COMPARATIVE STUDIES OF POPULATIONS OF PERCH (*Perca fluviatilis* L.) AND PIKE (*Esox lucius* L.) IN TWO SCOTTISH LOCHS

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Muhammed Shafi, B.Sc.(Hons), M.Sc.

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INTRODUCTION

The Present Study

Several aspects of the population biology of perch (*Perca fluviatilis* L.) and pike (*Esox lucius* L.) have been studied in various lakes in the Palaearctic area. Thus, in England, the perch and pike of Windermere have been extensively studied by Le Cren (1947, 1951, 1958) and Frost (1954, 1959, 1967) respectively. The perch and pike populations in Loch Lomond, however, the largest freshwater lake in Great Britain, have so far been rather neglected. The brief publication of Hartley (1947) on the growth of perch, based on only a small number of fish, and the work of Copland (1956) on the food and parasites of pike in Loch Lomond have been the only two studies carried out so far.

In 1966, it was decided to embark on a study of the population dynamics of perch and pike in Loch Lomond and the neighbouring Dubh Lochan. This project had as its principal aims (i) the estimation of the populations of various fish species in the Dubh Lochan (perch, pike and eels), (ii) the annual gross production of these fish there and (iii) a comparison of the populations of perch and pike with those in Loch Lomond with respect to age, growth, food and fecundity.

PREVIOUS WORK IN EUROPE

Perch, *Perca fluviatilis* Linnaeus, 1758

The literature on the growth, food and other aspects of perch biology, both in this country and elsewhere, is extensive. In Great Britain, Allen (1935) studied food and seasonal migrations, Hartley (1947) published brief notes on the food and growth of perch, while Smyly (1952) examined the food of perch fry. The extensive work of Le Cren (1947, 1949, 1958) made a major contribution to the study of perch in Great Britain. Using opercular bones instead of scales for the study of age and growth of perch from Windermere, Le Cren confirmed the view of Nilsson (1921) that the opercular bone is the best structure for age and growth studies of perch. Le Cren's technique and method was later successfully followed by McCormack (1965) in Ullswater and Williams (1967) in the River Thames. Healy (1954) also found the opercular bone very suitable in her study of perch in Lough Glore, Lough Rea and Barnagrow Lake in Ireland.

A variety of studies of perch has also been carried out in other countries in Europe. Haakh (1929), Roper (1936) and Tesch (1955) in Germany studied the food, age and growth of perch. Alm (1946, 1951, 1953) carried out many useful experiments to find out the possible reasons for the stunted growth of perch in Sweden. Deelder (1951) in Holland, Kucera (1948) and Krizenecky & Krizenecka-Pulankova (1951) in Czekoslovakia and Skōra (1964) in Poland have all studied the age and growth and some other aspects of perch in their respective countries.

Information on the closely related yellow perch (Perca flavescens L.) is also available from the United States. Hile (1941), Hasler (1945), Bardach (1951) and others have studied different aspects of this species in American waters.

With the exception of the brief note by Hartley (1947) on the age and growth of perch in Loch Lomond and the data on food supplied by O'Donoghue & Boyd (1934), Campbell (1955) and Mills (1964), little other information on perch is available from Scotland.

Pike, Esox lucius L.

The literature on pike in the British Isles and elsewhere is also fairly extensive and covers a variety of aspects of the ecology of this species. In Great Britain, Hartley (1947) published a short account of the age and growth of pike from waters in East Anglia. Allen (1939) examined the food of pike in Windermere. Frost (1954, 1959, 1963, 1965, 1967) studied the pike of Windermere extensively and showed convincingly that opercular bones are more suitable than scales for the study of age and growth in this species. The work of Healy (1956) is the only information available from Irish waters so far.

Alm (1919, 1921) and Nilsson (1921) in Sweden, Haakh (1929) in Germany, Oliva (1956) and others in Czeckoslavakia have all studied pike in Europe, while Beckman (1945), Carbine (1945) and Engel (1940) among others have provided information on the age and growth of pike of the same species in North America.

The study of the food of pike in Loch Lomond by Robertson (1886) and Copland (1956), the work of Munro (1957) on the food and growth of pike in Loch Choin and of Mills (1964) on the food of pike of the River Bran and Loch Luichart are the only sources of information available on pike in Scotland.

Only three fish species are known to occur regularly in the Dubh Lochan: Perch (*Perca fluviatilis* L.), Pike (*Esox lucius* L.) and Eel (*Anguilla anguilla* L.). On May 10, 1967, two trout (*Salmo trutta* L.) were caught in a gill-net set there for pike. Both fish were some 25 cm in length. There have been no other recent records of trout or any other fish species in the Dubh Lochan.

In contrast, fifteen fish species are known to occur in Loch Lomond (Hunter, Slack & Hunter, 1959): Brook Lamprey (Lampetra planeri [Bloch]), River Lamprey (Lampetra fluviatilis [L.]), Sea Lamprey (Petromyzon marinus L.), Salmon (Salmo salar L.), Trout (Salmo trutta L.), Powan Coregonus clupeoides Lacépède), Minnow (Phoxinus phoxinus [L.]), Roach (Rutilus rutilus [L.]), Stone Loach (Noemacheilus barbatula [L.]), Eel (Anguilla anguilla [L.]), Pike (Esox lucius L.), Three-spined Stickleback (Gasterosteus aculeatus L.), Ten-spined Stickleback (Pungitius pungitius [L.]), Perch (Perca fluviatilis L.), Flounder (Platichthys flesus [L.]).

THE HABITATS CONCERNED

Dubh Lochan

Morphology and geology

The more important features of the Dubh Lochan are summarised in Table 1.

Like many other Scottish lochs the Dubh Lochan was once occupied by an ice block, the movement of which led to

Figure 1. A contour map of the Dubh Lochan showing the transects A, B and C where fish were caught by traps.

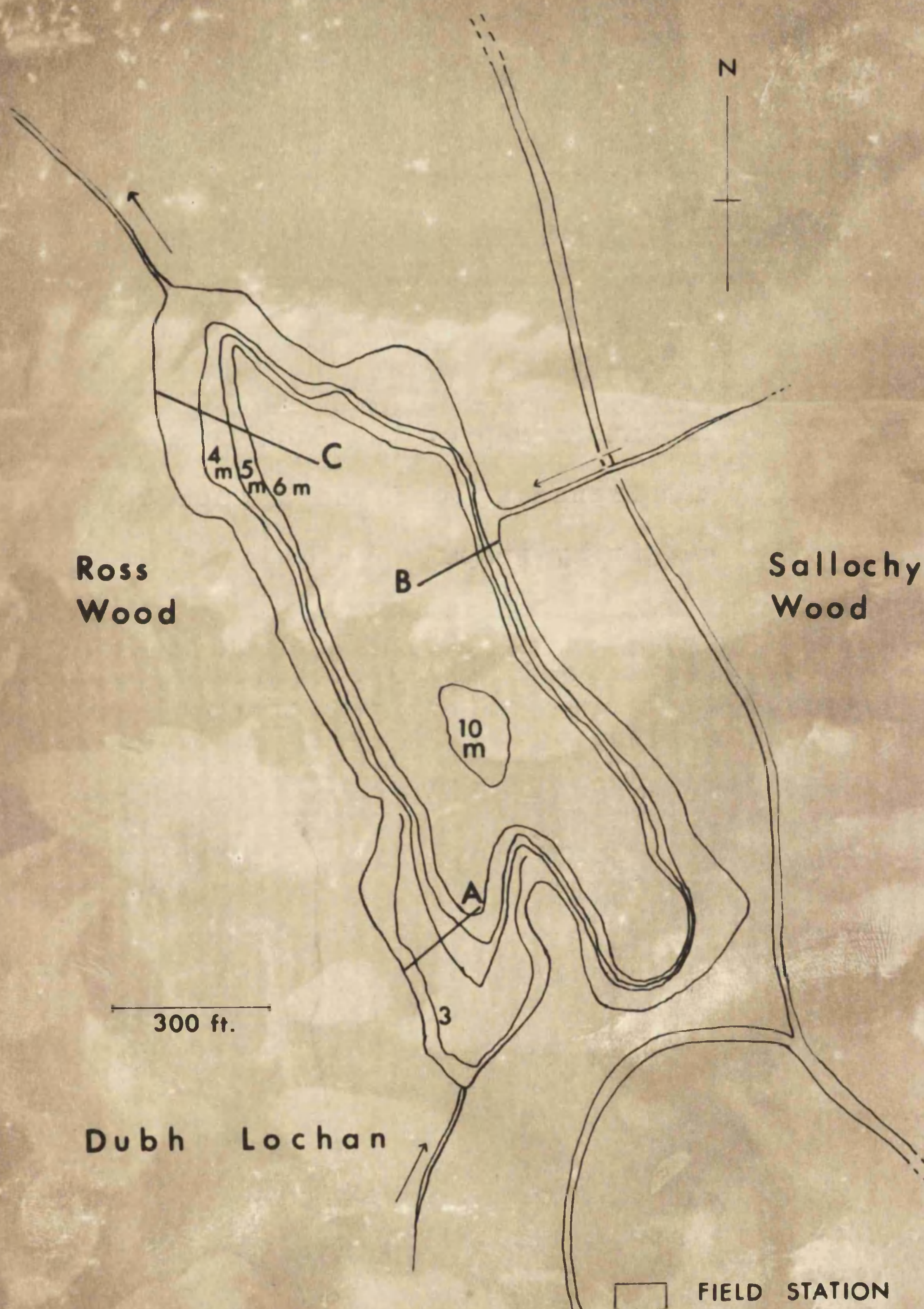
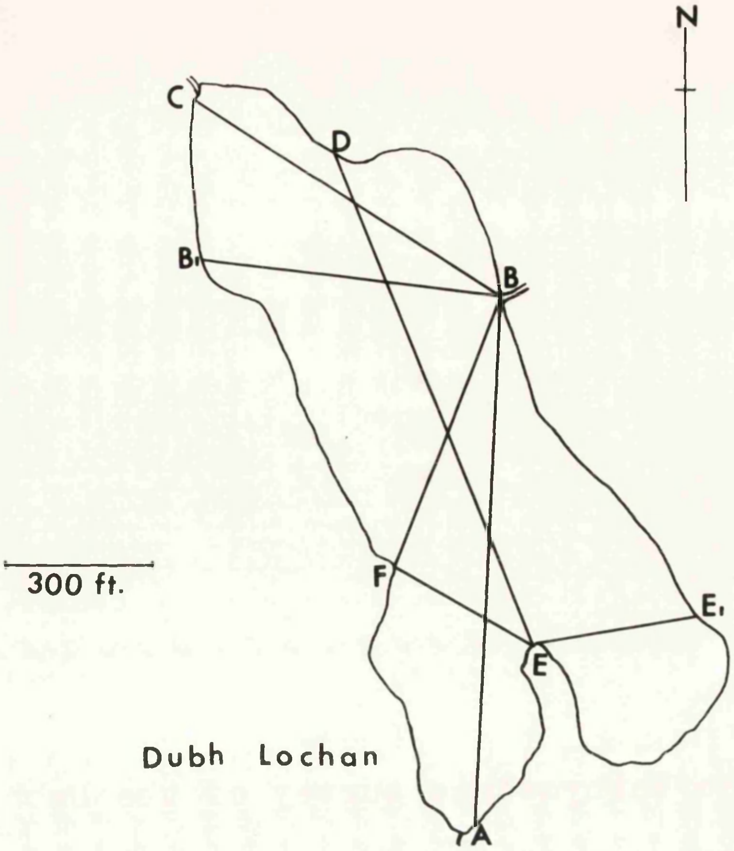
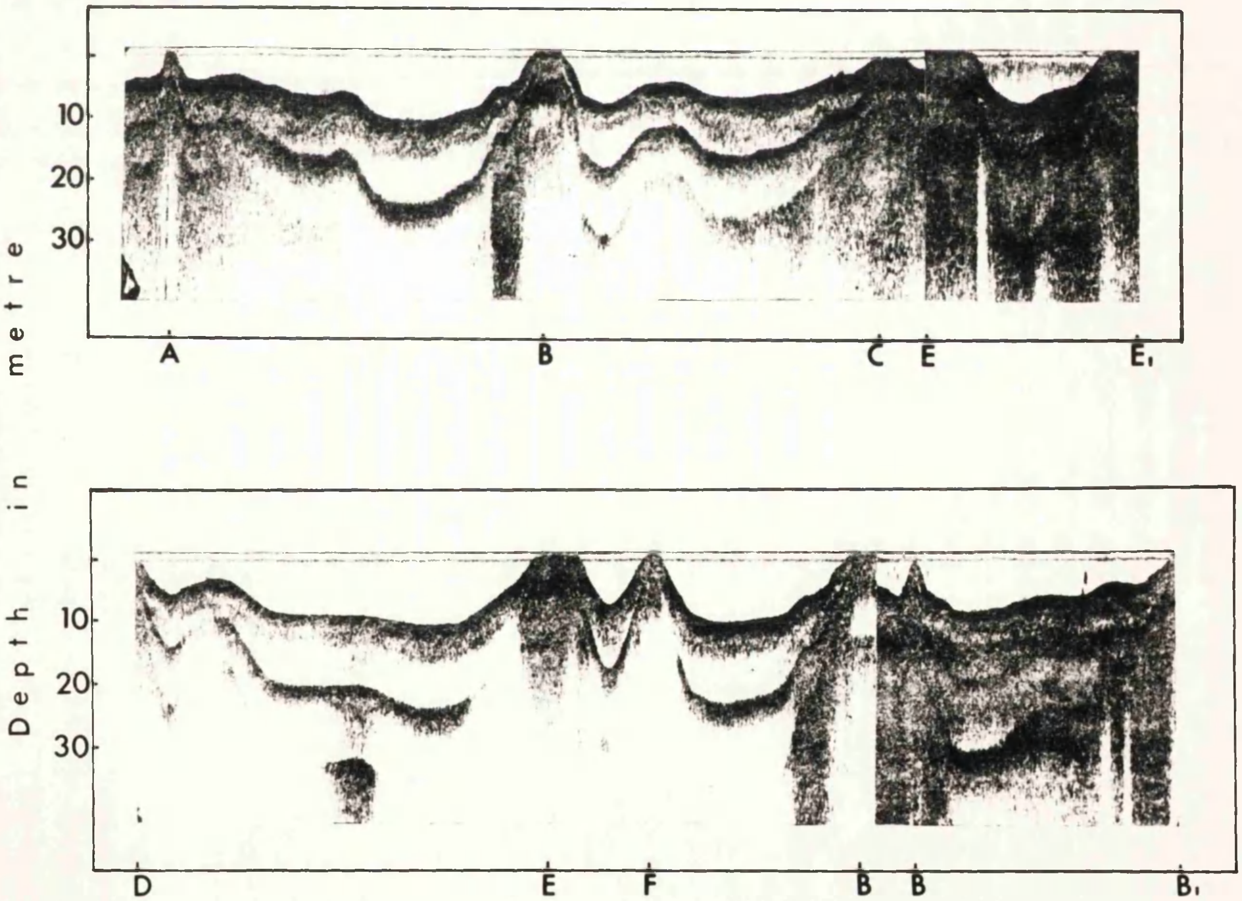

N
Ross Wood
Sallochy Wood
C
B
A
4 m
5 m
6 m
10 m
3
300 ft.
Dubh Lochan
FIELD STATION

Figure 2. The bathymetric survey of the Dubh Lochan showing echo-sounding transects.


N
C
D
B
B1
300 ft.
F
E1
E
Dubh Lochan
A


Depth in metre
10
20
30
A
B
C
E
E1
10
20
30
D
E
F
B
B
B1

the configuration of the present-day loch. Though the exact timing of the origin of many Scottish lochs is controversial, it is probable that the Dubh Lochan was formed during the Pliocene period at the same time as Loch Lomond (Lamond, 1931).

The Dubh Lochan lies in a region of woodland (mainly oak with some recently planted pine) growing on boulder clay and exposures of schistose grits and greywracke rocks. These rocks rise steeply on part of the western shore. An examination of the map (Fig. 1) will show that the southern end of the Dubh Lochan is divided into two parts by an inward extension of rocks which form a small peninsula.

On the eastern shore, the Dubh Lochan receives its major tributary. From the north side its effluent stream connects with Loch Lomond, the distance between the two lochs via this burn being about one kilometre. The present Zoology Field Station of Glasgow University is situated quite near the south-west corner of the Dubh Lochan. Sewage from the Field Station is treated in a septic tank followed by a percolating filter system before it enters the Dubh Lochan in the south-west corner.

The Dubh Lochan was not surveyed during the bathymetrical survey of the Scottish freshwater lochs

Figure 3. Weekly records of the water-level in the Dubh Lochan, during 1966-1967.

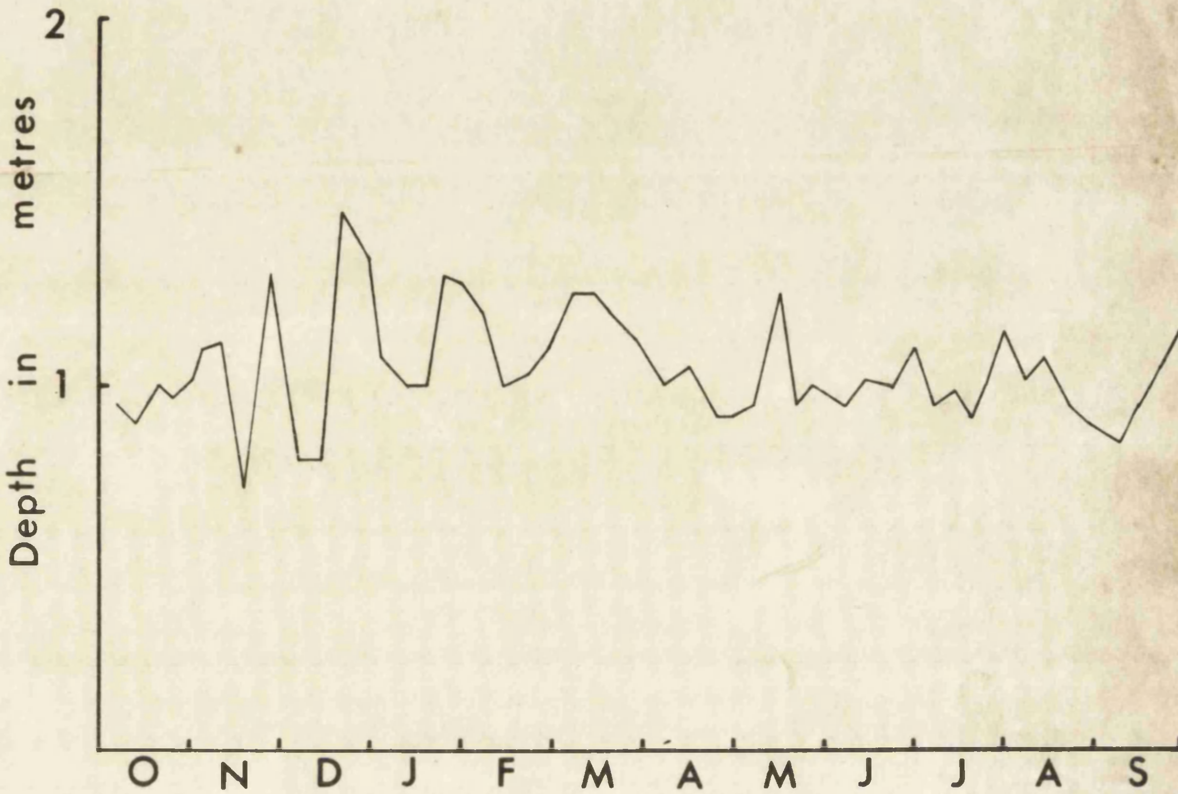
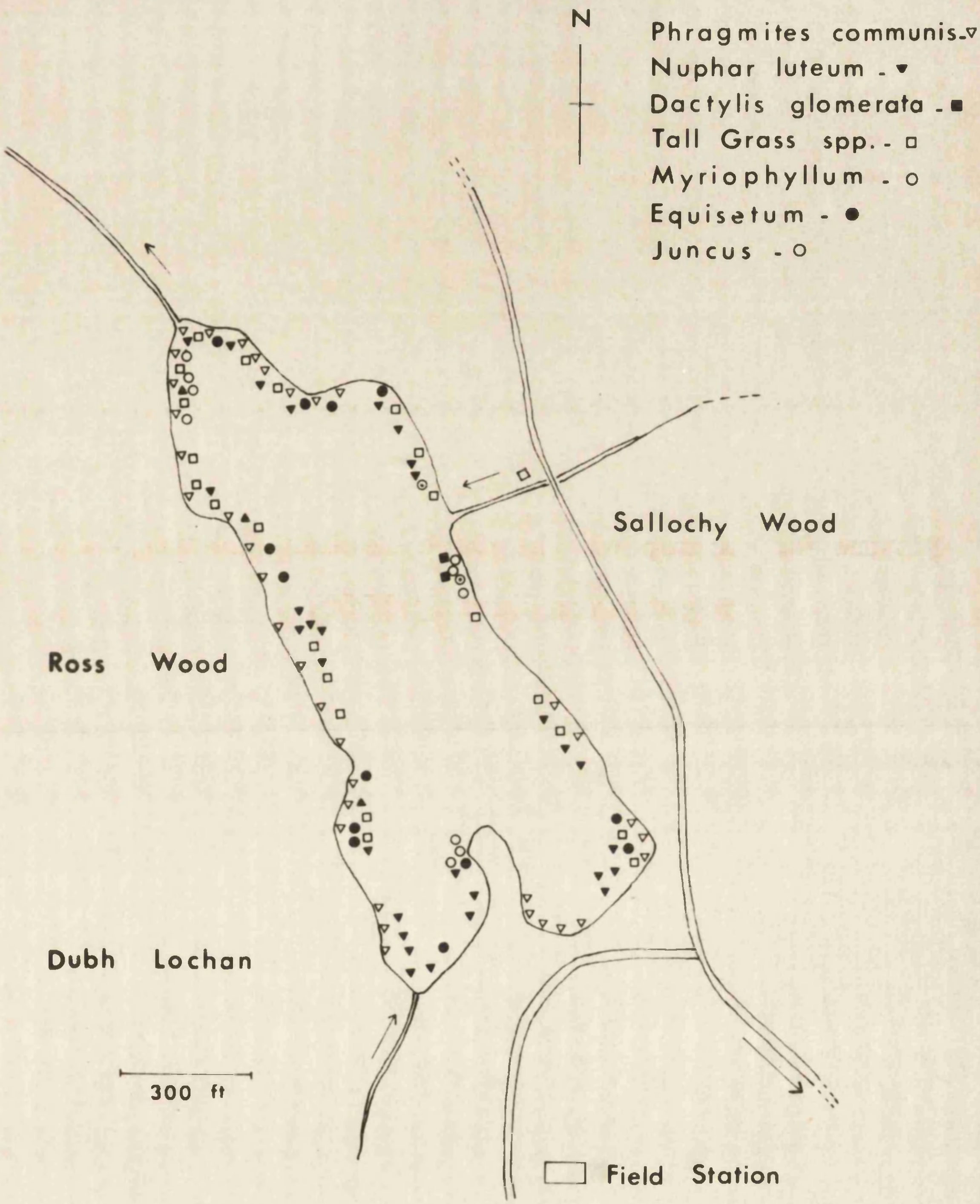

2
1
Depth in metres
O N D J F M A M J J A S

Figure 4. A map of the Dubh Lochan showing its vegetation during 1966.


N
Phragmites communis - ▿
Nuphar luteum - ▾
Dactylis glomerata - ■
Tall Grass spp. - □
Myriophyllum - ⊙
Equisetum - ●
Juncus - ○
Sallochy Wood
Ross Wood
Dubh Lochan
300 ft
Field Station

(Murray & Pullar, 1910), although many lochs of smaller dimensions were examined. However, with the help of a sensitive high-frequency echo-sounding apparatus, as used by Maitland (1969), a bathymetric survey was carried out in 1965. The results of this survey are shown in Figure 2. The maximum depth of the loch is 10 metres and it has an average depth of 4.7 metres.

Vegetation

Owing to the relatively static water level (Fig. 3) the communities of rooted aquatic plants in the littoral area are well established and extensive. These communities are dominated by *Phragmites communis*, tall grass spp., *Equisetum*, *Nuphar luteum*, *Juncus*, *Dactylis glomerata* and *Myriophyllum* (Fig. 4). The characteristic zonation is *Phragmites*, tall grass spp., *Nuphar luteum* and *Myriophyllum* from the bank into deeper water.

Temperature

Temperatures of both bottom and surface water were recorded regularly from October, 1966, to December, 1967, and from April, 1968 to June, 1968, from two maximum-minimum thermometers attached to buoys near the middle of the loch. During winter there was no difference in the temperature of deep and surface water (Fig. 5). The lowest bottom temperature recorded in the winter of 1966-67 was 2°C (Fig. 5b). Ice-cover occurred from time to time with the exception of a small area over the deepest part.

The highest temperature found was in August, 1967, when the water reached 18°C at the surface and 16°C at the bottom. There is normally a slight difference of temperature between the bottom and surface during summer.

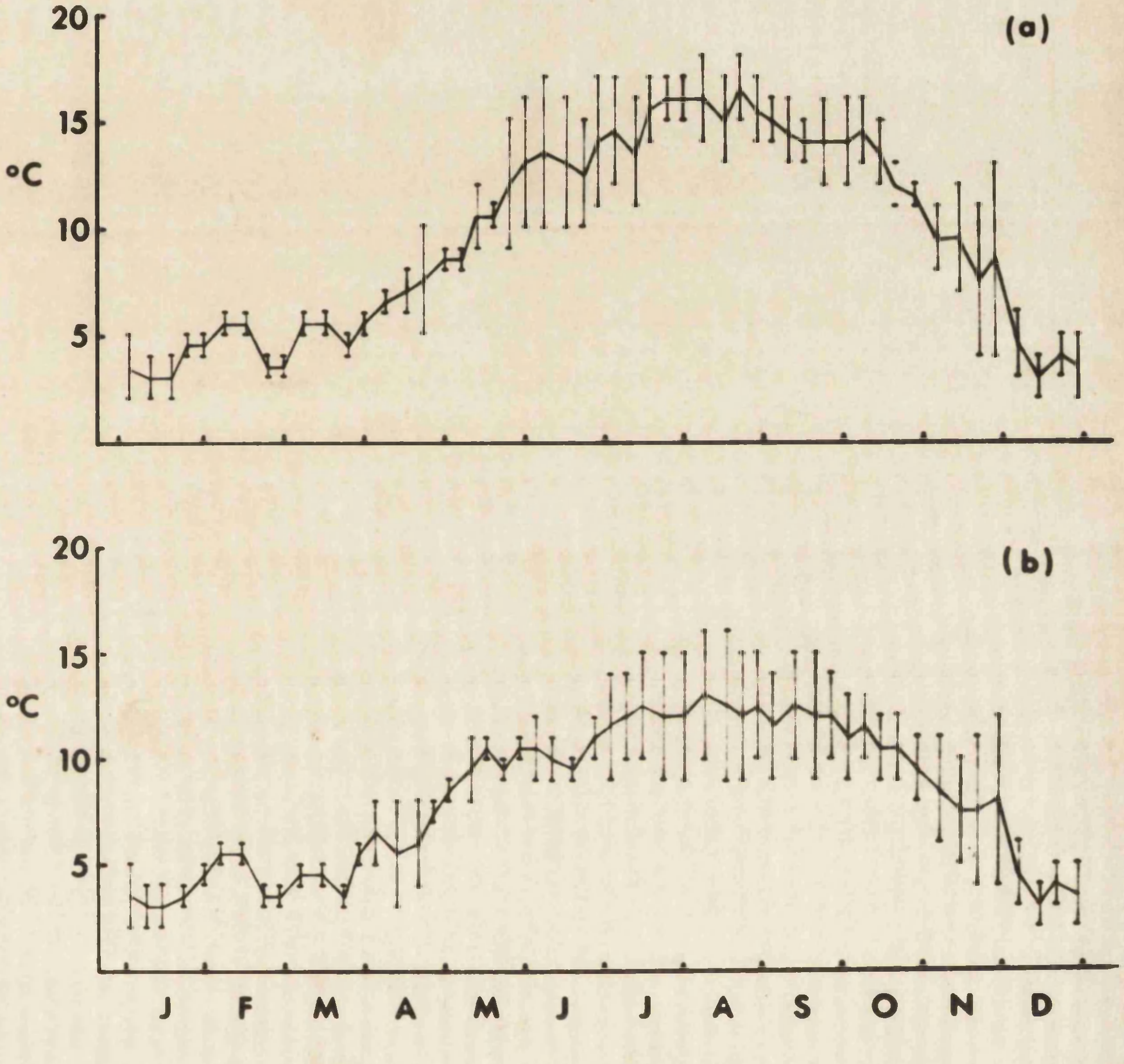
Bottom deposits

Samples of substrate from the Dubh Lochan at different depths were examined. Those from water depths of about 25 cm showed a bed of small stones, dead leaves, a sward of *Littorella lacustris* and *Lobelia dortmanna*. Water depths of about 100 cm gave samples of black mud with a massive growth of *Oedogonium*. In the middle, deeper, parts of the loch there is a fine black organic mud with some coarse vegetable debris.

Water level

Records of water level were noted once or twice a week from a pole, marked in cm, permanently positioned in one metre of water near the south shore. There is evidently a clear correlation between rainfall and water level in the Dubh Lochan. The level reached its highest in December and its lowest in November in 1966; but it

Figure 5. The weekly average, maximum, and minimum temperatures of (a) surface water and (b) deep water in the Dubh Lochan during 1967.


20
15
10
5
°C
(a)
20
15
10
5
°C
(b)
J F M A M J J A S O N D

normally does not remain near these limits for more than a few weeks. Generally, the water level is low during summer and high during winter (Fig. 3).

pH

The water of the Dubh Lochan is slightly acidic, the average pH being 6.2.

Dissolved oxygen

During periods of complete circulation the water at all levels in the Dubh Lochan is near saturation. Temporary thermal stratification occurs during periods of warm weather in summer. The average percentage saturations of oxygen on the surface and the bottom of the loch in summer, 1967, were 89.7 and 79.0 respectively, and in November, 1967, were 78 and 82 respectively (Mr R. Tippett, personal communication).

Other physical and chemical features

The appearance of the water in the Dubh Lochan is black: hence the Gaelic name (Dubh = black). The transparency of the water as indicated by secchi disc measurements is low. The disc disappears at an average of 2.7 metres in winter and at 3.5 metres in summer.

The dissolved electrolyte content is low; typical figures in 1967 were .36 mg/l for silicate; .21 µg/l for phosphate; .16 µg/l for ammonia and .27 µ/l for nitrate; conductivity is also low (Mr R. Tippett, personal communication).

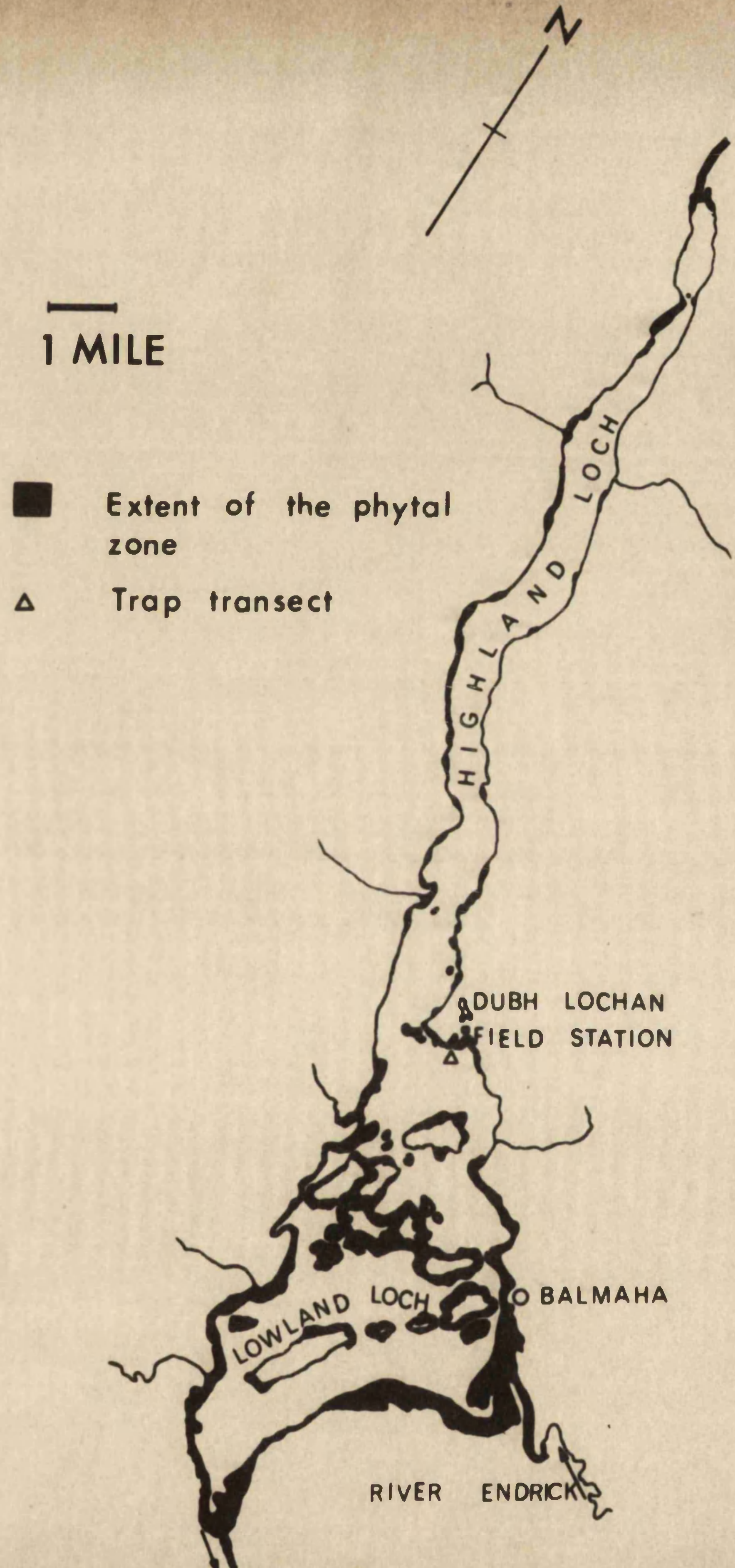
The Dubh Lochan is visited by a few casual anglers during the summer and, with the intention of introducing game fish, the Vale of Leven Angling Association unsuccessfully dynamited part of it in 1961. Although several dead pike were recovered, the species was not exterminated.

Classification

According to simple classification of lakes given by Thienemann (1925), the Dubh Lochan falls into the dystrophic type, i.e. a lake with acid humus and dy sediments (Hansen, 1961). Thunmark (Hansen, 1961) proposed that the dystrophic lakes should ideally be called polyhumous lakes, because the term trophic refers to nourishment; however, dystrophic means rich in humus.

It is reasonable, however, to adopt the standard terminology and state that the Dubh Lochan is a dystrophic or polyhumous lake for the following reasons: it is deep to shallow; it lies in old mountains; its water is dark

Figure 6. A map of Loch Lomond showing the phytal zone, the Field Station, Balmaha, and the transect where perch traps were dropped near the Field Station. (After Slack and others, 1957.)


N
1 MILE
Extent of the phytal zone
Trap transect
HIGHLAND LOCH
DUBH LOCHAN
FIELD STATION
LOWLAND LOCH
BALMAHA
RIVER ENDRICK

with a low transparency; large quantities of organic mud occur on the bottom (Rounsefell & Everhart, 1965).

Loch Lomond

The more important dimensions of Loch Lomond are summarised in Table 1.

The loch is divisible into two portions: a long, deep and narrow 'highland portion' and a wide, shallow 'lowland portion' (Fig. 6). The highland portion is about 25 km long; the lowland about 8 km long. The lowland portion is everywhere less than 30 m deep and is separated from the highland portion by a chain of islands rising from a band of shallow water 9 to 10 m deep. The catchment area covers ten times that of the loch and drainage enters by seven major and a large number of minor streams.

Temperature

Measurements of temperature made in 1903 by Murray & Pullar (1910) and in 1953 by Weerekoon show that, in winter, temperature differences in the water of Loch Lomond are very slight. The lowest bottom temperature recorded in the winter 1948-49 was 5°C. In severe winters, ice may cover the lowland part.

Vegetation

The highland and lowland regions (Fig. 6) differ significantly in the areas of water which are shallow enough to permit the growth of rooted plants (Slack, 1957). Too little light reaches below a depth of about 4 m for green plants to survive. Over the whole loch, water from zero to 4 m deep covers ten per cent of the total area but only two per cent of this is found in the highland portion of Loch Lomond (Slack, 1957).

Dissolved oxygen

During the period of complete circulation water at all levels of the loch is generally saturated with oxygen (Weerekoon, 1953). Even under stratified conditions the oxygen level is high. The lowest value recorded so far was in the hypolimnion of deep water in July when a value of sixty-two per cent was recorded (Slack, 1957).

Other physical and chemical features

The colour of the water is usually faint yellow. The transparency, as indicated by measurements with a secchi disc, is greater than in the Dubh Lochan, the disc disappearing at about 6 m in summer and 5 m in winter.

