increase in the growth pattern at some point during the first four years of life. The increased growth pattern is attributed to the entry of the fish into the loch from the nursery streams (see Plates 1 and 2). This effect has been reported for Loch Leven trout by Balmain & Shearer (1953) and for other lochs by Allen (1938); Ball & Jones (1960) and Treasurer (1976).

Of the 363 specimens studied for age and growth among the loch catches, 55.9% were found to be 1- migrants, 37.2% and 6.9% were found to be 2- and 3- migrants respectively. A close examination of the scales of these migrant trout also revealed that fish which entered the loch during the winter could be separated from those which entered the loch during the spring. The scales of the fish which entered the loch during the winter usually show a well-marked increase in circuli formation typical of loch growth immediately after the winter band while those that entered the loch in spring have the characteristic stream growth after the winter band before the distinct loch growth (see Plate 2). Among these trout, 52.5% of 1- migrants, 67.2% of 2- migrants and 72.7% of 3-migrants were found to have entered the loch during the winter.

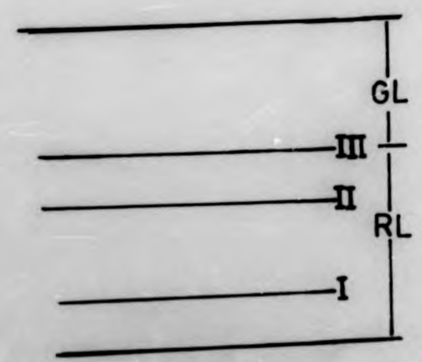
PLATE 1

(A) Scale from a I+ year old 1- migrant trout (16.7cm) taken on 28th June 1976, showing the first year summer (S) and winter (W) growth rings and a well-marked increase in growth in the loch (GL).

(B) Scale from a III+ year old 3- migrant trout (23.7cm) taken on 27th July 1976, showing three years of river growth (RL) and a faster growth in the loch (GL).



nt trout (16.7cm)
the first year
rings and a
the loch (GL).



rant trout (23.7cm)
three years of river
the loch (GL).

t trout (16.7cm)
he first year
ings and a
the loch (GL).

ant trout (23.7cm)
hree years of river
the loch (GL).

nt trout (16.7cm)
the first year
rings and a
the loch (GL).

rant trout (23.7cm)
three years of river
the loch (GL).

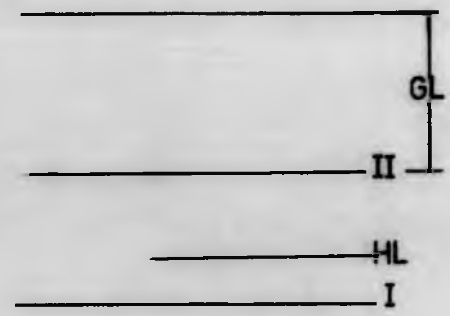
PLATE 2

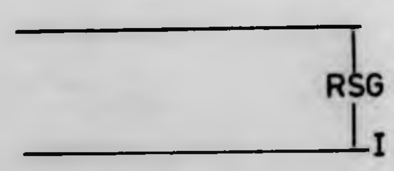
(C) Scale from a II+ year old 2- migrant trout (20.5cm) taken on 25th July, showing two years stream growth, a heavy irregular line showing no winter growth (HL) and a rapid loch growth (GL).

(D) Scale from a I+ year old 1- migrant trout (17.5cm) taken on 2nd October showing spring growth in the stream (RSG) before entry into the loch.

trout (20.5cm)
stream growth,
ter growth

rout (17.5cm)
rowth in the
ch.





trout (20.5cm)

stream growth,

ter growth

trout (17.5cm)

growth in the

och.

trout (20.5cm)
stream growth,
ter growth

rout (17.5cm)
rowth in the
ch.

This suggests that over half of the migration of juvenile trout into the loch took place before the beginning of the growth season.

(b) Size distribution of fish samples

Length-frequency distributions often exhibit modes among smaller fish which correspond to the youngest age groups. The monthly changes in the length structure of the loch juvenile trout population are shown by the length-frequency histograms in Fig.15. The length-frequency distribution patterns in the Loch Leven feeder streams are also shown in Fig.3a, b, c. Since juvenile trout migrate into Loch Leven at ages one, two and three and growth in the loch has been reported faster than in the streams (Campbell, 1957), fish of ages I+, II+ and III+ in the loch will be longer than their contemporaries in the streams. The entry of 2- and 3-migrant juvenile trout into the loch will therefore depress the mean lengths of their year classes in the loch and hence the irregular and widely dispersed length-frequency histograms in Fig.15.

(c) Growth in length

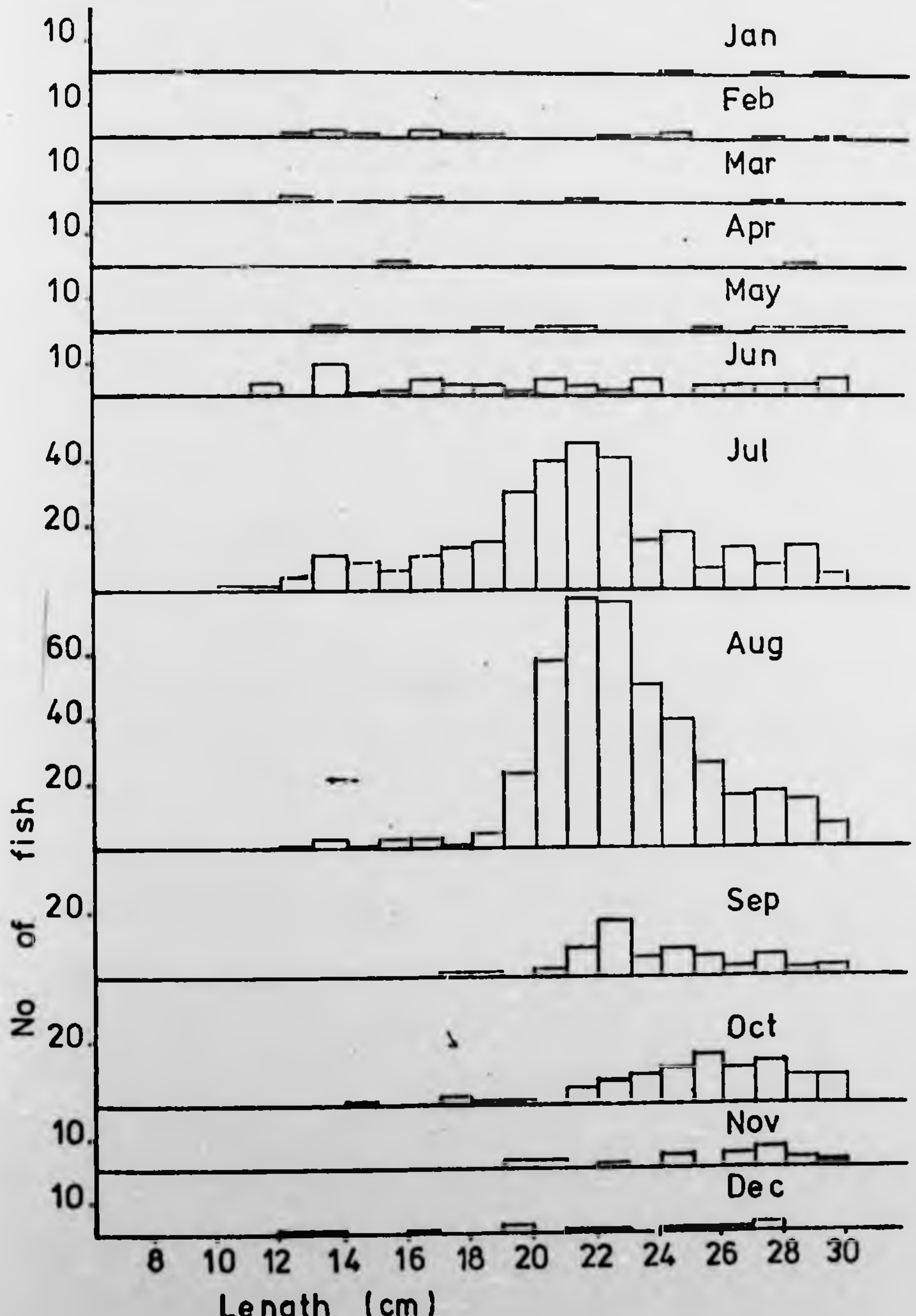
Length is a more reliable indicator of growth than weight because length once achieved is not lost but weight can be due to seasonal variations. Growth of scales is strictly proportional to growth in length of fish and as such more emphasis will be laid on length to determine the growth of Loch Leven trout.

There was a significant correlation ($r = 0.98$ $p < 0.001$) between the logarithms of scale length and fish length as shown in Fig.16. The calculated regression line gave the relationship: $y = 5.87\ x^{0.74}$, where y = fish length in cm and $\underline{x}$ = scale length × 48 (magnification), i.e. fish length = 5.87 (scale length × 48)$^{0.74}$.

FIG.15

Length frequency distribution of juvenile trout in Loch Leven 1976.

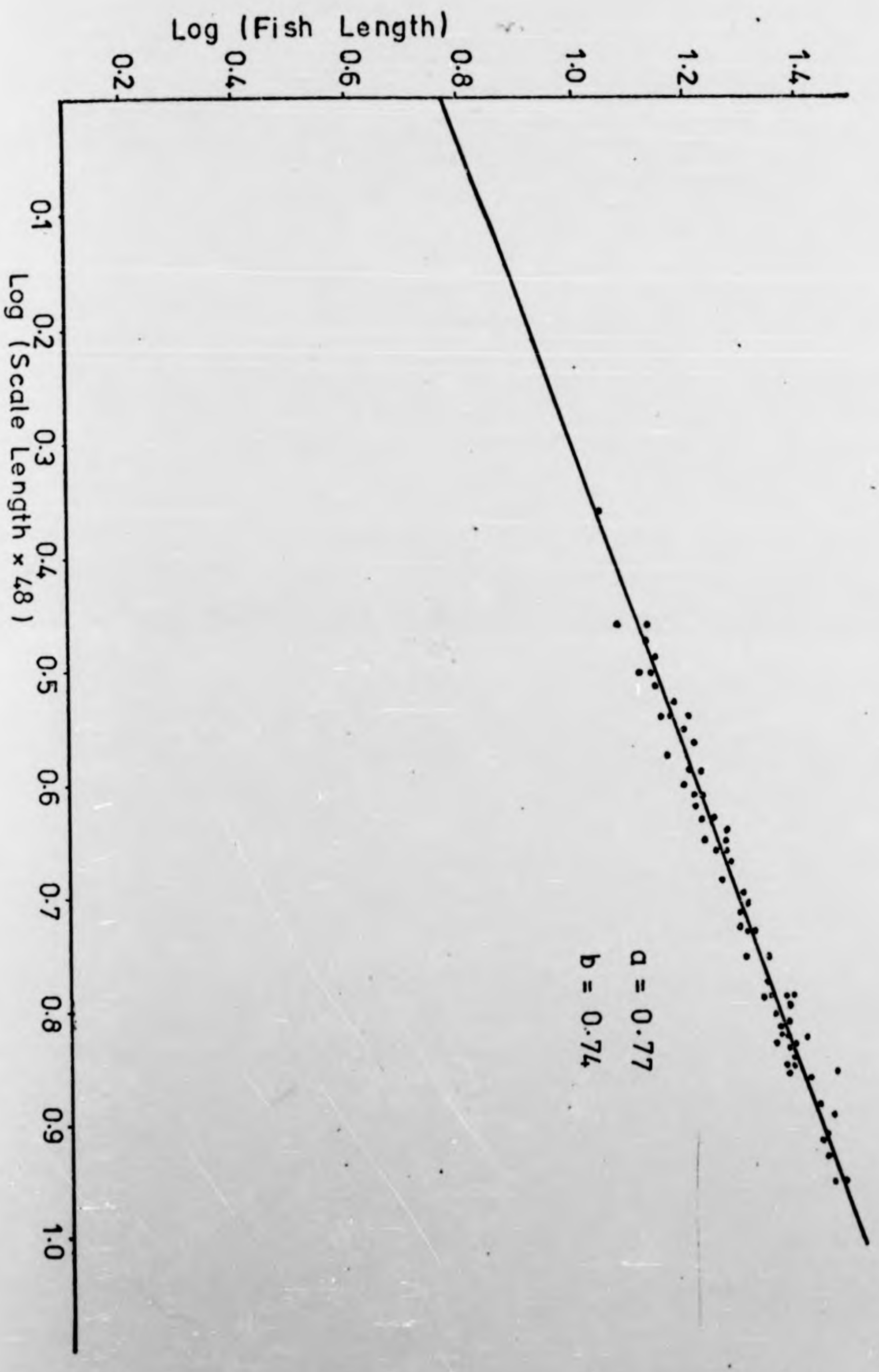
trout in



Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
10
10
10
10
10
10
40
20
60
40
20
20
20
10
10
No of fish
8 10 12 14 16 18 20 22 24 26 28 30
Length (cm)

FIG.16

Fish length/scale length relationship for Loch Leven juvenile brown trout.