The pH varies from 6.9 to 7.1 (Weerekoon, 1953) and the calcium content is low, usually between 7 and 12 p.p.m.

(A.V. Holden, personal communication).

Bottom deposits

Most of the bottom of Loch Lomond below a depth of 7 m has a deposit of typical 'gyttja' (Slack, 1954). Water depths less than 7 m show a bed of stones, silt or fine sand, depending on local conditions.

Water level

The water level of the loch varied by 1.7 m during the period April, 1948 to August, 1950, the highest values being reached in the autumn and winter, the lowest in the summer months (Weerekoon, 1953).

Classification

According to Thienemann's system, Loch Lomond is an oligotrophic lake because of the following characteristics: the low quantities of nutrient salts present; the absence of a period of winter stagnation; the high hypolimnetic oxygen content in summer; the great depth of the loch; the geological nature of its drainage basin (Weerekoon, 1953 and Slack, 1957).

MATERIAL AND METHODS

Capture

Most of the perch sampled in the Dubh Lochan were caught in traps during the spawning period, in April and May, in each year of the present work. The traps were the same as those used for Windermere perch by Worthington (1950) and Le Cren (1958).

Fifteen of these traps were used in the Dubh Lochan along three transects (Fig. 1, A, B, C), five in each transect. In each of these transects the five were placed at different known depths ranging from 2 to 9 m; the arrangement being partly shown in Figure 1.

All the traps were checked two or three times a week during the spawning period in April and May, and once each week for therest of the year. In the Dubh Lochan some fish were also caught in gill-nets of 6.3, 12.7 and 19.0 mm mesh (knot to knot) at different times of the year when the perch were not entering the traps at all. Five traps were arranged in a similar transect in Loch Lomond near the University Field Station (Fig. 6). Many other perch were caught during the spawning period by means of gill-nets set mainly near the former mouth of the River Endrick near Balmaha. These gill-nets had a ranging mesh size of 12.7, 19.0 and 25.0 mm (knot to knot). These nets were usually left overnight. Perch were also caught at different points in the vicinity of the Field Station throughout the year. The catches here, however, were small, even during the spawning period.

The catch of perch in traps per month, in the Dubh Lochan, has been summarised in Table 40. Only a few perch entered the traps between July and March. Most of them were caught in April and May, during the spawning season. The majority of the captures were made in traps placed in about 5 to 7 m of water. The number of fish caught in traps placed in 2 to 5 m depth was much less than this but more than those caught in traps in 7 to 9 m depth.

Most of the pike caught in the Dubh Lochan were taken in perch traps, mainly during the perch spawning period. At other times, pike were caught in gill-nets of 19 and 25 mm mesh (knot to knot). All the pike from Loch Lomond were caught in gill-nets set for perch or powan.

Initially, some of the traps were baited with raw fish flesh but this was later discontinued as the baiting was not found to be of importance. All the eels collected in this study were caught in the perch traps mentioned above.

Tagging and Marking

Perch and pike

The tagging and marking of all species in the Dubh Lochan was intended chiefly to supply data on the populations of adult fish and to obtain information regarding the extent of fish movement in the loch. Most of the fish used for tagging were caught in perch traps. A few of the pike were caught in gill-nets, but only those in good condition and which were still fit after tagging were used.

Eighteen general types of tags are defined and described by Rounsefell & Kask (1945). It was not certain which would be the most efficient type of tag for perch, pike and eels in the Dubh Lochan. But it was decided to use small, external plastic tags of different colours for perch and pike. Each tag was 8.5 mm in length, 3 mm wide and 1 mm thick. Each had an individual number printed on it and a small hole at one end. These tags were very light, durable and fairly successful as a general type of external tag. Thin silver wire of 25 standard wire gauge was used to attach the tag to the body just anterior to the first dorsal fin in the case of perch and the dorsal fin in pike. Before tagging the fork length of each fish was measured and its weight read on a field spring balance. A few scales were removed from each fish from the area, described by Le Cren (1947), in the case of perch and by Frost & Kipling (1959) in the case of pike, and these were preserved in scale-envelopes. The fish species, date, location of tagging and tag number were all recorded on these envelopes.

All tagging was carried out on the shore of the Dubh Lochan and the fish were never out of water except for a brief period during the tagging operation. Care was taken to avoid any damage during handling of the fish. All damaged or unhealthy fish were removed and used for stomach analysis etc.

In 1967, the operation of tagging and marking perch and pike was carried out from March 31 to June 15. During this period 485 perch taken from transect 'A' were tagged and released again in the same place. In 1968, 100 perch caught in traps along transect 'C' were tagged and released in the same place.

During the same period in 1967, thirty-nine pike were tagged and released in a similar way and in 1968, a further twenty-six specimens were tagged and released.

It was not possible to tag every fish in each sample of perch before returning it to the loch. Instead, the rest of the fish caught along each of the three transects in the Dubh Lochan were clipped using three different fin codes. This fin clipping of the perch was carried out at the same time as the tagging. In 1967, the posterior dorsal fins of perch caught in traps along transect 'A' were clipped. All the perch caught in traps along transect 'B' were marked by clipping the posterior dorsal and upper caudal fins; while the perch caught along transect 'C' were marked by clipping the posterior dorsal and lower caudal fins. From the three transects a total of 4,038 perch were clipped in one of these three ways.

In 1968, the pattern of clipping was altered to avoid any possible confusion with the previous year and also to confirm the data on movement obtained from the clipping experiment of the previous year. In 1968, the posterior dorsal and lower caudal fins of all the perch caught along transect 'A' were clipped. At transect 'B' the posterior dorsal fin and at transect 'C' the posterior dorsal and upper caudal fins were clipped in the usual way.

Maximum care was taken to avoid any damage to the fish during the clipping operation. Clean, sharp scissors were used. A quick, clean cut was made, at right angle to the axis of the dorsal and caudal fins, to remove about two-thirds of the fin (Stuart, 1958). Observations on the re-generation of clipped fins were made and are discussed below.

Eel

It was more difficult to find an efficient method of tagging or marking eels on account of their elongate stream-lined structure and soft, slippery body. The introduction of some kind of dye into the skin by incision was thought to be the best method for this species and eels removed from perch traps in the Dubh Lochan were marked from April 26 to June 15, 1967, in this way.

The eels were anaesthetised by immersing them in a solution of MS 222 (about 5 gm of MS 222 for 1,000 ml of water) for about 15 to 20 minutes. A pink rubber latex was then injected below the skin on the belly with the help of a syringe fitted with a thick hypodermic needle. The ventral surface of the skin of the eel is colourless and a strip of rubber latex some 2 cm long was clearly visible through the skin after marking. The operation was not an easy one due to the thick tough skin of the eel and several other factors. At first, a few marked eels were observed for three days in a cage in the Dubh Lochan and these were found to be active and healthy during this period. All marked eels, when released in the water, recovered rapidly and swam quietly away. Thirty-one eels of different lengths were marked and released in the Dubh Lochan in 1967.

Age and Growth Determinations

The size of fish in a population depends both on factors which affect the average age of the fish and on factors which affect their growth rate (Le Cren, 1958).

The rate of growth of fish can be very variable and in a single species can differ in both space and time. The present study on the age and growth of perch and pike from the Dubh Lochan and Loch Lomond was started with a view to gathering information on the comparative age and growth rates of the two populations.

Sources of material

The numbers of perch and pike taken from the Dubh Lochan were kept to a minimum so that the adult population was affected as little as possible during the population experiment in 1967 and 1968 (see Ricker, 1958). Those perch and pike which were found to be weak or damaged in traps or gill-nets were, however, taken and killed for age and growth studies. In addition, about 100 female perch were taken in both 1967 and 1968 for fecundity analysis and these were also studied for age and growth. In all, 194 perch were removed in 1966-1967 and 276 (including sixty-five immature fish) perch in 1968 from the Dubh Lochan for age and growth analysis.

In 1967, 255 perch were caught in gill-nets at the former mouth of the River Endrick in Loch Lomond, during the spawning period. In the same year, 152 perch were caught in traps along the transect in Loch Lomond near the

Field Station and in gill-nets in the same area. In 1968, 382 perch were caught in gill-nets at the old mouth of the River Endrick but only a few perch were caught in the traps near the Field Station. In addition, seven very large perch were caught in gill-nets and by rod in other parts of Loch Lomond. All these perch were used in the present study of age and growth.

Only fifteen pike were taken from the Dubh Lochan, during 1966-1967, for this study. In 1968, another nine pike were taken. These numbers were intentionally kept very low for the size of the pike population in the Dubh Lochan was thought to be small. During 1966-1968, thirty-two pike from Loch Lomond were caught by gill-nets and were analysed in the present age and growth study. In addition, analyses of the stomach contents of these and other fish were made available by Dr P.S. Maitland and Dr H.D. Slack.

Methods of collection of data

All fish caught during the spawning period were labelled and frozen. Later, they were washed and excess moisture was then removed by absorbent paper. The fork length of each fish was measured and the weights of all fish up to 120 gm in weight were measured on a Mettler 120 balance. Perch more than 120 gm in weight were measured on a Mettler P1200 balance. Weights of all pike were measured by field spring balances of different capacities.

The sex of each fish was noted on a scale-envelope and about twenty-five to thirty scales taken from the side, below the lateral line, and opposite the distal end of the pectoral fin of perch (Le Cren, 1947), and from an area, just above the lateral line and about midway along the body of pike (Frost, 1959). Both opercular bones were removed from each fish exactly as described by Le Cren (1947).

In 1967, field observations showed that perch spawned from April 16 to June 1 in the Dubh Lochan. In 1968, spawning started about a week later (possibly because of the cold spring in 1968) but again ended by the beginning of June. The conventional date of birth of perch was fixed as May 1 and age designation of the fish has been calculated accordingly, i.e. all fish are supposed to have completed each year of their life on May 1. In Loch Lomond, the time of spawning of perch was found to be a little later than in the Dubh Lochan. The onset of spawning was also apparently about one week later in the upper loch than in the lower loch. An excellent breeding ground is situated at the old mouth of the River Endrick where there is a large area of shallow water and many aquatic plants. Here, perch had started breeding by the last week of April in 1967, and this lasted till the first week of June in that year. The phytal zone in Loch Lomond near the Field Station (Fig. 6) is not suitable for perch spawning as there are few suitable macrophytes present. Here, perch did not start breeding until the middle of May and continued till the end of June in 1967. In 1968, in both places in Loch Lomond spawning was about a week later. Because of the above difference, the conventional birthday of perch in Loch Lomond was fixed as May 15 in each year, i.e. each perch completes each year of life on May 15.

Le Cren (1958) fixed the conventional birthday of perch in Windermere as April 15, thus all the perch were accepted as having completed their yearly life a few days or weeks before the actual event. Healy (1954) accepted the second winter zone on the opercular bone as a mark of the completion of the first year of life in Irish perch, when, in fact, these perch were actually on the verge of completing their second year of life.

Age and growth estimation of perch

The opercular bones, immediately after removal from the body of the fish, were kept in water in marked tubes for two days. Then the water was decanted and a very dilute solution of hydrogen peroxide (1 ml of hydrogen peroxide in about 5 ml of water) added and left for a further two days. The bones were then washed in water, cleaned with the help of a fine brush or a fine scalpel and dried.

The annual rings became very clear after the bones were dry. Cleaning of bones was much easier if they were treated immediately after their removal from the body of the fish (Le Cren, 1947). Opercular bones of perch from the Dubh Lochan, removed and dried without cleaning in 1965, were not cleaned very successfully by this method. The bones became slightly brittle and even after cleaning rings were not very clear.

At the beginning of this study of age and growth, both scales and bones were examined. The scales were read, in a 'Mikrops' industrial microprojector (no. 50/61), which magnified them about ten times. The opercular bones were examined with the help of a simple slide-projector (Le Cren, 1947). It was found that analysis of the bones was comparatively easier than that of the scales (because of the occurrence of many false rings in the latter) and the study of scales was given up. Scales were only studied later on in cases where the opercular bones were poor or for comparison with them.

With the help of a mirror, images, at a x8 magnification, of the two opercular bones from each fish were thrown vertically downwards on to a sheet of white paper. Light was polarised by placing a 'Polaroid' glass disc between the projector's condenser and the opercular bone. The centre of growth of the opercular found by Le Cren (1947) was accepted as being the correct centre of growth of this bone, though this point was not clearly marked on the projected bones. This centre was determined by noting the point where the opposing rings of the bone met. It is a little posterior to the midpoint of the circular anterior face of the bone, used by Nilsson (1921) as the centre of growth.

The edge of a narrow strip of paper, was placed on the projected image, along a line passing through the centre of the bone and perpendicular to its posterior edge. The position of the centre, the winter rings and the edge of the bone were marked off on this strip. The marked paper was then placed on graph paper so that the centre mark was at the origin and the edge mark opposite the recorded length of fish on the Y-axis of the graph paper. The respective growth in length for each year of life was then read off the Y-axis opposite the winter ring marks. This method of back-calculating the growth of a fish is known as the Dahl-Lea method (Le Cren, 1947). Ninety-five per cent of the bones from Dubh Lochan perch and about eighty per cent of the bones from Loch Lomond perch had no false rings. In other bones, the false rings were easily identified as they always occurred in the middle of a summer growth period (Le Cren, 1947).

In the Dubh Lochan, despite the general slow rate of growth, all the rings were very clear. During their study, it was also observed that although fast growth occurred at first it was not always maintained. Also growth rate usually slowed down notably in the third year in Loch Lomond perch. When examining scales of perch, younger than two years old, none was found to carry any false ring.

During the back-calculation of growth from the opercular bones, it was assumed that they grew in direct proportion to the fish. In 1967, the opercular bones of 196 perch from the Dubh Lochan and of 411 perch from Loch Lomond were tested to find the proportionality of growth by comparing the lengths of the fish and the opercular bones throughout their lives. The bones were measured from the centre to the posterior edge, along a line approximately perpendicular to that edge. The measurements were made to an accuracy of 0.01 mm with a pair of dividers and a vernier. The measurements of male, female and immature fish were treated

Figure 7. Mean opercular length against fish length of perch from the Dubh Lochan: (a) immature fish; (b) mature males; (c) mature females.

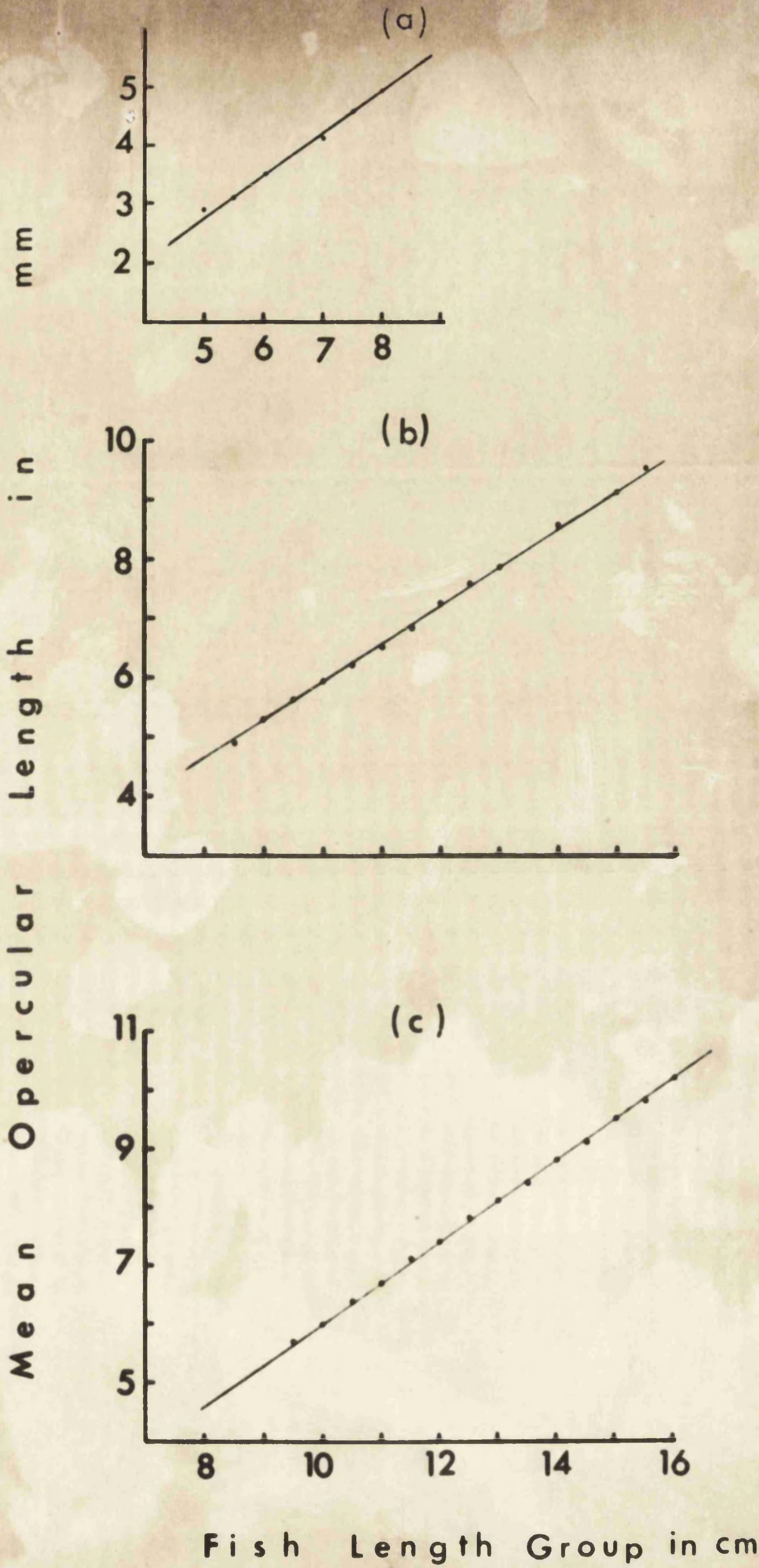
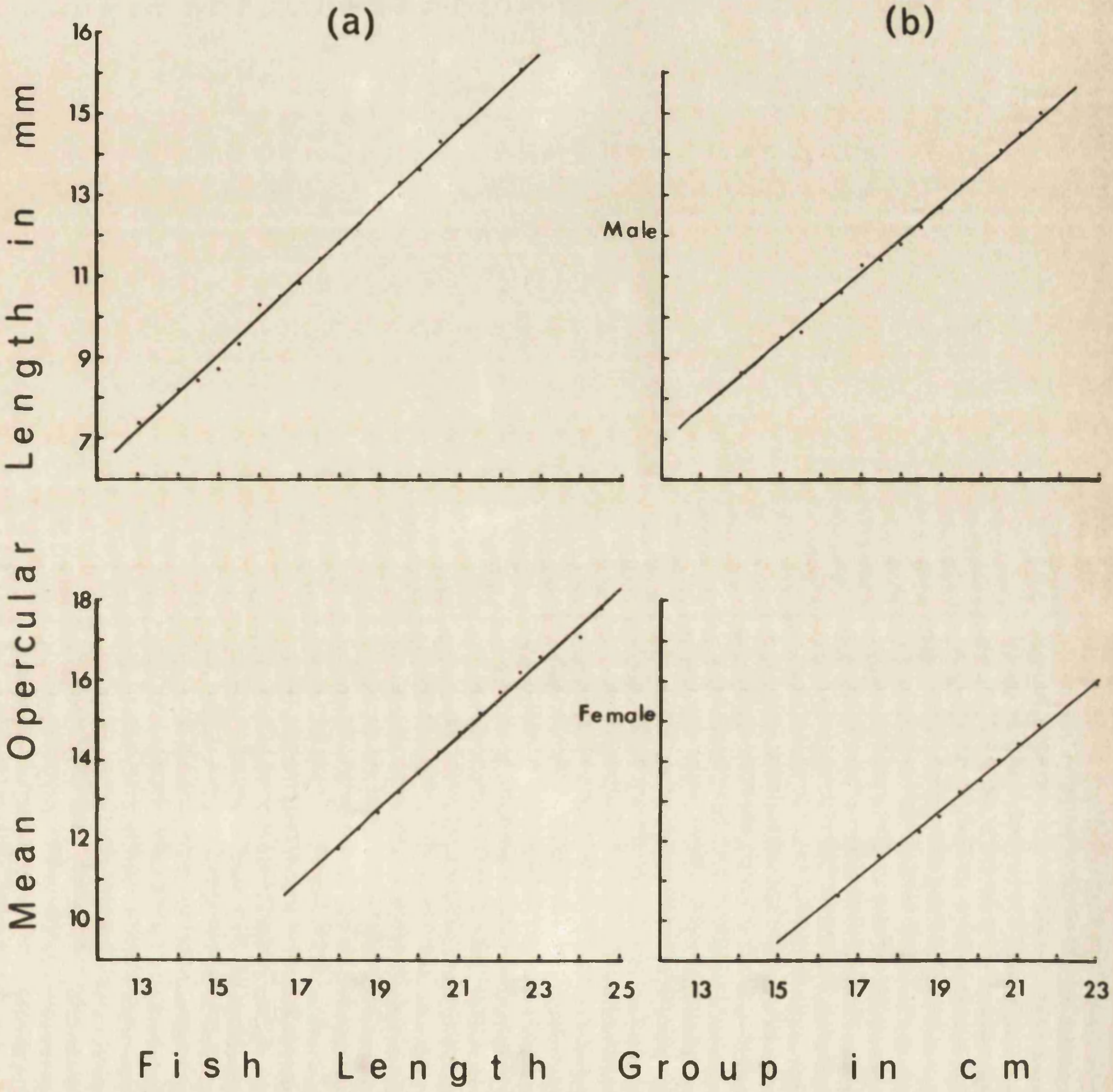

(a)
(b)
(c)
Mean Opercular Length in mm
Fish Length Group in cm
5
4
3
2
5 6 7 8
10
8
6
4
11
9
7
5
8 10 12 14 16

Figure 8. Mean opercular length were plotted against fish length of perch from Loch Lomond:
(a) male and female from Field Station area;
(b) male and female from Balmaha area.


(a)
(b)
16
15
13
11
9
7
18
16
14
12
10
Male
Female
13
15
17
19
21
23
25
13
15
17
19
21
23
Mean Opercular Length in mm
Fish Length Group in cm

separately. The fish were divided into 0.5 cm length groups and the mean opercular lengths calculated for each length-group. In the Dubh Lochan, the opercular bones of 128 females, forty-eight males and twenty immature fish were examined for this purpose. From Loch Lomond, the opercular bones of thirty-seven females, 366 males and eight immature perch were studied. The mean opercular lengths are given in Table 2.

When the mean opercular lengths are plotted against the mean fish lengths, it is clear that the points lie on a straight line both for Dubh Lochan and Loch Lomond perch. Regression lines were fitted to the mean fish lengths upon the mean opercular length for the three groups of fish from both places (Figs 7 and 8). All the points lay on or closely to (and equally on both sides of) the fitted straight lines, demonstrating isometric growth, i.e. the length of the opercular bone grows proportionately to the length of the fish.

The last year's growth of a few perch, caught in December, January and February, was taken as one year's growth.

Age and growth estimation of pike

Most previous European and American workers have used scales for the determination of age and growth of pike.

Frost (1959), however, successfully used the opercular bones of pike from Windermere for such studies. She found the scales unsatisfactory in such work for many reasons (i.e. many false rings, different growth-rates in the anterior and posterior parts, and the fact that scales are laid down after the fish has grown a little). In the present work on the age and growth of pike from the Dubh Lochan and Loch Lomond, the opercular bones were also used as the major source of information on age and growth, although a few scales from each pike were preserved as a check.

The opercular bones were excised and cleaned by rubbing with a cloth after immersion in hot water for a few minutes (Frost, 1959). The annual rings were mostly visible when the bone was completely dry, though in most of the bones, the first ring was obscure. The bones were kept in scale-envelopes with a record of the length, weight, sex, date and place of collection of the fish.

For the determination of age and growth the bones were projected in the same way as perch bones. Both the bones were examined and the better one selected for the back-calculation measurements. The centre of the bone used by Frost (1959) was used in the present study. The edge of a strip of paper was placed at right angles to the line used in locating the centre of the bone and the annual rings were marked off on this. These strips of paper were then used in the same way as those from perch to back-calculate lengths of the pike concerned.

Frost (1959) has shown that the growth of pike follows Ford-Walford's plot quite well. The method is briefly and clearly analysed by Rounsefell & Everhart (1965). Ford (1933) first assumed that the successive yearly increments added to length decrease in magnitude in geometric progression, until a limiting value of ultimate length is approached. Walford (1946) later changed the form of the growth curve by plotting "length at age x against length at age x + 1". According to the above assumptions, a straight line relationship will be obtained by analysis of this type. Frost (1959) has utilised the method very successfully in the case of Windermere pike.

In the opercular bones of most of the twenty-four pike from the Dubh Lochan which were studied, the first and sometimes the second winter rings were missing. However, the other rings were very clear and false rings were rare. Individual Ford-Walford plots were made for each of these twenty-four pike and by means of these the missing first and second annuli, in most of the fish, were revealed. The thirty-two pike from Loch Lomond were treated similarly and the first, second and sometimes third years' growth were obtained from the individual Ford-Walford plots.

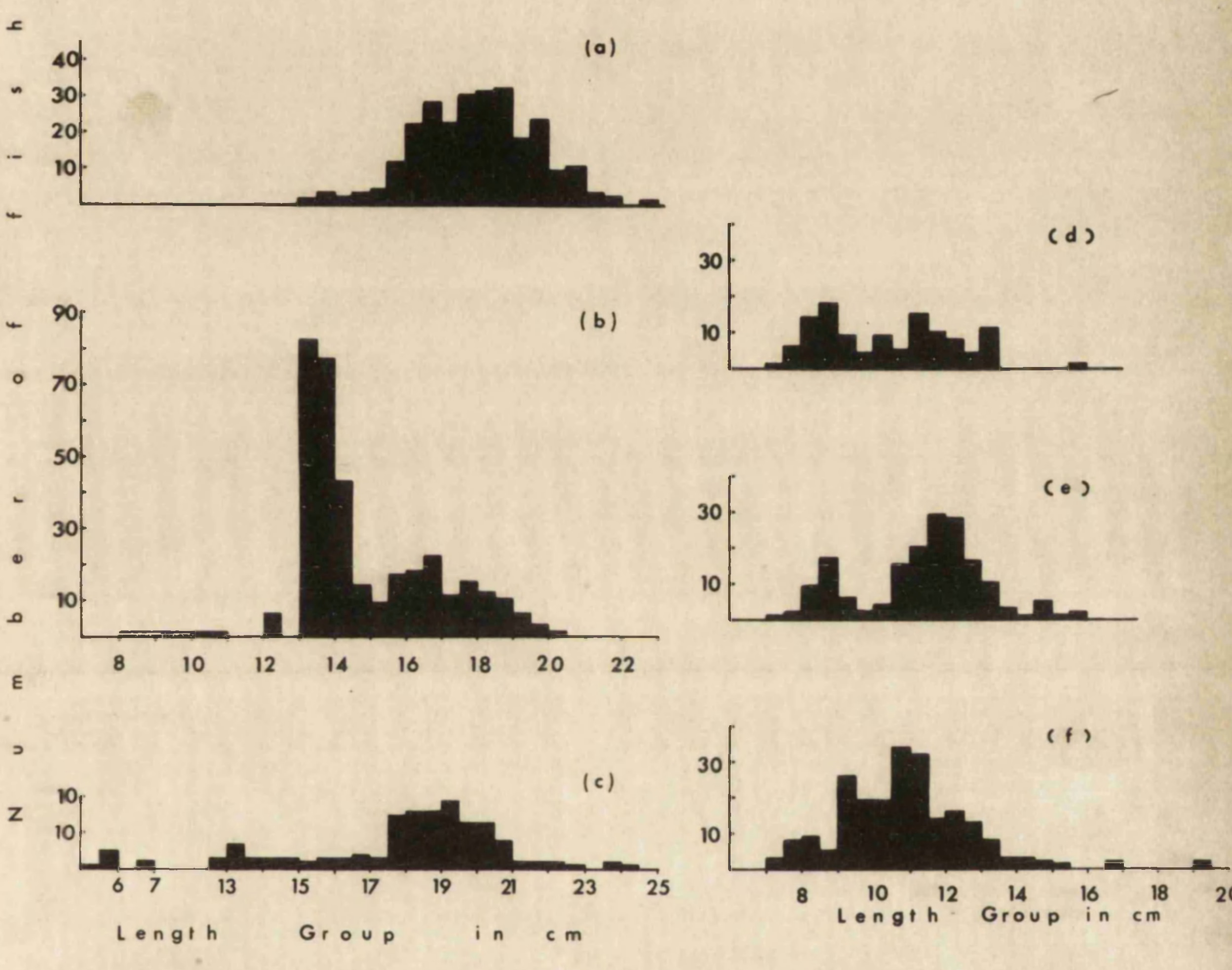
All the opercular bones from those pike, which were caught in late April, May and July, were found to show some plus growth after the last winter ring. Although this growth was small, it was carefully noted and not included in the calculation to determine the average growth. The last year's growth of a few pike, which were caught in December andJanuary, was accepted as a fùll year's growth. The bones of only one pike from Loch Lomond were rejected as being unreadable. The number of false rings was again very low in these fish and most normal rings were very distinct.

Stomach Analysis

Perch

The food of perch has been studied in the British Isles by Southern & Gardiner (1926), O'Donoghue & Boyd (1934), Allen (1934, 1935), Hartley (1940, 1947), Smyly (1951) and Campbell (1955). Alm (1922) in Scandinavia found that perch can be divided into three different size categories which feed on three different types of food organism. Changes in the diet of perch in relationship to size have also been observed by Allen (1935) and Hartley (1947) in Great Britain, and Roper (1936), Dobers (1922) and Brofeldt

Figure 9. The length-frequency distribution of perch from Loch Lomond (a, b and c) and the Dubh Lochan (d, e and f): (a) Balmaha, 1967; (b) Balmaha, 1968; (c) Field Station, 1966-67; (d) Dubh Lochan, 1965; (e) Dubh Lochan, 1967 and (f) Dubh Lochan, 1968.


Number of fish
(a)
40
30
20
10
(b)
90
70
50
30
10
8
10
12
14
16
18
20
22
(c)
10
10
6
7
13
15
17
19
21
23
25
Length Group in cm
(d)
30
10
(e)
30
10
(f)
30
10
8
10
12
14
16
18
20
Length Group in cm

(1922) in Germany.

Nilsson (1921) in Sweden, in his analysis of perch from the Gulf of Bothnia and Lake Mälar, could not find any difference in the food of perch of different sizes. Healy (1954) examined several thousand stomachs of perch from Irish waters and came to a similar conclusion.

Some American workers, studying the closely related species, Perca flavescens, showed similar results regarding the food of this perch to those of the European workers, except Nilsson (1921) and Healy (1954). Clemens, Dymond & Bigelow (1924), Sibley & Rimsky-Korsakoff (1930), Rawson (1930) and especially Couey (1935) found distinct differences in the food of perch of different sizes in American waters.

In all 1,269 perch stomachs were examined during the present work. Four hundred and eighty-eight of the fish concerned were from the Dubh Lochan (Fig. 9d, e, f). About three-quarters of these perch were caught in traps and the rest in gill-nets.

Seven hundred and eight-one stomachs were examined from Loch Lomond (Fig. 9a, b, c). One hundred and forty-five of these fish were caught in traps and gill-nets near the University Field Station in 1967 (Fig. 6); 636

were caught at the old mouth of the River Endrick near Balmaha (Fig. 6); 256 in 1967 and 380 in 1968. In both years, the fish were caught in gill-nets of ranging mesh size.

Pike

The food of pike in Loch Lomond has been studied by Robertson (1886) and Copland (1956). Day (1880), Allen (1939), Hartley (1947), Munro (1957) and Frost (1954) have studied its diet in other parts of Great Britain. The most detailed account of the food and feeding habits of pike was given by Frost (1954), based on an examination of several thousand pike from Windermere. Healy (1956) has studied the food of pike of Irish waters. Marshall & Gilbert (1904), Forbes & Richardson (1908), Clemens, Dymond & Bigelow (1924), Rawson (1932), McNamara (1937), Solman (1945), Hunt & Carbine (1951), Hourston (1952) and Johnson (1966) have studied food of pike in America and Canada.

Twenty-two stomachs of pike, studied for age and growth, from the Dubh Lochan were examined for food. After the necessary measurements had been taken, each stomach was removed by cutting the gut at oesophagus and pyloric sphincter and was then preserved in five per cent formalin.

Eels

Hartley (1940), Frost (1946), Cragg-Hine (1963), Rogers (1964) and Sinha & Jones (1967) have all made observations on the food of the eels in different habitats in the British Isles. Some work has also been carried out in Europe and elsewhere.

Stomach contents of twenty-two eels from the Dubh Lochan were analysed during the present work. All these eels were caught in perch traps.

Methods of assessment

Different workers have used a variety of methods in the analysis of the stomach contents of fish and other animals. The main methods have been critically reviewed by Hynes (1950) who classified them into three types: (a) numerical, concerned with the numbers of each food organism in each stomach; (b) occurrence, concerned with the number of stomachs in which any one organism occurs and (c) points, the exact procedure for which varies among different workers (Ricker, 1937; Hynes, 1950; Smyly, 1955; Horton, 1961; Maitland, 1965). The first two methods are relatively exact methods, but both have the great disadvantage of not considering the differences in bulk among various food items. Thus a single large food items, such as a Trichoptera larva, may be many times the size of numerous small items, such as chironomid larvae, though numerically it would count much less. This disadvantage becomes especially significant when stomach-contents include large items like fish.

Accurate estimates of the mass of different food items are usually difficult to obtain, largely due to the small size of the organisms concerned and the fact that they may be partly digested or covered with sticky mucus.

In the present work all three methods were employed in the analysis of stomach contents. Both the numbers of organisms and the length of each (where possible) were recorded. The bulk of each food item was estimated by a points method similar to that used by Smyly (1955). According to this points method the contents of each stomach were awarded a number of points depending on the size of the fish and also the fullness of the stomach as shown in Table 3, where the fish have been divided into three length-groups corresponding closely to the three age-groups. I-II, III-V and over V for Dubh Lochan perch and I, II-III and IV and over for Loch Lomond perch. After the preliminary step of deciding on the total points to be given to a stomach, this figure was then sub-divided among the component food items according to the estimate of their relative volumes. A crude method for the estimation of the volume of the food in fish-stomachs was tried by Swynnerton & Worthington (1940) but the more exact points method developed by Hynes (1950) and Smyly (1955) is much superior. In the present work, a volumeter (Slack, 1967) was used and found to be very useful for the actual measurement of small volumes of food items. The apparatus determines volumes by a displacement method up to an accuracy of 0.01 ml. All fish, found as stomach contents, were measured by dropping them into a longer glass tube of the same diameter as that used in the Slack volumeter and containing seventy per cent alcohol. The change in level of the alcohol in this tube, before and after adding the fish, was read by using a similar scale.

Owing to small catches of fish in some months, seasonal changes in food and changes in the food associated with size of fish were not analysed in full. Unfortunately, no fish were caught in Loch Lomond in July and August; and only a few were caught in the winter months, despite extensive netting near the Field Station. During the winter months also, gill-nets were set several times in Loch Lomond near Balmaha but only one perch was caught by these and its stomach was empty. As already noted, due to the population experiment being carried out on perch, the catch of mature fish from the Dubh Lochan, had to be restricted to a minimum.

Only the numerical and occurrence methods were used in the analysis of food of pike and eels in the present study.

Fecundity of Perch

In a study of the population dynamics of a fish species, it is normally highly desirable to know the numbers of eggs, fry and young produced (Lagler, 1949). Unfortunately, there is relatively little published literature on the fecundity of perch in different countries. The only information on the fecundity of perch in the British Isles is that of Pincher (1947) who examined only three ovaries, and of Healy (1954) who examined eleven ovaries from Irish perch. Bagenal (1967) has been examining ovaries of perch from Windermere and other English waters for the last few years but has yet to publish his results. The present investigation on the fecundity of perch from Loch Lomond and the Dubh Lochan, was carried out in order to estimate the average and range in the number of eggs laid by individual females and also to study the relationship between fecundity and length, weight, age and gonad weight of this species.

In 1967, 107 ripe female perch were taken in April and May from traps in the Dubh Lochan for fecundity analysis. In 1968, another 100 ripe females were taken in late April and early May. In January, 1967, nineteen female perch were caught in Loch Lomond and in the same year another thirty-three ripe females were caught, mostly in gill-nets near Balmaha, but a few in traps near the Field Station. Another twenty-seven females, caught in 1967, during the spawning period, were spent. The ratio of male to female perch, caught in 1967, in Loch Lomond, was five to one, i.e. out of 461 perch, only seventy-nine were females. In 1968, out of several hundred perch, caught in Loch Lomond, during the spawning period, there were only two females. Occasionally female fish in the traps were found with partially laid egg bands. Such fish were discarded for the purpose of fecundity analysis.

The ovary from each fish was removed in tact and placed in five per cent formalin. This not only preserved the ovary but made it much easier later on to separate the eggs from the ovarian wall. The most accurate method of enumeration of fish eggs is probably by an actual count (Lagler, 1949). Some freshly laid egg strands from the

Dubh Lochan and from Loch Lomond were collected and the number of eggs counted. Later, the number of eggs in the ovary of one perch from the Dubh Lochan was counted directly. However, this method of direct counting was found to be too time-consuming and was discarded as a standard procedure.

According to Lagler (1949), there are three other methods of estimating the number of eggs in a given batch: (a) the Von Bayer method in which the average diameter of the eggs is found by means of a small graduated metal trough and the number per quart for eggs of various diameters is obtained from the Von Bayer Table. This method was not considered to be suitable for perch eggs because of their small size and the fact that they are laid in bands. (b) The volumetric method in which the number of eggs in a known volume is counted and then by measuring the volume of the remainder of the sample, the total number of eggs is calculated by proportion. A different but more accurate volumetric method is by counting 100 eggs, measuring the volume of water they displace, comparing this with the displacement of the entire sample and calculating the number by proportion. (c) The gravimetric method in which a known number of eggs are weighed following removal of excess moisture or a standardised drying procedure (Maitland, 1969) and their weight is compared to that of the whole sample for calculation of total number. All perch used in the present work were deep frozen, when caught, and the ovaries dissected out several weeks later, the gravimetric dry method being employed to estimate the number of eggs.

Following preservation, each ovary was washed in water. After the removal of the ovarian wall 100 eggs along with their surrounding tissues were removed from the middle of each ovary and placed in a small Baetson jar. The remainder of the ovary was placed in a larger Baetson jar and both jars were labelled. The jars were then placed in an electric oven and dried for several days at 50°C. It was found that the ovaries of Dubh Lochan perch took four to five days to reach constant weight at 50°C and those of Loch Lomond perch (which were normally much larger) took seven to eight days under the same conditions.

The dry weights of the smaller and larger portion of each ovary were then measured by a Mettler P120 balance and the total number of eggs calculated by proportion.

PERCH

Length-weight Relationship

Dubh Lochan

The relationship between length and weight in fish follows approximately the cube law and can be expressed by the formula, $W = aL^3$, in which, W = weight, L = length and a = a constant representing the condition of the fish (Le Cren, 1951). When expressed logarithmically (Le Cren, 1951; Rounsefell & Everhart, 1965) the formula becomes log W = log a + b log L, in which, 'b' represents the slope of the line and log a its position. Both can be determined by fitting a straight line to the logarithms of L and W or by computing them from the following normal equation for the regression method of least squares:

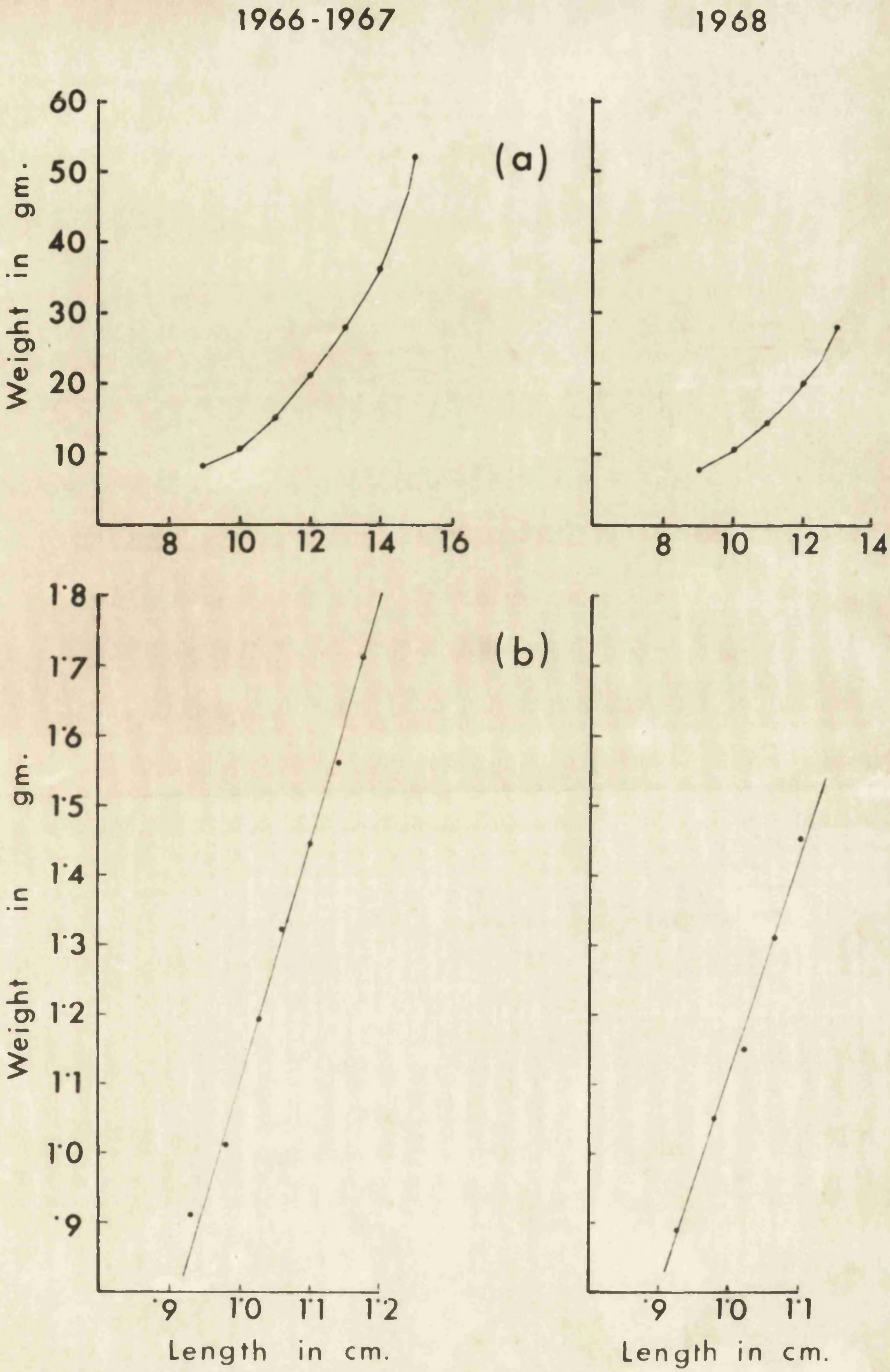
$$b = \frac{\Sigma(\log W \log L) - \frac{(\Sigma \log W)\ (\Sigma \log L)}{n}}{\Sigma(\log L)^2 - \frac{(\Sigma \log L)^2}{n}}$$

and

$$a = \frac{\Sigma \log W}{n} - b\ \frac{\Sigma \log L}{n}$$

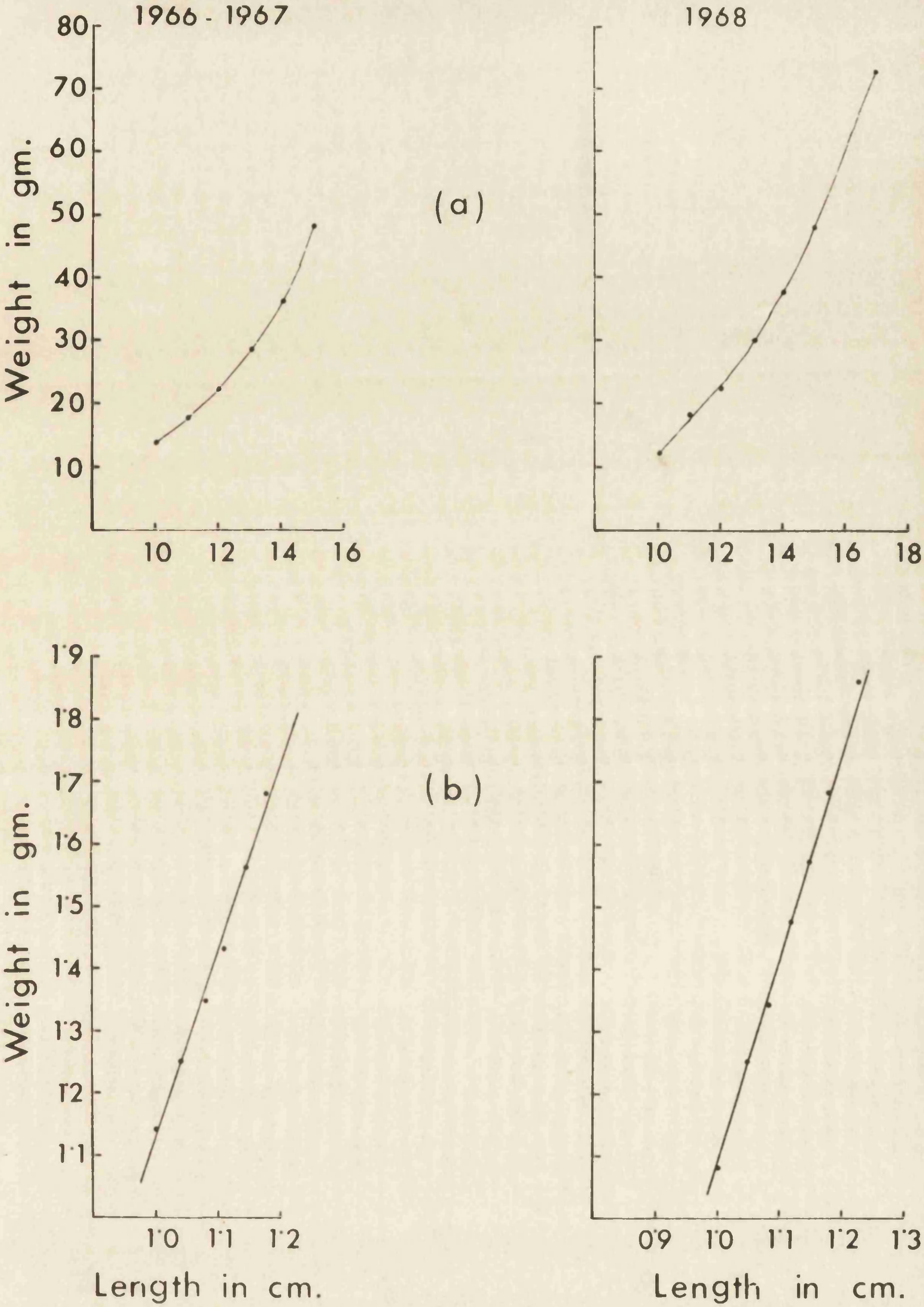
The data for length-weight relationships were obtained from fish caught as already described. When the lengths of all mature male and female perch, taken in 1966-67 and

Figure 11. The length-weight relationship of mature male perch from the Dubh Lochan: (a) length against weight, on arithmetic scale; (b) length against weight, on logarithmic scale.



1966-1967
1968
(a)
Weight in gm.
60
50
40
30
20
10
8
10
12
14
16
8
10
12
14
(b)
Weight in gm.
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
·9
·9
1·0
1·1
1·2
·9
1·0
1·1
Length in cm.
Length in cm.

Figure 12. The length-weight relationship of mature female perch from the Dubh Lochan: (a) length against weight, on arithmetic scale; (b) length against weight, on logarithmic scale.


1966 - 1967
1968
(a)
(b)
Weight in gm.
80
70
60
50
40
30
20
10
10
12
14
16
18
1·9
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
0·9
1·0
1·1
1·2
1·3
Length in cm.

1968 from the Dubh Lochan were plotted against their weights on an arithmetic scale, smooth growth curves were obtained (Figs 11a and 12a); and yielded straight lines when plotted on a logarithmic scale (Figs 11b and 12 b).

When the fish were divided into groups according to their sex and time of capture and the value of 'b' for each group found graphically by plotting log length against log weight, the values often differed from each other (Table 4). For each of these groups, a regression was then calculated for the logarithm of weight on the logarithm of length, by the method of least squares; the lengths being arranged in 5 mm groups. The value of 'b' obtained by the method of least squares agreed in general with the value of 'b' obtained graphically (Table 4). The ninety-five per cent fiducial limits of the regression coefficients 'b' for regression of log weight on log length of different groups of male and female perch were also calculated (Table 4).

Results

O group fish

These fish were caught in September, 1968, and their regression coefficient, when calculated, was 3.03064. This is not significantly different from 3.0 (the cube).

Mature males

The regression coefficient for male perch was 3.50321 which is significantly different from 3.0. The sub-group regression coefficients varied from this, that for August was 3.07977 and, for September-October, 2.91304. These results were based on very small numbers of fish however and may therefore not be typical.

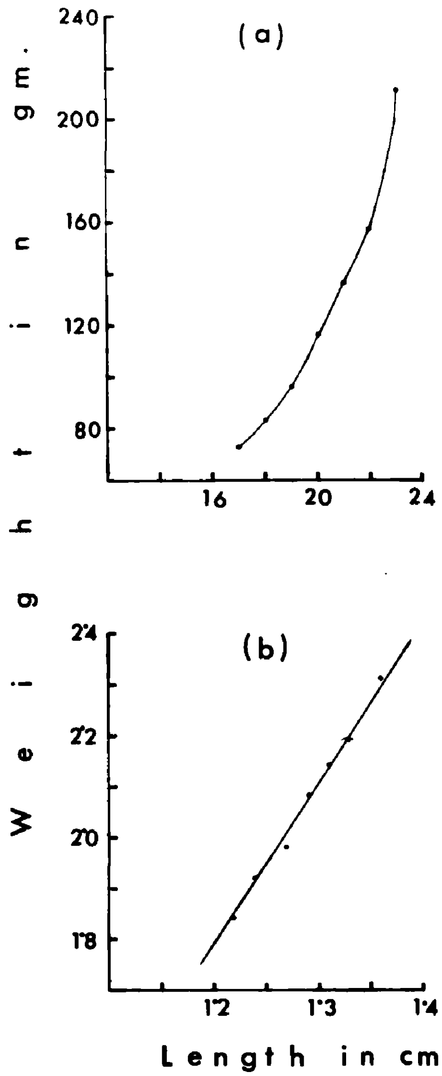
Mature females

The coefficient 'b' for all female perch was 3.30452; this is significantly different from 3.0 but is not significantly different from that of the males. There is some difference between sub-group regression coefficients and the value of 'b' for spent females was 3.38307; this high value could be due to the fact that most of them had recovered from spawning. The coefficients of regression of male and female perch for April-May were not significantly different from each other.

Loch Lomond

The data for length-weight relationships were obtained from fish taken as noted above. The lengths of male and female perch, from Loch Lomond, caught in 1966-67 and 1968,

Figure 13. The length-weight relationship of mature female ([1966-67] a and b) and male (c, d, e and f) perch from Loch Lomond: (a, c and e) length against weight, on arithmetic scale; (b, d and f) length against weight, on logarithmic scale.



(a)
(b)
1966-1967
1968
(c)
(e)
(d)
(f)
Weight in gm.
Weight in gm.
Weight in gm.
Length in cm
Length in cm.
Length in cm.
240
200
160
120
80
16
20
24
2'4
2'2
2'0
1'8
1'2
1'3
1'4
120
80
40
14
18
22
2'1
1'9
1'7
1'5
1'1

were plotted against their weights on arithmetic (Figs 13a, c, e) and on logarithmic scales (Figs 13b, d, f). Smooth curves and straight lines were obtained respectively from these plottings.

As in the case of the Dubh Lochan perch, the fish were then divided into many sub-groups according to sex and time of capture. The values of 'b', found graphically (which were different from each other) agreed in general with the values obtained by the regression method of least squares (Table 4). Ninety-five per cent fiducial limits for the regression coefficient 'b' for regression of log weight on log length of different groups of perch of both sexes were calculated (Table 4).

Results

O group fish

These fish were caught in September, 1967, and their regression coefficient was 3.1118; this is not significantly different from 3.0.

Mature males

The regression coefficient of all the males together was 3.39684 which is significantly different from 3.0. It does not differ from the sub-group regression for September-

October which was 3.57142.

Mature females

The regression coefficient 'b' for all the females together was 3.49313; this is significantly different from 3.0 but again is not significantly different from that of the male perch from Loch Lomond. The value of 'b' again does not differ from the sub-group regression for September-October which was 3.6363. The coefficients of regression for male and female perch for April-May were not significantly different from each other.

Discussion

According to Le Cren (1951) the length-weight relationship of perch from Windermere cannot be described by a single regression and the length-weight coefficient is greater than the cube. Results from Loch Lomond and the Dubh Lochan agree with this statement. The pooled regression coefficients of 0 and 1 group perch from Windermere (Le Cren, 1951) and the 0 group from both Loch Lomond and the Dubh Lochan were not significantly different from 3.0.

In contrast to Windermere perch, except for two-year-old females (Le Cren, 1951) and perch from Ullswater (McCormack, 1965), there is no significant difference between the regression coefficients of male and female perch from both Loch Lomond and the Dubh Lochan. The 'b' coefficients of male and female perch from Ullswater (McCormack, 1965) differ significantly from each other but neither is significantly different from 3.0.

Age and Growth

Age composition and length-frequency

The age compositions of each year's sample of perch from the Dubh Lochan and from Loch Lomond are given in Table 5. In the Dubh Lochan, both 1967 and 1968 were characterised by the dominance of age-groups III, IV and V. The scarcity of two-year-old fish in the collections is probably due in part to the size selective action of the traps and to the fact that samples were taken during the spawning run and therefore includes only mature perch. All the O group were caught in small mesh-nets at the end of summer. The small numbers of perch of age group VI and older reflect the scarcity of older fish on the fishing ground sampled.

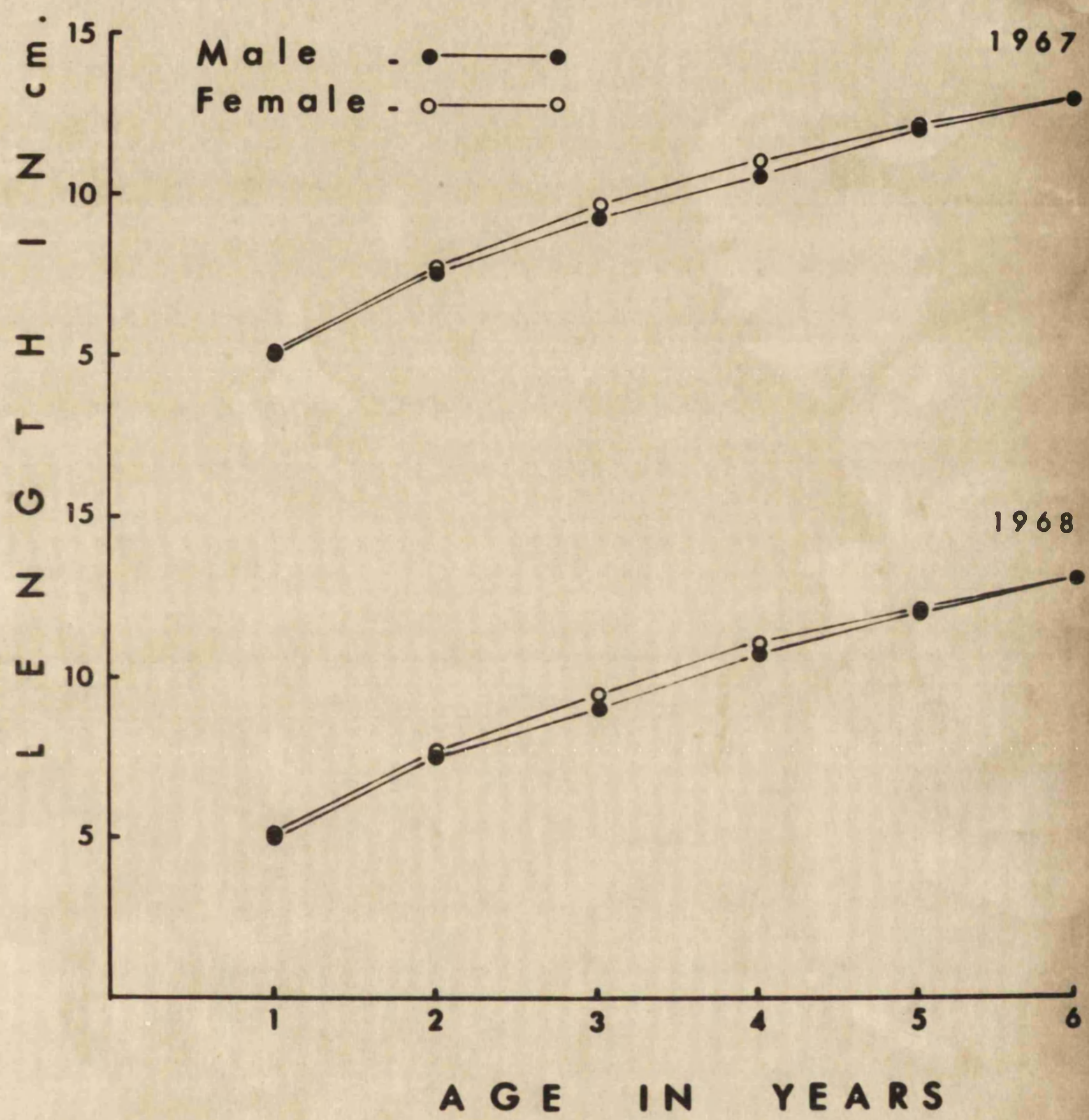
The 1967 collection from Loch Lomond near the Field Station is characterised by the dominance of age-groups VI and VII. The 1967 collection from the Balmaha area, however, is characterised by the dominance of age-groups IV and VI. In the 1968 collection from the Balmaha area, age-group III was a new very strong year-class. The age-group IV of 1967 was also well represented as age-group V in 1968.

The length-frequencies of all perch caught in the March-June period in 1965, 1967 and 1968, from the Dubh Lochan, are given in Figure 9d, e and f. Length-frequencies of perch from Loch Lomond, near Balmaha, caught in the April-May period in 1967 and in 1968, are given in Figure 9a, b and c.

As may be seen from Figure 9 (Dubh Lochan), the 8-10 cm length-group dominates in the 1965 collection. These have presumably reached the 11-13 cm stage by 1967 when they are still dominant. The 8-10 cm length-group in the 1967 collection is also a large length-group which has possibly become the important 10.5-12 cm length-group in 1968. The poor catches of fish larger than 14 cm in 1968 could be due to the selective action of the traps.

Figure 9 (Loch Lomond) shows that the 17-19 cm length-group dominated the 1967 catch. The absence of perch more than 19 cm in the 1968 catch might be because the fish were caught in early May, just at the beginning of the spawning period in that year. Thus the older perch, especially

Figure 15. The growth in length of perch from the Dubh Lochan.


L E N G T H I N cm.
15
10
5
15
10
5
Male
Female
1967
1968
1
2
3
4
5
6
A G E I N Y E A R S

the females, which come late to the breeding ground would be missed. The spawning started one week later in 1968, because of the cold spring, this could be the reason for the absence of older perch in early May from the spawning ground.

Presentation of results

The combined mean lengths were first calculated for each age-group, for each year of life and for each year of sampling. The final mean lengths for each age for all the samples represent the basic data for the various comparisons in growth-rate. The growth curves for lengths (Fig. 15) of these data from the Dubh Lochan are smooth and regular. The method of Le Cren (1958) for calculating means was also used to overcome any irregularity caused by the loss of a large proportion of the fish from each of the last few successive years. Le Cren's method was followed after the first three years of life in male perch and the first four years in females. The method was not found to be of particular value in this situation, due to the lack of variation in the growth, in the relatively stable environment of the Dubh Lochan. Thus if the data for males from 1966-1967 are examined (Table 6), it is found that their mean length at three years old was 9.3 cm. Four-year-old perch from that year had a mean of 10.6 cm. However, these four-year-old perch were 9.4 cm at three years and thus grew 1.2 cm in their fourth year. This increment, when added on to the mean length of 9.3 cm at three years old, gives a mean of 10.5 cm at four years old, i.e. 0.1 cm less than the mean found by calculating from the fourth year's growth of all male perch in that year-class. When Le Cren's method was followed, this sort of result was obtained at each age for both sexes. Therefore, mean growth in length in a particular age was calculated from the average growth in length of all fish in that particular age-group.

For the mean growth in length of perch from Loch Lomond, Le Cren's method, when tried, was also found to be less useful than expected. For example, the mean length of seventy-one male perch (Table 7), caught in 1966-1967, was 17.0 cm for five-year-old perch and for sixty-one perch of the same year-class at six years old was 18.3 cm. The sixty-one six-year-old perch, however, were 17.1 cm at five years and thus grew 1.2 cm in their sixth year. Addition of this increment to the mean length of 17.0 at five years old, gives a mean of 18.2 cm at six years old, i.e. 0.1 cm less than the mean found by calculating from the sixth year's growth of all males in that year-class. Because of this, therefore, the mean growth in length of each age-group was calculated in the same way as for the Dubh Lochan perch. The growth curves for length obtained from these data for Loch Lomond perch are again smooth and regular.

Thus the growth-data for each sex are available in the following forms: (a) for each age the combined means for each sampling year; (b) the final means for each age of fish from the two lochs; (c) the increment in length for each year's growth. Weights for each final mean length for age and the increments in weight were obtained from the length-weight relationship of the fish of each sex.

The accuracy of the back-calculation of growth

The accuracy of estimates of size back-calculated from the opercular bones can be tested in two ways (Le Cren, 1947): (i) by comparing the mean lengths of samples of fish caught in one year with the mean of the back-calculated lengths from samples caught in later years, and (ii) by comparing the known lengths recorded at different times, of individual fish, which are marked and returned to the population or kept in aquaria, with the lengths back-calculated from the operculars when these fish are ultimately killed.

The accuracy of estimates of growth back-calculated from the opercular bones of perch from the Dubh Lochan can be tested in both ways but the evidence for perch from Loch Lomond is available only from the first category.

Le Cren (1947) critically reviewed all the factors complicating such comparisons. In the Dubh Lochan there is little fishing for perch at any time of the year while in Loch Lomond only a few perch are caught by anglers during the summer months. Thus natural mortality is much more important than that due to fishing by man. All the perch, from both lochs, were caught in the same places, at the same times of the year. There is no observed variation in the mean size of perch from different parts of the Dubh Lochan although, there is a slight difference in the mean size of perch from the lower and upper parts of Loch Lomond.

The mean-lengths of some age-groups, obtained by actual measurements and by back-calculations from similar samples taken in a year later, have been compared for fish from both the Dubh Lochan and Loch Lomond and the results are shown in Tables 8 and 9.

The smallest difference among the comparisons in Table 8 for the Dubh Lochan perch is 0.1 cm; in other three comparisons there are differences of 0.13 cm and 0.16 cm. The values of P, in a 't' test (Bailey, 1959), in all four comparisons, were not significant and the differences therefore could have arisen by chance (Le Cren, 1947).

The smallest difference among the four comparisons in Table 9 for Loch Lomond perch is 0.09 cm and the largest is 0.31 cm. The values of P, in a 't' test in all four comparisons, were again not significant and these differences too might have arisen by chance.

Out of several hundred perch tagged in April-May, 1967, only thirteen were recovered in April-May, 1968. These recaptured fish also provide additional evidence on the accuracy of the back-calculations. (Many other recoveries (119 fish) were made soon after tagging during the population experiment in 1967 but, of course, had made very little growth in the intervening period.) The details of the thirteen recoveries after one year of tagging are given in Table 10. At the time of tagging each fish was measured and its length recorded to the nearest mm. Tagging took place at the beginning of the growing season and the recoveries were made almost exactly one year later. In Table 10 fish nos 3, 5, 8, 9, 10 and 12 show a back-calculated length at the time of tagging which is in exact agreement with the actual length at tagging. Fish nos 1, 2 and 4 show a back-calculated length only 1 or 2 mm more than the actual length at tagging while fish nos 6, 7, 11 and 13 show a back-calculated length 1 or 2 mm less than the actual length at tagging. These small differences are not significant.

Sixty-nine O group perch caught in late September and early November in the Dubh Lochan had a mean length of 5.4 cm which is 0.35 cm greater than the back-calculated mean length of males (Table 6) and 0.2 cm greater than the back-calculated mean length of females (Table 6) at one year. Le Cren (1947) found a similar situation in the case of some perch from Windermere. He noted that "this difference between actual and back-calculated lengths seems to occur only in one-year-old fish and is rarely large enough or frequent enough to be very significant". He also commented that "there is a heavy mortality among the young perch, and the length-frequency curves of fish of one age group very often show a positive skew, which may well be due to a mortality that is heavier among fish smaller than the mean, than among those larger". The differences found in the data for Dubh Lochan perch could well be due to the same reason.

Age and Growth Analysis

Dubh Lochan

The back-calculated mean lengths (Tables 11 and 12) at the end of the first year of life of males and females are different and some variation is found among the year-classes of each sex. An analysis of variance, using means weighted on the reciprocals of the numbers of fish (Table 11) from which they were derived, shows that the difference between the year-classes when one year old is significant at a five per cent level. When a two sample 't' test, based on males and females of the same collection, was carried out, it was found that there is no significant difference between the combined means of male and female perch. Therefore, the first year's growth of perch from the Dubh Lochan varies from year to year and small differences at the end of the first year of life of males and females are not significant.

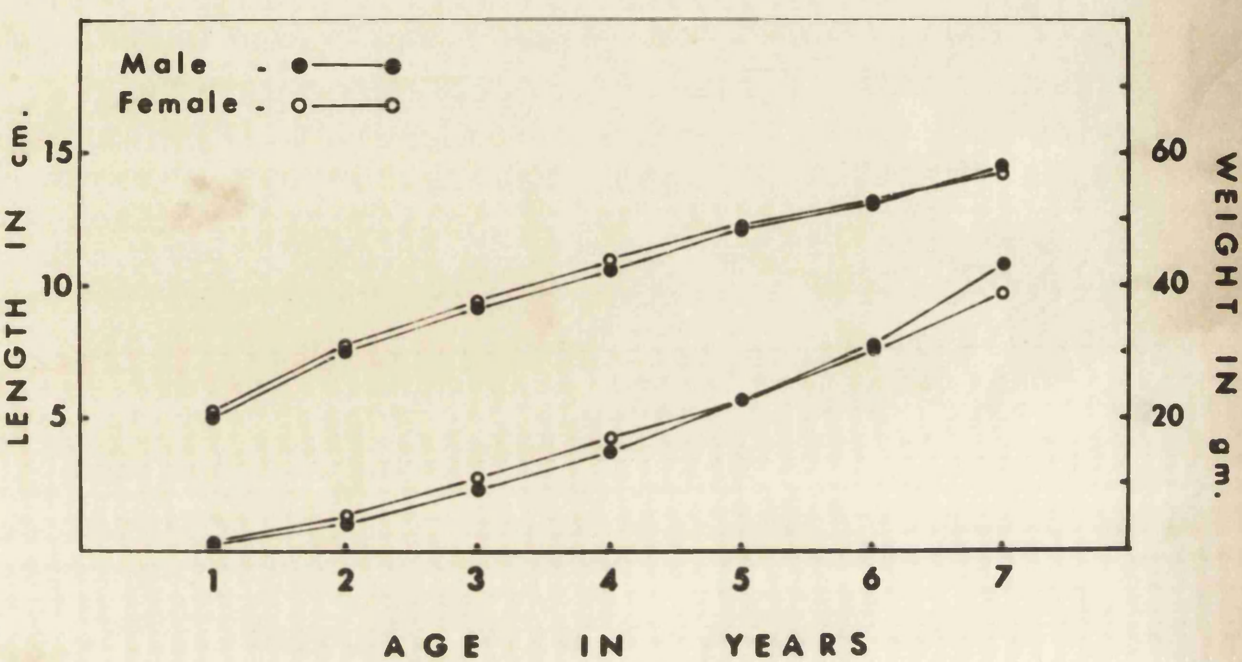
The average incremental growth of Dubh Lochan perch in the first two years is good (Table 16) but after this period the growth-rate decreases rapidly. Alm (1946) found that in a stunted population of perch in Sweden the length of eight to ten year old fish was normally only about 15 cm. A similar situation is found in the Dubh Lochan where eight year old perch have a length of only 15 cm; lengths in excess of this are reached only by a few individuals.

Eight male 1+ perch, caught in early November, 1967, were found to have fairly well-developed testes; the following year in April, another eight male perch (two years group) of 7.1 cm to 7.8 cm in length were found to be mature and ready to spawn. No immature two-year-old males were caught, presumably because only ripe fish enter the traps. Thus, at least some of the male perch in the Dubh Lochan mature when two years old. In 1967, a single three-year-old ripe female was taken from the traps during the spawning period. During the same period in 1968, four ripe three-year-old females were caught. No immature three-year-old females were caught in either year, while all older females caught were mature. Thus it would appear that female perch start to mature when three years old.

Female perch in the Dubh Lochan are slightly larger and weigh more than the males up to the age of five years (Fig. 16). From the seventh year onwards, the males become slightly larger and heavier than the females.

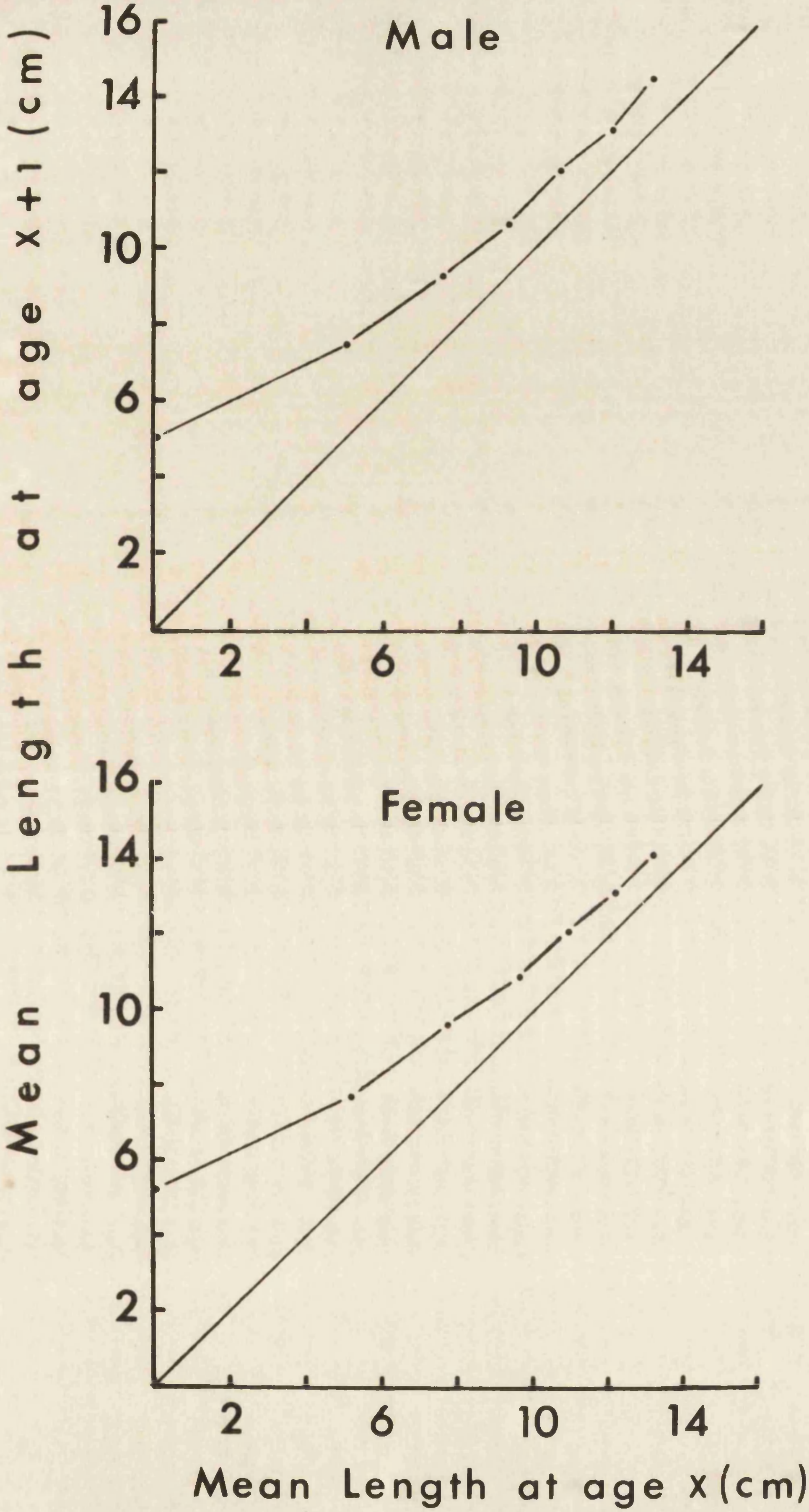
According to Beverton & Holt (1958), the growth of most fish follows a formula of the Von Bertalanffy type in which the growth rate decreases as the fish reaches its ultimate length. Growth of Dubh Lochan perch is not of this type. When the growth in length of both sexes at age (x + 1) was plotted against their length at age 'x' (Ford, 1933; Walford, 1946), it was found that the

Figure 16. The growth in length and weight of male and female perch in the Dubh Lochan, 1966-1968.



Male - ●——●
Female - o——o
LENGTH IN cm.
15
10
5
WEIGHT IN gm.
60
40
20
1
2
3
4
5
6
7
AGE IN YEARS

Figure 17. Ford-Walford plots of the mean length at age x against mean length at age (x + 1) for male and female perch from the Dubh Lochan, 1966-1968.