Log (Fish Length)
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Log (Scale Length × 4.8)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
a = 0.77
b = 0.74

Loch Leven

From this regression line the growth in length was obtained by back-calculation. The lengths of fish at each age of life for the different migrant groups of juvenile trout are shown in Table 5 and Fig.17. The lines in Fig.17 are extended to meet the length axis at 2.4cm, which is taken as the length of trout fry at birth.

TABLE 5

The mean back-calculated lengths for different age groups of Loch Leven juvenile brown trout

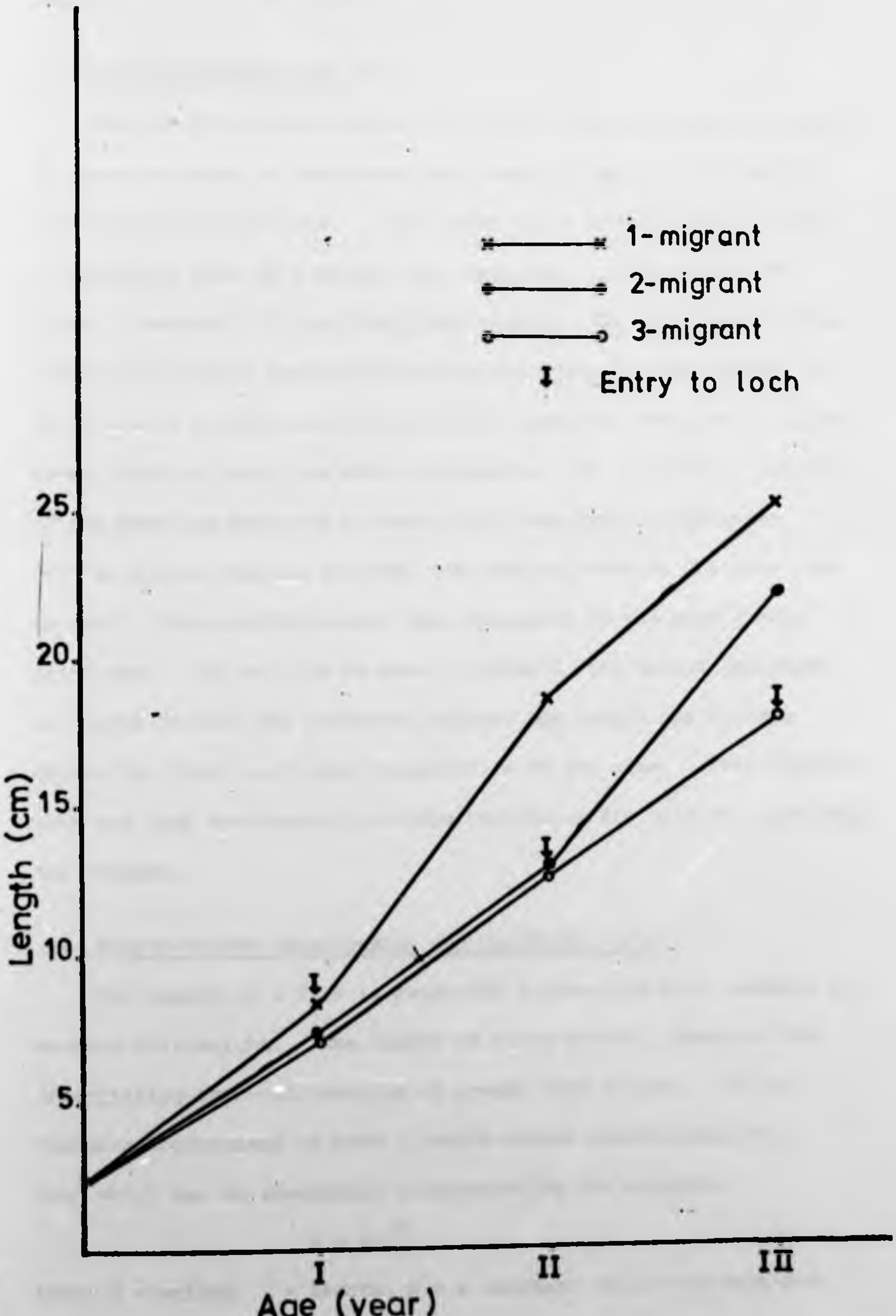
Category of Fish	No. of fish in sample	*Length at age (cm) I	II	III
1- migrants	203	8.3 ± 0.50 (203)	18.6 ± 1.80 (57)	25.2 ± 0.47 (13)
2- migrants	135	7.4 ± 0.57 (135)	12.9 ± 1.31 (135)	22.1 ± 1.36 (10)
3- migrants	25	7.2 ± 0.73 (25)	12.6 ± 1.24 (25)	17.9 ± 1.55 (25)
All migrants	363	7.8 ± 0.75 (363)	14.7 ± 1.40 (217)	21.7 ± 1.27 (48)

* Figures in brackets indicate the number of fish in sample used to calculate the mean length

Growth in length at age I was faster in the 1- migrant group than the 2- and 3- migrant groups in the nursery streams. All the fish specimens show a marked length increase in their first year in the loch as clearly shown on their scales (see Plates 1 and 2). As remarked by Campbell (1957) growth of trout in the loch was influenced by the numbers of years spent in the streams before migration into the loch. This therefore accounts for why the 2- and 3- migrant groups which remained longer in the streams before migration show smaller growth than their 1- migrant contemporaries that arrived earlier in the loch.

FIG.17

Growth in length of juvenile trout in Loch Leven obtained by back-calculation from scales.


1-migrant
2-migrant
3-migrant
Entry to loch
25.
20.
15.
10.
5.
Length (cm)
I
II
III
Age (year)

h Leven

Examinations carried out on the scales of selected stream trout and migrants caught in the traps show that they were composed of three age groups.

(d) Specific Growth Rate (G):

The specific growth rates (G) for the different migrant groups of juvenile trout in Loch Leven are shown in Table 6 with examples from other British lochs. As in most other lochs, (G) is highest in the first year of life and then decreases as the fish grows older. However, for all loch year classes, (G) is highest in the first loch year of the different migrant groups. The changes in the specific growth rate with the mean length in that year for Loch Leven juvenile trout are shown in Fig.18. It is evident that fish of the same age may grow at nearly the same rate in different migrant groups when in the same environment, fish of the same size do not. The specific growth rate decreases as the mean length increases. As can also be seen in Table 6, the actual increment in length for all the different migrant age groups was highest during the first loch year irrespective of the size. This suggests that the loch environment provides facilities for better growth than the streams.

(e) Length-Weight Relationship and Condition Factor

The length of a fish is generally quicker and more accurate to measure than weight. The length of trout is also important for interpreting back-calculations of growth from scales. It is therefore convenient to have a length-weight relationship of a fish which can be adequately represented by the equation:

$$W = a L^b$$

where W = weight, L = length, a = a constant and b = an exponent

FIG.18

Changes in specific growth rate of juvenile trout with size in Loch Leven.

le trout with

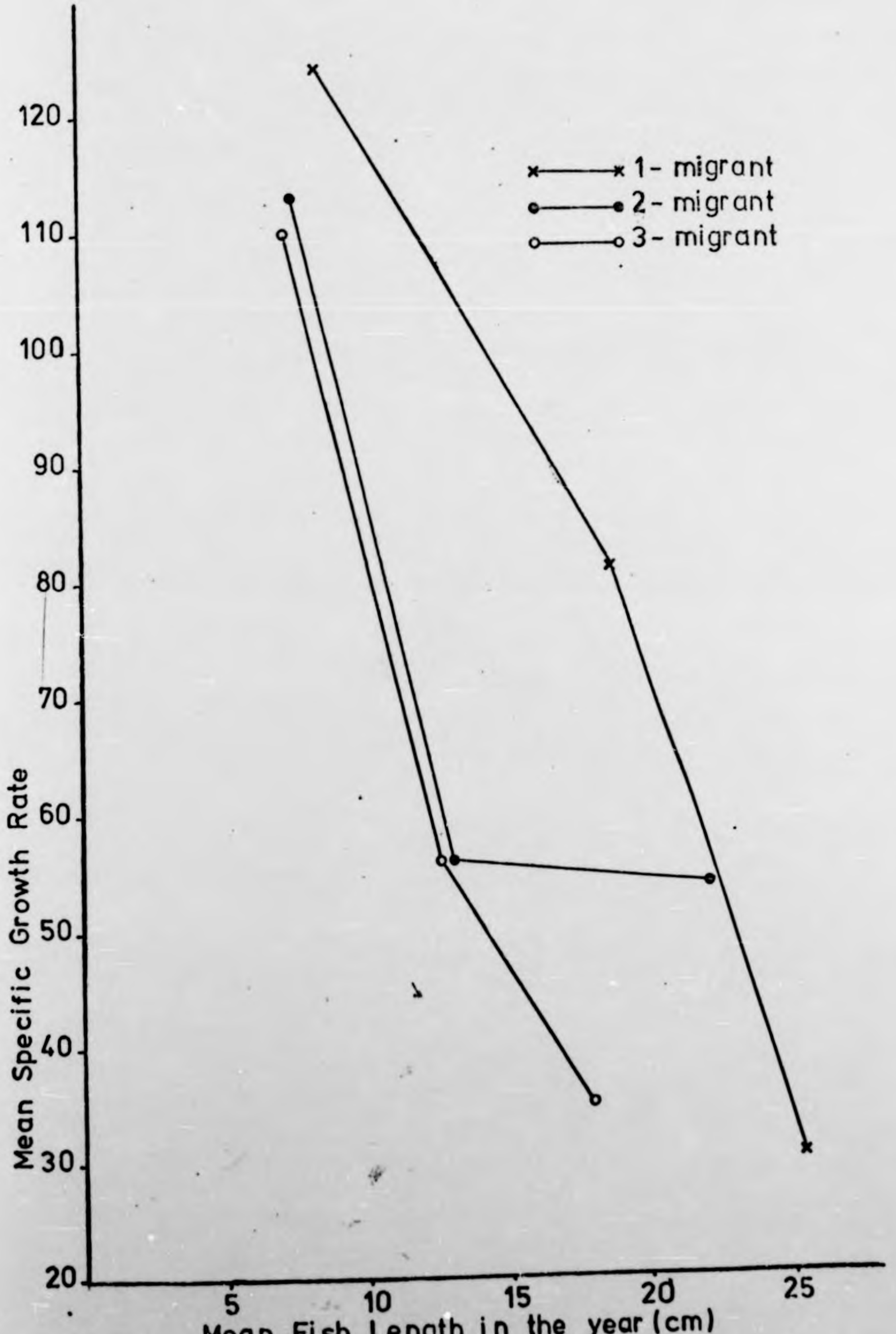


TABLE 6

Specific Growth Rate and Annual Increments in Length of Juvenile Trout from Loch Leven with Examples from Other Lochs

Loch	*Growth during year 0 - I	I - II	II - III
Loch Leven: 1- migrants	124 (5.9)	81 (10.3)	30 (6.6)
2- migrants	113 (5.0)	56 (5.5)	54 (9.2)
3- migrants	110 (4.8)	56 (5.4)	35 (5.3)
Mean of all fish	118 (5.4)	63 (6.9)	39 (7.0)
†Loch of Strathbeg: 1- migrants	113 (5.0)	119 (16.9)	28 (8.0)
2- migrants	98 (4.0)	71 (6.7)	83 (16.9)
Average all fish	110 (4.8)	106 (13.6)	40 (10.2)
††Windermere	89 (3.4)	85 (7.9)	45 (7.8)
††Three Dubs Tarn	128 (6.2)	74 (9.5)	19 (3.7)
††Llyn Tegid	133 (6.7)	51 (6.2)	35 (6.4)

* All calculations above are based on the assumption that the initial size of trout fry is 2.4cm. Figures in brackets indicate actual increment in length (cm) of fish.

† Treasurer (1976)

††Frost & Brown (1967)

lying between 2 and 4. The above equation can be represented as:

$$\log W = \log a + b \log L \quad .$$

From the regression line determined by plotting the logarithms of weight against the logarithms of length, the regression coefficient is b and log a is the intercept of the line with the y-axis. By plotting the logarithms of the lengths of the loch juvenile trout against the logarithms of weight, the regression line drawn through these points by the method of least squares as seen in Fig.19 shows that there was a significant correlation ($r = 0.98$, $p < 0.001$) between them. The calculated regression gave the relationship:

$$w = 0.0056\ L^{3.24} \quad ,$$

where w = fish weight in gm. and L = fish length in cm.