Male
Female
Mean Length at age x+1 (cm)
Mean Length at age x (cm)
16
14
10
6
2
2
6
10
14

resultant line curves away to a slope more or less parallel to the 45° line after two or three years of life (Fig. 17). Le Cren (1958) andWilliams (1967) found similar patterns of growth in perch from Windermere and the River Thames respectively. Le Cren (1958) observed that it is possible that changes in diet correlated with increase in size may account for this. Perch from Ullswater (McCormack, 1965), however, followed the Von Bertalanffy growth formula well. Although some perch change over to a diet of fish at a length of about 12 cm in the Dubh Lochan, their number is not very significant. However, it is difficult to say with certainty why perch in the Dubh Lochan do not follow the Von Bertalanffy growth formula.

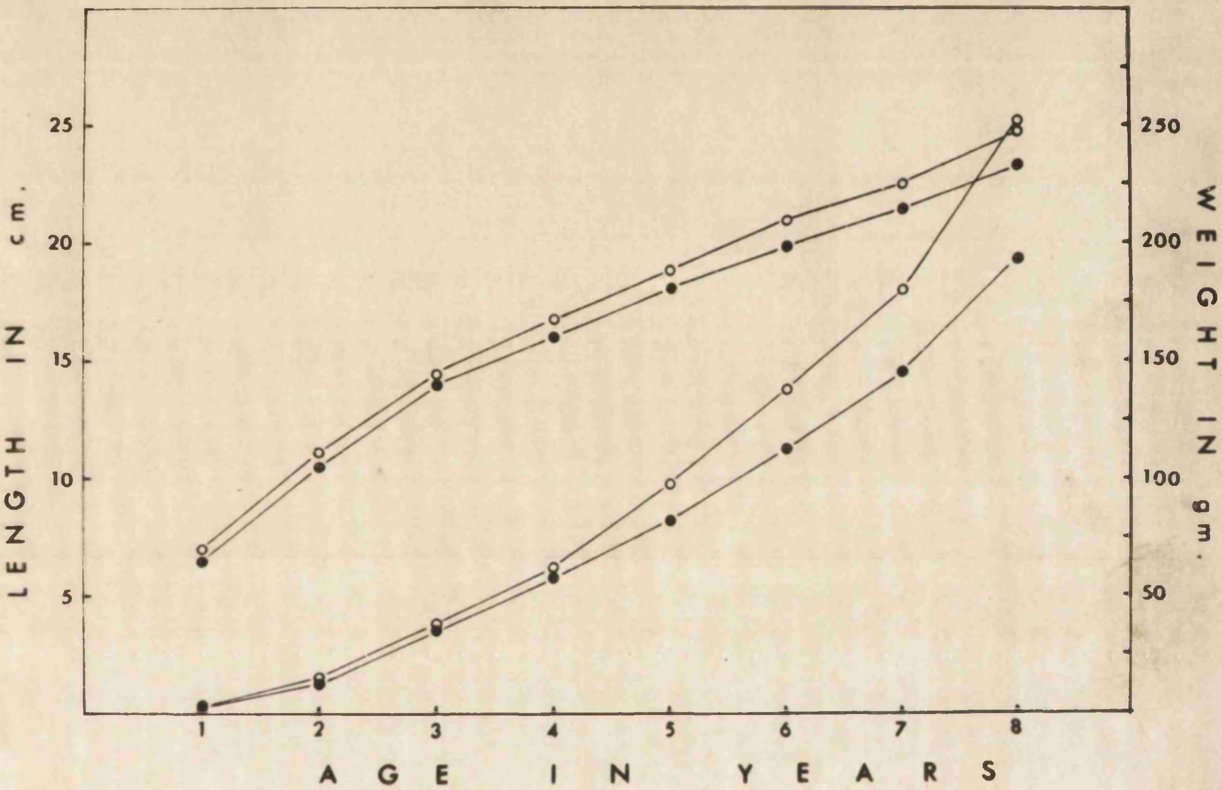
Loch Lomond

The back-calculated mean lengths (Table 13) at the end of the first year of life of males and females caught near the Field Station are different and variations are also found among the year-classes of each sex. One way analysis of variance, using means weighted on the reciprocals of the numbers of fish (Table 13), from which they were derived, shows that the differences among the year-classes at one year of age are significant at a five per cent level. When a two sample 't' test, based on males and females from the same collection, was carried out, it was found that there is no significant difference between the 'combined means' of male and female perch. The back-calculated mean lengths (Table 14) at the end of the first year of life of males and females caught near Balmaha in 1967, are also significantly different using a one way analysis of variance. However, when a two sample 't' test based on males and females from Balmaha, was carried out, it was found that there is significant difference between the 'combined means' of males and females.

The average incremental growth in Loch Lomond during the first few years is high after which the growth-rate decreases gradually (Table 16). The growth of males near the Field Station in their first year is 1.3 cm more than that of males near Balmaha, but from the second year onwards, growth is always slightly superior in the Balmaha male perch (Table 7). Females from the Field Station area grow slightly more in the first year than females from Balmaha. Again from the second year onwards, females from Balmaha grow faster than those in the Field Station area. This could well be related to differential food supplies in different parts of the loch.

The final means (Table 7) of perch from Loch Lomond show that there is a difference in growth between males and

Figure 18. The growth in length and weight of male and female perch in Loch Lomond, 1966-1968.


LENGTH IN cm.
25
20
15
10
5
WEIGHT IN gm.
250
200
150
100
50
1
2
3
4
5
6
7
8
AGE IN YEARS

females throughout life. The difference becomes more prominent from the fourth year of life onwards. The weights of those perch, calculated from the final mean lengths of males and females, also show a difference from the beginning of life, again increasing sharply from the fourth year onwards (Fig. 18). There is a difference of 3.4 gm at the end of the fourth year of life. An examination of Table 7 shows that the females grew faster than the males after this age and the annual weight increments of females were much greater than those of males.

The testes of four 1+ male perch from the Field Station area, caught in January and February, 1967, were found to be well developed. Twelve 2+ males, caught in the same area, during the spawning period, were also found to be ripe. Six 2+ male perch, caught at Balmaha, in 1968, were all mature. No immature two-year-old male perch were caught. Two hundred and sixty-four three-year-old male perch, caught in different areas, during the spawning period, were all mature. Thus in Loch Lomond male perch start to mature when two years old. No three-year-old females, mature or immature, were caught during the present work. The youngest females, caught at Balmaha in 1967, were four years old and all were mature. The back-calculated length

Figure 19. The growth in length of perch from Loch Lomond: (a) Field Station, 1967; (b) Balmaha, 1967; (c) Balmaha, 1968.

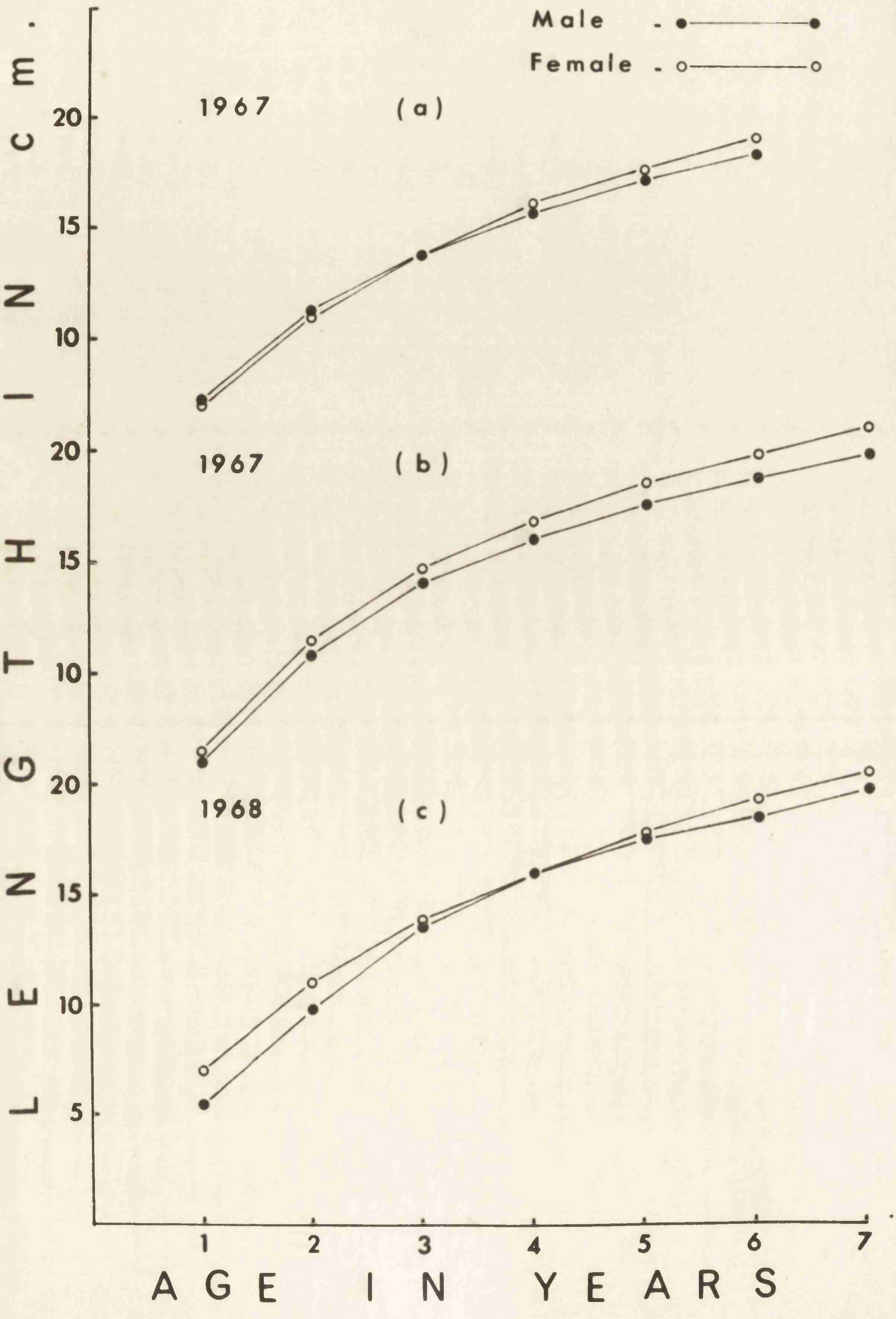
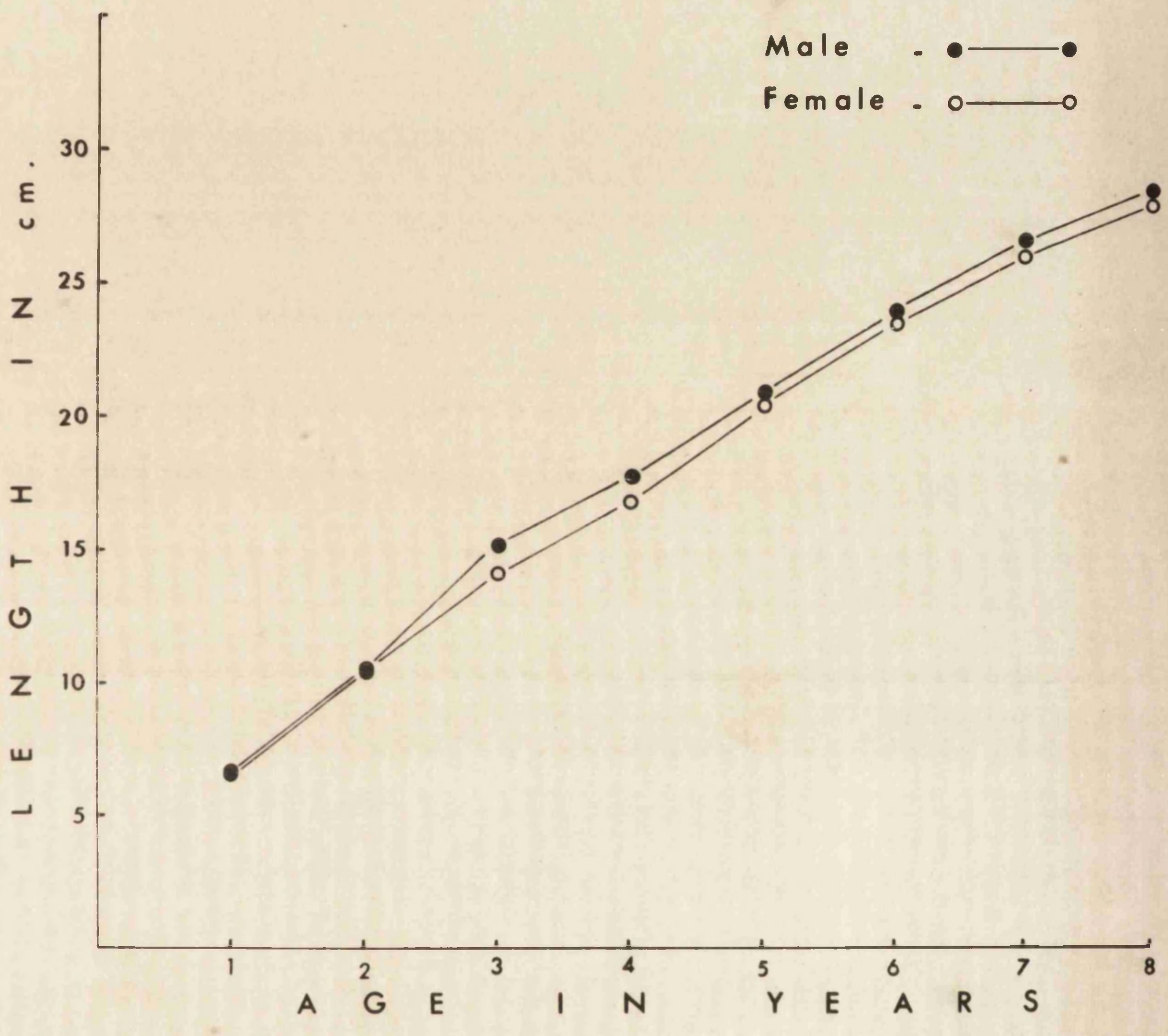

Male
Female
1967
(a)
1967
(b)
1968
(c)
LENGTH IN cm.
AGE IN YEARS
20
15
10
5
1
2
3
4
5
6
7

Figure 20. The growth in length of perch of exceptionally large size from Loch Lomond.


Male
Female
30
25
20
15
10
5
L E N G T H I N cm.
1
2
3
4
5
6
7
8
A G E I N Y E A R S

at the end of the third year is slightly greater in females than in males and the weights of females, calculated from final mean lengths, at three years old, are slightly more than the weights of males. It appears probable that female perch become mature when three years old.

An examination of Figure 19a reveals that male perch from the Field Station area are slightly larger than females in the first two years of life. The females, however, become slightly larger than males from the fourth year of life onwards. There is a difference in the rate of growth between males and females from the Balmaha area throughout life (Fig. 19b and c).

Of seven perch of exceptionally large size (ranging from 28 to 37 cm in length), only one was a male. This showed a slightly different growth-rate from the females. Figure 20 and Table 17 show that all these large fish grew normally in the first three years. After this the growth-rate changed and increased.

Like perch in the Dubh Lochan, Loch Lomond perch do not follow the Von Bertalanffy growth formula. When the growth in length of males and females at age (x + 1) was plotted against length at age 'x', it was found that the

Figure 21. Ford-Walford plots of the mean length at age x against mean length at age (x + 1) for male and female perch from Loch Lomond, 1966-1968.

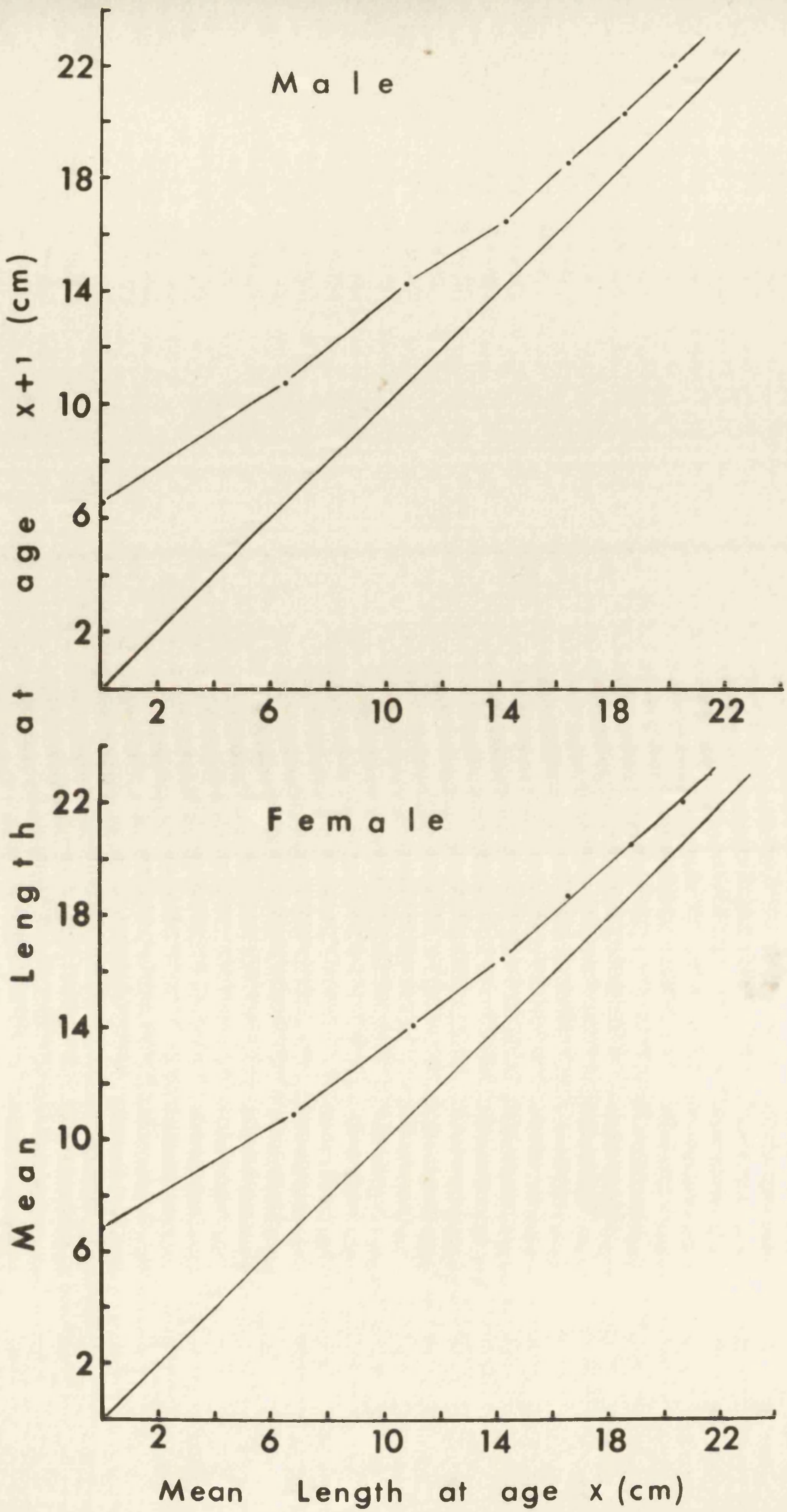
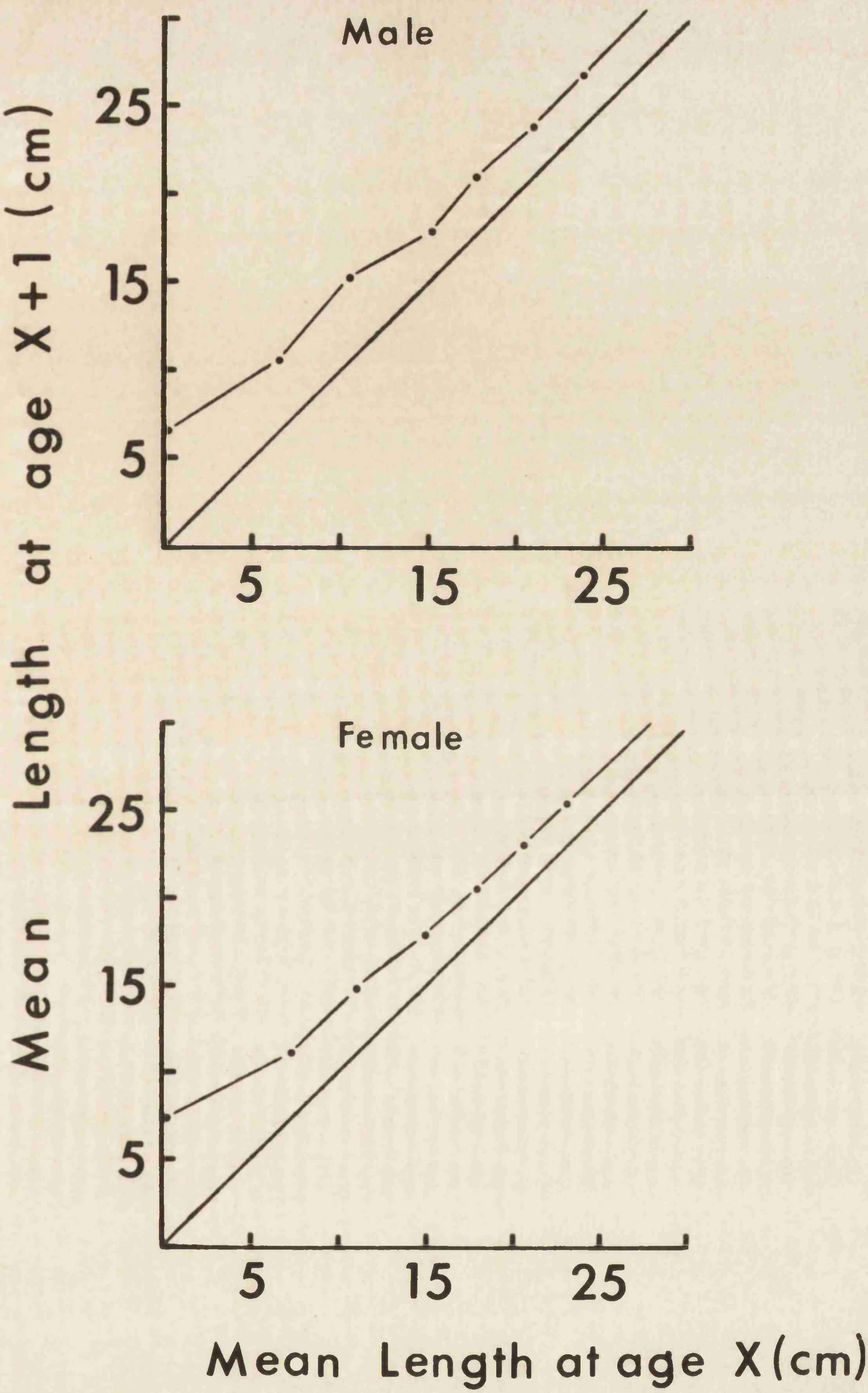

Male
Female
Mean Length at age x+1 (cm)
Mean Length at age x (cm)
2
6
10
14
18
22

Figure 22. Ford-Walford plots of the mean length at age x against mean length at age (x + 1) for male and female perch of exceptional growth from Loch Lomond, 1966-1968.


Male
Female
25
15
5
5
15
25
Mean Length at age X+1 (cm)
Mean Length at age X (cm)

line curves away to a slope more or less parallel to the 45° line after three to four years of life (Fig. 21). The lengths of the seven large perch, when plotted similarly, also failed to follow the Von Bertalanffy growth formula (Fig. 22). About nineteen per cent of the fish in the Field Station area were found to be feeding on fish (Fig. 33); all of these perch were older than three years. Two per cent of the fish in the Balmaha area were found to be feeding on fish (Fig. 34). However, it should be noted that these fish were all caught on the spawning grounds where their diet may not be the same as during the rest of the year.

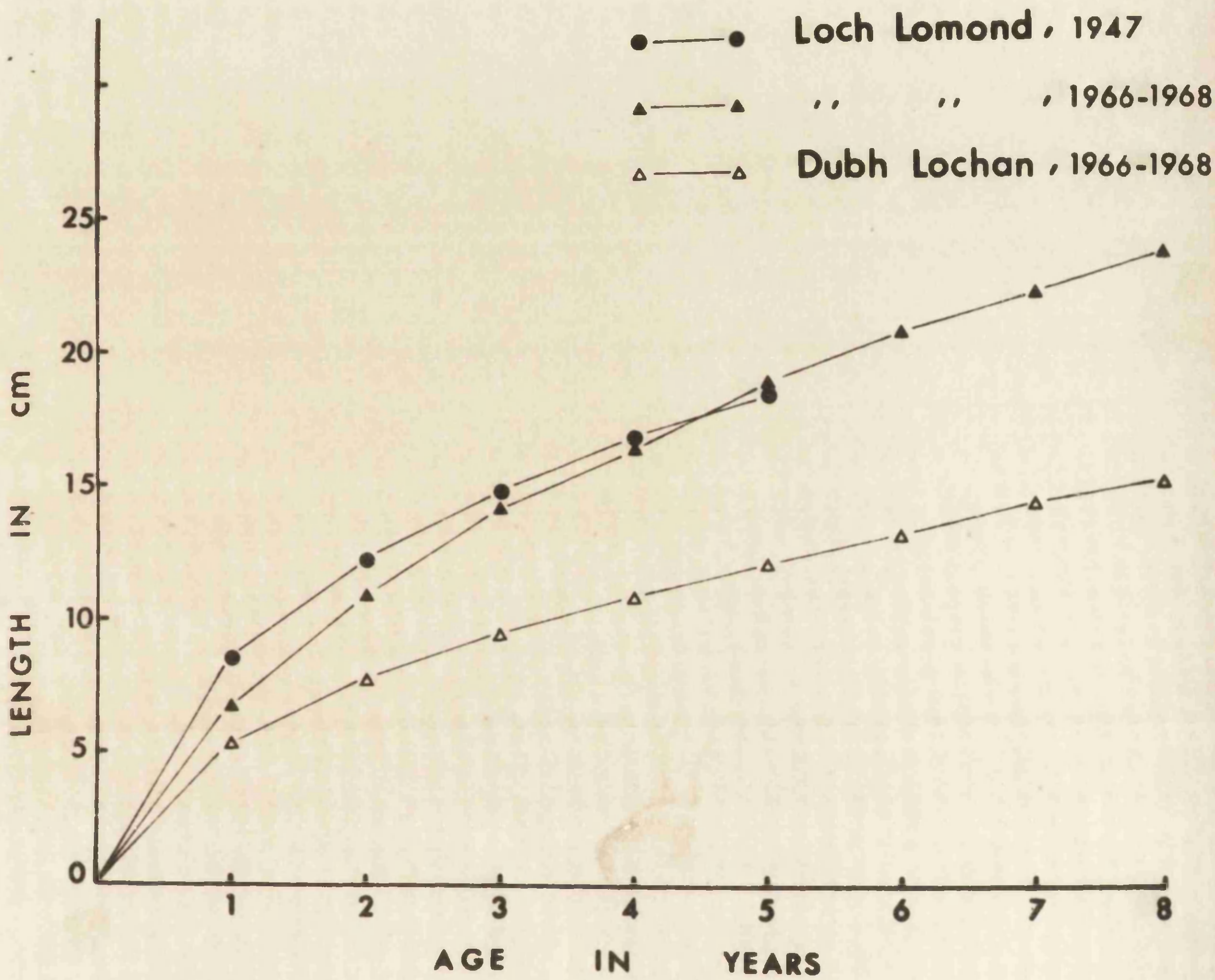
Hartley (1947) published data on the growth in length of perch from Loch Lomond. It is noted that from his results the lengths of fish in the first four years are slightly more than those found in the present work (Fig. 23). There is no obvious reason for such differences which are, however, very small. During the present work the fork length of the fish was measured and it is possible that Hartley based his studied of growth-rate on the total length. If this is the case, a fictitious difference is to be expected.

Comparison between the growth of perch from Loch Lomond, the Dubh Lochan and elsewhere

The growth-curves of perch from the Bodensee published by Haakh (1929), from Krugloe by Svetovidove (1929), from Windermere by Le Cren (1958), and from Abborrtjän II by Alm (1946), have been plotted (Fig. 24) along with those of perch from Loch Lomond and the Dubh Lochan. In addition, the growth-rates of perch in some other waters in the British Isles and other European countries are given in Table 18.

From the data it is clear that the growth of perch varies considerably in different waters and therefore that the age for the same length is different in different waters. The growth of Bodensee perch in Germany and of those in Lake Krugloe in Russia is the fastest of all. The figures of growth from certain Finnish (Segerstråle, 1933) and German (Roper, 1936) lakes are lower than those of some lakes in Norway (Olstad, 1919) and Sweden (Nilsson, 1921). The growth of Windermere perch (Le Cren, 1958) before 1941 was much slower than the present growth-rate in Loch Lomond. Figure 24 shows, however, that the growth-curves from Windermere in 1949 exceeded the present growth-rate of Loch Lomond perch. This increase in growth-rate of Windermere perch is due to an experiment started in 1941

Figure 23. The growth in length of perch in Loch Lomond [(Hartley, 1947) and (1966-1968)] and the Dubh Lochan (1966-1968).



Loch Lomond , 1947
,, ,, , 1966-1968
Dubh Lochan , 1966-1968
LENGTH IN cm
0
5
10
15
20
25
1
2
3
4
5
6
7
8
AGE IN YEARS

Figure 24. The length growth-curves of perch from Loch Lomond, the Dubh Lochan and other habitats: (a) Bodensee, males and females (Haakh, 1929); (b) Krugloe, males and females (Svetovidov, 1929); (c) Windermere females, 1949; (d) Windermere males, 1949 (Le Cren, 1958); (e) Loch Lomond, females, 1966-1968; (f) Loch Lomond males, 1966-1968; (g) Windermere males, pre-1941 (Le Cren, 1958); (h) Abborrtjan II females (Alm, 1946); (i) Dubh Lochan females, 1966-1968; (j) Dubh Lochan males, 1966-1968; (k) Abborrtjan II males (Alm, 1946).

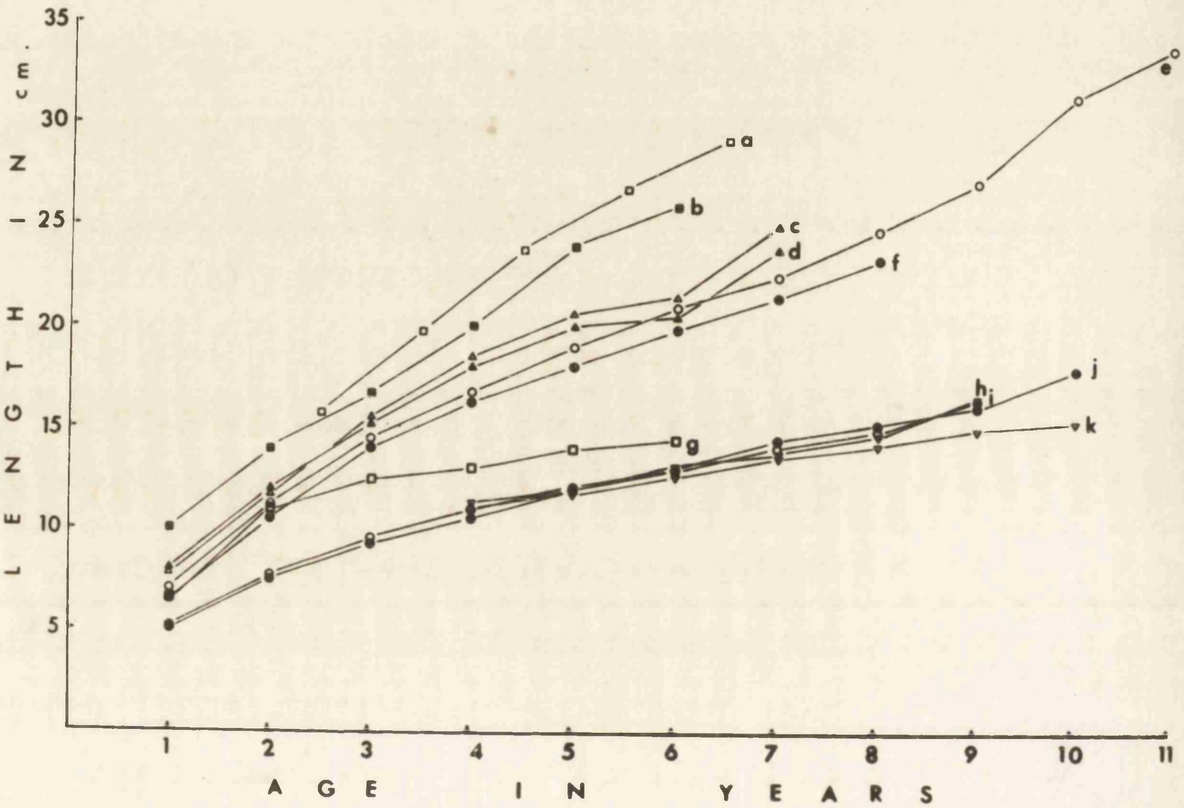
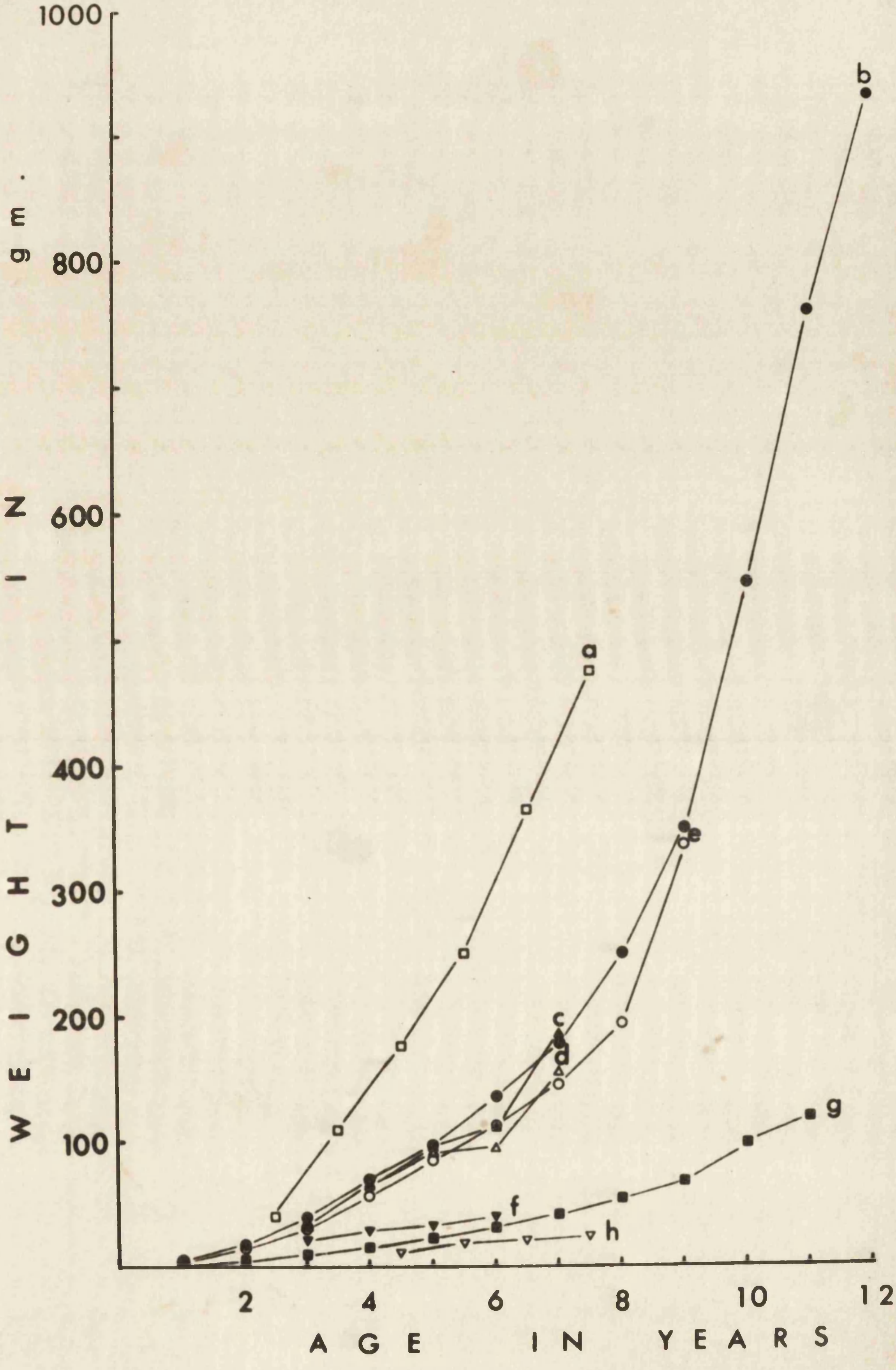

LENGTH IN cm.
35
30
25
20
15
10
5
a
b
c
d
e
f
g
h
i
j
k
1
2
3
4
5
6
7
8
9
10
11
AGE IN YEARS

Figure 25. The weight growth-curves of perch from Loch Lomond, the Dubh Lochan and other habitats: (a) Bodensee (Haakh, 1929); (b) Loch Lomond females, 1966-1968; (c) Windermere females, 1949 (Le Cren, 1958); (d) Windermere males, 1949 (Le Cren, 1958); (e) Loch Lomond males, 1966-68; (f) Windermere pre-1941 (Le Cren, 1958); (g) Dubh Lochan males, 1966-1968; and (h) Abborrtjan II (Alm, 1946).


1000
800
600
400
300
200
100
W E I G H T I N g m .
2
4
6
8
10
12
A G E I N Y E A R S
a
b
c
d
e
f
g
h

to reduce the population density of perch in that lake.

Table 18 shows that the early growth of Loch Lomond perch is similar to that of Swedish perch (Nilsson, 1921). Ullswater perch (McCormack, 1965) grew more in early years but a little less later on in comparison to Loch Lomond perch. Loch Lomond perch grew faster than those of the River Thames (Williams, 1967), Pellinge (Segerstråle, 1933), Prussian lakes (Röper, 1936) and St.Oivann (Olstad, 1919).

The Windermere (1949) perch weighed slightly more than Loch Lomond perch up to the age of five years but after the sixth year both males and females from Loch Lomond weighed more (Fig. 25). Some of the Loch Lomond perch increase rapidly in weight when they are seven or eight years old. The largest perch, caught from Loch Lomond, during the present work, was thirteeen years old and 910 gm in weight.

The rate of growth of Dubh Lochan perch, particularly the females, was similar to that of the stunted population of Abborrtjän perch, studied by Alm in 1946 (Figs 24 and 25).

Reasons for the stunted growth of perch in Dubh Lochan

Alm (1946) discusses in detail the reasons for the stunted growth of perch in some Swedish waters. Deelder

(1951) has also investigated the stunted growth of perch in some Dutch waters. From knowledge obtained from their research and the information obtained on the Dubh Lochan perch and their environment during the present work, it is possible to make some comments on the possible reasons for the stunted growth of the perch population in the Dubh Lochan.

Very low temperatures in winter may reduce the consumption of food and ultimately the period of growth in certain waters (Alm, 1946). Most of the Dubh Lochan is covered with ice for periods during winter and low temperatures may continue until late in spring as they did in 1968. The amount of food in the stomach of a fish depends on the rate of digestion which in turn varies with water temperature (Leonard, 1942; Ricker, 1937 and Bajkov, 1935) and the type of food consumed (Hess & Rainwater, 1939). However, Ivlev (1939) and Gerking (1955) found that the efficiency of conversion of food to energy is constant and independent of temperature. Thus, the very low temperatures in part of the year might be one of the contributory reasons for stunted growth in the Dubh Lochan.

Deelder (1951) has observed that, in the populations which he studied, the initial growth of stunted perch up to about 13 cm is good. Stunted growth afterwards could be ascribed to a shortage of prey-fish. The initial growth of perch in the Dubh Lochan is also fairly good but along with the possible change of diet at a length of about 11 cm from invertebrates to fish, the perch are forced to continue relying mainly on bottom fauna etc. Good prey-fish of a small size, such as, sticklebacks, minnows and small Cyprinidae are absent, and might be an important factor in producing stunting.

Cannibalism is found to some extent in the Dubh Lochan but the abundance of aquatic plants, at the time of greatest growth (i.e. summer), allows large areas of shelter for the smaller perch. Thus few of them are easily available as food for older members of the population (Deelder, 1951).

The large population of perch in the Dubh Lochan means that very few perch can grow to a large size. It has been well established by Alm (1946) and Deelder (1951) that medium size perch rarely try to feed on smaller ones. In the Dubh Lochan, too, it has been found that very few medium size perch feed on smaller perch (Tables 22 and 23).

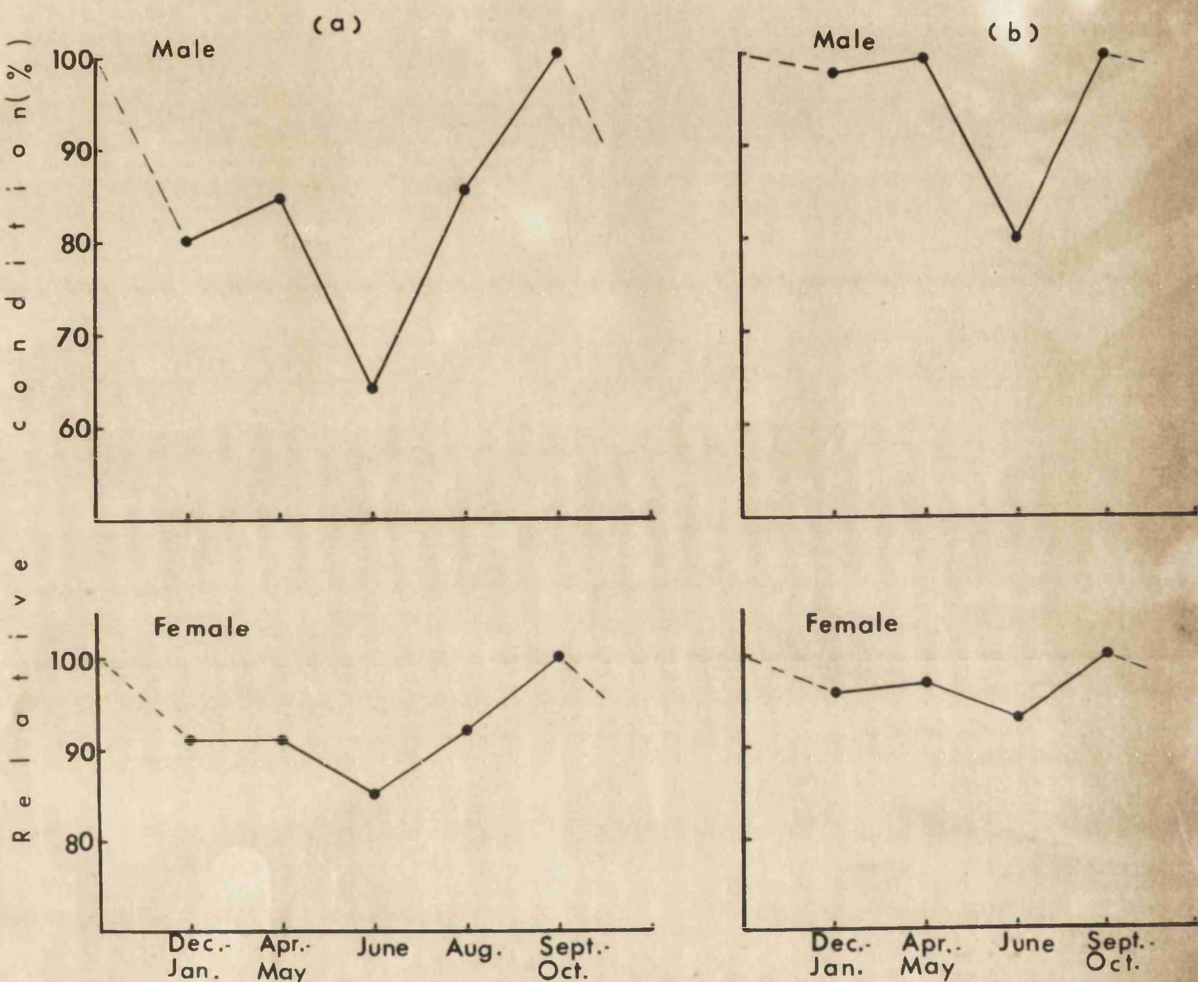
Alm (1946) observed that hereditary poor growth has never been found in perch populations. Thus, stunted perch disclose good growth after transplantation to more favourable environments. In 1967, fertilized eggs from Dubh Lochan perch were planted in a small pond near Milngavie, which has no perch population. Eggs from Loch Lomond perch were planted at the same time in a similar small pond in the same area. If these fish have survived it is hoped that data obtained on their growth may provide extremely interesting comparisons with each other and with the parent populations.

Fecundity of Perch

Seasonal cycle in condition

Le Cren (1951) has discussed in detail the factors which complicate the condition of fish. The conventional formula for condition, $K = \frac{W}{cL^3}$, has not been used in the present study for it has been found that perch from both the Dubh Lochan and Loch Lomond do not follow the cube law exactly. Instead, relative condition factors have been calculated from $Kn = \frac{W}{aL^n}$ (Le Cren, 1951). The weight $(\hat{W})$ of male and female fish in each sample, caught at different times of the year, was first calculated from the formula $\log W = \log a + b \log L$ (Le Cren, 1951) and then individual relative condition factors were calculated from the formula $Kn = \frac{W}{\hat{W}}$ in which Kn = relative condition and W = actual weight. The mean relative condition of males and females in each

Figure 26. Seasonal changes in relative condition of male and female perch of (a) the Dubh Lochan and (b) Loch Lomond, expressed as a percentage of the maximum.



(a)
(b)
Male
Female
Relative condition(%)
100
90
80
70
60
Dec.-
Jan.
Apr.-
May
June
Aug.
Sept.-
Oct.

sample was found and was plotted as a percentage of the maximum (Fig. 26).

The data from both the Dubh Lochan and Loch Lomond were not really adequate for a critical study of condition in these populations. The samples are very poor in some months, e.g. only two spent males and nine spent females were taken from the Dubh Lochan in May-June.

Dubh Lochan

The data are slightly more complete for mature female fish. It can be seen (Fig. 26a) that these fish reach their peak of condition in September and October. They then lose condition slightly in December-January and the condition remains the same during the spawning season in April-May. Samples of newly spent females in May and early June have a mean relative condition of about eighty-five per cent. After this they recover and their condition increases through August.

The mature males show a similar seasonal cycle in condition, but the fall in spent males appears to be rather sharp; this could be due to the small numbers in the sample at this time. There is some rise in condition in April-May on the eve of spawning. After spawning the males increase in condition rapidly and reach their maximum in September-October.

Loch Lomond

The data for mature females, especially spent females, are more complete than those for males. The condition in females is more or less constant throughout the year with a slight fall during winter and after spawning (Fig. 26b). There is some rise in condition just before spawning, as observed by Le Cren (1951) in the case of Windermere perch. The relatively high condition (ninety-six per cent) found in spent females may be because they had recovered a little between spawning and capture. These fish also reach their peak of condition in September-October.

The cycle of condition in mature males is almost the same as that in females; the sharp fall after spawning in males could again be due to the relatively small number of fish in the sample.

The sex-ratio

Dubh Lochan

It is apparent from Table 19 that there were fewer females than males in the catches from the traps. Alm (1951) has found great variation in the sex-ratio of the perch captured in Swedish waters. He observed that though the sex-ratio is 50:50, at the spawning season and especially in stunted populations more males are caught than females, sometimes up to one hundred per cent. Worthington (1950-51) observed that in Windermere "perch traps set in the spring during the spawning season do not catch both sexes equally but have a strong tendency to select males. Two-thirds of the catch from the north basin from 1943 to 1946 were males and ~~one~~ one-third were females". Later Smyly found more females in the traps than males in the north basin (Worthington, 1950-51). According to McCormack (1965) the traps are highly selective for males and therefore are useless as measures of real sex-ratio.

It has been observed that during the spawning period males are more abundant in the smaller length-groups and females in larger length-groups. Alm (1951) and Healy (1954) also found more males in the younger length-groups but Roper (1936) found the same proportion of males and females in the younger length-groups.

Loch Lomond

The proportion of males to females caught in gill-nets during the spawning period in 1967, was about 5:1. Three hundred and eighty-two males and seventy-nine females were caught in that year. In the next year the situation was even more extreme and only two females were caught along with several hundred males. The difference in the numbers of males and females may be due to the general belief that female perch come to the spawning ground later than males and that all the fish at Balmaha were caught at the beginning of the spawning season.

Egg development and mortality

The size of fresh eggs of perch varied from 2 to 2.25 mm in the Dubh Lochan and from 2 to 2.5 mm in Loch Lomond. A 't' test based on the data of egg size at the two places shows that there is a significant difference between the mean size (Dubh Lochan: 2.095 mm; Loch Lomond: 2.3 mm) of eggs at a .01 per cent level. The period of development from the date of fertilization to hatching was observed. Freshly laid eggs were observed in an aquarium in the laboratory as well as among weed in shallow water in the Dubh Lochan. It was found that 117 to 126 degree-days were required for the development of perch fry between fertilization and hatching. Varley (1967) noted that perch need from 120 to 260 degree-days for this development. The length of perch fry at hatching was 5 to 6 mm in the Dubh Lochan.

Fertilized eggs at different stages of development were collected from the Dubh Lochan and were preserved in five per cent formaldehyde. Later, the age of each collection was established and the number of dead eggs in a standard batch of 100 was counted. The mortality rate was lowest at the beginning of development and gradually increased as development proceeded. The mean mortality rate between fertilization and hatching was 9.98 per cent. This low rate of mortality during the egg stage agrees with the findings of Le Cren (1965) who observed that fluctuations in the year-class strength must be due to differing survival rates after egg-laying and probably after hatching. Le Cren found in his observations on populations of young trout that the mortality rate was correlated with density and that most of the fry had little or no food in their stomachs.

Fecundity of Dubh Lochan perch

Data from 107 female perch collected in 1967 show that the fecundity varied from 1,550 eggs (for a fish with a length of 11.1 cm and a weight of 18 gm) to 6,648 eggs (for a fish with a length of 14.9 cm and a weight of 52 gm). The mean number of eggs was 3,690 for fish with a mean length of 12.1 cm and a mean weight of 25.6 gm. The average number of eggs per kilogram of fish was 141,923.

Data from 100 female perch collected in 1968, show that the fecundity in this year varied from 1,823 eggs (for a fish with a length of 9.5 cm and a weight of 12 gm) to 9,513 eggs (for a fish with a length of 16.9 cm and weight of 82 gm). The mean number of eggs was 3,691 for a fish with a mean length of 11.8 cm and a mean weight of 26.0 gm. The average number of eggs per kilogram of fish was exactly the same as that of 1967. Healy (1954) found 116,000 eggs per kilogram of fish in the case of Irish perch. Pincher (1947) found 82,000 to 95,000 of eggs per kilogram. Female perch in the Dubh Lochan thus appear to produce more eggs per kilogram of body than either of these populations. One full band of eggs laid in a perch trap was recovered and it was found by direct count to contain 4,200 eggs, slightly more than the average number estimated indirectly.

The mean number of eggs found in females in both years was the same. When, however, the fecundity data for 1967 and 1968 are tested statistically, it is found that the variability in fecundity is significant between these years at a five per cent level. This variability is shown diagrammatically as scatter diagrams of fecundity and length, weight and dry gonad weight in Figure 27a, b and c.

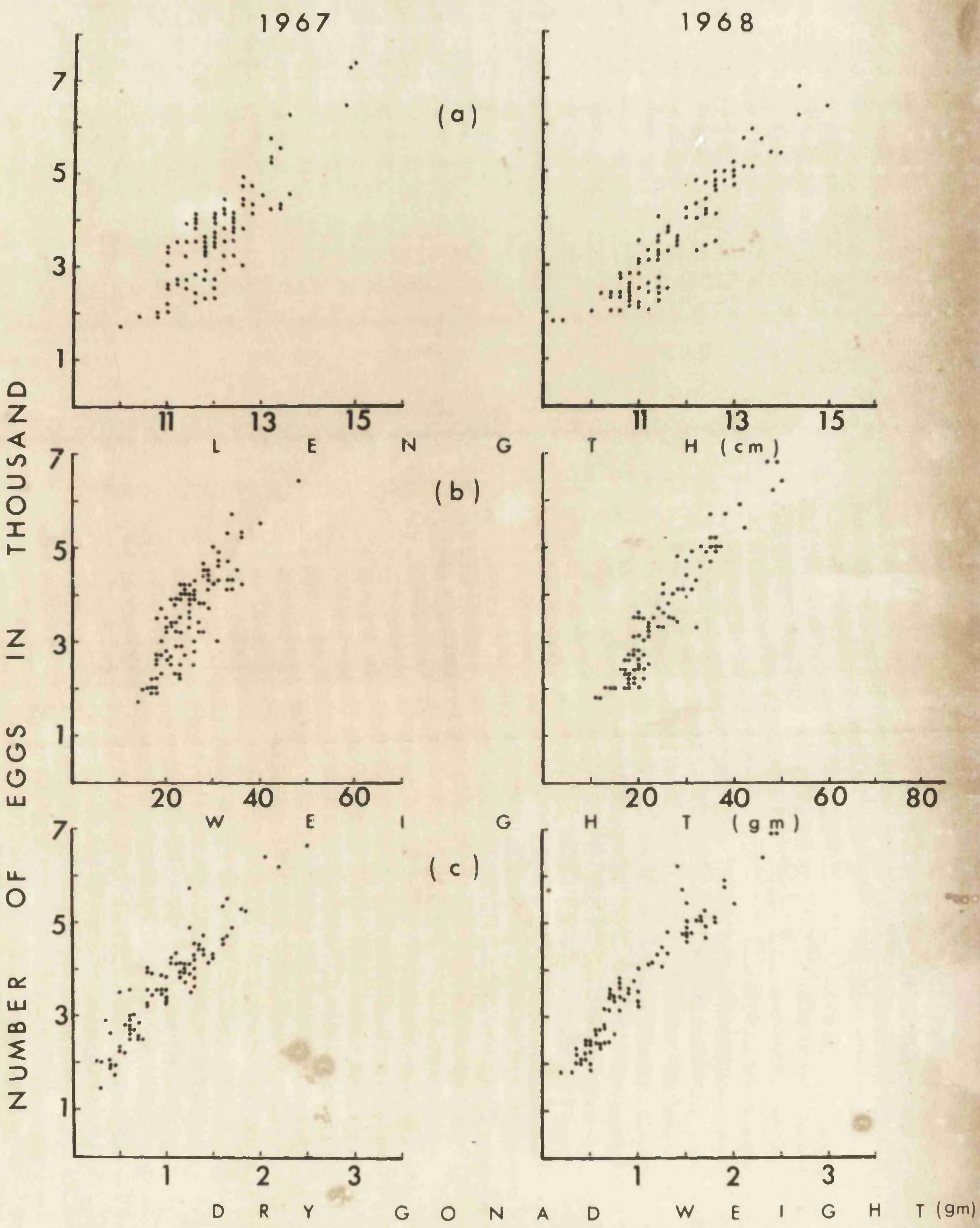
Fecundity and length

Figure 27a suggests that the relationship between fecundity and length would be of the form log F = log a + b log L, where F = fecundity, L = length and a and b are a constant and exponent to be obtained from the data. Therefore, analyses of the regressions of the logarithm of fecundity on the logarithm of length in each year, were carried out. The values of the regression coefficient 'b' along with its ninety-five per cent fiducial limits are given in Table 20. When tested statistically, the values of 'b', in both years, were found to be not significantly different from three. Thus, the fecundity of female perch in the Dubh Lochan follows the cube of their length.

Fecundity and weight

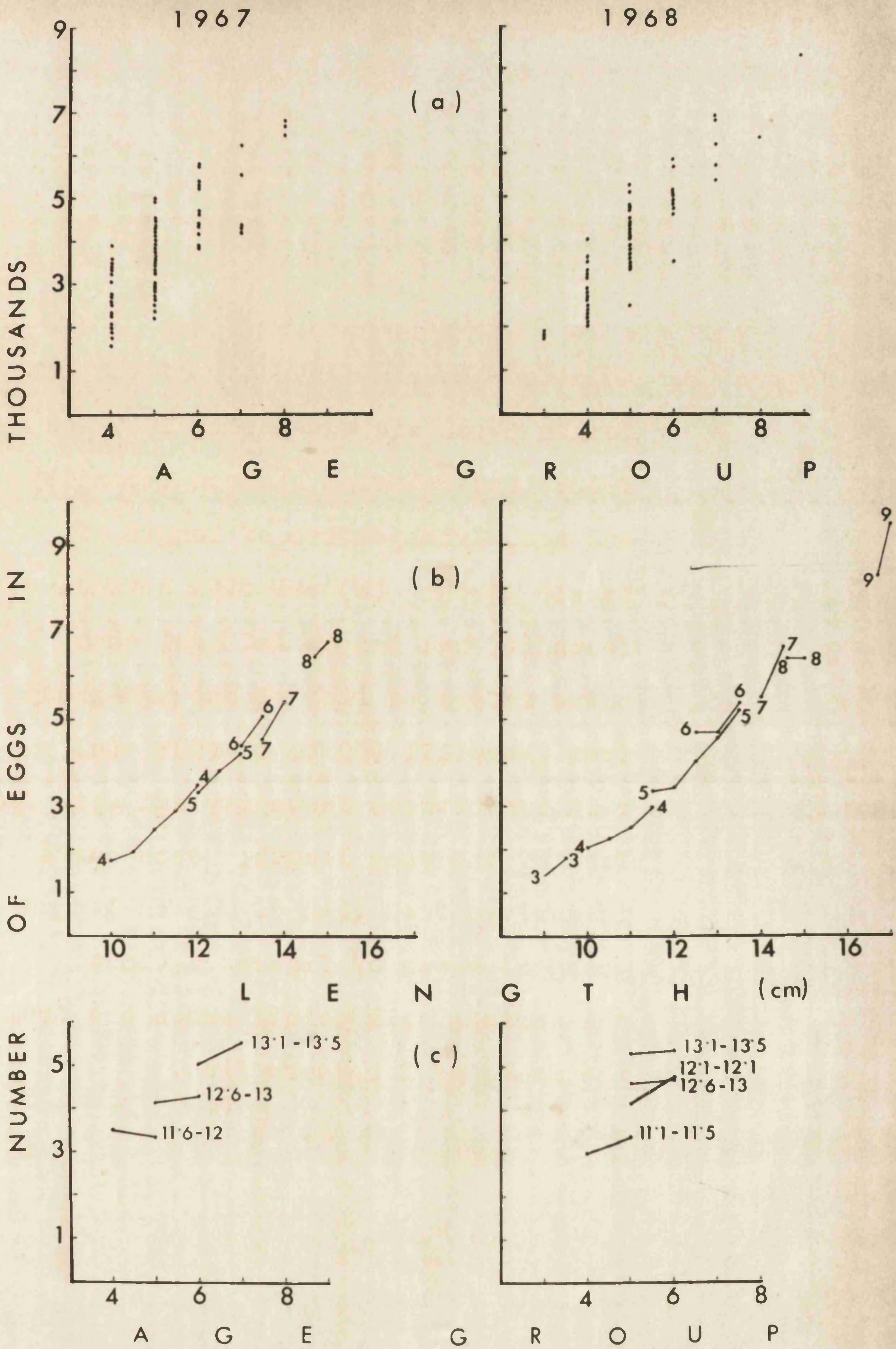
Figure 27b suggests that the relationship between fecundity and weight may be linear. Therefore, the logarithm of the weights of females in both years were plotted against the logarithm of their fecundities and in both years a straight line was obtained by the method of linear regression. The values of 'b' along with their ninety-five per cent fiducial limits are given in Table 20. It can be seen that the relationship between fecundity and weight is linear in both years. This result might be

Figure 27. Scatter diagrams showing the relation of (a) fecundity and length, (b) fecundity and weight and (c) fecundity and dry gonad weight of female perch of the Dubh Lochan during 1967 and 1968.



1967
1968
(a)
(b)
(c)
NUMBER OF EGGS IN THOUSAND
L E N G T H (cm)
W E I G H T (gm)
D R Y G O N A D W E I G H T (gm)

Figure 28. Relation between fecundity of the Dubh Lochan perch and age during 1967 and 1968: (a) relation between fecundity and age, irrespective of length of female perch; (b) relation between fecundity and length and age, each curve refers to fish of one age-group from group III (3) to IX (9); (c) relation between fecundity and age, for fish of the same length; each curve is derived from fish of 0.5 cm length group as shown by figures against the curves; all points shown are from the means of 2 or more fish.


1967
1968
(a)
(b)
(c)
THOUSANDS
NUMBER OF EGGS IN THOUSANDS
AGE GROUP
LENGTH (cm)
13·1 - 13·5
12·6 - 13
11·6 - 12
12·1 - 12·1
11·1 - 11·5

expected for the relation between weight and length is similar (see length-weight relationship) to that between fecundity and length.

Fecundity and age

When fecundity is plotted against age, a positive correlation is found in both years (Fig. 28a). The variation in fecundity between fish of the same age was similar to the variation observed between fish of the same weight or length. Simpson (1951) has observed that, since length increases with age, it is necessary to separate these two factors in order to determine the effect of age alone. This has been done in the present work by plotting fecundity against length for fish of the same age (Fig. 28b) and by plotting fecundity against age for fish of the same length (Fig. 28c). Figure 28c shows that there is no definite evidence of increased fecundity with age in smaller fish and that even among larger fish the apparent increase is small. Figure 28b shows, however, that for fish of the same age, the increase in fecundity with size of the fish, in both years, is very great. Thus, age alone, apart from its relation to size, appears to play no significant part in determining the fecundity of female perch.

The relationship between fecundity and age has also been analysed by converting both fecundity and age to logarithms (Bagenal, 1957). Analysis of the regression of the logarithm of fecundity on the logarithm of age shows that their relationship is non-linear. The value of 'b' (Table 20), in both years, was more than one and when tested statistically they were found to be significantly different from one at the 0.1 per cent level.

Fecundity and gonad weight

An analysis of regression of the logarithm of fecundity on the logarithm of dry gonad weight shows that their relationship is not linear. The value of 'b' (Table 20), in both years, was less than one and when tested statistically, it was found that these values are significantly different from one at the 0.1 per cent level.

Analysis of gonad weight of female perch from the Dubh Lochan

Analyses of the logarithms of dry gonad weights on lengths and on weights for different age-groups, were carried out to examine the relationship between the age of females and their gonad weights. The results of these analyses are summarised in Table 21.

There is a significant difference between the coefficients for the regressions of dry gonad weight on length for the same age-groups in 1967 and 1968 (Table 21). There is no significant difference between the coefficients of the total regressions of the two years (Table 21). There is no definite correlation between gonad weight and increasing age. The coefficients for the regressions of dry gonad weight on body weight were more or less the same and indicate a linear relationship between them. This means that there is no difference in the gonad weight/flesh weight ratio in the different age-groups.

Fecundity of Loch Lomond perch

The data from fifty-one female perch collected in 1967 show that the fecundity of the fish varied from 8,480 eggs (for a fish with a length of 18.3 cm and weight of 76.2 gm) to 28,333 eggs for a fish of 26.2 cm and 271.5 gm. Only two females were collected in 1968. These fish contained 54,545 and 46,177 eggs and were 32.7 and 27.6 cm in length and 670 and 420 gm in weight respectively. The mean number of eggs, based on the females caught on April 28, 1967, was 14,855. These fish had a mean length of 18.9 cm and a mean weight of 119 gm. One full string of eggs, collected from the spawning ground at Balmaha in 1967, was found by direct count to contain 9,600 eggs. The average number of eggs per kilogram of fish was 124,831. This is lower than the average from the Dubh Lochan but higher than that of Irish perch (Healy, 1954).

There is considerable variability in the fecundity of perch, although the general level can be related to the length, weight and gonad weight of the fish concerned. This can be seen from the scatter diagrams of fecundity against length, weight and dry gonad weight shown in Figure 29a, b and c.

Fecundity and length

Figure 29a suggests that the relationship between fecundity and length would be of the form log F = log a + b log L as in the Dubh Lochan fish. Analysis of the regression of the logarithm of fecundity on the logarithm of length was carried out. The value of the regression coefficient 'b' with its ninety-five per cent fiducial limits is given in Table 20. The value of 'b' which is less than and significantly different from three shows that the fecundity increases at a rate a little below the cube of the length.

Fecundity and weight

Figure 29b suggests that the relationship between fecundity and weight may be linear. Analysis of the regression of the logarithm of fecundity on the logarithm

Figure 29. Scatter diagrams showing the relation of (a) fecundity and length, (b) fecundity and weight and (c) fecundity of dry gonad weight of female perch of Loch Lomond during 1967.

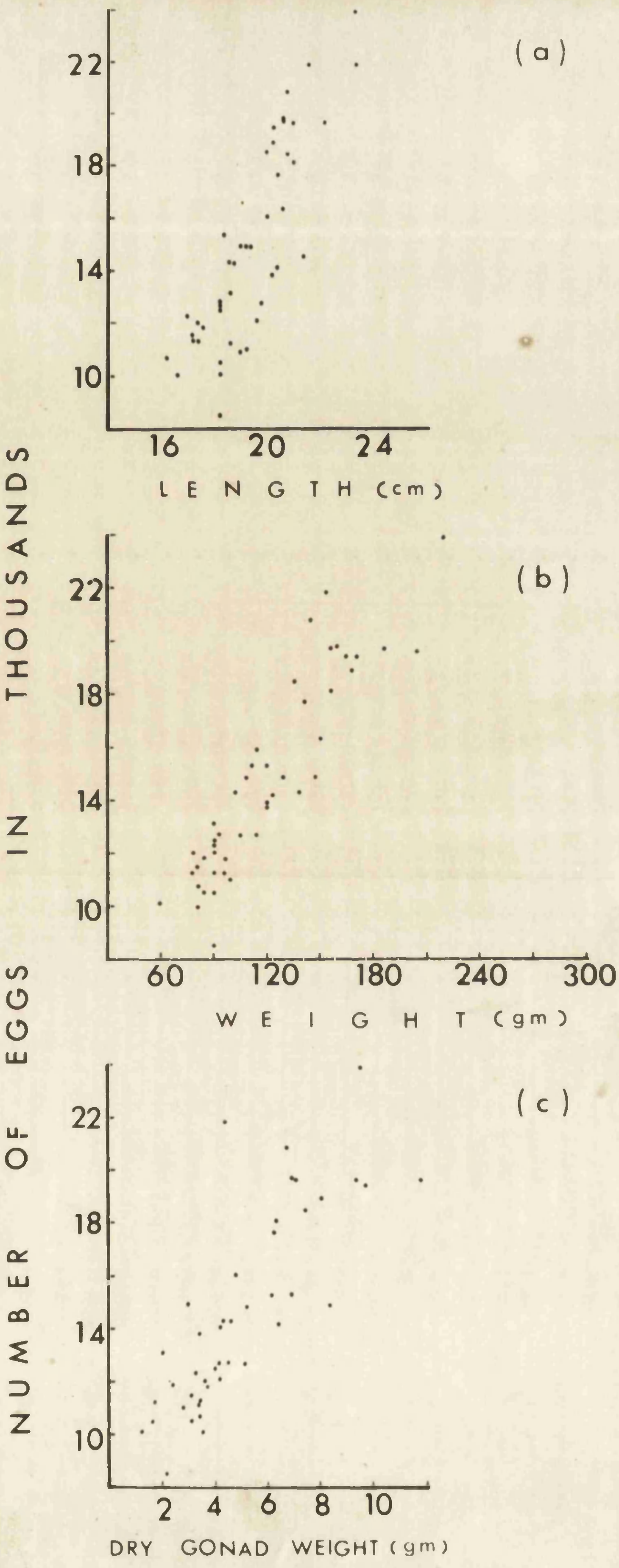
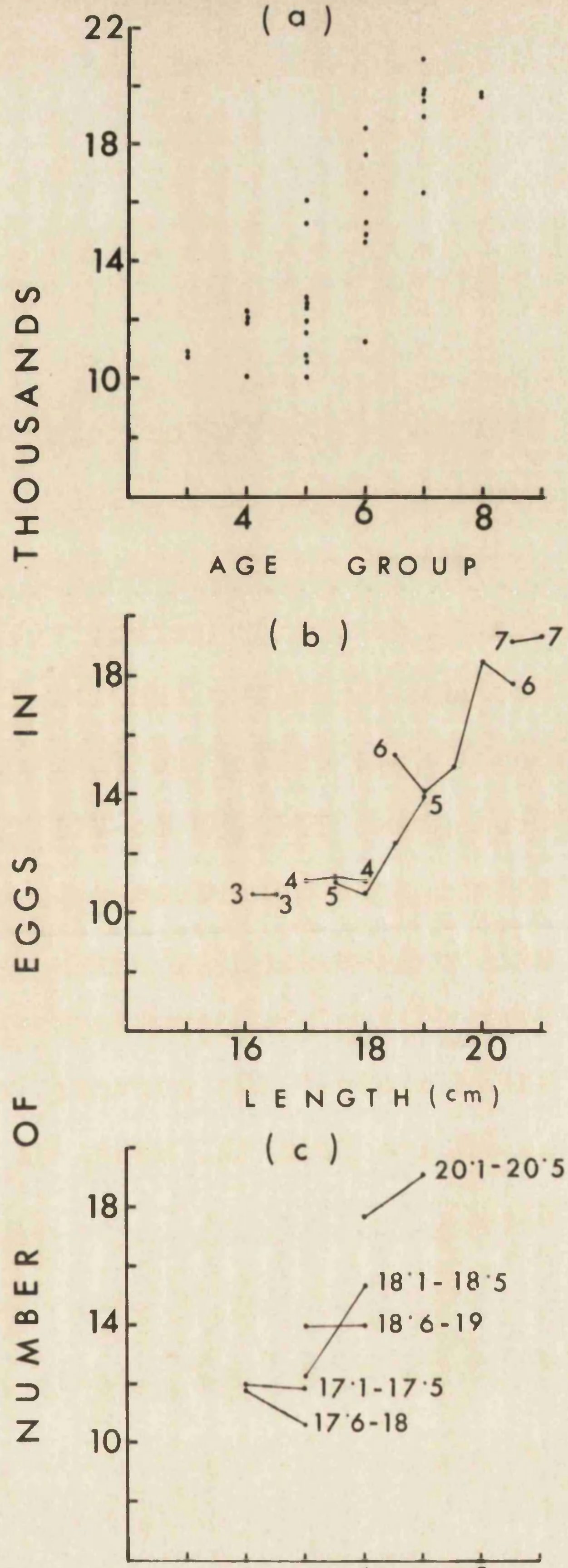

NUMBER OF EGGS IN THOUSANDS
(a)
22
18
14
10
16
20
24
LENGTH (cm)
(b)
22
18
14
10
60
120
180
240
300
WEIGHT (gm)
(c)
22
18
14
10
2
4
6
8
10
DRY GONAD WEIGHT (gm)

Figure 30. Relation between fecundity of Loch Lomond perch and age during 1967: (a) relation between fecundity and age, irrespective of length of female perch; (b) relation between fecundity and length and age; each curve refers to fish of one age group from group III (3) to VII (7); (c) relation between fecundity and age for fish of the same length; each curve is derived from fish of 0.5 cm length-group as shown against the curves; all points shown are from the means of two or more fish.



NUMBER OF EGGS IN THOUSANDS
(a)
22
18
14
10
4
6
8
AGE GROUP
(b)
18
14
10
16
18
20
LENGTH (cm)
(c)
20·1-20·5
18·1-18·5
18·6-19
17·1-17·5
17·6-18
18
14
10
4
6
8
AGE GROUP

of weight showed the value of 'b' (Table 20) to be less than one. Hence the relationship between fecundity and weight is non-linear. This might be expected for the relationship between weight and length is not similar to that of fecundity and length.

Fecundity and age

When fecundity is plotted against the age of female perch, irrespective of length, it was found that there is a positive relationship (Fig. 30a). The variation in fecundity between fish of the same age was similar to the variation observed between fish of the same weight and length. Fecundity against length for fish of the same age (Fig. 30b) and fecundity against age for fish of the same length (Fig. 30c) were plotted. Figure 30c shows that there is no increase in fecundity with age in smaller fish, although there is some increase in larger fish. The increase with the size of the fish (Fig. 30b) is much more distinct. Thus, it can be assumed that the size of the fish plays a more significant part in determining the fecundity of female perch than their age.

Analysis of the regression of the logarithm of fecundity on the logarithm of age shows that their relationship is almost linear. The regression coefficient 'b' (Table 20) is less than one and when tested statistically it was found to be just significantly different from one.

Fecundity and gonad weight

An analysis of the regression of the logarithm of fecundity on the logarithm of dry gonad weight shows that their relationship is non-linear. The value of the regression coefficient 'b' (Table 20) was less than and significantly different from one.

Analysis of the gonad weight of female perch from Loch Lomond

Analyses of the logarithms of the dry gonad weight on the lengths and weights for different ages were carried out to investigate the relationship between the ages of females and their gonad weights. The analyses were based on April data only and the results are summarised in Table 21.

There is a significant difference between the coefficients for the regressions of dry gonad weight on length among different age-groups. The coefficients for the regressions of dry gonad weights on body weights are almost the same and indicate a linear relationship as in the Dubh Lochan perch.