For an ideal fish n = 3 (Le Cren, 1951) and this value was obtained for Windermere trout by Allen (1938).

Tesch (1968) remarked that differences may occur in the length-weight relationship due to sex, maturity, season and even time of day due to stomach fullness. Variations in the length-weight relationship have been frequently studied under the general name "condition" (Le Cren, 1951). Such changes in "condition" have usually been analysed by means of a "condition factor", K, calculated as a ratio between the observed weight and that expressed from the observed length. The "condition factor", K, is generally expressed according to the equation:

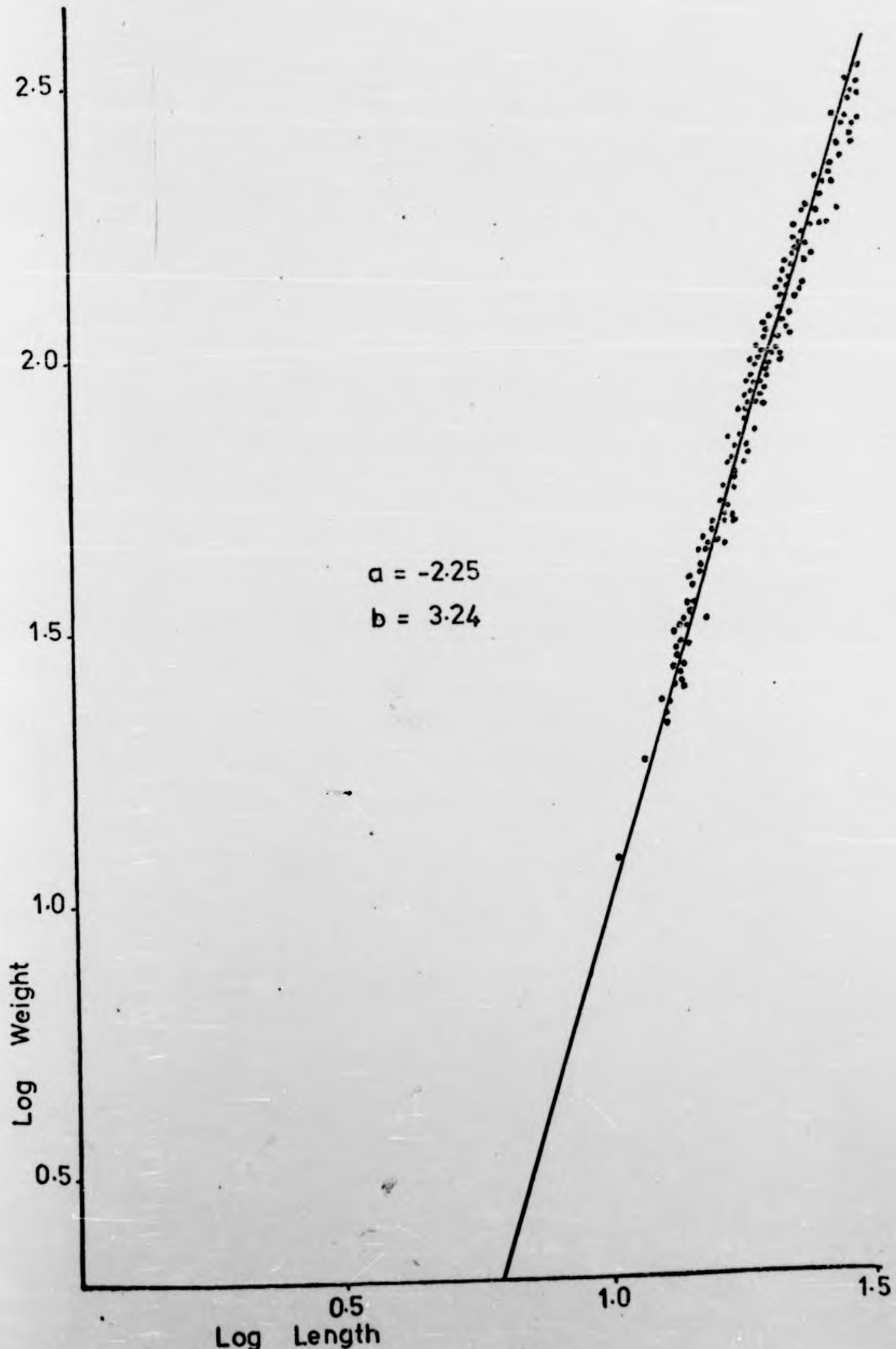
$$K = \frac{100W}{L^n} \quad ,$$

where n = an exponent determined by measuring the slope of a straight line fitted to a plot of log weight against log length as in Fig.19,

FIG.19

Log length/Log weight relationship for Loch Leven juvenile trout.

Loch Leven



where n = b = 3.24. For an ideal fish, K was measured from the equation:

$$K = \frac{100W}{L^3} \quad \text{(Hile, 1936; cit Le Cren, 1951)}$$

where L = length in centimeters and W = weight in grams. The exponent, b, for Loch Leven juvenile trout which is 3.24 could be taken as three approximately. The values of K can thus be reliably used to compare the condition of fish for different seasons. Table 7 gives the mean monthly condition factor for Loch Leven juvenile trout. Variations due to sex and maturity are ignored because the juvenile trout population encountered in this study are immature. Since the regression line obtained for the length-weight relationship was a straight line, there was therefore no fundamental change in the length-weight relationship with age amongst the sampled juvenile trout population.

TABLE 7

The Monthly Mean Condition Factor for Loch Leven Juvenile Trout

Month	No. of fish	Mean K	S.D (K)
January	5	1.104	0.136
February	17	1.095	0.094
March	5	1.015	0.073
April	4	1.079	0.147
May	7	1.009	0.109
June	58	1.143	0.072
July	134	1.224	0.094
August	145	1.246	0.091
September	64	1.217	0.089
October	92	1.104	0.059
November	26	1.074	0.071
December	12	1.080	0.131

The value, K, was calculated for samples of juvenile trout and this ranged from 0.904 to 1.496, the highest in July. The mean values of K at all times of the year are quite high and thus indicating the good condition of juvenile trout in the loch.

The mean K values for juvenile trout caught by the different sampling methods in the loch during the month of June 1975/76 are shown in Table 8. These K values were similar for all the sampling methods employed and this fact indicates that the gillnets used were not selective for any particular type of juvenile trout in the loch.

TABLE 8

The Mean Condition Factor for Juvenile Trout Caught by Different Sampling Methods in June 1975/76

Sampling Method	No. of Fish	K	S.D.(K)
Seining	9	1.149	0.061
Trawling	4	1.129	0.063
Gillnetting	45	1.143	0.068

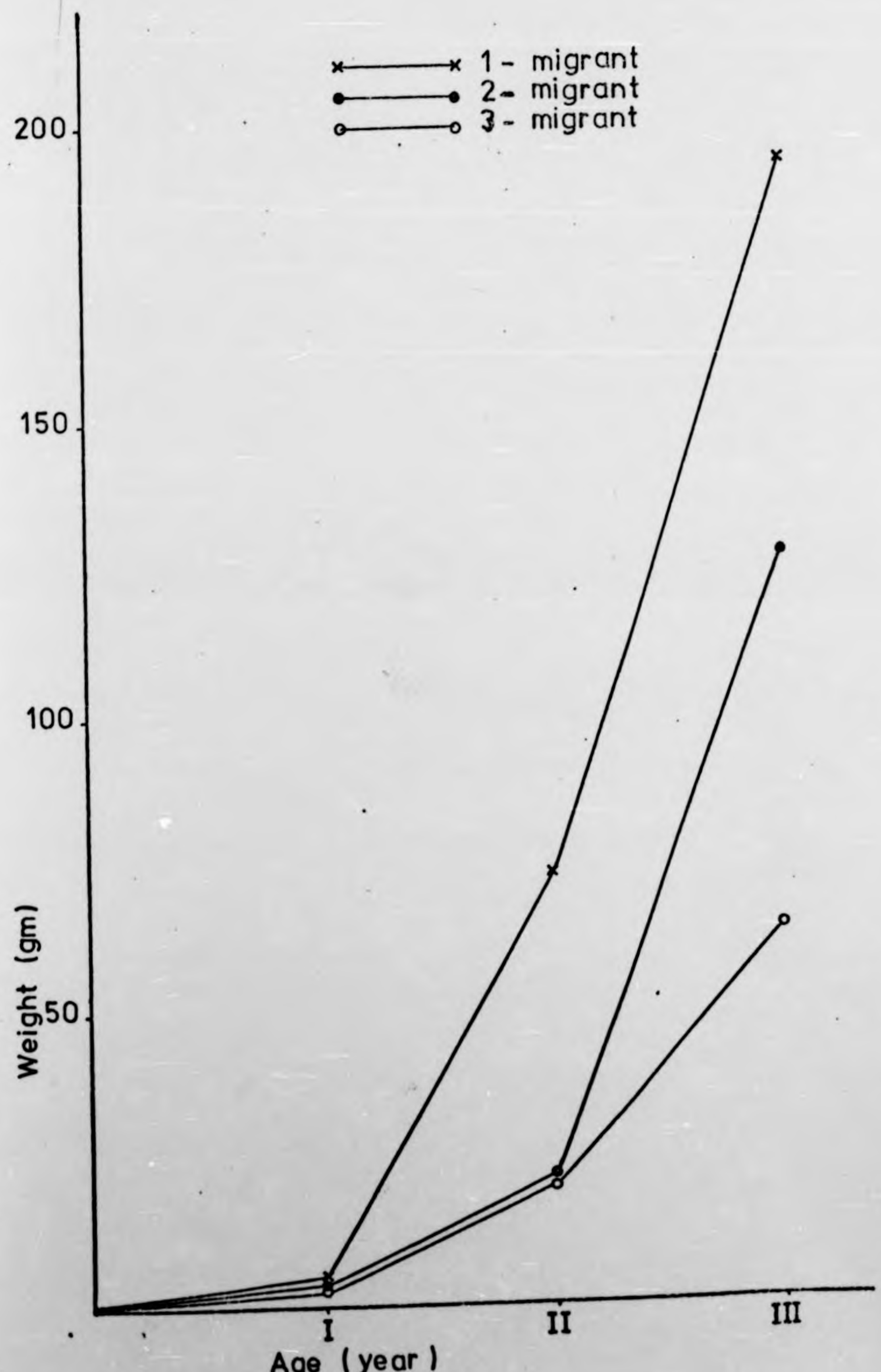
(f) <u>Growth in Weight</u>

Growth in weight was determined by the conversion of mean lengths (Table 5) using the length-weight regression coefficient. The resulting weights for every migrant group at each age are illustrated in Fig.20. Though the weight curves are similar to those obtained for the lengths, differences between the migrant groups become more pronounced with an increasing size of fish.

FIG.20

Growth in weight of juvenile trout in Loch Leven obtained from the back-calculated lengths.

och Leven obtained



Discussion

Three age groups of juvenile trout were involved in the migration from the nursery streams into Loch Leven. This is similar to results obtained for some British lochs (Allen, 1938; Ball & Jones, 1960). This however differs from some Scottish lochs as obtained by Campbell (1957) for Loch Tummel and Treasurer (1976) for the Loch of Strathbeg where four and two migrant groups occur respectively. Results in this study also show that 56% of the loch juvenile trout sampled are 1- migrants. This is similar to what was found at Loch of Strathbeg (Treasurer 1976) but differs from most other lochs: Lake Windermere, Loch Tummel and Llyn Tegid, where most of the juvenile trout are predominantly 2-migrants. Campbell (1957) also reported that in Northern Scottish lochs, majority of the young trout spend two years in the nursery streams before migrating into the loch. Early migration into the loch is normally associated with small lochs or small nursery streams which are probably seasonal or with limited spawning facilities (Campbell, 1957). This however is not the case in Loch Leven where there are large spawning grounds and where the capacity of the nursery streams is probably not a limiting factor. Campbell (1957) also remarked that the faster growing fish migrated first. Disease outbreaks among spawning fish in Loch Leven in the early 1970s (Thorpe & Roberts, 1972), and a declining population size of spawners should have led to reduced egg-deposition, and reduced juvenile trout populations in the streams. Compensatory growth increases among the reduced juvenile trout populations would then lead to earlier migration from the streams. Hence 56% of the juvenile trout input into the lochwere 1- migrants.