Food of Perch

Dubh Lochan

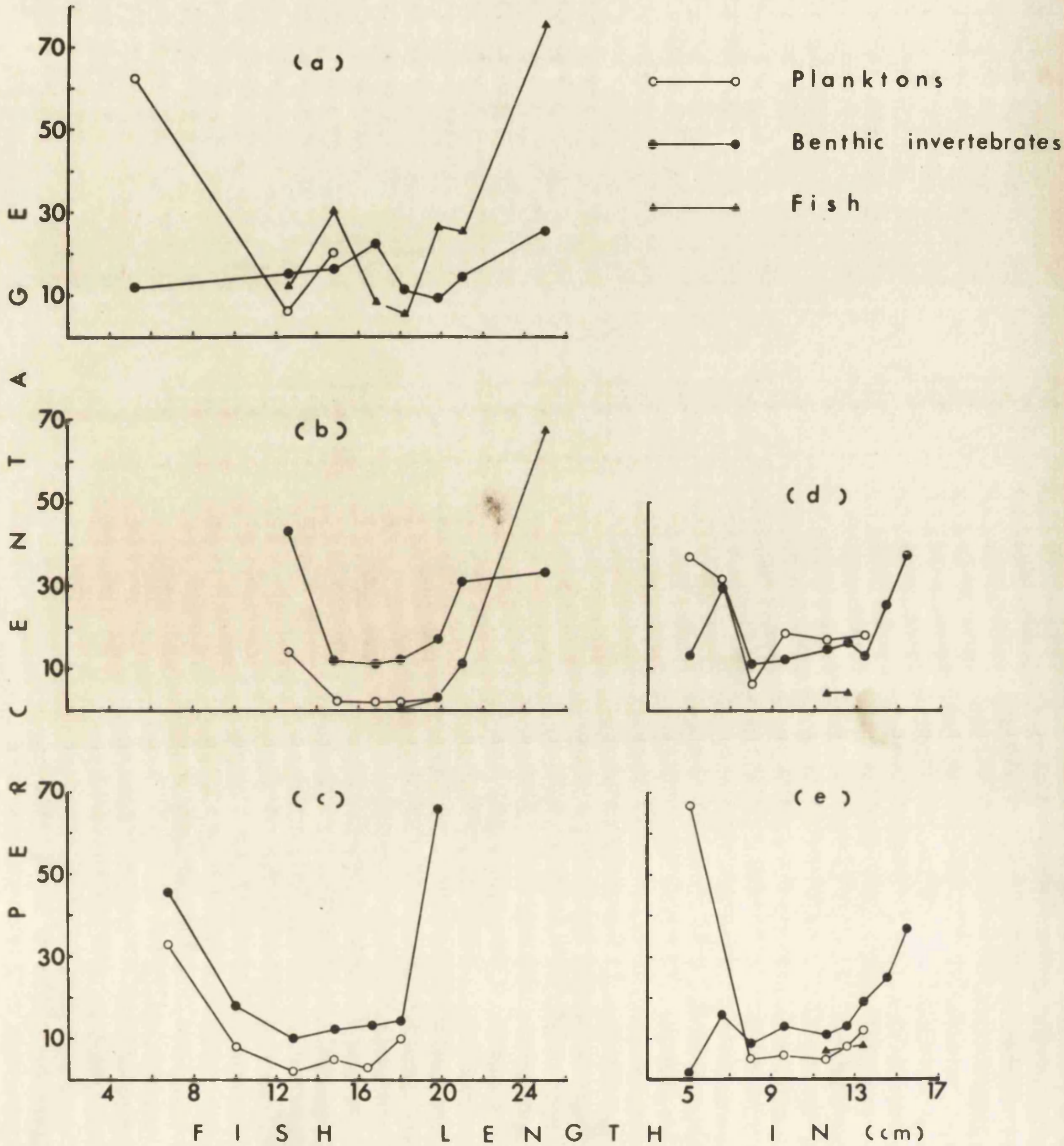
Fry

The stomachs of sixty-four fry were analysed along with older perch and the percentages of perch containing each food organism are given in Tables 22 and 23. *Holopedium*, *Cyclops* and *Daphnia* were the most important food animals eaten by fry in both 1967 and 1968 followed by chironomid pupae and larvae and *Chaoborus* larvae. Windermere perch fry frequently eat *Cyclops* and *Daphnia* but also *Bosmina* and *Diaptomus* in large numbers (Smyly, 1952). The absence of the last two from the stomach of Dubh Lochan perch may be explained by their relatively low abundance, especially of *Bosmina* compared with the other genera. Undoubtedly *Holopedium* was the most important single food item for Dubh Lochan fry. One hundred per cent of the fry were feeding on it in 1968 (Table 23). There is also evidence of a correlation between the availability and relative abundance of *Holopedium*, *Cyclops* and *Daphnia* in the stomachs of perch fry (unpublished data, Mr S.G. Dunn). *Gammarus* and *Hirudinea*, eaten by perch fry in Windermere, are absent in the Dubh Lochan. Smyly (1952) noted cannibalism among perch fry during July in Windermere; as no fry were caught in July and August in the Dubh Lochan, a comparison could not be made.

Mature fish

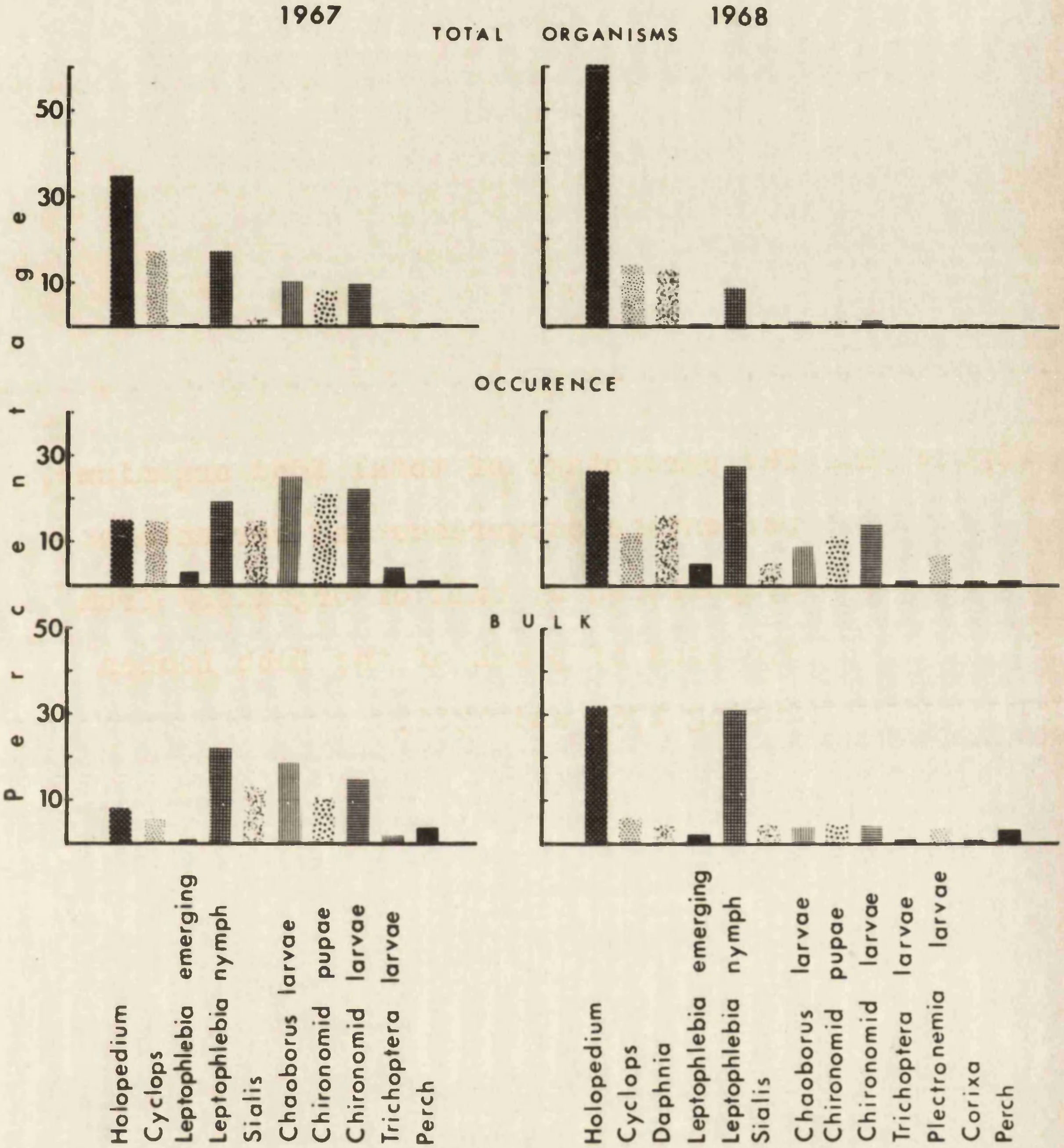
According to Alm (1922) the smallest perch feed on planktonic Crustacea, the middle sized fish on insect larvae and other bottom living invertebrates, while the largest perch feed chiefly on fish. Allen (1935) has shown that the food of perch changes with the size of fish during summer and that the size of food organisms increases with the size of the fish. Nilsson (1921) and Healy (1954), however, did not find any change in food with increased size of fish. The percentage of perch in each size group which contained each of the food animals in the Dubh Lochan (Fig. 31d and e) clearly shows that the planktonic organisms were eaten by perch up to a length of 14.4 cm in both years, and that no perch below a length of 11.6 cm had eaten any vertebrate food. Insect larvae and other benthic invertebrates were eaten by fish of all sizes. The size of these invertebrates increases with an increase in the size of the perch. Figure 31d and e shows that there is a sharp change at a length of 8 cm in the amount of plankton eaten. Figure 31d and e also shows that benthic invertebrates were the main food of larger perch. In the Dubh Lochan, where the growth of perch is stunted, pike and eels

Figure 31. The percentage of perch containing each type of food plotted against the length of perch of Loch Lomond; (a) Field Station area, 1967; (b) Balmaha area, 1967; (c) Balmaha area, 1968 and of Dubh Lochan, (d) 1967, (e) 1968.



(a)
(b)
(c)
(d)
(e)
Planktons
Benthic invertebrates
Fish
PERCENTAGE
FISH LENGTH IN (cm)

Figure 32. The percentage of total food organisms, percentage occurrence and percentage composition by bulk of organisms from stomachs of perch of the Dubh Lochan during 1967 and 1968.



1967
1968
TOTAL ORGANISMS
OCCURENCE
BULK
percentage
50
30
10
30
10
50
30
10
Holopedium
Cyclops
Leptophlebia emerging
Leptophlebia nymph
Sialis
Chaoborus larvae
Chironomid pupae
Chironomid larvae
Trichoptera larvae
Perch
Holopedium
Cyclops
Daphnia
Leptophlebia emerging
Leptophlebia nymph
Sialis
Chaoborus larvae
Chironomid pupae
Chironomid larvae
Trichoptera larvae
Plectronemia larvae
Corixa
Perch

being the only other fish present, small perch are the only food fish but do not constitute an important food for medium sized perch. This agrees with Alm's (1946) and Eschymere's (1938) findings. McCormack (1968) recently observed that Windermere perch eat the same species as recorded by Allen (1935) but that the proportions differ considerably. Also the distinction found by Allen between individuals that fed mainly on plankton, on bottom living forms or on fish, no longer seems clear.

It was found that the percentage by number, the percentage occurrence and the percentage composition by bulk of food organisms, in the stomachs of perch from the Dubh Lochan, gave more or less the same results (Fig. 32), i.e. the results from the different methods of assessment were substantially similar. Hynes (1950) too obtained essentially similar results in his comparison of these different methods.

Holopedium and *Cyclops* represented the two highest percentages of total organisms (Fig. 32) in the stomachs of all perch including the sixty-four fry examined. *Leptophlebia* nymphs, *Chaoborus* larvae, chironomid pupae and larvae were the principal food of adult perch in the Dubh Lochan. *Sialis* and Trichoptera larvae were also important. The only vertebrate food eaten by perch was small fish of the same species, the percentage frequency of occurrence of which was one in 1967 and 1.3 in 1968; these were not therefore of importance in its diet.

Empty stomachs

Table 24 shows the percentage of perch examined in winter and in summer whose stomachs were empty. Allen (1935) found more empty stomachs in winter than in summer in Windermere perch, but McCormack (1968) recently reported a high proportion of perch with empty stomachs in late summer. Healy (1954) found a fairly high percentage of empty stomachs in summer in some Irish waters. Few perch were caught in winter from the Dubh Lochan and thus the data are rather inadequate for the winter period. The percentage of empty stomachs even in the two summers was fairly high however. Table 24 shows that larger perch tended to have empty stomachs more often than smaller ones in summer and this agrees with Allen's (1935) findings.

It should be noted that the methods of capture used in this study, gill-net and perch trap, are not ideal for an examination of the food of the fish concerned. Thus fish may be held alive for considerable periods before being examined during which time much of the material in their stomachs may be digested. It is likely therefore that the proportions of empty stomachs found during this work might well be higher than normal.

Two per cent of fish in 1967 and one per cent in 1968 had plant material in their stomachs.

Parasites

Five per cent of the perch stomachs (Table 25), in both years, were found to contain Camallanus lacustris (Zoega), a parasitic nematode. .5 per cent of the stomachs in 1967 contained Bunodera luciopercae (Müller), a trematode parasite. This is the only European species, in the Family Bunoderidae, which occurs in perch in Great Britain (Dawes, 1947).

Food during the spawning period

During the spawning period Chaoborus and chironomid larvae were eaten in large numbers by perch in 1967. Chironomid pupae, Leptophlebia nymphs and Sialis larvae were other slightly less important food organisms in that year. In 1968, however, Leptophlebia nymphs were of major importance (Table 26). This change may simply be due to the different relative abundance of food organisms in each year. Holopedium, Cyclops and Trichoptera larvae were also important food organisms of perch during the spawning periods. Only three perch were found to have been cannibalistic during the spawning period in 1967. Fifty per cent of the stomachs in 1967 and forty-seven per cent in 1968 were empty.

Seasonal aspects

The food of perch at different times of the year is shown in Table 27. Only a few perch were caught in some months and therefore the data have been divided into four groups, each consisting of three months. *Holopedium* was eaten throughout the year, though they became scarce from December to February when the population in the lochan is very low. *Leptophlebia*, both adults (emerging) and nymphs, *Sialis*, *Chaoborus* larvae, and chironomid pupae and larvae were eaten by all fish from March to May, when they were abundant in the loch, but were eaten much less from June to August, when they were less available. These food organisms were also eaten infrequently during the winter months.

Loch Lomond

Fry

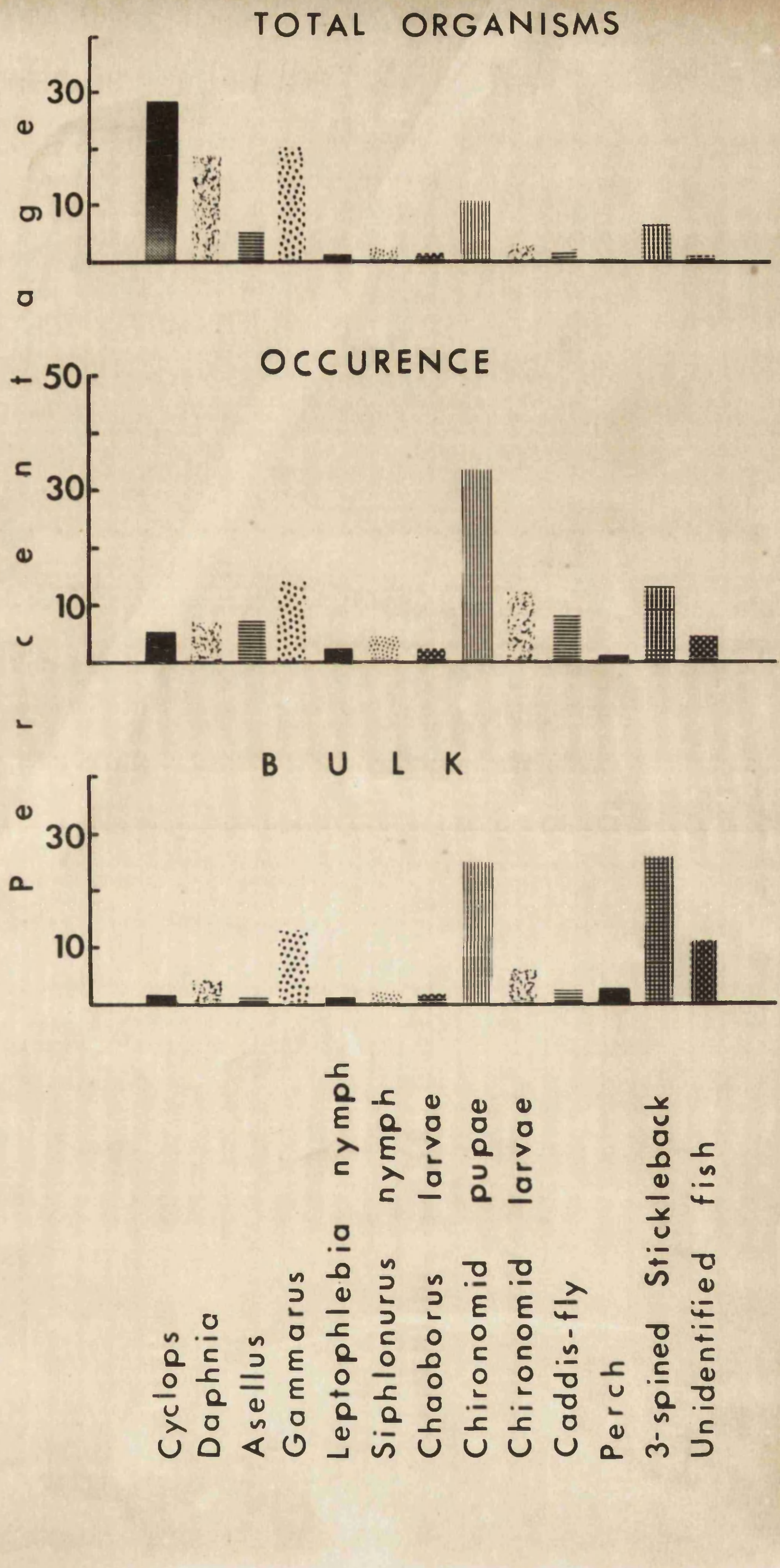
The contents of the stomachs of eight perch fry, caught near the Field Station, are noted in Table 28. The food of these fry was similar to that of those from Dubh Lochan apart from the absence of *Holopedium* which is not found in

Loch Lomond (Slack, 1957). *Daphnia* and *Cyclops* were eaten by seventy-five per cent and fifty per cent of fry from Loch Lomond respectively. The only benthic organisms eaten were chironomid larvae, occurring in twelve per cent of fry. *Bosmina* and *Diaptomus*, eaten in large numbers by Windermere fry (Smyly, 1952), are abundant in Loch Lomond but had not been eaten by any of the fry examined.

Mature fish

It was found that the food of perch in Loch Lomond also changes with the size of the fish. The size of the food organism also increases with the size of the fish. Figure 31a, b and c shows that plankton was eaten by perch up to a length of 16.8 cm and that no perch below the length of 12.6 cm had eaten any fish. Again, larger Crustacea, insect larvae and other benthic invertebrates were eaten by all fish above a length of 12.6 cm but it was observed that the size of these food organisms increased with the size of the perch. A similar situation was found in perch from the Balmaha area (Table 29) where no perch below a length of 18.1 cm had eaten any fish. Planktonic organisms were eaten by perch of all length-groups but their percentage frequency of occurrence was insignificant in larger fish.

Figure 33. The percentage of total food organisms, percentage occurrence and percentage composition by bulk of organisms from the stomachs of perch of Loch Lomond near Field Station during 1967.


TOTAL ORGANISMS
OCCURENCE
BULK
Percentage
30
10
50
30
10
30
10
Cyclops
Daphnia
Asellus
Gammarus
Leptophlebia nymph
Siphlonurus nymph
Chaoborus larvae
Chironomid pupae
Chironomid larvae
Caddis-fly
Perch
3-spined Stickleback
Unidentified fish

Cyclops and chironomid pupae were all very important items in the diet of Loch Lomond perch. Three-spined sticklebacks, chironomid larvae, *Daphnia*, *Asellus*, *Siphlonurus* nymphs, Trichoptera larvae and unidentified fish were also of significance in their food (Fig. 33). Thus the situation is similar to that in Windermere (Allen, 1935), where chironomid pupae, larvae and *Gammarus* were important food items in the diet of perch.

Food during the spawning period at Field Station area

Table 30 shows that *Cyclops*, *Daphnia*, *Gammarus*, chironomid pupae and three-spined sticklebacks were the main diet of perch in Loch Lomond near the Field Station during the spawning period in 1967 while *Gammarus*, Chydoridae and chironomid pupae and larvae were the principal diet in 1968. Of these organisms *Gammarus* was the most important.
Table 30 also shows that the highest percentage frequency of occurrence was made up by chironomid pupae in 1967 and by *Gammarus* in 1968. *Gammarus*, chironomid pupae, three-spined sticklebacks and unidentified fish represented the highest percentage composition by bulk in 1967; *Gammarus* and perch formed the main bulk of the diet in 1968.

Seasonal aspects

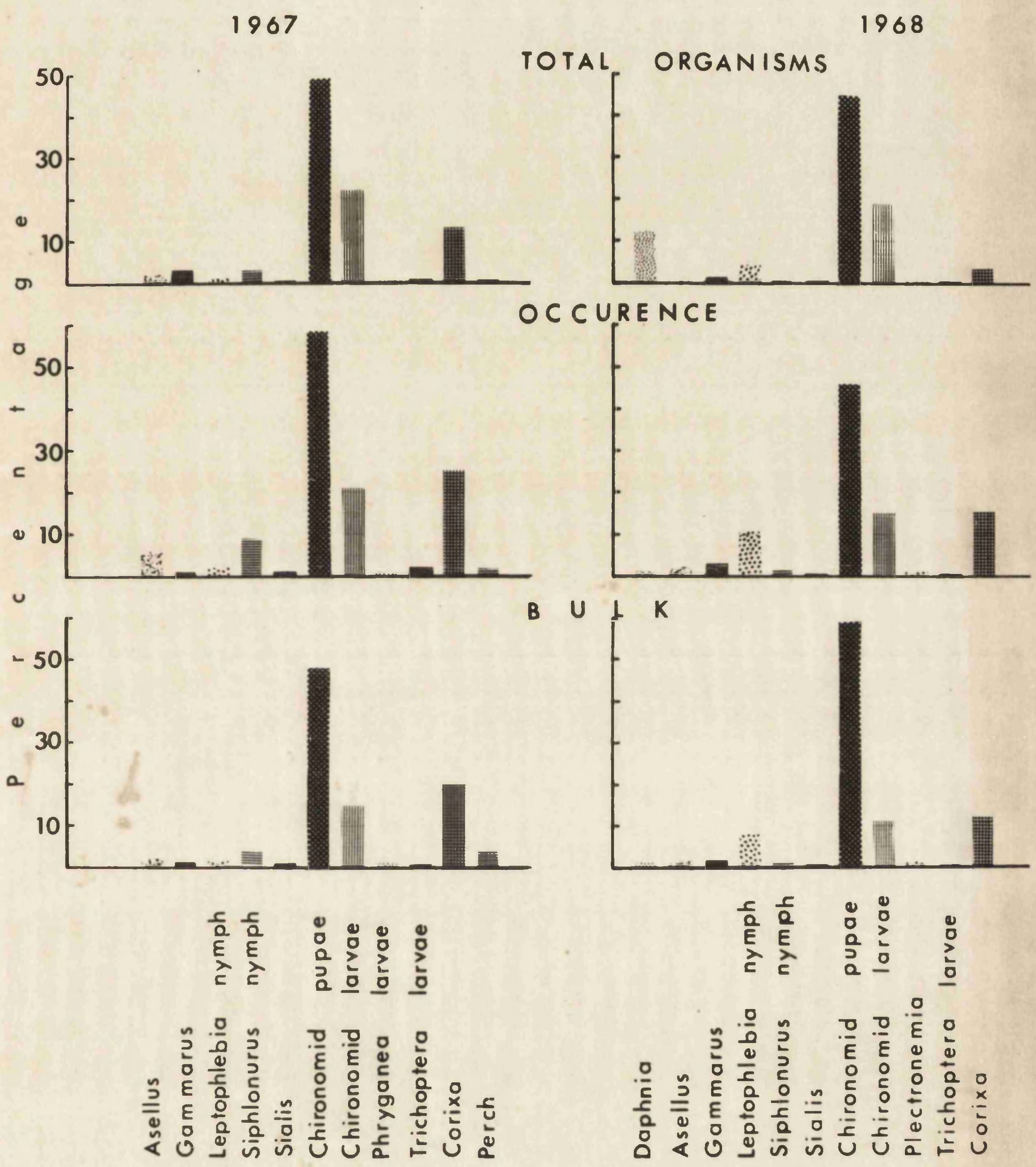
Table 31 shows that chironomid pupae and larvae were eaten throughout the summer while fish were common in the diet from May to January. Unfortunately, no perch were caught in July, August or November. *Asellus*, *Gammarus*, chironomid pupae and larvae and fish were the principal constituents of the diet in May and June. Sticklebacks and smaller perch formed the main food in the winter months.

Food during the spawning period in the Balmaha area

Figure 34 shows that very large numbers (forty-nine per cent) of chironomid pupae were eaten by perch during the spawning period in 1967. Chironomid larvae and *Corixa* (thirteen per cent) were also eaten in large numbers in the same year. Chironomid pupae (45.3 per cent) were again a major item in the diet in 1968. Chironomid larvae (19.1 per cent) and *Corixa* were also present in significant numbers. The high percentage of *Cyclops* and *Daphnia* in 1968 could well be due to the fact that more smaller perch (Fig. 9) were caught in 1968.

Gammarus (which formed the principal food in the Field Station area) was insignificant (1.3 per cent) at Balmaha. However, chironomid pupae were eaten in large numbers in both areas in both years. *Corixa* (instead of *Gammarus* as at the Field Station area) represented the second highest percentage frequency of occurrence at Balmaha. Several

Figure 34. The percentage of total food organisms, percentage occurrence and percentage composition by bulk of organisms from stomachs of perch of Loch Lomond at Balmaha during 1967 and 1968.



1967
1968
TOTAL ORGANISMS
OCCURENCE
BULK
Percentage
50
30
10
Asellus
Gammarus
Leptophlebia nymph
Siphlonurus nymph
Sialis
Chironomid pupae
Chironomid larvae
Phryganea larvae
Trichoptera larvae
Corixa
Perch
Daphnia
Plectronemia

other differences were evident in the diet of perch at the two places (see Fig. 34) and can be explained by similar differences in the benthic fauna of the two areas. Cannibalism was found in only two per cent of the perch examined in 1967. No perch stomach had contained any vertebrate in 1968. The absence of smaller perch or other small fish on the breeding ground may be the reason for this low occurrence.

One noteworthy feature of the food of perch at Balmaha was *Corixa* which were eaten in some numbers in both years. According to Frost & Macan (1948), few fish eat corixids. Allen (1935) found no *Corixa* among the food of 643 perch from Windermere and similarly Swynnerton & Worthington (1940) found none among the food of fifty-eight perch from Haweswater. According to Frost & Macan (1948), Corixidae are confined to reed-beds in shallow water in Windermere and Haweswater. It is not known whether or not perch visit these reed-beds during the spawning periods there. Healy (1954) found that a fairly high percentage of perch in some Irish waters eat *Corixa*.

Empty stomachs

The percentage of empty stomachs (Table 24) in perch was higher in winter than in summer. This agrees with the data of Allen (1935) for Windermere perch. The fact that larger fish had empty stomachs more frequently than smaller perch in Loch Lomond also agrees with Allen's results.

Two per cent of the perch in 1967 and one per cent in 1968 had plant material in their stomachs. No plants were found in the stomachs of any perch from the Field Station area. Since perch appear to be almost exclusively carnivorous, it is likely that plant material was taken inadvertently with food.

Parasites

Acanthocephalus lucii (Müller) was present in two per cent of the stomachs (Table 25) and *Camallanus lacustris* (Zoega), a parasitic nematode, in five per cent of the stomachs from the Field Station area. Higher percentages of these parasites were found in perch from the Balmaha area in 1967. Seven per cent of these stomachs also contained *Bunodera lucioperca* (Müller). The incidence of parasites in the stomachs of perch from the Balmaha area in 1968 was very low.

Population estimates of perch of Dubh Lochan

The method of estimating populations of animals by marking a number of individuals, releasing them and then finding the number of marked individuals in a second similar sample has been used by many ecologists (Le Cren, 1965). The name of the technique has varied: 'sample censusing', 'estimation by marked members', 'the mark-and-recapture method', the 'Petersen method' and the 'Lincoln Index' (Ricker, 1958) being among the common titles used. According to Le Cren (1965), Dahl was the first worker to use the method to estimate a total population but he suggested that the method should be known as the 'Petersen method' since Petersen (1894) was one of the main founders of marking techniques.

During the present attempt to enumerate the fish population in the Dubh Lochan Schnabel's (1938) method of maximum likelihood (later modified by Thompson (Lagler, 1949)) was found to be the most suitable method of computation. Ricker (1958) found that three possible sources of error occur in Schnabel's method: (a) due to recruitment, (b) due to natural mortality and (c) due to fishing mortality. The possible influence of errors from these sources was considered during the present study.

The marking experiments on the perch population of the Dubh Lochan were carried out during the spawning periods in 1967 and 1968. In each year the experiments extended over a period of about two months - a period that allowed sufficient time for the redistribution of marked fish but was not so great that errors from mortality and recruitment were likely to be significant. Only the mature fish which entered the traps for breeding have been considered in these population estimates. 0+, 1+ and 2+ perch are not, therefore, included as the traps were not suitable for them. A large number of fish (4,523 in 1967 and 4,264 in 1968) were marked to give as reliable results as possible (Table 32).

During the periods of population estimation all fish were replaced in the Dubh Lochan except those few which were damaged or weak and 100 females in each year retained for fecundity analysis. There was no other significant fishing in the Dubh Lochan throughout the years concerned. The marking of fish by tagging and clipping has already been discussed. In applying recovery figures to the calculations of the populations the combined tagged and clipped recoveries from the traps have been used.

According to DeLury (1951) Schnabel's population technique is affected by the influence of natural mortality. If it is assumed, however, that the effect of natural mortality is the same on tagged and untagged fish, as it is hoped would be the case then the point is not a significant one. It is apparent that free mixing of the perch

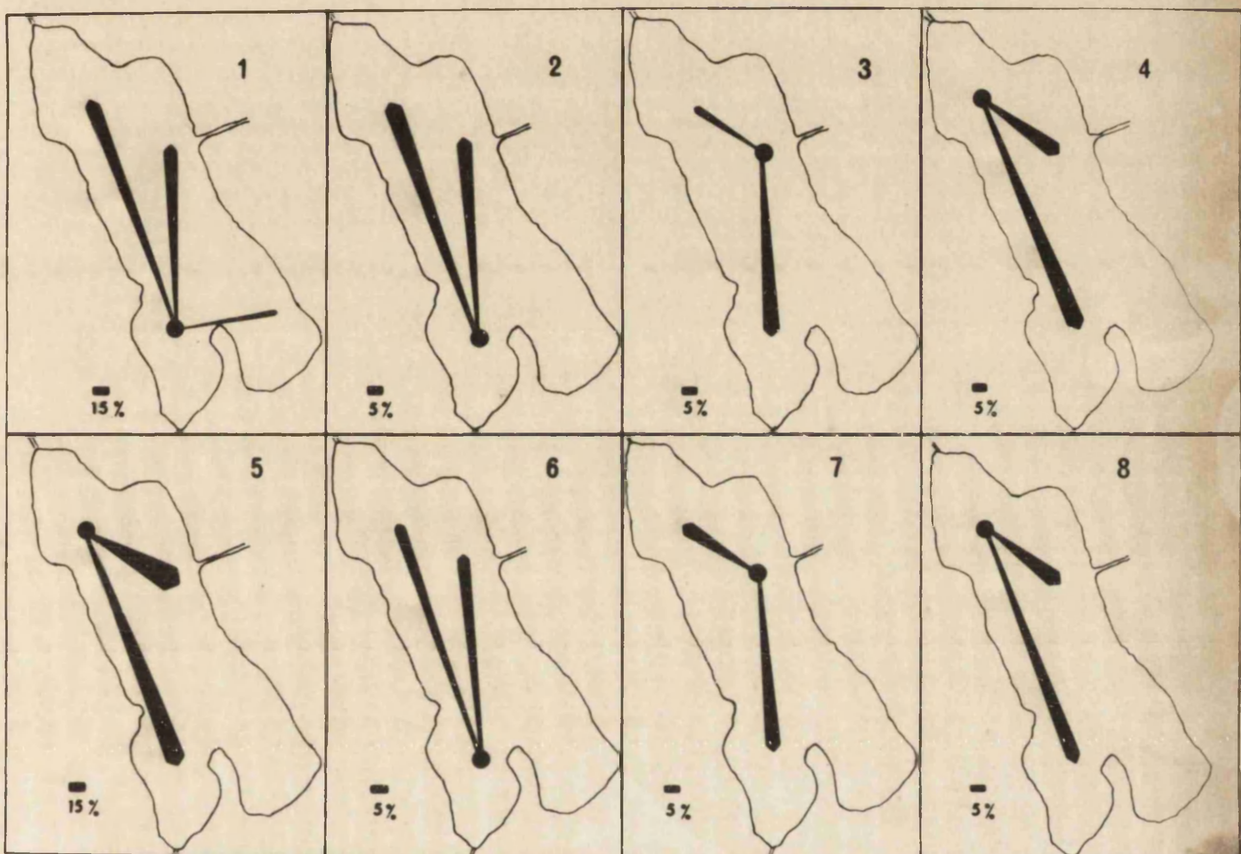
Figure 35. Maps of Dubh Lochan showing the movement of perch in percentage of total recapture of tagged and clipped fish in 1967 and 1968:

1 - movement of tagged perch in 1967

5 - movement of tagged perch in 1968

2, 3, 4 - movement of clipped perch in 1967

6, 7, 8 - movement of clipped perch in 1968.


1
15 %
2
5 %
3
5 %
4
5 %
5
15 %
6
5 %
7
5 %
8
5 %

population did take place during the period of the experiment (Fig. 35). Therefore, it was not necessary to subdivide the Dubh Lochan when making population estimates. No dead marked fish were found in the loch during the experiment or at other times of the year and it appears that the marked fish were more or less normal in behaviour, etc. Although a slow growth-rate was observed among those tagged (Table 34), this is unlikely to have had any effect on the population estimate as such.

Schnabel's modified method is a simple one which weights daily averages as the study proceeds. On each of several days of catching, marking, and releasing fishes, the population is estimated by the following formula:

$$P = \frac{\Sigma AB}{\Sigma C}, \text{ where,}$$

P = estimated population on any date

A = number of fish caught on any date

B = number of marked fish in the loch on any date

C = number of recaptures on any date

AB = product of A and B

Σ AB = sum of all products (AB) calculated to date

Σ C = sum of all recapture to date

Data from the experiments in 1967 and 1968 are shown in Tables 32, ~~and 33.~~

In 1967, the experiment was carried out from March 31 to May 25, the period during which perch entered the traps in large numbers. The population was estimated at 11,268 mature perch or 1,649 fish/hectare or 33.9 kg/hectare of water (Table 35). In the next year the experiment took place from April 5 to June 2, and the population was estimated at 11,581 mature perch or 1,695 fish/hectare or 39.4 kg/hectare of water. In both years the traps were emptied and fish were marked or tagged eighteen times during the two months of the experiment. A summary of the estimates of the adult perch population along with the ninety-five per cent confidence limits and standard errors are given in Table 35. Limits of confidence were calculated by taking recaptures (ΣC) as a Poisson variable (Ricker, 1958). The results from both years agree closely. These may reflect similar recruitment and mortality in the two years. The confidence limits give a fairly good idea of the extent of the variability in the numbers on which the estimate is based.

Schnabel's method is not suitable for computing the standard error of the estimate obtained (Ricker, 1945). However, the standard error (Table 35) has been estimated (partly from Ricker, 1958) from the reciprocal of P.

It is insufficient to measure a fish population in terms of numbers of individuals alone; the size of the individuals must also be taken into account (Le Cren, 1965). The average weight of all fish taken was estimated and the total weight of unspawned mature perch at the time of spawning was calculated in both years (Table 35).

Mortality, survival and change in biomass of perch in the Dubh Lochan

The estimated abundance of successive age groups of male and female perch in the Dubh Lochan in 1967 and 1968 is given in Table 36. The data for females may not be correct for the methods of collection were probably adequate only for males. When log frequency was plotted against age to give a catch curve, the right descending limb of the curve was smooth in both 1967 and 1968, up to the age of six years. The higher frequency of perch older than six years in 1967 samples (Table 36) might be due to the fact that some older fish were caught by gill-nets in that year.

The calculations of instantaneous growth rates (Table 36) over yearly periods were done accoring to Ricker (1958). The instantaneous growth rates of female perch in the Dubh

Lochan, in both years, were more or less the same as those of 1949 female perch in Windermere (Le Cren, 1958) but less than those of Thames perch (Williams, 1967).

Turning to rates of instantaneous mortality and annual survival of male and female perch in 1967 and 1968 (Table 36) were also calculated according to Ricker (1958). Allen (1951) has shown that, even in a heavily fished trout stream, anglers were responsible for only 6.5 per cent of the total fish mortality, while Williams (1967) found a very low mortality due to angling among perch in the River Thames. In the Dubh Lochan, where angling is negligible, the right descending limb of the catch curve, therefore, represents only the natural mortality (Ricker, 1958). The instantaneous rates of mortality of male and female perch in the Dubh Lochan in 1967 were 0.61 and 0.66 respectively. The instantaneous rate of mortality of perch (Le Cren, 1965) in Windermere, before the start of reduction in the perch population in 1941, was 0.44. The higher rate in the Dubh Lochan may be due to the high density of the population there and to predation by pike. The total bulk of perch in the Dubh Lochan, however, increased since G-Z (Table 36) is positive in both 1967 and 1968 (Ricker, 1958).