The results obtained in this study indicate that the loch offers better conditions for trout growth than the streams in the earlier part of their life. This is evident in Table 5 and Fig.17, where the growth of trout in their first loch year was high irrespective of age. There is further evidence from the actual length increments and the growth rates (G) for different migrant groups in the loch (Table 6) that under the same conditions, smaller trout grew faster than the larger trout of the same age. The specific growth rate declines with age as seen in Table 6. The specific growth rates also decrease with increasing size independently of age, hence the lower value for the 1- migrant group in the II - III age group as compared with the higher values for the 2- and 3- migrant contemporaries with smaller sizes.

The growth in the length of brown trout at Loch Leven obtained in this study is however less than that reported by Worthington (1939 in Litt) for age III but higher than those for the ages I and II. Since his figures were not separated into different migrant groups in the loch, the present result cannot be adequately compared. In comparison with other lochs shown in Table 6, the growth rate of juvenile trout in Loch Leven is relatively good though less than those recorded by Treasurer (1976) for the loch of Strathbeg. The higher growth in the loch of Strathbeg might be due to the fact that most of the fish spent a greater part of their first year of life in the loch. In Lake Windermere and Llyn Tegid where most of the fish are 2- migrants, entry into the loch seems not to have had a marked increase in their respective growth rates.

The effect of water chemistry on the growth of trout has been very well discussed by various workers. Frost & Brown (1967) reported that growth was good in hard alkaline waters but poor in soft acid waters, though they emphasized that growth was not proportional to water hardness. Campbell (1961) studied the relationship between trout growth and alkalinity in some northern Scottish lochs and he concluded that there was no direct relationship between growth rate and alkalinity. The growth rate of trout was thought by Swynnerton & Worthington (1939) to be correlated with the amount of change a loch has undergone in its general productivity. Compared with other lochs of different alkalinities, it can be concluded that the relatively good growth of Loch Leven brown trout appears to be related to its high productivity.

CHAPTER 5

THE FOOD OF JUVENILE TROUT IN LOCH LEVEN

Introduction

Most of the field studies on the food and feeding of trout of all sizes have been studied in the streams as well as in lochs (Allen, 1938; Campbell, 1955; Ball, 1961; Elliott, 1967, 1972, 1975; Tusa, 1968; Hunt & Jones, 1972). The limited information that is available on the food of juvenile trout has come mainly from work in the streams (Frost, 1939, 1950; McCormack, 1962; Kennedy & Fitzmaurice, 1968). The food of juvenile trout in the lochs have only been studied as part of brown trout of all sizes and none has been devoted to juvenile trout alone.

The nature of the food of a fish is controlled first by what is available and secondly by the behaviour of the fish (Allen, 1938). Trout is an opportune carnivore according to Ball (1961), Frost & Brown (1967), taking whatever food is most accessible. McCormack (1962) however observed in a stream that young trout do exhibit some selection on the drift fauna. The selectivity of brown trout has also been reported by Allen (1938) and Hunt & Jones (1972). In Lake Windermere, Allen (1938) observed that as a trout grows it takes bigger food organisms, the larger fish tending to be exclusively piscivorous. Selectivity of trout on _Gammarus_ and _Asellus_ in Llyn Alaw has also been reported by Hunt & Jones (1972).

Seasonal dietary changes appear to be determined by changes in the availability of the food organisms (Allen, 1938). The drop in the feeding of trout from October to December was reported by

Ball (1961) to be associated with falling temperatures and decreasing daylight. The daily food consumption of brown trout has also been observed by Elliott (1975) to be affected by a large number of factors which include the size of the fish and the amount of food eaten in a meal.

Frost & Brown (1967) reported that the diet of trout in lakes included cladocerans and copepods which often form the greater part of the zooplankton. Brown trout caught from the deep water in Lake Windermere was reported by Allen (1938) to feed on planktonic crustacea and chironomid pupae. Pyefinch (1960) also reported that trout in Loch Tummel fed on chironomids and terrestrial insects during the summer and on Asellus and caddis fly during the winter.

In Loch Leven, Thorpe (1974c) found that adult trout diet includes Asellus, Daphnia, chironomids along with perch fry. The food of juvenile trout in Loch Leven will be studied with the aim of determining the quality of the food and also its relation to the habitat, season and fish size.

Materials and Methods

The food of brown trout was studied by the examination of 662 stomachs of juvenile trout between October 1974 and December 1976. The food consumption was estimated only on the basis of the analysis of the contents of the stomachs because considerable digestion in the intestine would not permit the determination of the exact number of individual organisms. These stomachs were obtained from trout caught by beach seining, trawling and gillnetting. Some methods of collecting fish are more satisfactory than others for food analysis studies. Some of these fishing methods provide empty stomachs but as seen in Table 9, no distinctions were found between the stomach contents of fish caught and as such all the samples are treated as one. These samples were collected at different times of the day and therefore no attention was paid to the diurnal variation in feeding.

TABLE 9

The Efficiency of Fishing Methods for Food Studies

Fishing Method	Total No. of juvenile trout	No. of trout with food	No. of trout with full stomach
Seining	21	20	4
Trawling	8	7	0
Gillnetting	633	260	42
Total	662	287	46

The stomachs of all the fish examined for food were removed soon after capture and dissected. The estimates of degree of fullness of the stomachs were made visually in accordance with the classification established by Ball (1961). The wet weights and volume of the food contents in each stomach were measured and then the contents were preserved in 70% alcohol for later analysis. The stomach contents were later analysed by the following methods.

Numerical method: The number of individuals of each food item in each stomach was counted after sorting them into their different species groups under a low-power binocular microscope. The total number of each food item in all the stomachs examined was then summed up. These are then expressed as percentages of the total number of food organisms present in all fish stomachs examined.

(b) The occurrence method: The number of stomachs in which each food item occurred was listed and expressed as a percentage of the total number of the stomachs examined.

(c) The dry weight method: The food organisms having been sorted out and counted were dried in quantities in an oven at 65°C for three days (Elliott, 1967). The dry weight of each food component was then determined.

The wet weight and volume methods were abandoned in this investigation because most of the food items encountered were too small to be accurately measured.

For a qualitative determination of the kinds of food consumed, only fish with full stomachs were used. As the sampling methods used in this study could not be controlled so as to avoid most of the fish regurgitating their food, estimates were therefore based on those fish which were caught with full stomachs.

Results

(a) The composition of the food

The food organisms found in the juvenile trout stomachs are listed in Table 10. The percentage composition of the total food found in the stomachs of all juvenile trout examined was assessed by number and occurrence methods as shown in Table 11.

Allen (1938) and Ball (1961) classified the food of trout into three categories:

(i) the permanent bottom fauna which includes the annelids, the molluscs, the malacostraca, the arachnids and the nematodes;

TABLE 10

List of Food Organisms

ANNELIDA :	HIRUDINEA :	*Helobdella stagnalis* (L.)
		Erpobdella octoculata (L.)
MOLLUSCA :	GASTROPODA :	*Valvata piscinalis* (Muller)
		Potamopyrgus jenkinsi (Smith)
		Lymnaea truncatula (Muller)
	BIVALVIA :	*Anodonta anatina* (L.)
		Pisidium sp.
ARTHROPODA :	CRUSTACEA :	*Daphnia hyalina* var. *lacustris* (Sars)
		Bythotrephes longimanus (Leydig)
		Cyclops strenuus abyssorum (Sars)
		Gammarus pulex (L.)
		Asellus aquaticus (L.)
	INSECTA :	Ephemeroptera
		Hemiptera:
		Aquatic: *Gerris thoracicus* (Schummel)
		Terrestrial
		Trichoptera
		Coleoptera:
		Dytiscus marginalis (L.)
		Haemonia appendiculata (Panzer)
		Diptera:
		Orthocladidae
		Chironomus plumosus (L) - larva
		Chironomus plumosus (L) - pupa
		Glyptotendipes paripes (Staeger)
		Stictochironomus sp.
		Tanypoda
		Hymenoptera
	ARACHNIDA :	Hydracarina
NEMATODA		

TABLE 11

Food Composition of Juvenile Trout by Number and Occurrence

	Number		Occurrence	
	Actual	%	Actual	%
Helobdella stagnalis (L.)	31	0.049	8	2.79
Erpobdella octoculata (L.)	2	0.003	1	0.35
Valvata piscinalis (Muller)	12	0.019	8	2.79
Potamopyrgus jenkinsi (Smith)	3	0.005	3	1.05
Lymnaea truncatula (Muller)	1	0.002	1	0.35
Anodonta anatina (L.)	1	0.002	1	0.35
Pisidium sp.	22	0.035	7	2.44
Daphnia hyalina var. lacustris (Sars)	54010	85.177	133	46.34
Bythotrephes longimanus (Leydig)	911	1.437	31	10.80
Cyclops strenuus abyssorum (Sars)	119	0.188	17	5.92
Gammarus pulex (L.)	3	0.005	1	0.35
Asellus aquaticus (L.)	256	0.404	32	11.15
Ephemeroptera	6	0.009	2	0.70
Gerris thoracicus (Schummel)	14	0.022	10	3.48
Terrestrial Hemiptera	1	0.002	1	0.35
Trichoptera	2	0.003	2	0.70
Dytiscus marginalis (L.)	1	0.002	1	0.35
Haemonia appendiculata (Panzer)	3	0.005	3	1.05
Orthocladidae	171	0.270	23	8.01
Chironomus plumosus (L.): larva	303	0.478	37	12.89
Chironomus plumosus (L): pupa	5652	8.914	187	65.16
Glyptotendipes paripes (Staeger)	2	0.003	1	0.35
Stictochironomus sp.	4	0.006	1	0.35
Tanypoda	1350	2.129	18	6.27
Hymenoptera	2	0.003	2	0.70
Hydracarina	9	0.014	6	2.09
Nematoda	518	0.817	66	23.00
Animal remains	+		9	3.14

(ii) the temporary bottom fauna consisting of larvae and pupae chironomids; other insect nymphs, larvae and pupae;

(iii) the midwater and surface food which includes the cladocerans, copepods, adult aquatic and terrestrial insects.

The major food items of juvenile trout are found to be Chironomus plumosus and Daphina hyalina which are temporary bottom and midwater food organisms respectively. The importance of Chironomus plumosus was underestimated while Daphnia hyalina was overestimated by the number method. Though Chironomus plumosus formed 9.4% of the total food by number, it occurred in 78% of all the juvenile trout examined whereas Daphnia hyalina which formed 85% by number only occurred in 46% of the total juvenile trout examined. Similarly, in the analysis carried out on the juvenile trout with full stomachs shown in Table 12, Chironomus plumosus occurred in 98% of the total number examined while Daphnia hyalina occurred in only 22%.

The importance of Chironomus plumosus as the major food item was further highlighted in Table 12 where it formed 92% of the total dry weight of all the food in the stomachs. Though Daphnia hyalina formed 54% by number of the food, this only amounted to 2.4% of the total dry weight of all the food. Thorpe (1974c) reported that Asellus, chironomids and Daphnia formed 24.2%, 15.1% and 9.1% respectively of the total wet weight of food consumed by adult trout in Loch Leven. In this study however, Asellus was found to constitute only 2.5% of the dry weight and it was much lower than the chironomids in the diet of juvenile trout.

TABLE 12 - The Qualitative and Quantitative Analysis of the Food of Juvenile Trout as shown by Fish with Full Stomachs

Food Item	Number Actual	Number %	Occurrence No.	Occurrence %	Dry Weight (mg)	Dry Weight %
Erpodella octoculata (L)	2	0.018	1	2.174	6.000	0.030
Pisidium sp.	10	0.091	1	2.174	9.470	0.048
Daphnia hyalina var. lacustris (Sars)	5930	53.924	10	21.739	480.330	2.438
Bythotrephes longimanus (Ley)	28	0.255	3	6.522	2.660	0.013
Cyclops strenuus abyssorum (Sars)	22	0.200	2	4.348	1.562	0.008
Gammarus pulex (L)	3	0.027	1	2.174	5.000	0.025
Asellus aquaticus (L)	166	1.510	2	4.348	449.660	2.536
Orthocladidae	2	0.018	1	2.174	3.188	0.016
Chironomus plumosus - larva	11	0.100	3	6.522	25.185	0.128
Chironomus plumosus - pupa	3515	31.963	42	91.304	18154.975	92.135
Tanypoda	1104	10.039	3	6.522	459.264	2.331
Hymenoptera	1	0.009	1	2.174	2.000	0.010
Nematoda	203	1.846	28	60.870	55.419	0.281

(b) Seasonal variation in the food

Table 13 shows the monthly variation in the food composition by number of all juvenile trout examined. The food components show considerable seasonal variation. It is quite evident that more food items were available to the fish during the summer months than during the winter. *Chironomus plumosus* which is the major food item occurred mainly during the summer in the pupal form and in the autumn in the larval form. The orthoclads were prominent in the spring. *Daphnia hyalina* occurred all through the year but its importance declined during the summer when chironomids were abundant in the diet. *Bythotrephes* and *Cyclops* which are of little importance appeared during the summer and autumn. *Asellus* became important in the diet during the winter. Most of the molluscs found in the diet were also present during the winter. It therefore seems as if juvenile trout in the loch fed mainly on the temporary bottom and midwater fauna during the summer but changed to a mixed diet of permanent, temporary bottom and midwater fauna in winter.

(c) Food in relation to size

As found out in Chapter 4, the age of juvenile trout in Loch Leven is not solely dependent on the size of the fish and as such a particular size range cannot be demarcated for fish which have only spent one year in the loch. However, an arbitrary division comprising (i) juvenile trout below 20cm and (ii) those between 20 and 30cm will ensure that most of the fish in the first group would be in their first year in the loch. Table 14 shows the percentage occurrence of each food item present in the two size groups of juvenile trout. There were no marked differences between

TABLE 13 - Food Composition by Number (%) in the Stomachs of Juvenile Trout for Different Months in the Loch

Food Organism	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
H. stagnalis						0.09	0.04			0.11	5.08	
E. octoculata						0.04						
V. piscinalis					0.03	0.06				0.02	6.78	
P. jenkinsi										0.02		
L. truncatula						0.02						
A. anatina											1.69	
Pisidium sp.					0.13	0.09		0.16		0.01	1.69	
D. hyalina		39.04		66.67	97.84	30.28	43.51	93.48	99.56	98.66	33.89	
B. longimanus						16.76		0.05	0.18	0.36	5.08	
C. strennus					0.05	0.02		0.08		0.49		
G. pulex						0.06						
A. aquaticus		3.42			0.08	4.70	0.07			0.06	18.64	25.00
Ephemeroptera						0.11				0.01		
G. thoracicus					0.05	0.04	0.05	0.02	0.03			
Terrestrial Hemiptera						0.02						
Trichoptera		0.68							+			
D. marginalis		0.68										
H. appendiculata							0.01			0.01		
Orthocladidae		56.16	96.97	5.56	0.36		0.20	0.02	0.01			
C. plumosus - larva				5.56	0.31	0.71	1.84	0.02	0.02	0.24	23.73	75.00
C. plumosus - pupa				19.44	0.85	35.60	39.22	6.16	0.14	0.01		
G. paripes							0.02					
Stictochironomus sp.					0.10							
Tanypoda					0.15	2.61	13.85					
Hymenoptera							0.02					
Hydracarina					0.05	0.11				0.01	1.69	
Nematoda						8.66	1.15		0.04			
Unidentified animal remains			3.03	2.78		0.02		0.02		0.01	1.69	
No. of stomachs examined	1	5	1	2	7	60	214	184	59	96	26	7
No. of stomachs with food	-	3	1	2	7	60	107	33	31	32	9	2

TABLE 14

The Percentage Occurrence of Food Organisms in Juvenile Trout in Relation to Fish Size

Food Item	Fish Size < 20cm	Fish Size 20-30cm
Helobdella stagnalis	37.5	62.5
Erpobdella octoculata	-	100
Valvata piscinalis	-	100
Potamopyrgus jenkinsi	-	100
Lymnaea trunculata	-	100
Anodonta anatina	100	-
Pisidium sp.		100
Daphnia hyalina	23.3	76.7
Bythotrephes longimanus	19.4	80.6
Cyclops strenuus abyssorum	5.9	94.1
Gammarus pulex	-	100
Asellus aquaticus	56.2	43.8
Ephemeroptera	-	100
Gerris thoracicus	30	70
Terrestrial hemiptera	-	100
Trichoptera	100	-
Dytiscus marginalis	100	-
Haemonia appendiculata	33.3	66.7
Orthocladidae	52.2	47.8
Chironomus plumosus - larva	43.2	56.8
Chironomus plumosus - pupa	32.0	68.0
Glyptotendipes paripes	100	-
Stictochironomus sp.	-	100
Tanypoda	44.4	55.6
Hymenoptera	50	50
Hydracarina	33.3	66.7
Nematoda	31.8	68.2

the food items consumed but molluscs seem to occur more in the stomachs of trout between 20 and 30cm. Daphnia too occurred more in the stomachs of juvenile trout over 20cm. Since both fish groups were caught in the same environment, there are chances of their feeding on similar food organisms available in the habitat.

Discussion

The results obtained in this study suggest that juvenile trout is a carnivore, feeding mostly on what is available. Chironomus plumosus which emerged as the major food item of juvenile trout in the loch has earlier been reported to be present in the mud zone of Loch Leven by Charles et al. (1974). The dominance of C. plumosus in the diet of juvenile trout mainly during the summer months might be correlated with their reported emergence between May and August and also to the large size of their larvae. Maitland & Hudspith (1974) also reported that C. plumosus occurred only in small numbers in the sandy inshore zone. The fact that C. plumosus was selected as the major food item of juvenile trout suggests that the fish fed on the loch bottom and that it was feeding on what was readily available in its environment. Chironomids too have been reported as components of trout food in other lochs (Allen, 1938; Pyefinch, 1960; Hunt & Jones, 1972).

The relative abundance of Daphnia hyalina in the diet of juvenile trout in the loch supports Ball's (1961) suggestion that trout may feed at the loch bottom or midwater. The presence of Daphnia and other planktonic crustaceans in the food of trout have also been reported by Allen (1938) and Frost & Brown (1967). George (1975) reported that Daphnia hyalina dominated the spring and summer crops of zooplankton in Loch Leven. This therefore explains why Daphnia hyalina was the dominant planktonic crustacean fed upon by juvenile trout in the loch.

Asellus and molluscs were not as prominent in the diet of juvenile trout in this study as compared with the results obtained for adult trout by Thorpe (1974c). As earlier mentioned, molluscs occurred more in the stomachs of the larger size of juvenile trout. It therefore appears that as juvenile trout are being recruited into the adult stage, molluscs become more prominent in their diet. The dominant food item of adult trout in Loch Leven was perch fry (Thorpe, 1974c). Allen (1938) also reported that trout only eat fish when they reach a certain size. Within the size range of juvenile trout studied, none was found to feed on fish and this confirms Allen's (1938) suggestion that feeding on fish by trout was restricted to the adult stage. Apart from perch fry, other major food items recorded by Thorpe (1974c) for adult trout were Asellus, chironomids and molluscs in an order of descending importance. Juvenile trout in this study, however, fed on chironomids, Daphnia, Asellus, nematodes and molluscs in a descending order of importance. This clearly indicates that the food of juvenile trout differs from that of the adults and as such they do not compete for the same food.

Seasonal variations were observed in the food of juvenile trout in this study. The seasonal changes in the composition of the diet can be related to the availability of the food item. Tusa (1968) distinguished two periods basically different as regards the composition of trout food: the growing season (May - October) when brown trout food contains both aquatic and airborne organisms, and that outside the growing season: the winter season (November - April) when the food consisted mostly aquatic organisms. Though there were only few airborne organisms in the diet of juvenile trout in this study, their occurrence during the summer months confirms Tusa's (1968) observations.

Majority of the juvenile trout caught in the loch during this study were in the offshore areas and as such the food items in their stomachs would bear a relationship with organisms found in their habitat. Bryant & Leybourn (1974) reported the abundance of nematodes in the surface layer of the mud in Loch Leven. Maitland & Hudspith (1974) also reported the presence of chironomids, Asellus and molluscs in the mud zone of the loch. The presence of these organisms in the diet of juvenile trout as well as Daphnia which occurs abundantly in the water column above the mud zone indicates that juvenile trout fed to a great extent on the offshore mud zone fauna of the loch and on the resources available in the habitat.

The total food consumption by juvenile trout in the loch could not be estimated quantitatively from the results obtained in this study. Thorpe (1974c) estimated the total food consumption of adult trout from field experiments by netting at about 3-hourly intervals throughout a 24-hour period in each month. Due to sampling difficulties, juvenile trout samples could not be obtained at 3-hourly intervals over a 24-hour period and as such only static values of stomach contents were obtained and these do not necessarily represent the true proportions of the separate components in the diet. Elliott (1975) reported that the daily food consumption of brown trout was affected by the amount of food eaten in a meal, the number of meals in a day, the rate of gastric evacuation, the water temperature, the activity of the fish, the type of food eaten and the availability of food organisms. With no knowledge about the number of meals eaten in a day and the rate of gastric evacuation of the different food components, the food intake cannot be assessed quantitatively. For example, chironomids with chitinous exoskeletons could only break up slowly and molluscs with more durable shells would even pass through the fish more slowly still. The different dietary components would therefore be evacuated at different rates and as such the consumption values, based on static samples are likely to be gross under-estimates. The results obtained in this study on the static values of stomach contents cannot therefore be adequately compared with that obtained by Thorpe (1974c) for the adult trout in Loch Leven.

CHAPTER 6

THE EMIGRATION OF JUVENILE TROUT FROM THE LOCH INTO THE OUTFLOWING RIVER LEVEN

Introduction

The emigration of juvenile and adult trout via the outflowing River Leven has been studied by Thorpe (1974b). In his investigation he found that 51 juvenile trout ranging between 10.5 and 19.8cm emigrated from the loch through the sluice gates in the first week of June 1972. This emigration out of the loch into the River Leven was described as part of the general dispersal process of fish in the loch. During this study on the population ecology of juvenile trout in the loch, it was important to follow up Thorpe's (1974b) work and find out how the emigration of juvenile trout has changed over the years and how far this has affected the entire juvenile trout population in the loch.

Materials and Methods

Thorpe (1974b) monitored the emigration of trout from the loch into the outflowing River Leven by the use of a box trap set in one of the five channels immediately below the sluice gates. This process of monitoring continued during this study. The sluice trap was visited occasionally and the trout caught were then removed and the trap cleaned. The lengths of all specimens of juvenile trout caught in the trap were measured and scale samples were removed from each specimen for age determination. From the scales, the time of entry into the loch from the streams was also investigated.

Results and Discussion

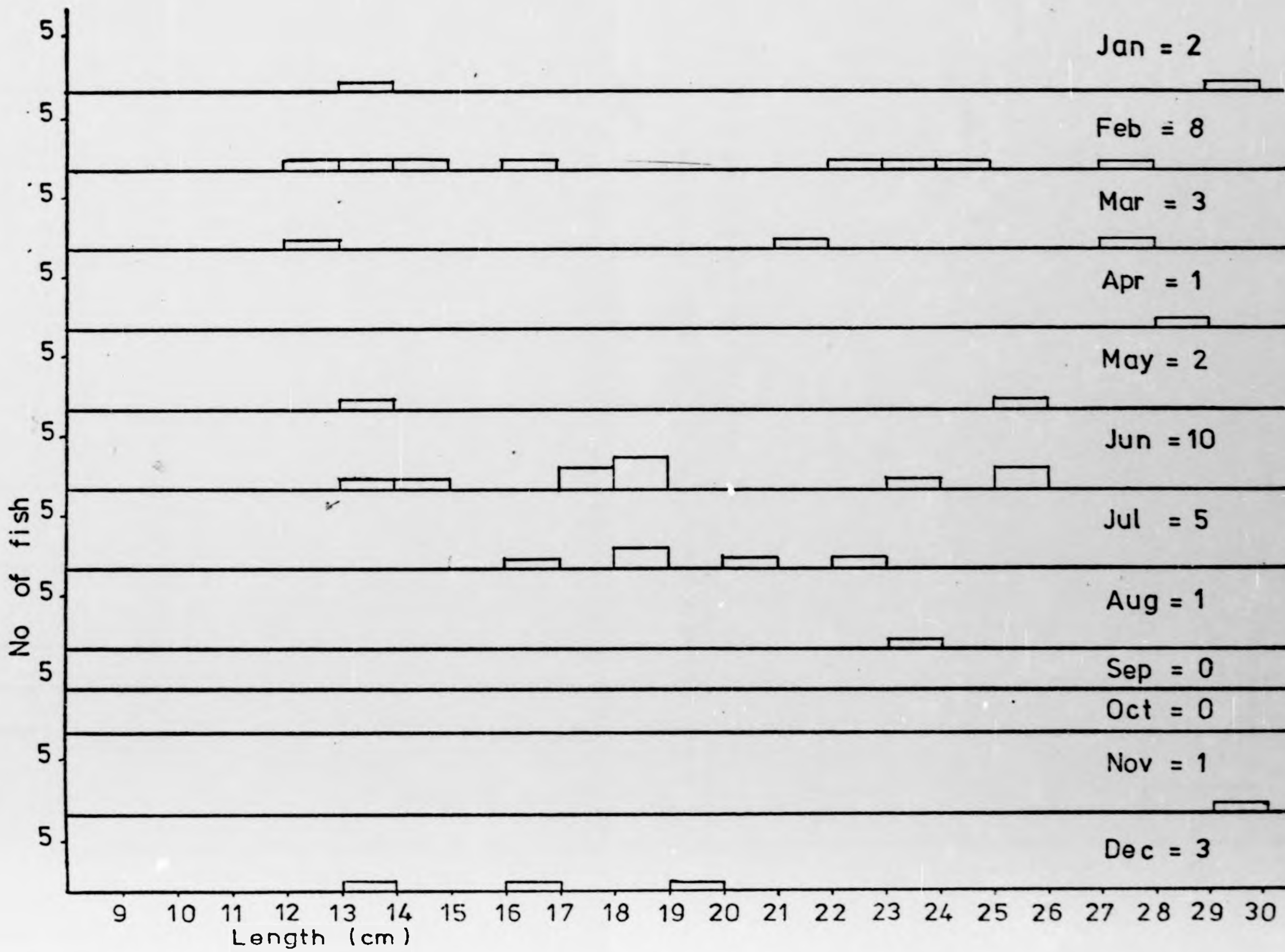
The results obtained in this study are based entirely on juvenile trout catches in the box trap at the sluices between January 1975 and December 1976. The monthly length-frequency distributions of juvenile trout caught in the sluice trap is shown in Fig.21. There is no particular size range of juvenile trout emigrants that is peculiar to a particular month. Fig.22 shows the monthly emigration pattern of juvenile trout from the loch into River Leven. It is evident that emigration occurs throughout the year except for the months of September and October when none was observed. Major emigration takes place during the winter and summer with peaks occurring in February and June respectively.