From the data on instantaneous growth and instantaneous mortality, the change in biomass of a brood with age, in 1967 and 1968, has been estimated. In Table 36, which excludes the very few immature fish caught, the biomass of year III males in both 1967 and 1968, for which Z and G (Table 36) were known, was taken as 1,000 weight units. The biomass of year IV females in 1967 was proportional to the number and average weight of year III males and year IV females. The biomass of year III females in 1968 was proportional to the number and average weight of year III males and females. Table 36 shows that the maximum biomass of male perch in the Dubh Lochan was reached at an age of three years (or earlier) and that of female perch at four years in both 1967 and 1968. Male and female River Thames perch reach their maximum biomass at the age of three years (or earlier) and five years respectively (Williams, 1967). Thus, the females in the Dubh Lochan reach their maximum biomass one year earlier.

Chapman (1968) has discussed in detail the methods of computing fish production. The data obtained during the present work are not very suitable for fish production computations. However, a production of approximately 54 to 61 kg (wet weight) has been estimated for perch in the Dubh Lochan over the period May 1967 to April 1968. The production of adults (over year III) and young (from hatching to three years old) has been estimated separately.

If the sex ratio of perch as found in the traps in 1967 is accepted, the 4,341,717 eggs were laid and ~~434,172~~ 3907,748 eggs were batched in 1967 (average mortality of eggs up to hatching was ten per cent). The total number of year III perch in the Dubh Lochan in 1967 was 5,445 (see Table 36). These fish were hatched in 1964. If the total number of eggs hatched in 1964 and 1967 is taken as being the same, the mortality of young perch for the first three years of life would amount to 98.75 per cent. The average increment in wet weight in the first three years of life was 3.34 gm. Therefore, a total production of (5,445 x 3.34 = 18.2 kg of fish flesh would be a rough estimate for the first three age-groups of perch in 1967.

If, however, the sex ratio is 50:50, then a total of 20,815,272 eggs could have been laid and 2,081,527 eggs hatched in 1967. With this sex ratio, the total number of year III perch would be 3,279 in 1967, and the mortality rate for the first 3 years would be 99.8 per cent. The total production for the first three age-groups would be 10.9 kg. The lower production estimate for the first three years might be due to the fact that no year III females were caught in 1967 (see Table 36).

From the estimated number of adult perch (see Table 36) in 1967 and 1968 and knowledge of annual increments in weight, the production of each age-group during 1967-68 has been calculated: IV, 28.5 kg; V, 9.6 kg; VI, 2.4 kg; VII, 1.98 kg; VIII, 155 gm and IX 448 gm, giving a total production for adult perch from May 1967 to April 1968 of 43.1 kg.

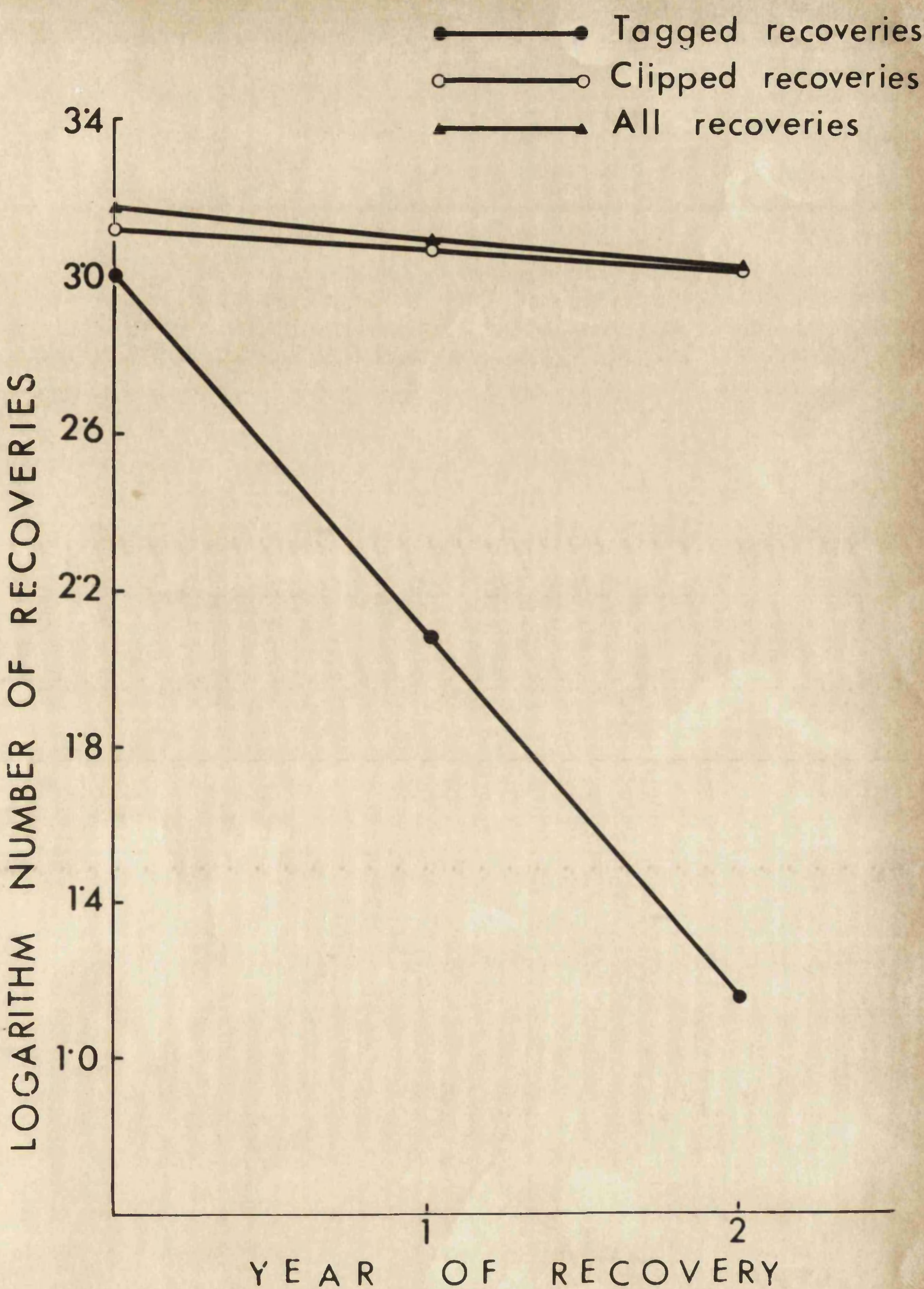
The production figures (54 to 61.3 kg or 0.79 gm/m^2 to 0.88 gm/m^2) of perch in the Dubh Lochan during 1967-68 were low as might be expected in a dystrophic loch of this type. The high density of the population of perch must also have affected this annual production. Johnson & Hasler (1954) found a production of 1.9-8.4 gm/m^2/year for trout in a dystrophic lake in Michigan, while Johnson (1966) found an annual production of 0.14-0.51 gm/m^2/year for pike in Windermere, but it must be remembered that these being different species they will have different food relationships.

Further Information Relevant to the Mark-Recapture Data

Recapture, effects of tagging and mortality of tagged and clipped perch

During tagging both sexes were tagged though at all times males predominated. The numbers recaptured differed

Figure 36. Decline in recoveries of marked perch (see Table 38) in the Dubh Lochan.


Tagged recoveries
Clipped recoveries
All recoveries
3·4
3·0
2·6
2·2
1·8
1·4
1·0
LOGARITHM NUMBER OF RECOVERIES
1
2
YEAR OF RECOVERY

in the two years - twenty-four per cent in 1967 and fourteen per cent in 1968, the higher recapture being made in 1967 when most fish were tagged, the lower recapture in 1968 when fewer fish were tagged.

Table 37 shows that the rate of natural mortality was least in the 12.7-13.4 cm length-group and that the rate was more or less uniform in other length-groups except those over 14.5 cm of length where mortality was slightly higher. In 1968, the rate of mortality was the highest in the smallest length-group (Table 37).

If mortality rates are constant from year to year, and, if the marked fish die at the same rate as unmarked individuals, the total annual percentage survival rate (i.e. the complement of the mortality rate, from all cases) should be the same as the percentage of marked fish recovered in any one year is of the number of marked fish recovered in the year immediately preceding (Hart, 1943). Consequently, logarithms of marked fish recaptured plotted against the year of recovery should lie along a straight line whose slope is indicative of the mortality rate and whose Y-intercept is the logarithm of the number of marked fish which could have been expected as recoveries in the first year had there been no sharp change in condition (Fig. 36).

Table 38 shows that the actual number of tagged recoveries in 1967 was slightly higher than expected (from Fig. 36), whereas the actual number of clipped recoveries was slightly below the expected (from Fig. 36) number. The actual number of total recoveries was 286 less than the expected (from Fig. 36) number in 1967. This shows that there was no sharp change in condition among the marked fish during the population estimate. The total annual percentage survival rate for all marked fish was 82.6 per cent. However, the total annual percentage survival rate for clipped fish was ninety per cent but for tagged perch was only 11.8 per cent. Therefore, the high percentage survival rate of marked fish was due to the high survival of clipped fish.

The effects of tags on the rate of recapture of perch in Dubh Lochan have been analysed according to Ricker (1942) and the results are summarised in Table 39. If tags had no adverse effects upon the fish, columns 3 and 6 of the Table 39 would be equal, within the limits of sampling error, and column 7 close to 100. It can be seen that the mortality of tagged perch was higher than that of clipped fish in both years. The recaptures of tagged perch in 1968 were relatively much less frequent than those of clipped ones.

Most tagged perch showed retarded growth. A comparison of the growth of tagged and untagged perch of the same age-group caught at the same time from the same place is given in Table 34.

The length of each untagged fish one year before capture, i.e. the length at the time of tagging was back-calculated from the opercular bone. From a comparison with the normal growth of untagged fish it was found that the growth of perch in the Dubh Lochan was retarded due to tagging by an average of 0.6 cm in length in one year. No false rings, however, due to tagging, were found in the last summer band of the operculars.

It is possible that a preference on the part of pike for those perch with coloured tags might have added to the high mortality of tagged perch. Lawler & Smith (1963) found a higher predation by pike on small fish with yellow tags compared to those with transparent tags. Yellow and blue tags were used to mark perch in the Dubh Lochan. Four yellow and one blue tagged perch were recovered from the stomachs of pike in the Dubh Lochan in May 1967. The shortest period found between tagging and death due to predation by pike was thirteen days and the longest was thirty-seven days.

Movement of perch

Seasonal migration of perch in the Dubh Lochan and Loch Lomond from shallow to deep water and back again appears to take place prior to the winter and summer periods respectively. Table 40 shows that in the present study perch entered traps mainly during the spawning period though Allen (1935) caught several hundred perch in traps in Windermere during the winter. Perch in the Dubh Lochan and Loch Lomond rarely entered traps during winter, even when traps were placed in deep water. Very few perch entered traps after June when the spawning was virtually over.

The information from marked perch indicates that these fish move freely in the Dubh Lochan. Figure 35 (1) shows that, of the fish caught, tagged and released at transect A, 12.6 per cent were recaptured at each of transects B and C. In 1968, fish were caught, tagged and released at transect C but twenty-one per cent were recaptured at transect A and twenty-eight per cent at transect B (Fig. 35 (5)).

Figure 35 (2, 3, 4, 6, 7 and 8) shows that there was considerable movement of clipped fish from transect A to transect B and vice versa, from transect A to transect C and vice versa and from B to C and vice versa. The shortest time recorded for a tagged perch to move from transect C to transect A was five days. Most tagged perch recaptured had moved from the station of release to another station, within two to three weeks from tagging and release.

Regeneration of fins

The low mortality of the clipped perch (Table 39) shows that the clipping of posterior dorsal, upper and lower lobes of caudal fin was very successful. Almost all clipped fins of fish taken in 1967 were found to have regenerated by the next spawning period, in 1968. Each regenerated fin was, however, smaller than normal and had not grown perfectly (Stuart, 1958). Thus, normally a little distortion had taken place beyond the line of the cut causing a permanent slight expansion of the fin as well as making the mark more easily visible. Because of these characters all regenerated fins were identifiable.

Discussion

The main physico-chemical factors of both Dubh Lochan and Loch Lomond, though the former is rather nutrient poor, suggest that both are suitable habitats for a number of fish species. Because of the low fishing rate there, the Dubh Lochan seemed a most useful water to attempt a mark-and-recapture experiment to establish the size of the fish population.

Large populations of perch were found in both lochs during the present investigation. Many of the data show that both waters exhibit similar features to those in similar environments in other countries. Variations were found in the year-class composition of both Loch Lomond and the Dubh Lochan populations. Alm (1952), Le Cren (1955) and McCormack (1965) have all shown that variations in the year-classes in perch populations are very common.

Le Cren (1965) has found that in Windermere there is no correlation between the number of female perch that spawned and the year-class strength. Ninety per cent of the fertilized eggs hatch in the Dubh Lochan and therefore the size of future year-classes appears to depend, not on the mortality of fertilized eggs, but on probably varying rate of mortality which occur in the first few weeks after hatching (Le Cren, 1965). Pike appear to be the main predators of perch in the Dubh Lochan but their number there is small and the luxurious growths of vegetation in the loch during summer makes predation on perch fry difficult. Cannibalism appears to be of little importance. It is unlikely that either of these mortality factors is the principal reason for the variation in the survival rate of perch fry.

Variations in the year-classes of perch have been found to be synchronous in many waters (Le Cren, 1965). This would suggest that climatic and possibly subsequent energy flow relationships may be important factors. Long term observations are necessary, however, to correlate these with the characteristics of perch populations in the Loch Lomond area.

The mortality and growth of perch in the Dubh Lochan are such that the maximum biomass of a brood is reached at an early age and small size (year III or earlier; 9.2 cm). In Loch Lomond, besides natural mortality, there is considerable angling for perch, especially in the lowland part of the loch during summer (the population of perch seems to be larger in the lowland than in the highland part of Loch Lomond), where most of the perch for the present study were caught.

Although perch is considered to be a schooling fish, many single perch were caught in gill-nets in the highland part of the loch. This shows that the schooling behaviour is not strictly followed and individuals may often stray from the school.

Differential behaviour between the sexes exists during the spawning period. More males appear to stay continuously on the spawning ground than females.

More male perch than females were caught in the traps in the Dubh Lochan. The small number of female perch, too, caught in gill-nets in Loch Lomond, is also probably due to the fact that netting was carried out mainly during the spawning period.

The average number of eggs per kilogram of fish was slightly less in the case of Loch Lomond perch than in those from the Dubh Lochan and several other differences in the two populations were found but in other respects they were similar. For example, among fish of the same size, fecundity was found to have little relation to age both in Loch Lomond and in the Dubh Lochan and it varied greatly. Factors such as food supply and temperature at the time of growth may have been responsible (Simpson, 1951).

Alm (1946) and Le Cren (1958) both found that population density has no effect on first-year growth and little effect on second-year growth. The present results from the Dubh Lochan agree with this. Dubh Lochan perch showed stunted growth from the third year onwards. Four possible reasons can be put forward for such stunting: (a) the very low water temperature in the early part of the year; (b) the absence of suitable prey-fish of a small size (e.g. sticklebacks, minnows and small cyprinids); (c) the abundance of aquatic plants in summer, making it difficult for medium-sized and large perch to prey upon young of their own species, and (d) a very dense population of perch, among which there is probably considerable competition for the available larger food organisms.

Many factors, physical and chemical, may exercise direct or indirect control over the growth-rate of fish. Besides food and population density, temperature is a factor that has been recognised to be of primary significance in this respect. Le Cren (1958) has shown that temperature is of great importance in the growth of perch, and that differences in the growth of year-classes may well be due simply to temperature differences in the years concerned. No records of temperature in the Dubh Lochan prior to the present study are available and it is not therefore possible to examine directly the relationship between temperature and the growth of perch there.

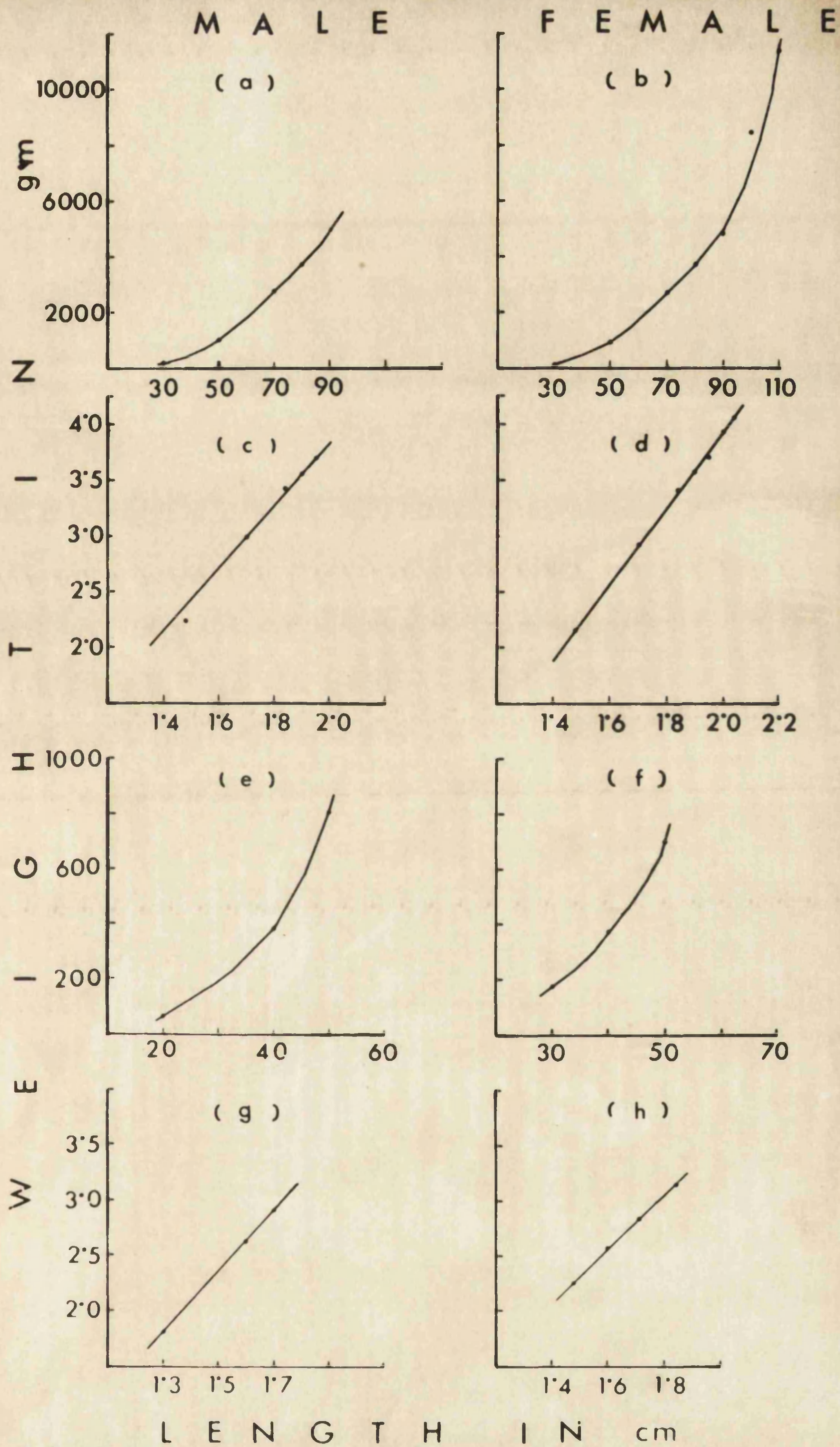
Female perch in both Loch Lomond and the Dubh Lochan grow larger than males. The males in both places, however, mature when two years old and the females when three years old. These observations agree with those on perch populations in other waters (e.g. Le Cren, 1958).

Neither Loch Lomond nor Dubh Lochan perch follow the Von Bertalanffy growth formula; this again compares with perch from Windermere and the River Thames. Ullswater perch, on the other hand, do follow this growth formula very well. Le Cren (1958) has suggested that the change in diet with increase in size as a reason for the growth pattern of Windermere perch.

Any experiment involving a reduction of the perch population in the Dubh Lochan would not necessarily disturb the food relationships among the remaining fish there. Though perch appears to be the dominant food item of eels in the Dubh Lochan, this result was based on eels, caught in perch traps, where perch would be easily available as food and Frost (1946) found that only one per cent of eels in Windermere feed on perch. The pike population in the Dubh Lochan is very small and would probably be influenced by a reduction in the perch.

Although outside the scope of this study it may be noted that in 1967, fertilised eggs from Dubh Lochan perch were planted in a small pond near Milngavie, Dunbartonshire, which has no perch population. Eggs from Loch Lomond perch were planted at the same time in a similar small pond in the same area. If these fish have survived it is hoped that data obtained on their growth may provide extremely interesting comparisons with each other and with the parent

Figure 38. The length-weight relationship of male and female pike of Loch Lomond (a, b, c and d) and the Dubh Lochan (e, f, g and h): (a, b, e and f) length against weight, on arithmetic scale; (c, d, g and h) length against weight on logarithmic scale.



M A L E
F E M A L E
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
W E I G H T I N gm
10000
6000
2000
30 50 70 90
30 50 70 90 110
4·0
3·5
3·0
2·5
2·0
1·4 1·6 1·8 2·0
1·4 1·6 1·8 2·0 2·2
1000
600
200
20 40 60
30 50 70
3·5
3·0
2·5
2·0
1·3 1·5 1·7
1·4 1·6 1·8
L E N G T H I N cm

populations and will help to show whether or not the growth-rate is influenced by genetic factors.

PIKE (*Esox lucius* L.)

Length-Weight Relationship of Pike

Dubh Lochan

The lengths of male and female pike, when plotted against weights (Fig. 38e, f) on an arithmetic scale, give curves suggesting a cube-relationship. When the logarithm of length is plotted against the logarithm of weight (Fig. 38g, h), a straight line is obtained for each sex showing a similar length-weight relationship. The length-weight relationship of male and female pike was calculated using the formula log W = log a + b log L, when, W = weight, L = length, a = a constant and b = an exponent ideally equal to three (Frost, 1967). The equations for males and females obtained from the length-weight relationship are as follows:

Mature male: $\log W = -2.6566 + 3.3471 \log L$

Mature female: $\log W = -2.4464 + 3.2400 \log L$

When tested statistically it was found that there was no significant difference between regression coefficients 'b' of male and female fish. The regression coefficient 'b' of male pike was significantly different from three but 'b' of female was not significantly different from three. Frost (1967) found that 'b' of both male and female pike from Windermere differed significantly from three.

Loch Lomond

Figure 38a, b, c and d, suggests that the lengths and weights of pike from Loch Lomond follow a cube-relationship. The correlation coefficients 'b' of male and female pike, caught in late April and May, were calculated from the formula log W = log a + b log L and the equations for each sex are as follows:

Mature male: Log W = -2.6141 + 3.2951 log L

Mature female: Log W = -2.2196 + 3.1147 log L

When tested statistically it was found that, as in the Dubh Lochan pike, there was no significant difference between the 'b' of males and females. However, the regression coefficients 'b' of both males and females do not differ significantly from three, i.e. the Loch Lomond pike follow the cube-law closely. A comparison of the value of 'b' for pike from different waters is given in Table 41. Male and female pike from Windermere do not follow the cube-law exactly. The pike of Loch Choin, however, a Scottish water

(Munro, 1957) seem to follow the cube-law closely and their length-weight relationship is similar to that of Loch Lomond fish.

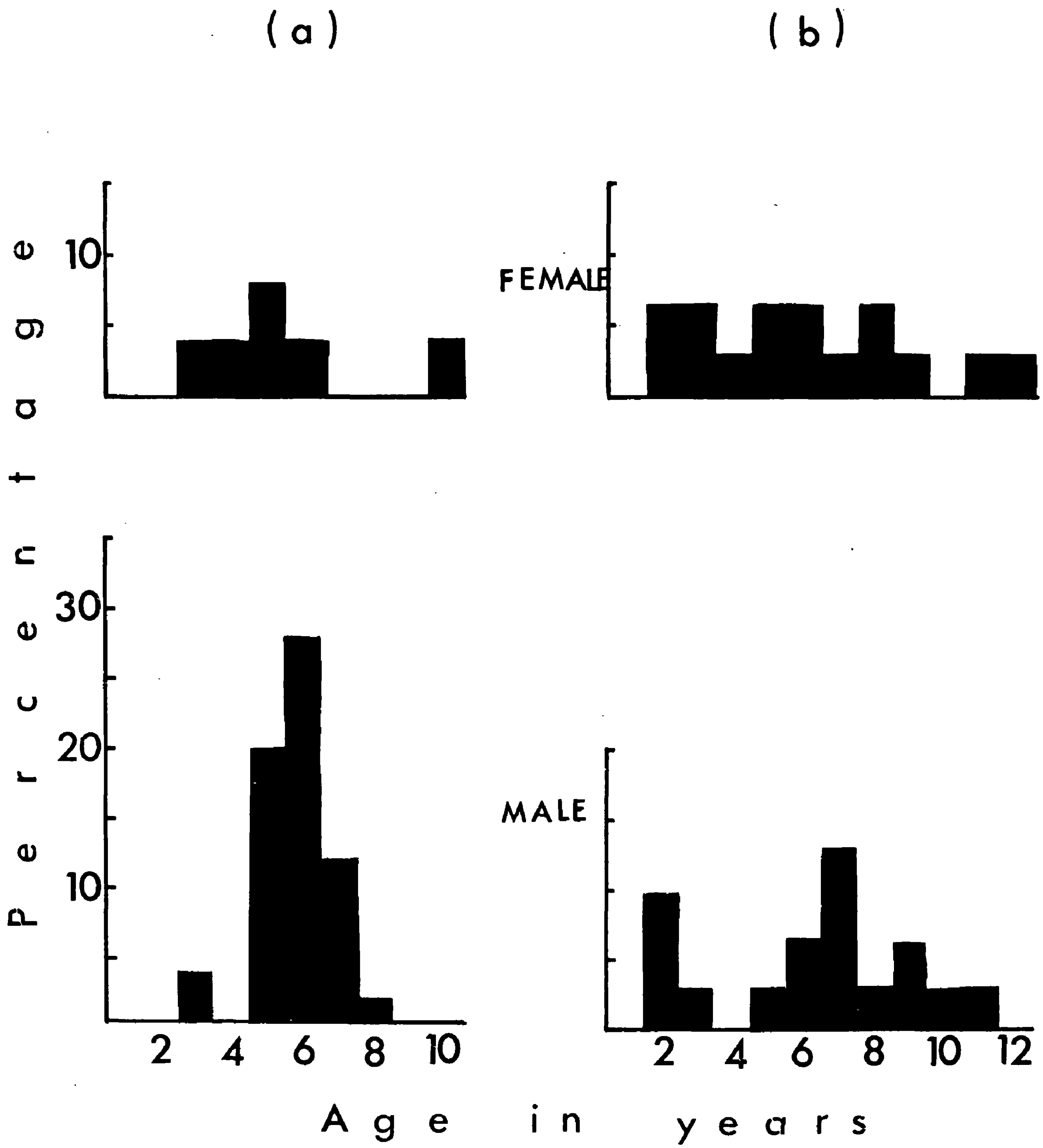
Determination of the Age and Growth of Pike

Dubh Lochan

The proportional relationship between the growth of the opercular bone and the fish was found by the method described by Frost (1959). The projected images of the opercular bones of twenty-two fish ranging in size from 20 to 70 cm were measured from the chosen centre (Frost, 1959) to the posterior edge of the bone. When the opercular lengths were plotted against fish lengths, the points lay on a straight line. A regression line was calculated based on the mean opercular lengths and mean fish lengths. The estimated regression line shows that the length of the fish and the opercular bone grows isometrically, i.e. the opercular bone grows in direct proportion to the fish throughout life.

Frost (1959) has established that the growth patterns on the opercular bones of pike are of an annual character. In the present work some evidence was also obtained to show that the different zones on the opercular bones of pike are formed annually: (a) the opercular bones of one small (14.3 cm) pike, caught in the Dubh Lochan, had no

Figure 39. The percentage age distribution of pike in (a) the Dubh Lochan and (b) Loch Lomond caught during 1966-1968.



(a)
(b)
FEMALE
MALE
Percentage
10
30
20
10
2
4
6
8
10
2
4
6
8
10
12
Age in years

Figure 40. Growth in length of pike from various waters: (a) Lough Rea, males and females (Healy, 1956); (b) Lake Mendota, males and females (Van Engel, 1940); (c) Windermere females, 1939-59 (Frost, 1967); (d) Loch Lomond females; (e) Windermere males, 1939-59 (Frost, 1967); (f) Loch Lomond males; (g) Dubh Lochan females; (h) Loch Choin, males and females (Munro, 1957); (i) Dubh Lochan males; (j) Great Slave Lake (Miller & Kennedy, 1948); and (k) Wisconsin waters (Van Engel, 1940).

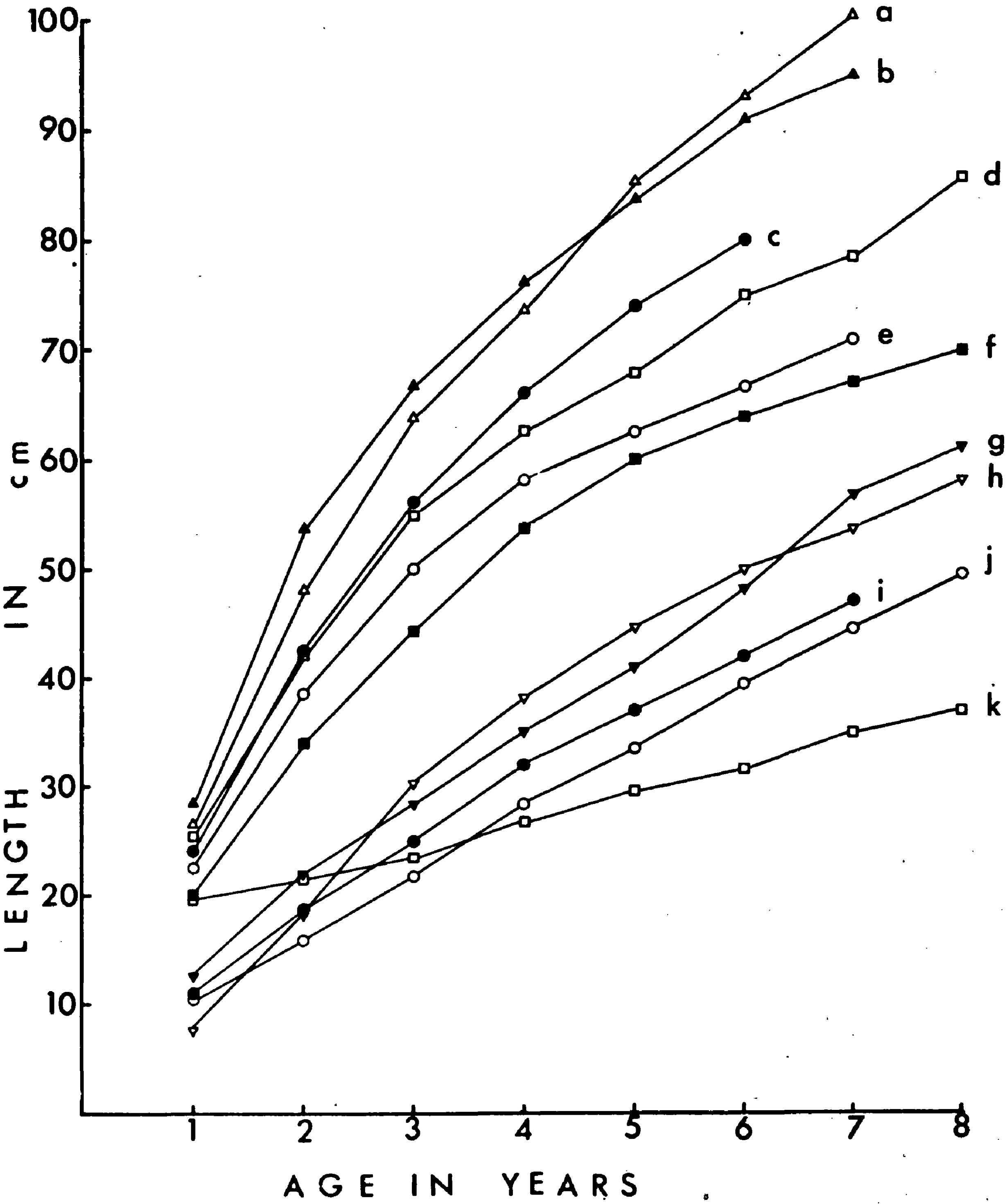
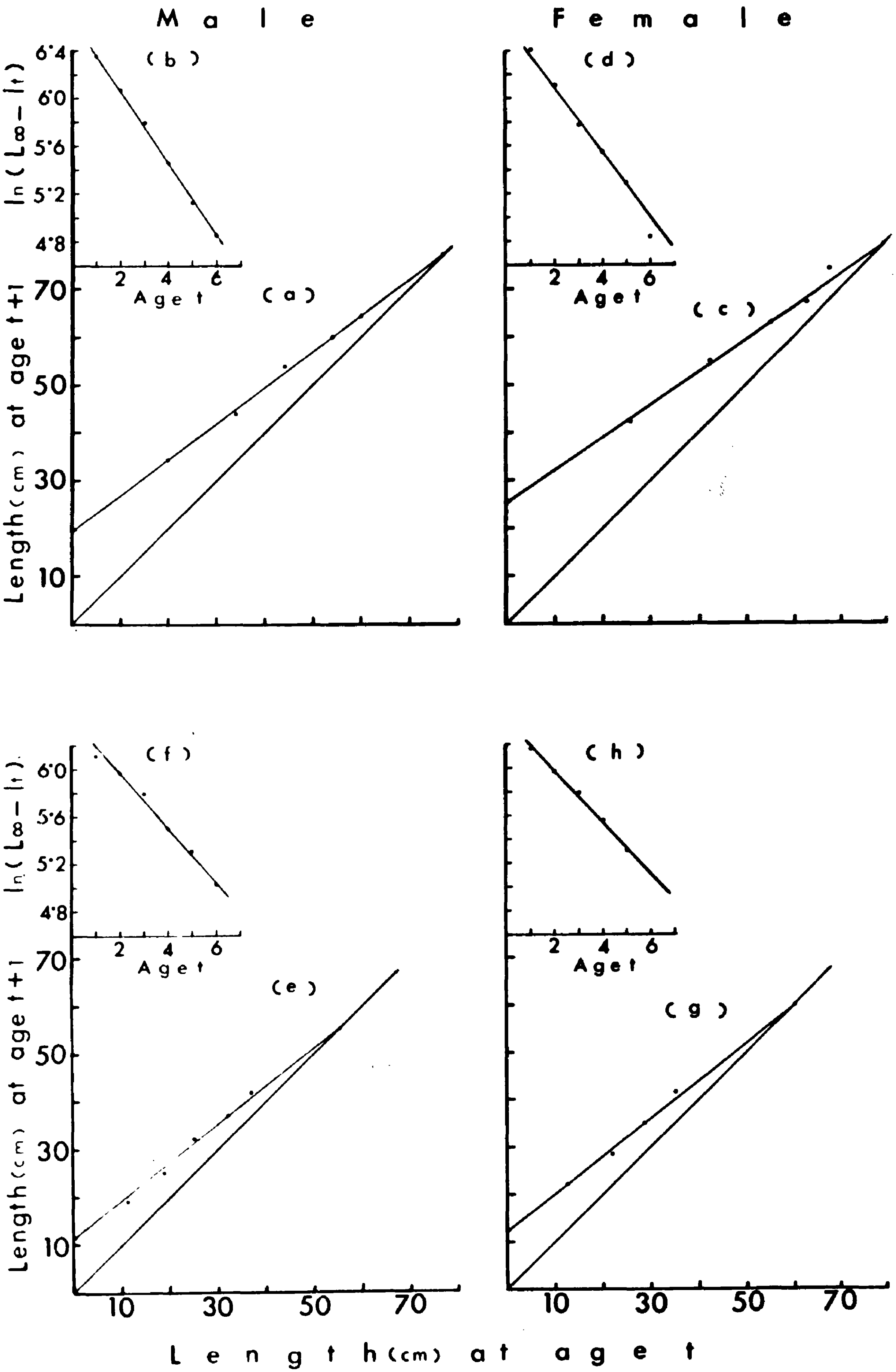

LENGTH IN cm
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7
8
AGE IN YEARS
a
b
c
d
e
f
g
h
i
j
k

Figure 41. Walford plots (a, c, e and g) and plots of ln (l_{∞}-lt) against age t (c, d, f and h) for male and female pike of Loch Lomond (a, b, c and d) and the Dubh Lochan (e, f, g and h).


Male
Female
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
ln(L∞ − lt)
Age t
Length(cm) at age t+1
Length(cm) at age t
6·4
6·0
5·6
5·2
4·8
2
4
6
70
50
30
10

annulus; (b) the growing edge of the opercular bones of pike taken in summer and winter showed opaque white zones and transparent dark zones respectively; and (c) as shown in Table 10 the actual lengths of two pike at the time of tagging agreed well with the lengths back-calculated from the opercular bones at the time of recapture. It is, therefore, assumed that the winter rings are of annual occurrence.

All pike caught in the last week of April and in May had plus growth on the edge of their opercular bones. It would appear that the summer ring is probably started in late April. In Windermere pike (Frost, 1959) the summer ring is started in early May.