No relationship was found between the emigration and the loch water level and temperatures. Emigration of juvenile trout from the loch starts in November, a month after the beginning of immigration into the loch and this extends until August, a month after immigration into the loch ceased. This pattern of emigration from the loch was found to be similar to that observed by Thorpe (1974b) for 1971 and 1972. However the number of emigrants from the loch appears to be less than that observed for the 1971/72 period. The number of emigrants from the loch cannot be relied upon because the sluice gates were opened at irregular times.

The length frequency distribution histograms for all juvenile trout emigrants during this period of study are shown in Fig.23. From this it seems as if emigration of juvenile trout from the loch is not size dependent. Examinations made on the scales collected from the emigration trout show the time of their entry into the

FIG.21

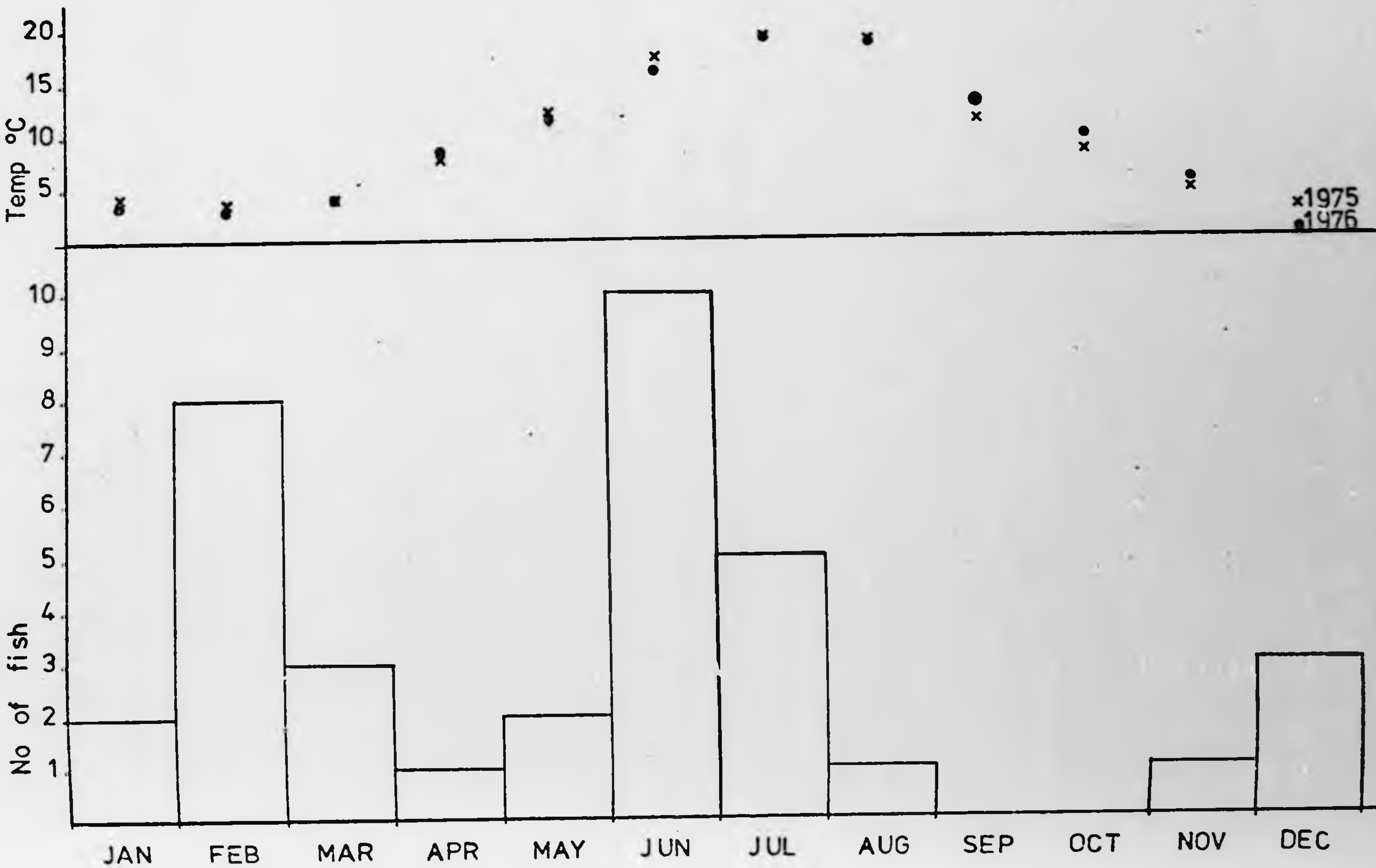
Length frequency of trap-caught juvenile trout emigrants from the loch into River Leven (1975-76)



No of fish
5
Jan = 2
Feb = 8
Mar = 3
Apr = 1
May = 2
Jun = 10
Jul = 5
Aug = 1
Sep = 0
Oct = 0
Nov = 1
Dec = 3
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Length (cm)

FIG.22

Monthly emigration pattern of trap-caught juvenile trout from the loch in River Leven (1975-76).

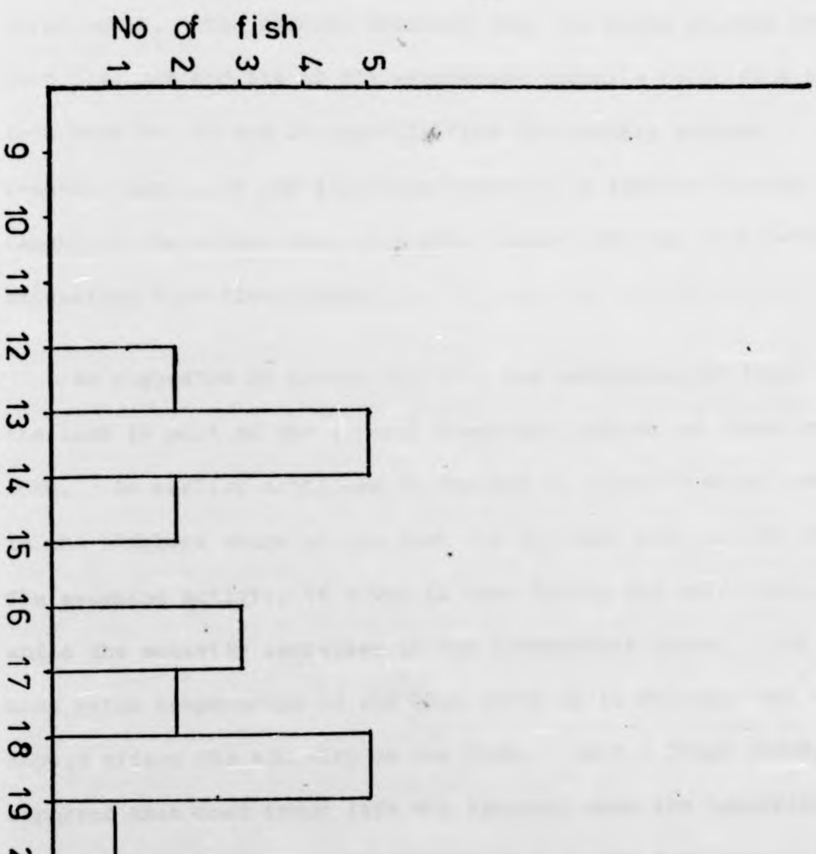


Temp °C
No of fish
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
×1975
•1976

trout

FIG.23

Length frequency of total trap-caught juvenile trout emigrants from the loch into River Leven (1975-76).


No of fish
1
2
3
4
5
Length (cm)
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

loch and their ages when they were emigrating from the loch into River Leven. The results obtained from the scale studies show that 51%, 38% and 11% of all emigrating juvenile trout from the loch were 1-, 2- and 3- migrants from the nursery streams respectively. It was also found that 6% of these emigrants were caught at the sluice trap soon after entry into the loch before emigrating into River Leven.

As suggested by Thorpe (1974b), the emigration of trout from the loch is part of the general dispersal pattern of trout in the loch. As earlier mentioned in Chapter 3, juvenile trout remain in the offshore areas of the loch for the most part of the year. The swimming activity of trout is less during the cold temperatures while the activity increases as the temperature rises. The lowest mean water temperature of the loch water is in February and this should affect the activity of the fish. Ball & Jones (1960) reported that most trout left the littoral when the temperature rose higher than 12°C. The sudden rise in the loch mean water temperatures above 12°C in June might increase the activity of the fish. These changes in the activities of the fish might disperse the juvenile trout towards the sluice gates where high water currents might passively displace them out of the loch. There is no obvious environmental factor yet identified that initiate emigration of trout from the loch. Emigration from the loch might be inherent in some sea going trout which though finding loch conditions satisfactory, prefer to emigrate from the loch through the sluices via the River Leven into the sea. Though emigration of juvenile trout from the loch into the outflowing River Leven takes place, there is no evidence to show that the number of emigrants drastically affect the loch population of juvenile trout.

CHAPTER 7

GENERAL DISCUSSION

In this study on the population ecology of juvenile trout in the loch, attempts have been made by repeated observations on the fish populations in the different localities to identify how environmental factors and biological characteristics intrinsic to the population interact to determine their number in a particular region before recruitment into the Loch Leven fishery. Recruitment can be linked largely on the extent and suitability of the spawning grounds available. If large areas of bed are suitable, many young will be added to the stock each year provided the number and fecundity of the spawning adults are sufficient to utilize all available spawning grounds but if there are few suitable areas, recruitment would be small.

Le Cren et al (1972) remarked that one of the principal biological aspects still requiring much elucidation was the whole field of juvenile stages, their ecology and variable survival of brown trout. They added that the natural variations in the year-class sucess still remained one of the greatest influences on population abundance.

Elliott (1966) observed brown trout fry of about 2.5cm in drift samples in an English stream in March and April. The downstream dispersal of fry immediately after emergence have also been reported by Kalleberg (1958), Le Cren (1965) and Mortensen (1977). Solomon & Templeton (1976) also reported that the downstream movements between hatching and six months of age were largely passive, and represented a functional migration to areas suitable for feeding during early life. Kalleberg (1958) also observed that the depth of water and the rate of flow were important for fry dispersal and that there would be more crowding in still water. These along with the earlier mentioned suggestion by Manion (1977) indicate that initial movement of juvenile trout in the autumn started with increased stream flow arising from the onset of floods. The peak of migration of juvenile rainbow trout was reported by Stauffer (1972) at temperatures between 9° and 17°C in spring while Manion (1977) linked this in brook trout with rising water temperatures of about 10°C. It can therefore be concluded that increase in water flow caused by heavy rainfall initiate an autumn downstream migration of juvenile trout in Loch Leven tributaries while the peak of migration occurred between temperatures of 7° and 12°C in spring.

According to Mann (1971) the number of fish present at any time in a given site was governed by mortality, emigration and immigration. Since the selected electrofishing sites investigated in this study were only temporarily screened off from other parts of the stream, the juvenile trout populations were therefore subject to immigration, emigration and mortality. Regier & Robson (1967) defined mortality as the decrease in the numbers in a population which was closed to immigration and emigration. On this basis, mortality in this study will only account for the dead juvenile trout due to natural causes rather than a total decrease in the population numbers with time. It was not possible to measure the mortality of juvenile trout in the streams directly from the electrofishing catches. Similarly, with a lack of information on the survival and mortality of stream juvenile trout, it was impossible to estimate the total input of juvenile trout from the streams into the loch. However, from the results obtained in this study on the stream population densities at different months of the year, the migration pattern of juvenile trout into the loch and the size of fish at different age groups, it is possible to estimate the mortality of juvenile trout in the streams and hence the input of juvenile trout into the loch if some assumptions are made.

If it is assumed that juvenile trout are evenly distributed all over the stream area, then the mean population densities of juvenile trout obtained from the electrofishing exercises can be taken to be representative of the entire area of the nursery streams. Results obtained in Chapters 2 and 4 show that the stream populations of juvenile trout comprised three age groups of trout. As shown in Fig.7, migration into the loch takes place between October and July. With over 98% of the migration carried out by June, it can be assumed that there was virtually little or no movement of juvenile trout from the electrofishing sites in the streams between June and September. As mentioned in Chapter 2, trout fry were not caught by the electrofishing gear in June and as such the June populations of juvenile trout at the stream sites only comprised I+ and II+ age groups. The length of a 1- migrant juvenile trout at the end of their first year of growth was 8.3 ± 0.50cm as shown in Table 5. The fastest growing 1- migrant juvenile trout by September would therefore be less than 9.0cm. All juvenile trout above 9.0cm in September can be assumed to belong to I+ and II+ age groups. The actual total numbers of I+ and II+

juvenile trout in the streams by June and September can be obtained from Table 1 and Fig.3a & c for North Queich and Gairney burns respectively. From these, the mean decrease in the population from June was calculated to be 3.8 per cent per month over the following three months among the I+ and II+ stream juvenile trout.

Le Cren (1973) observed that heavy mortality occurred in the first three weeks of trout life and thereafter it was much lower and relatively constant for the next ten months. Mortensen (1977) also reported that mortality was low after the first few months of rout emergence. As earlier reported in Chapter 2, the birth date of Loch Leven trout was chosen as March 1, with a trout fry size of 2.4cm. Juvenile trout obtained by electrofishing in September 1976 should have survived the early mass mortality associated with trout fry, being about six months old then. If it is assumed that mortality among six months old juvenile trout and over proceed at the same rate as that of the I+ and II+ stream juvenile trout, then the input of juvenile trout into the loch can be calculated as follows:

Total area of nursery streams	=	$540{,}000m^2$ (Thorpe, 1974c)
Mean stream population density in September	=	$1.103/m^2$
∴ total stream population of juvenile trout by September 1976	=	595,620
Mean stream population density in May 1977	=	$0.276/m^2$
∴ total stream population of juvenile trout by May 1977	=	149,040
∴ total decrease in stream population between September 1976 and May 1977	=	446,580

Estimated monthly mortality of stream juvenile trout	=	0.038
Since September stream trout population	=	595,620
∴ May population of stream trout	=	$595{,}620\ (1 - 0.038)^8$
	=	436,888
∴ total decrease in stream trout population due to mortality	=	595,620 - 436,888
	=	158,732
Total decrease in stream population due to mortality and emigration	=	446,580
∴ total decrease in stream trout population due to emigration	=	446,580 - 158,732
	=	287,848

As shown in Fig.7, 92.1% of the migration of juvenile trout into the loch should have taken place by May. Estimated total annual input of juvenile trout would then be 312,539.

The results obtained in this study showed that juvenile trout preferred the offshore mud zone to the inshore sand zone of the loch at all times of the year. The presence of juvenile trout in the offshore region of the loch could be associated with the nature of the bottom and the food of trout. Juvenile trout depended on the mud zone of the loch for its food because of the availability of chironomids, which are temporary bottom fauna on the mud surface and on Asellus, molluscs and nematodes which are permanent bottom fauna on the mud surface in the loch. Juvenile trout also fed on the midwater Daphnia population which are available at all times of the year in the offshore water column of the loch. This result shows the importance of chironomids, Daphnia, Asellus, molluscs and nematodes in the links between the trophic levels in the loch.

It was also shown that juvenile trout concentrations tend to live segregated from the perch populations though there were areas of overlap. This separation among the two fish groups was further highlighted by the sudden disappearance of juvenile trout concentrations from the deeper offshore areas of the loch during the winter (October - March) when perch populations were reported by Thorpe (1974c) to have moved into the deeper waters of the loch. Perch too have been reported to feed on chironomids, Asellus and Daphnia by Allen (1935), Swynnerton & Worthington (1939), Campbell (1955), McCormack (1970), Craig (1974) and Thorpe (1974c). Since juvenile trout and perch fed on similar food items, there was every reason to suspect some competition for food between them. Trout and perch have been reported by Thorpe (1974c) to be potential competitors for food. Open competition for common food items appears to have been avoided by the fact that the two fish groups lived separated from one another in the same habitat. Such interactive segregation between trout and char which have similar preferences for habitat and food have been reported by Nilsson (1963) in Scandinavian lakes. The seasonal movements being exhibited by juvenile trout and perch populations in Loch Leven suggest some form of complementary living among the two fish groups.

The difference in the distribution of pike and trout at some times of the year reduced the possibility of trout being eaten (Frost & Brown, 1967). Trout are well-known prey of pike (Swynnerton & Worthington, 1939; Frost, 1954; Campbell, 1955; Mann, 1976). Frost (1954) also reported that trout were eaten especially in the autumn when they were congregating at the mouth of the streams for their autumn spawning migration. Most of the pike caught in this study were in the inshore area of the loch during the winter. Pike in Loch Leven fed on perch, young pike, sticklebacks, lamprey and trout between 1967 and 1972 (Thorpe, personal communication). Over 50% of the trout eaten were adults. The distribution of majority of the juvenile trout population in the offshore areas of the loch provided an atmosphere where juvenile trout cannot be heavily preyed upon by pike.

Campbell (1971) remarked that in small lochs where nursery streams are small and possibly seasonal only, most trout migrate to the loch during the first year of life. This situation was reported for the Three Dubs Tarn by Frost & Smyly (1952) where the length of juvenile trout at the age of I was 8.6cm. Campbell (1971) also reported that if the first year growth averaged more than 7cm, it indicated that the trout spent majority of their first year of life in the loch itself. This hypothesis by Campbell (1971) seems not to apply in Loch Leven where juvenile trout at the end of the first year of life averaged 8.3, 7.4 and 7.2cm for 1-, 2- and 3- migrant trout respectively. Le Cren (1973) reported that growth in streams was strongly inversely density dependent. As earlier reported, disease outbreaks among spawning trout in the early 1970s (Thorpe & Roberts, 1972) which also affected spawning adults during this study must have reduced the number of adult spawners and consequently affecting the juvenile trout production in the streams. This low population density of juvenile trout in the streams must have enhanced their fast growth and hence 55.9% of the juvenile trout input into the loch were 1- migrants.

Growth of juvenile trout in their first loch year was relatively high as shown in Table 5 and this shows that the loch environment provides better growth for juvenile trout. As reported by Campbell

(1971) fast growth could equally occur in lochs with high or low alkalinities. He suggested that the relative abundance of food would appear to be the prime factor controlling the rate of growth of trout. Loch Leven is a shallow loch with abundant and rich food supply for trout (Frost & Brown, 1967). The IBP results on Loch Leven also portrayed it as being rich and that it supported a variety of animals which could serve as abundant food for trout and other fish. Juvenile trout in Loch Leven fed on chironomids, *Asellus* and nematodes which were abundant in the mud zone of the loch and on *Daphnia* which had a high productivity in the plankton. The relatively good growth of juvenile trout in Loch Leven can therefore be attributed to the high productivity of the loch.

As shown in Table 7, the "condition factor" for juvenile trout at all months of the year was high and above 1. This is an indication of the good condition of the juvenile trout in the loch. The juvenile trout samples in this study were mostly immature except for a few III+ age group males which were observed maturing. The stage of maturity among juvenile trout investigated seems not to have affected the "condition factor". The relatively higher "condition factors" observed during the summer can be attributed to higher food consumption noticed among the juvenile trout at that period.

As earlier mentioned, only eight recaptures were made from a total catch of 849 juvenile trout in the loch out of a total number of 1079 marked migrants to the loch. Though the recaptures are low, an estimate of the population (N) of juvenile trout in the loch in 1976 could be made from Petersen's original equation, modified for bias by Bailey (1951) thus:

$$N = \frac{m\ (c + 1)}{r + 1}$$

where m = number of juvenile trout marked;

c = number of juvenile trout examined for marks; and

r = number of marked juvenile trout recaptured.

$$N = \frac{1079\ (849 + 1)}{(8 + 1)}$$

$$= 101{,}906$$

95% confidence limits of N = 37,798 - 166,014.

Thus the final estimate (N) was within 62.9% of the true value of N. However, Robson & Regier (1964) demonstrated that the probability of the statistical bias will be less than 2% if $mc > 4N$. Since $mc > 4N$ in this situation, the estimate of the population of juvenile trout will not be much biased.

As earlier reported, fin-clipping put little or no stress on the fish and as such the chances of differential mortality occurring between the marked and unmarked fish was minimal. Furthermore, sources of error to this estimate will be reduced since the marked fish remained distinguishable from the unmarked and there was virtually no recruitment into the loch during the recapture period. However, when this estimate is compared with the estimated annual input of juvenile trout of 312,539, there is every reason to suspect that the juvenile trout input was overestimated. A source of error in the input estimate might have arisen from the fact that juvenile trout in the streams might have not been evenly distributed all over the total area of the nursery stream. Though mortality may be high among the juvenile trout population in the loch before they are recruited into the fishable stock, it is reasonable to expect that the estimate of 101,906 juvenile trout will be able to support the Loch Leven fishery over or about the present level.

An estimate of juvenile trout being recruited into the loch is necessary for any effective management of the fishery. The estimates obtained in this study might be improved upon if a long-term marking technique is carried out on the loch immigrants from the streams. The recaptures could then be made three to five years later in the loch among the recruited stages by beach seining and by the anglers. Though emigration from the loch into River Leven is at present negligible, the emigration monitoring should be improved and continued. This will however require a better and regular programme of operating the sluice gates.

Personal observations made on the angling catches in the loch show that many undersize trout are taken away occasionally. It may be necessary to protect the juvenile trout from angling pressure so that they can realize the good growth potential in the loch and also increase the number of spawning adults. There is at present no threat to the Loch Leven fishery. However, the information obtained in this study on the stream population densities; the input of juvenile trout into the loch; the distribution, food, age and growth of the prerecruitment loch trout will contribute to how the trout population can be controlled if any adverse condition occurs.

REFERENCES

ALLEN, K.R. (1935) The food and migration of the perch (Perca fluviatilis) in Windermere. J. Anim Ecol 4 : 264-273

ALLEN, K.R. (1938) Some observations on the biology of the trout (Salmo trutta) in Windermere. J. Anim. Ecol. 7 : 333-349

BAILEY, N.T.J. (1951) On estimating the size of mobile populations from recapture data. Biometrika 38 : 293-306

BALL, J.N. (1961) On the food of brown trout of Llyn Tegid. Proc. Zool. Soc. Lond. 137 : 599-622

BALL, J.N. & JONES, J.W. (1960) On the growth of brown trout of Llyn Tegid. Proc. Zool. Soc. Lond. 134 : 1-41

BALMAIN, K.H. & SHEARER, W.M. (1953) Further notes on the fisheries of Loch Leven. BTSC 83 40 FN 53, Scottish Home Office

BERRY, J. (1933) Notes on the migration of salmon smolts from Loch Ness, Summer 1932. Fisheries, Scotland Salm. Fish 1 : 1-11

BROWN, M.E. (1957) Ed. The physiology of fishes : New York Academic Press, Vol.2 Behaviour

BRYANT, V.M.T. & LAYBOURN, J.E.M. (1974) The vertical distribution of Ciliphora and Nematoda in the sediments of Loch Leven, Kinross. Proc. Roy. Soc. Edinb. B 74:265-273

CAMPBELL, R.N. (1955) Food and feeding habits of brown trout, perch and other fish in Loch Tummel. Scot. Nat. 67: 23-28

CAMPBELL, R.N. (1957) The effect of flooding on the growth rate of brown trout in Loch Tummel. Sci. Invest. Freshwat. Fish Scot. 14, 7pp

CAMPBELL, R.N. (1961) The growth of brown trout in acid and alkaline waters. Salm. Trout Mag. No.161: 47-52

CAMPBELL, R.N. (1963) Some effects of impoundment on the environment and growth of brown trout (Salmo trutta L.) in Loch Garry, Inverness-shire. Sci. Invest. Freshw. Fish Scot. 30, 27pp

CAMPBELL, R.N. (1971) The growth of brown trout Salmo trutta L. in northern Scottish lochs with special reference to the improvement of fisheries. J. Fish. Biol. 3: 1-28

CHARLES, W.N., EAST, K., BROWN, D., GRAY, M.C. & MURRAY, T.D. (1974) The production of larval Chironomidae in the mud at Loch Leven, Kinross. Proc. Roy. Soc. Edin. B 74: 241-258

CRAIG, J.F. (1974) Population dynamics of perch, Perca fluviatilis L. in Slapton Ley, Devon. I. Trapping behaviour, reproduction, migration, population estimates, mortality and food. Freshwat. Biol. 4 : 417-431

ELLIOTT, J.M. (1966) Downstream movements of trout fry (Salmo trutta) in a Dartmoor stream. J. Fish. Res. Bd. Can 23: 157-159

ELLIOTT, J.M. (1967) The food of trout (Salmo trutta) in a Dartmoor stream. J. Appl. Ecology 4: 59-71

ELLIOTT, J.M. (1972) Rates of gastric evacuation in brown trout, Salmo trutta L., Freshwat. Biol. 2 : 1-18

ELLIOTT, J.M. (1975) Number of meals in a day, maximum weight of food consumed in a day and maximum rate of feeding for brown trout, Salmo trutta L. Freshwat. Biol. 5: 287-303

FROST, W.E. (1939) River Liffey Survey II: The food consumed by the brown trout (Salmo trutta L.) in acid and alkaline waters. Proc. R. Ir. Acad. B 45: 139-206

FROST, W.E. (1950) The growth and food of young salmon (Salmo salar) and trout (S. trutta) in the River Forss, Caithness. J. Anim. Ecol. 19: 147-158

FROST, W.E. (1954) The food of pike Esox lucius L. in Windermere. J. Anim. Ecol. 23: 339-360

FROST, W.E. & BROWN, M.E. (1967) The Trout, London, Collins

FROST, W.E. & SMYLY, W.J.P. (1952) The brown trout of a moorland fish pond. J. Anim. Ecol. 21: 62-86

GEORGE, D.G. (1975) Zooplankton. Loch Leven Research Group: Annual Report 1975, 34pp

GRAHAM, T.R. & JONES, J.W. (1962) The biology of Llyn Tegid trout 1960. Proc. Zool. Soc. Lond. 139: 657-683

HOAR, W.S. (1953) Control and timing of fish migration. Biol. Review, 28: 437-452

HOAR, W.S. (1976) Smolt transformation: evolution, behaviour and physiology. J. Fish. Res. Bd. Can. 33: 1233-1252

HOLDEN, A.V. & CAINES, L.A. (1974) Nutrient chemistry of Loch Leven, Kinross. Proc. Roy. Soc. Edinb. B 74: 101-121

HOLLIDAY, F.G.T., TYTLER, P. & YOUNG, A.F. (1974) Activity levels of trout (Salmo trutta) in Airthrey Loch, Stirling and Loch Leven, Kinross. Proc. Roy. Soc. Edinb. B 74: 315-331

HUNT, P.C. & JONES, J.W. (1972) The food of brown trout in Llyn Alaw, Anglesey, North Wales. J. Fish Biol. 4: 333-352

HUNT, P.C. & JONES, J.W. (1972) Trout in Llyn Alaw, Anglesey, North Wales. II Growth. J. Fish. Biol. 4: 409-425

JUNGE, C.O. & LIBOSVARSKY, J. (1965) Effect of size selectivity on population estimates based on successive removals with electrical fishing gear. Zool. Listy 14 (2): 171-178

KALLEBERG, H. (1958) Observations in a stream tank of territoriality and competition in juvenile salmon and trout (Salmo salar L and S. trutta L.) Rep. Inst. Freshw. Res. Drottingholm 39: 55-98

KENNEDY, M. & FITZMAURICE, P. (1968) The early life of brown trout (Salmo trutta L.) Irish Fish Invest. A. No.4

KIRBY, R.P. (1974) The morphological history of Loch Leven, Kinross. Proc. Roy. Soc. Edinb. B 74: 383-389

LE CREN, E.D. (1951) The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (Perca fluviatilis). J. Anim. Ecol. 20: 201-219

LE CREN, E.D. (1961) How many fish survive? Yearb. Riv. Bds. Ass. 76 (9): 57-64

LE CREN, E.D. (1965) Some factors regulating the size of populations of freshwater fish. Mitt. int. verein theor. angew. Limnol. 13: 88-105

LE CREN, E.D. (1973) The population dynamics of young trout (Salmo trutta) in relation to density and territorial behaviour. Rapp. P. v. Reun. Cons. Perm. Int. Explor. Mer. Vol.164: 241-246

LE CREN, E.D., KIPLING C. & McCORMACK, J.C. (1972) Windermere: effects of exploitation and eutrophication on the salmonid community. J. Fish. Res. Bd. Canada, 29: 819-832

LESLIE, P.H. & DAVIES, D.H.S. (1939) An attempt to determine the absolute number of rats in a given area. J. Anim. Ecol. 8: 94-113

MAITLAND, P.S. & HUDSPITH, P.M.G. (1974) The zoobenthos of Loch Leven, Kinross, and estimates of its production in the sandy littoral area during 1970 and 1971. Proc. Roy. Soc. Edinb. B. 74: 219-239

MANION, P.J. (1977) Downstream movement of fish in a tributary of Southern Lake Superior. The Progressive Fish-Culturist Vol.39, No.1: 14-16

MANN, K.H. (1967) The cropping of the food supply. In The Biological Basis of Freshwater Fish Production Ed. Gerking, S.D. Blackwell Scientific Publications. Oxford & Edinburgh

MANN, R.H.K. (1971) The populations, growth and production of fish in four small streams in Southern England. J. Anim. Ecol. 40: 155-190

MANN, R.H.K. (1976) Observations on the age, growth, reproduction and food of the pike Esox lucius (L) in two rivers in Southern England. J. Fish. Biol., 8: 179-197

McCORMACK, J.C. (1962) The food of young trout (Salmo trutta) in two different becks. J. Anim. Ecol. 31: 305-316

McCORMACK, J.C. (1970) Observations on the food of perch (Perca fluviatilis L.) in Windermere. J. Anim. Ecol. 39: 255-267

MILLS, D.H. (1971) Salmon and Trout: a resource, its ecology, conservation and management. Edinburgh: Oliver & Boyd

MORGAN, N.C. & McLUSKY, D.S. (1974) A summary of the Loch Leven IBP results in relation to lake management and future research. Proc. Roy. Soc. Edinb. B. 74: 407-416

MORTENSEN, E. (1977) The population dynamics of young trout (Salmo trutta L.) in a Danish brook. J. Fish Biol. 10: 23-33

MÜLLER, K. (1969) Die Tages - und Jahresperiodik der Bachforelle (Salmo trutta L.) am Polarkreis. Aquilo (Ser Zool), 8: 50-62

MUNRO, W.R. (1961) The effect of mineral fertilizers on the growth of trout in some Scottish lochs. Verh. int. Ver. Limnol. 14: 719-721

MUNRO, W.R. & BALMAIN, K.H. (1956) Observations on the spawning runs of brown trout in the South Queich, Loch Leven. Freshwat. Salm. Fish. Res., 13 : 17pp

NILSSON, N.-A. (1963) Interaction between trout and char in Scandinavia. Trans. Amer. Fish. Soc. 92: 276-285

NORTHCOTE, T.G. (1967) The relation of movements and migrations to production in freshwater fishes. In "The Biological Basis of Freshwater Fish Production" - Ed. Gerking, S.D. Blackwell Scientific Publications, Oxford & Edinburgh

PEMBERTON, R. (1976) Sea trout in North Argyll sea lochs: population, distribution and movements. J. Fish. Biol. 9: 157-179

PYEFINCH, K.A. (1960) Trout in Scotland A study of brown trout research at Pitlochry 70pp Her Majesty's Stationery Office, Edinburgh

REGIER, H.A. & ROBSON, D.S. (1967) Estimating population number and mortality rates. In "The Biolcgical Basis of Freshwater Fish Production" Ed. Gerking, S.D., Blackwell Scientific Publications, Oxford & Edinburgh

ROBSON, D.S. & REGIER, H.A. (1964) Sample size in Petersen mark-recapture experiments. Trans. Am. Fish Soc. 93: 215-226

SEBER, G.F. & LE CREN, E.D. (1967) Estimating population parameters from catches large relative to the population J. Anim. Ecol. 36: 631-643

SMITH, J.R. (1974) The structure and physical environment of Loch Leven, Scotland. Proc. Roy. Soc. Edinb. B. 74: 81-100

SOLOMON, D.J. (1975) Observations on some factors influencing the migration of smolts of salmon (Salmo salar L.) and migratory trout (S. trutta L.) in a chalkstream. International Council for the Exploration of the Sea Anadromous and Catadromous Fish Committee, CM 1975/M11

SOLOMON, D.J. & TEMPLETON, R.G. (1976) Movements of brown trout Salmo trutta L. in a chalkstream: J. Fish Biol. 9, 411-423

STAUFFER, T.M. (1972) Age, growth and downstream migration of juvenile rainbow trout in a Lake Michigan tributary. Trans. Am. Fish. Soc. 101 (1): 18-28

STUART, T.A. (1953) Spawning migration, reproduction and young stages of loch trout (Salmo trutta L.) Sci. Invest. Freshwat. Fish. Scot. 5, 39pp

STUART, T.A. (1957) The migration and homing behaviour of brown trout (Salmo trutta L.) Sci. Invest. Freshwat. Fish. Scot. 18: 1-27

STUART, T.A. (1958) Marking and regeneration of fish. Sci. Invest. Freshwat. Fish. Scot. 22: 1-14

SWYNNERTON, G.H. & WORTHINGTON, E.B. (1939) Brown trout growth in the Lake District: a study of the conditions in "acid" lakes and tarns. Salm. Trout Mag. No.97: 337-355

TESCH, F.W. (1968) Age and growth. In "Methods for Assessment of Fish Production in Freshwaters" Ed. Ricker, W.E. IBP Handbook No.3. Blackwell Scientific Publications: Oxford & Edinburgh

THORPE, J.E. (1974a) Estimation of the number of brown trout Salmo trutta (L.) in Loch Leven, Kinross, Scotland J. Fish. Biol. 6: 135-152

THORPE, J.E. (1974b) The movements of brown trout, Salmo trutta (L) in Loch Leven, Kinross, Scotland. J. Fish Biol. 6: 153-180

THORPE, J.E. (1974c) Trout and perch populations at Loch Leven, Kinross, Scotland. Proc. Roy. Soc. Edinb. B 74: 295-313

THORPE, J.E. & ROBERTS, R.J. (1972) An aeromonad epidemic in the brown trout. J. Fish Biol. 4: 441-451

TREASURER, J.W. (1976) Age, growth and length-weight relationship of brown trout Salmo trutta (L) in the Loch of Strathbeg, Aberdeenshire. J. Fish Biol. 8: 241-253

TUSA, I. (1968) On the feeding biology of the brown trout (Salmo trutta m. fario L.) in the Loucka creek. Zool. Listy 17(4) 379-395

VOLOVIK, S.P. (1967) Metody Ucheta I nekotorye osobennosti povedeniya pokatnoi moloti gorbushi v rekakh sakhalina. Tikhookeanskii nauchno -issledovatel'skii Institut Rybnogo Khozyaistva l Okeanografii (Tinro) Vol.61: 104-117 [Method of counting and some features of the behaviour of the seaward-migrating young of the pink salmon in the rivers of Sakhalin] Russian-English Translation Dept. of Fisheries and Forestry, Ottawa, Canada (1971)

WENT, A.E.J. & FROST, W.E. (1942) River Liffey Survey v. Growth of brown trout (Salmo trutta L.) in alkaline and acid waters. Proc. R. Irish Acad. 48B: 67-84

WHITE, H.C. (1939) Factors influencing descent of Atlantic salmon smolts. J. Fish Res. Bd. Can. 4 (5): 323-326

MORGAN, N.C. (1974) Historical background to the International Biological Programme Project at Loch Leven, Kinross. Proc. Roy. Soc. Edinb. B 74: 45-55