Age

The oldest pike caught was a female ten years old while the oldest males were three fish of seven years. Figure 39a shows the age distribution of pike caught in gill-nets and traps in the Dubh Lochan.

Growth

The results obtained from the back-calculation of growth from the opercular bones of pike from the Dubh Lochan are given in Table 42 and Figure 40g and i. The pattern of growth was the same throughout life except in two pike in which the pattern of growth changed between the fourth and fifth years. The growth-rate appeared to be determined in the first year (i.e. slow growth in this year was never followed by fast growth in later years, and vice versa) which may be determined by availability of food or perhaps by genetic factors. From Table 42 it can be seen that females mostly grow slightly longer than the males. Frost (1963) found that pike in Windermere grow at the same rate up to the age of three years but thereafter the females grow faster than males.

From the final Walford plots (Fig. 41e and g), based on the mean growth of males and females, the trial final lengths (l_∞) were found (Rounsefell & Everhart, 1965). These trial final lengths (l_∞) were then checked by plotting log ($l_\infty - l_t$) against age for fish for each sex; adjustments being made where necessary until the best fitting values of final length (Fig. 41f and h) and values of K were obtained (Ricker, 1958). The formulae found for each sex were as follows:

Male $l_t = 57.5\,(1-e^{-0.22t})$

Female $l_t = 61.0\,(1-e^{-0.22t})$

The growth of pike in the Dubh Lochan is much slower than that in Windermere. Figure 40 shows that the first two years of growth here was greater than that of pike in Loch Choin (Munro, 1957) but the latter grew faster from the third to sixth year. The growth of pike in Great Slave Lake (Miller & Kennedy, 1948) was less throughout the life than that of fish in the Dubh Lochan. With the exception of the first year, the Dubh Lochan pike always grow much faster than pike in some Wisconsin waters (Van Engel, 1940).

Since perch are present in the Dubh Lochan in large numbers, its pike might be expected to grow faster than those in Loch Choin which contained no other species except for a few eels. Van Engel (1940) and Miller & Kennedy (1948) found that the rate of growth of pike varies inversely with latitude. The Dubh Lochan though it has a similar latitude to Athabaska and Lesser Slave Lake (Miller & Kennedy, 1948) is further south than Loch Choin. The dissimilarity of climates of continental and island lakes will over-rule any effect of latitude.

Loch Lomond

As with pike from the Dubh Lochan the proportional relationship between the growth of the opercular bone and the fish was investigated. The opercular bones of seventeen pike from Loch Lomond ranging in size from 28.5 to 74.5 cm were measured as described above and the opercular length, when plotted against fish length gave a straight line. A regression line was calculated and the same result obtained. This shows that in Loch Lomond pike, too, the opercular bone grows in direct proportion to the length of the fish.

All pike caught in Loch Lomond in the last week of April and May showed plus growth. It is assumed that as in the case of the Dubh Lochan pike the summer ring of the opercular bones of Loch Lomond pike first appears in late April.

Age

The oldest pike from Loch Lomond was a female aged twelve years and the oldest male eleven years. Loch Lomond is well known for very large pike but none were caught during the present work. The age-distribution of pike caught in Loch Lomond is given in Figure 39b.

Growth

The results obtained from back-calculations of growth using the opercular bones are given in Table 43 and Figure 40d and f. As with the Dubh Lochan pike the pattern of growth once established appeared to be the same throughout life. From Table 43 and Figure 40 it was found that females grew quicker and were thus larger than the males throughout life. This divergence between the sizes of the two sexes became greater in succeeding years; in this the pike of Loch Lomond resemble those of Windermere (Frost, 1965) and of Loch Choin (Munro, 1957).

From the final Walford plots (Fig. 41a and c), based on the mean growth of males and females, the trial final lengths ($l\alpha$) were obtained (Rounsefell & Everhart, 1965). These trial final lengths ($l\alpha$) were then checked by plotting log ($l\alpha - lt$) against the age of fish of each sex; adjustments being made where necessary until the best fitting value of final length (Fig. 41b and d) and value of K were obtained (Ricker, 1958). The formulae found for each sex of pike are as follows:

$$\text{Male } lt = 77.0\ (1-e^{-0.30t})$$

$$\text{Female } lt = 87.0\ (1-e^{-0.31t})$$

A comparison of the growth in length of Loch Lomond pike with pike from other waters is given in Figure 40. This shows that Loch Lomond pike grow slightly less in length than those of Windermere (1939-59). However, the Dubh Lochan and Loch Choin (Munro, 1957) pike grow very slowly in comparison with the Loch Lomond pike. According to Frost (1965) the published data on the growth of pike in East Anglia (Hartley, 1947) is doubtful as Hartley probably overestimated the age of most of his fish. These data are not, therefore, included here. The pike of Lough Rea (Healy, 1956) and Lake Mendota (Van Engel, 1940) grow faster than those of Loch Lomond.

A comparison (Fig. 42) of the growth in weight of Loch Lomond pike with that of pike in Windermere (Frost, 1963) shows that females are heavier than males of the same age in both waters. Windermere males were heavier than the males of Loch Lomond up to the age of five years; afterwards the latter were always heavier. In the first four years and again after the age of seven years the female pike of Loch Lomond weighed much more than the females of Windermere.

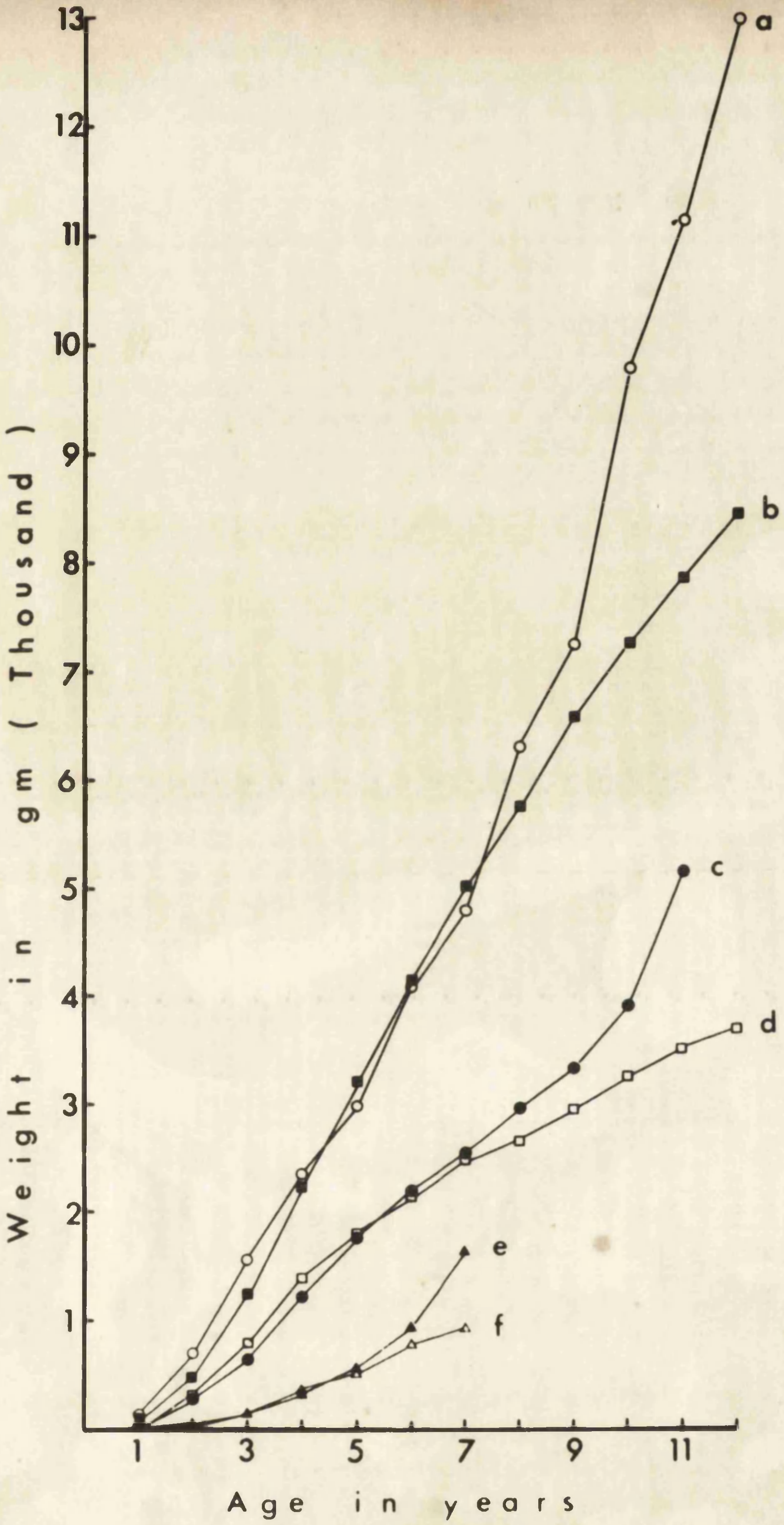
Figure 42 also shows that the weights of female pike from the Dubh Lochan and those of Loch Choin (Munro, 1957) were similar up to the age of the first five years; afterwards the Dubh Lochan females were always heavier.

Food of Pike

Dubh Lochan

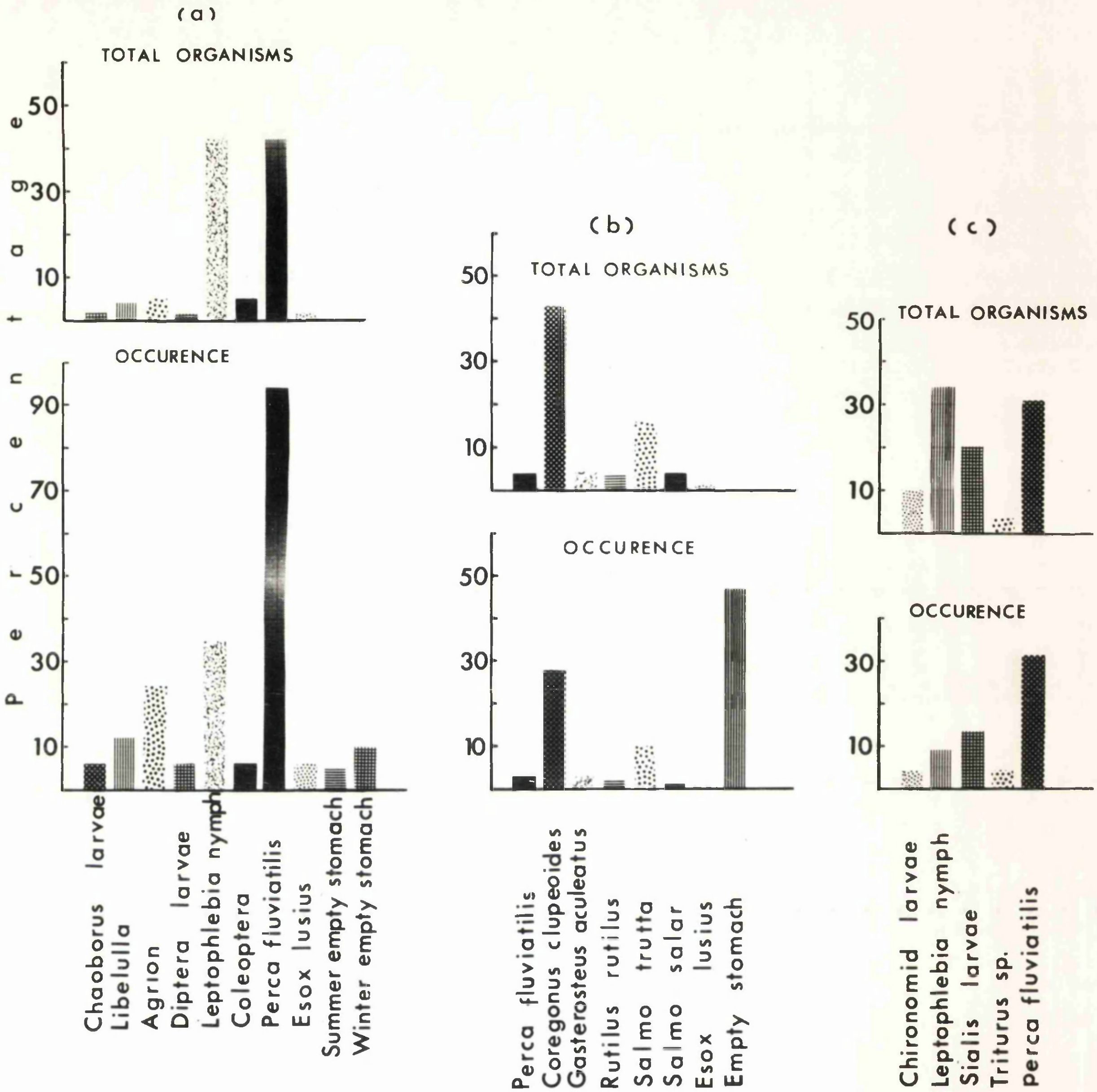
The stomachs of twenty-two pike from the Dubh Lochan were examined. The percentage of total food organism and percentage occurrence of food organisms in these

Figure 42. Growth in weight of pike from various waters: (a) Loch Lomond females; (b) Windermere females, 1930-39 (Frost, 1963); (c) Loch Lomond males; (d) Windermere males, 1930-39 (Frost, 1963); (e) Dubh Lochan females and (f) Loch Choin males and females (Munro, 1957).



Weight in gm (Thousand)
1
2
3
4
5
6
7
8
9
10
11
12
13
1
3
5
7
9
11
Age in years
a
b
c
d
e
f

Figure 43. The percentage of total food organisms and percentage occurrence of organisms from stomachs of pike of (a) the Dubh Lochan and (b) Loch Lomond and of (c) eels of the Dubh Lochan.



(a)
TOTAL ORGANISMS
OCCURENCE
Percentage
10
30
50
70
90
Chaoborus larvae
Libelulla
Agrion
Diptera larvae
Leptophlebia nymph
Coleoptera
Perca fluviatilis
Esox lusius
Summer empty stomach
Winter empty stomach
(b)
TOTAL ORGANISMS
OCCURENCE
Perca fluviatilis
Coregonus clupeoides
Gasterosteus aculeatus
Rutilus rutilus
Salmo trutta
Salmo salar
Esox lusius
Empty stomach
(c)
TOTAL ORGANISMS
OCCURENCE
Chironomid larvae
Leptophlebia nymph
Sialis larvae
Triturus sp.
Perca fluviatilis

stomachs are given in Figure 43a. It can be seen that though Leptophlebia nymphs and perch were eaten by pike in equal number the fact that the percentage occurrence of the larger food organisms, perch, was the highest indicates that this is the most important food of pike in the Dubh Lochan.

Perch were eaten by all sizes above a length of 19 cm; and perch and pike constituted the main food of pike above 39 cm in length, with invertebrates in the smaller fish (Leptophlebia, Libellula and Agrion). Ten per cent of the stomachs of pike were found to be empty.

In Windermere pike longer than 30 cm (Allen, 1939) or 20 cm (Frost, 1954) feed mainly on fish. Pike smaller than 20 cm feed on invertebrates (Frost, 1954) as in the Dubh Lochan. Invertebrates formed a significant part of the diet of Irish pike up to 60 cm in length (Healy, 1956). Fish were the main diet of pike larger than this.

A few pike only were recorded from the stomachs of both Irish and Windermere pike whereas cannibalism by pike in Loch Choin (Munro, 1957) was very common. One pike 24.2 cm in length was recorded from the stomach of another pike of 49.3 cm from the Dubh Lochan. Frost (1954) found a few eels in the stomachs of pike in Windermere while

Munro (1957) found unusual numbers of frogs in the stomachs of pike from Loch Choin. However, neither were found in the stomachs of pike in the Dubh Lochan, although eels and toads occur in some numbers there.

Loch Lomond

The data on the stomach contents of 193 pike from Loch Lomond, caught mostly in gill-nets from 1955 to 1967 are given in Table 45 . All these fish, ranging in length from 22 to 108.5 cm, were caught from October to April. The percentage frequency of occurrence of each food organism (Fig. 43b) shows that the food consisted mainly of fish and that powan were eaten by the highest number of pike. Trout was the next most important food while perch, roach and sticklebacks were eaten to some extent.

Frost (1954) found that perch, trout and char were the main food of Windermere pike. Cannibalism was negligible and the eel was of no importance as a food in both Loch Lomond and Windermere. Perch, trout and pike were the main food of pike over 60 cm in Irish waters (Healy, 1956). Perch (Frost, 1954) were the main food of pike in Windermere, especially from May to September. No pike were caught in Loch Lomond during these months. Although powan and trout were eaten in highest numbers by pike in Loch Lomond in each of the seven months of the samplings from October to

April, it is likely that perch are important during the summer months when they would be present in shallower water. However, Copland (1956) found that powan were also eaten in large numbers in summer by pike in Loch Lomond. Robertson found one powan in the gut of a pike from Loch Lomond as early as 1886. All these records show that powan is the main food of pike in Loch Lomond throughout the year.

Forty-seven per cent of the stomachs of pike of Loch Lomond were empty in winter and spring (October to April). Frost (1954) found that forty-eight per cent of pike stomachs in Windermere were empty in winter (November to March) and 47.5 per cent in summer (April to October). Healy (1956) found very high percentages of empty stomachs in some Irish pike which were caught by gill-nets.

Population Estimates of Pike in the Dubh Lochan

The mark and recapture method used for perch in the Dubh Lochan, was also employed with pike there and the population was estimated from the formula $P = \frac{\Sigma AB}{\Sigma C}$, as explained above. In 1967, the experiment was carried out for two months from April 15 to June 15 (Table 44), a period when pike were likely to be caught in shallow water. During this time fifty-one pike were caught by gill-nets and in traps, of which thirty-nine were tagged by the method described.

The external tag in front of the dorsal fin was found not to be suitable for this species, for in several cases the flesh round the wire, instead of healing, developed into an open sore. However, all tagged pike recovered were still carrying their tags one year after tagging. In 1968, the estimate was repeated from April 12 to June 8 (Table 44) and thirty-six pike were tagged during this period.

The estimated population in both years shows that the Dubh Lochan has a very small population of pike. It is also indicated by the high percentage recapture of tagged pike (Table 37) and the periodic recapture of some fish.

A summary of the population estimate of adult pike along with the ninety-five per cent confidence limits and standard errors are given in Table 35. The limits of confidence were calculated by taking recapture (ΣC) as a Poisson variable (Ricker, 1958). The standard error was estimated from the reciprocal of P (Ricker, 1958). The data of both years establish the small size of the population.

Fecundity of Pike of Loch Lomond

The fecundity of twelve female pike whose lengths ranged from 42.8 to 99.5 cm, was studied. These fish were caught in gill-nets from December to February, 1966-1967. The ovaries of these fish were treated in the same way as those of perch. The dried weights of the smaller (100 eggs) and larger portion of each ovary were then measured using a Mettler balance and the total number of eggs calculated by proportion.

The average number of eggs in the ovary of a female pike from Loch Lomond was 83,104, for a fish with an average length of 60.8 cm and an average weight of 2,831 gm. The mean number of eggs was twenty-nine per gram of body weight. This agrees closely with that of Windermere pike (Frost, 1967) which produce an average number of twenty-seven per gram of body weight. The average number of eggs per kilogram of body was 29,355 in Loch Lomond, 26,455 in Windermere (Frost, 1967) and 28,100 in Lough Rea (Healy, 1956). Pincher (1947) who counted the number of eggs of four ovaries and found that the average number per kilogram of body was 35,200.

There was a wider range in the number of eggs from fish of almost similar size in Loch Lomond, as observed by

Carbine (1944), Carlander (1950) and Frost (1967) in pike from a variety of other waters.

Discussion

The present population estimate for pike in the Dubh Lochan shows that the population there is not a large one. However, it compares quite favourably with the few other detailed studies. Thus Munro (1957) found a standing crop of only 4.8 lb/acre or 2.2 kg/acre of pike in Loch Choin. The present results show that the standing crop of pike in the Dubh Lochan (6.8 lb/acre or 3.1 kg/acre) was more than this in 1967 (Table 35).

The Dubh Lochan is occupied by several species of aquatic birds during spring and summer every year. A few of these birds are known to eat both perch and pike. One red-breasted merganser was caught in a gill-net left over-night in the shallow water for pike. The stomach of this bird was empty. However, it has been shown by Mills (1964) that in the River Bran over sixty-two per cent goosanders were feeding on perch and six per cent on pike. Predation by such birds could therefore add to the natural mortality of pike (and perch) in the Dubh Lochan.

The length-weight relationships of pike in Loch Lomond is similar to those of pike from Loch Choin (Munro, 1957), another Scottish loch; all of them follow the cube-law closely. Windermere pike do not do this (Frost, 1967). However, like Windermere pike, both Loch Lomond and Dubh Lochan pike follow Ford-Walford's plot quite well. The pattern of growth was the same throughout the life in both waters, again agreeing with Frost's finding. Much variation in the growth-rate during the first few years was found in Loch Lomond and the Dubh Lochan, in particular between the lengths of 20 to 40 cm; it is not possible to say with certainty to which age-group any fish between these two lengths belongs. This varying rate of growth was also observed by Frost (1959) in Windermere pike and may be related to food supply or some genetic factors.

Female pike, both in Loch Lomond and in the Dubh Lochan, grew faster than the males throughout life. Both sexes in Windermere (Frost, 1963), however, grow at the same rate up to the age of three years and thereafter the females grow faster.

Though perch constituted the main diet of adult pike in the Dubh Lochan, powan and trout (both absent from the Dubh Lochan) were the main food of adult pike in Loch Lomond. According to Frost (1954) seasonal changes in the diet of pike in Windermere are almost entirely governed by the availability of the fish food species. Powan are present at certain times of the day in considerable numbers in the littoral zone of Loch Lomond and pike prey on them, especially in December and early January, when the powan are spawning in shallow water (Maitland, 1969).

Observation on the Population of Eels (Anguilla anguilla L.) in the Dubh Lochan

Thirty-one eels were caught and tagged in the Dubh Lochan in 1967, but none of these was ever recaptured. No explanation can be offered for this. It appears probable, however, that there are more eels in the Dubh Lochan than pike. The eels were always caught in perch traps and occurred there more frequently than pike. Sometimes several eels were taken in one trap. Most of the eels caught were quite large ranging from 23 to 68 cm in length and 41 to 475 gm in weight.

Twenty-two eels were caught in traps in 1968. Their length varied from 33 to 60 cm. The stomachs of these fish were analysed for food and the results are given in Figure 43c. Perch appeared to be the dominant food item, though it is uncertain whether this was due to the fact that these were easily available inside the trap. (The number of eels feeding on fish in Windermere was negligible, only one per cent having eaten perch there (Frost, 1946).)

Leptophlebia nymphs, chironomid and Sialis larvae were eaten by eels in the Dubh Lochan and in Windermere. A newt (Triturus helveticus) was recorded from the stomach of one eel from the Dubh Lochan.

CONCLUSIONS

Thus the present study puts forward data relating to the populations of perch and pike in two lochs, which though in very close geographical proximity, afford very different habitats for these fish. The Dubh Lochan is a small distrophic fairly uniform environment in which only one other species of fish (eel) is present. Loch Lomond, on the other hand, is the largest loch in Great Britain, presents a variety of different habitats within it and contains some thirteen other fish species. Human influence, virtually absent from the Dubh Lochan, may be important in Loch Lomond, at least in some parts of the southern basin.

As might be expected, the populations in these lochs show considerable differences from each other. A distinct contrast in diet in both species is clearly likely to be related to the differential availability of food items in the two waters. Other differences, notably in growth, are apparent and may or may not be related to the question of food. Many of these have already been presented and discussed in some detail.

In drawing any final general conclusions about the results, the question of the 'success' of the two species in the lochs is worth considering briefly. Conventionally, the populations of both perch and pike in Loch Lomond might be considered the more successful for both species show rapid growth here and may reach individual lengths and weights as large as found elsewhere in the British Isles. Thus from the commercial (equated here to angling) viewpoint both species are more successful than in the Dubh Locha, where perch in particular are very stunted. Another, and more realistic, criterion of success is the actual standing crop of fish flesh per unit area in the two lochs. Though detailed standing crop figures for perch and pike are not available for Loch Lomond it is virtually certain that, considering the loch as a whole, they will be considerably less for both species than in the Dubh Lochan. The Dubh Lochan though poor chemically and with fish which are stunted individually, is able to maintain standing crops of both perch and pike higher than those in Loch Lomond and in several other waters in this country.

SUMMARY

1. The populations of perch (*Perca fluviatilis* L.) and pike (*Esox lucius* L.) in Loch Lomond and in the nearby Dubh Lochan were investigated using methods appropriate to the parameters being measured.

2. The length-weight relationships of perch from both lochs were determined from a series of regressions of log weight on log length. There was no significant difference between the coefficients 'b' of male and female perch from both lochs. The coefficients 'b' of both sexes of perch were always significantly different from three.

3. The opercular bones of perch were used to study age and back-calculated growth. The bones from both places showed isometric growth. All available evidence showed that such back-calculation of growth are accurate. Growth in the Dubh Lochan was slower than in Loch Lomond, after the first two years which was fairly good in both waters.

4. The growth of perch in both Loch Lomond and the Dubh Lochan does not follow the Von Bertalanffy growth formula.

5. Male and female perch in both lochs mature when two and three years old respectively.

6. The seasonal cycle in the condition of perch at both places was investigated, using the relative condition factor; this was at a maximum in September-October and a minimum in June.

7. The eggs of the Dubh Lochan perch were slightly but significantly larger than those from Loch Lomond. A low mortality rate between laying and hatching was assessed.

8. The fecundity of female perch in both lochs was studied. The average number of eggs per kilogram of fish was 141,923 in the Dubh Lochan and 124,831 in Loch Lomond. The fecundity in the Dubh Lochan followed the cube of the length but that in Loch Lomond increased at a little less than the cube of length. The relationship between fecundity and weight was linear for Dubh Lochan females but non-linear for Loch Lomond females. There was no difference in the gonad/flesh weight ratio in the different age-groups of females of both places.

9. The food of a total of 1,269 perch from both places was studied, using the number, occurrence and points methods. Holopedium, Cyclops and Daphnia were the important foods of perch fry in the Dubh Lochan, and Leptophlebia, Chaoborus and Chironomidae of adults there. Daphnia, Cyclops and Chironomidae were the main foods of perch fry in Loch Lomond while Cyclops, Gammarus, Chironomidae, Corixa and three-spined sticklebacks were the main food of adult perch there.

10. The population of adult perch in the Dubh Lochan was estimated at 1,649 fish or 33.9 kg per hectare in 1967 and 1,695 fish or 39.4 kg per hectare in 1968.

11. Mortality and growth of perch in the Dubh Lochan were such that the maximum biomass of a brood was reached at an early age and a small size (year III or earlier, 9.2 cm).

12. The length-weight relationship of pike were as follows:

Dubh Lochan

Mature male: $\log W = -2.6566 + 3.3471 \log L$

Mature female: $\log W = -2.4464 + 3.2400 \log L$

Loch Lomond

Mature male: $\log W = -2.6141 + 3.2951 \log L$

Mature female: $\log W = -2.2196 + 3.1147 \log L$

13. The age and growth of twenty-four pike from the Dubh Lochan and thirty-two pike from Loch Lomond was studied from opercular bones and estimations were confirmed from recaptured tagged pike from the Dubh Lochan and other sources. The pattern of growth was found to be the same throughout life. Females always grew more than the males in both places.

14. The growth of pike follows Von Bertalanffy's formula well and the growth formula were as follows:

Dubh Lochan

Male: $lt = 57.5\ (1-e^{-0.22t})$

Female: $lt = 61.0\ (1-e^{-0.22t})$

Loch Lomond

Male: $lt = 77.0\ (1-e^{-0.30t})$

Female: $lt = 87.0\ (1-e^{-0.31t})$

15. The food of twenty-two pike from the Dubh Lochan and 193 pike from Loch Lomond was studied. Perch and *Leptophlebia* nymphs were the main foods of pike above a length of 19 cm in the Dubh Lochan. Cannibalism was negligible. Powan and trout were the main food of pike in Loch Lomond. Ten per cent of the stomachs in the Dubh Lochan and forty-seven per cent in Loch Lomond were empty.

16. Thirty-nine pike in 1967 and thirty-six in 1968 were tagged in the Dubh Lochan during a population experiment based on the mark-recapture method. A very small population of pike was found there, estimated at eighty-nine adult fish in 1967 and fifty-one in 1968.

17. The fecundity of twelve female pike from Loch Lomond was studied. The number of eggs produced per kilogram of body was 29,355, although the relationship was not a close one.

18. In 1967, thirty-one eels from the Dubh Lochan were marked by injecting coloured rubber latex but the experiment was discontinued.

19. The stomachs of twenty-two eels in the Dubh Lochan were found to contain mainly perch, *Leptophlebia*, Chironomidae and *Sialis*.

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APPENDIX

Table 1. Dimensions and situations of Loch Lomond and the Dubh Lochan.

	Loch Lomond	Dubh Lochan
Length	*36.4 Km	419 m (average)
Area	*71.1 sq.Km	68297 m^2
Areas of drainage basin	*699 sq.Km	-
Maximum depth	*192 m	10 m
Average depth	*37 m	4.7 m
Volume	2691 million cu.m	402283 cu.m
Variation in surface level	**1.8 m (June, 1948 to June, 1950)	.75 m (Dec., 1966 Dec., 1967)
Height of surface above mean sea-level on 30-5-1903	*7.3 m	12 m approx.
Latitude	between 56°18½' N and 56°0' N	between 56°7.9' W and 56°8.3' N
Longitude	between 4°31' W and 4°43' W	between 4°36' W and 4°36½' W

*Information derived from Murray & Pullar (1910).

**Information derived from Weerekoon (1956).

Table 2. Mean length of opercular in relation to length of perch (Dubh Lochan and Loch Lomond).

Both Sexes				Male				Female		
Length group (cm)	No.	Mean length (cm)	S.D.	Length group (cm)	No.	Mean length (cm)	S.D.	No.	Mean length (cm)	S.D.
Dubh Lochan, 1967										
5.0	1	2.7	-	8.5	8	4.93	.22	-	-	-
5.5	9	3.08	.12	9.0	18	5.35	.22	-	-	-
6.0	2	3.37	.10	9.5	7	5.64	.12	1	5.75	-
6.5	-	-	-	10.0	2	5.95	.07	1	6.00	-
7.0	5	3.97	.04	10.5	2	6.22	.03	2	6.45	.21
7.5	1	4.55	-	11.0	1	6.50	-	14	6.73	.23
8.0	2	4.92	-	11.5	1	6.80	-	21	7.11	.23
				12.0	1	7.20	-	27	7.44	.20
				12.5	2	7.55	.07	24	7.79	.17
				13.0	2	7.80	.21	14	8.07	.14
				13.5	-	-	-	14	8.36	.36
				14.0	1	8.55	-	1	8.80	-
				14.5	-	-	-	2	9.10	-
				15.0	2	9.12	.18	4	9.55	.13

Table 2. (Continued)

Both Sexes				Male				Female		
Length group (cm)	No.	Mean length (cm)	S.D.	Length group (cm)	No.	Mean length (cm)	S.D.	No.	Mean length (cm)	S.D.
<u>Dubh Lochan, 1967</u>										
				15.5	1	9.55	-	1	9.80	-
				16.0	-	-	-	2	10.25	.21
<u>Loch Lomond (at Field Station), 1967</u>										
5.5	1	3.00	-	13.0	3	7.40	.32			
6.0	5	3.38	.18	13.5	7	7.77	.18			
6.5	-	-	-	14.0	3	8.23	.06			
7.0	2	4.20	-	14.5	3	8.38	.06			
				15.0	3	8.70	.17			
				15.5	2	9.35	-			
				16.0	3	10.36	.03			
				16.5	3	10.53	.03			
				17.0	4	10.85	.21			
				17.5	3	11.43	.03			
				18.0	13	11.80	.16	3	11.76	.14
				18.5	12	12.32	.25	4	12.27	.07
				19.0	13	12.83	.18	6	12.75	.24
				19.5	14	13.32	.22	5	13.24	.10
				20.0	8	13.64	.17	3	13.70	.22

Table 2. (Continued)

Both Sexes				Male				Female		
Length group (cm)	No.	Mean length (cm)	S.D.	Length group (cm)	No.	Mean length (cm)	S.D.	No.	Mean length (cm)	S.D.
Loch Lomond (at Field Station), 1967										
				20.5	5	14.31	.24	8	14.24	.18
				21.0	3	14.71	.21	5	14.77	.13
				21.5	1	15.15	-	1	15.20	-
				22.0	-	-	-	2	15.67	.11
				22.5	1	16.15	-	1	16.25	-
				23.0	-	-	-	1	16.65	-
				23.5	-	-	-	-	-	-
				24.0	-	-	-	1	17.00	-
				24.5	-	-	-	1	17.85	-
Loch Lomond (at Balmaha), 1967										
				13.0	1	7.75	-			
				13.5	1	8.15	-			
				14.0	3	8.60	.06			
				14.5	1	9.00	-			
				15.0	3	9.53	.14			
				15.5	4	9.63	.17			

See Over

Table 2. (Continued)

Both Sexes					Male			Female		
Length group (cm)	No.	Mean length (cm)	S.D.	Length group (cm)	No.	Mean length (cm)	S.D.	No.	Mean length (cm)	S.D.
Loch Lomond (at Balmaha), 1967										
				16.0	10	10.37	.30			
				16.5	22	10.63	.32	1	10.60	-
				17.0	22	11.17	.26	5	11.08	.39
				17.5	16	11.33	.31	6	11.62	.29
				18.0	28	11.80	.25	2	11.92	.04
				18.5	25	12.16	.28	5	12.22	.32
				19.0	16	12.71	.30	5	12.66	.16
				19.5	17	13.22	.29	2	13.22	.18
				20.0	20	13.64	.36	2	13.52	.18
				20.5	6	14.18	.21	3	14.00	-
				21.0	6	14.59	.18	4	14.38	.39

Total numbers of operculars: Dubh Lochan 196 Loch Lomond 389

Table 3. Numbers of points allotted to each stomach according to its fullness and the length of the perch.

Dubh Lochan

Stomach	Length of fish (cm)		
	under 8	8 to 11.6	11.7 and over
full	60	80	100
3/4 full	45	60	75
1/2 full	30	40	50
1/4 full	15	20	25

Loch Lomond

Stomach	Length of fish (cm)		
	under 10	10 to 15	over 15
full	60	80	100
3/4 full	45	60	75
1/2 full	30	40	50
1/4 full	15	20	25

Table 4. Comparisons of values of the regression coefficient (b) obtained by the graphic method and by the method of least squares in regressions of log weight on log length for each group of fish; and the ninety-five per cent confidential limits of the regression coefficient (b).

Time of capture	Value of 'b' graphically	Value of 'b' by the method of least squares regression	Confidential limits of 'b' lower limit	Confidential limits of 'b' upper limit
DUBH LOCHAN				
Male:				
April-May	3.53	3.5493	3.3186	3.7800
August	3.00	3.07977 (8 fish only)	1.1960	4.9636
September-October	3.52	2.91304 (4 fish only)	2.1746	3.6514
All males together	-	3.50321	3.0002	4.0063
Female:				
April-May	3.44	3.4442	2.7191	4.1693
Spent	3.33	3.38307	2.5287	4.2375
August	3.11	3.04769 (7 fish only)	2.5484	3.5469
September-October	3.05	3.0251	2.8004	3.2498
All females together	-	3.30452	2.8087	3.8003
O-group fish, Sept.	-	3.03064	-	-
LOCH LOMOND				
Male:				
April-May	3.28	3.31516	3.0640	3.5663
September-October	3.57	3.52128	2.3597	4.6829
All males together	-	3.39684	2.96165	3.83203
Female:				
April-May	3.33	3.34716	2.5646	4.1297
Spent	3.31	3.3433	2.91372	3.77306
September-October	3.64	3.6071 (9 fish only)	2.0891	5.1251
All females together	-	3.49313	2.8899	4.09636
Fish of exceptionally large size	-	3.09131 (6 fish only)	1.99061	4.19201
O-group fish, Sept.	-	3.1118	-	-

Table 5. Age and year-class composition of collections of perch from the Dubh Lochan and Loch Lomond

Year of capture	Place of capture	Item	AGE-GROUPS												
			O-group	I+& II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XII
1967	Dubh Lochan	No. of fish	12	8	34	42	59	17	11	6	3	-	-	-	-
		% of sample	6.2	4.1	17.5	21.6	30.4	8.8	5.7	3.1	1.5	-	-	-	-
		year-class	1967	1965	1964	1963	1962	1961	1960	1959	1958	-	-	-	-
1968	Dubh Lochan	No. of fish	57	8	51	90	35	15	6	2	2	-	2	-	-
		% of sample	21.3	3.0	19.0	33.6	13.0	5.6	2.2	0.7	0.7	-	0.7	-	-
		year-class	1968	1966	1965	1964	1963	1962	1961	1960	1959	-	1957	-	-
1967	Loch Lomond near Field Stat.	No. of fish	8	16	5	9	16	40	36	16	5	-	-	-	-
		% of sample	5.3	10.6	3.3	6.0	10.6	26.5	23.8	10.6	3.3	-	-	-	-
		year-class	1967	1965	1964	1963	1962	1961	1960	1959	1958	-	-	-	-
1967	Loch Lomond near Balmaha	No. of fish	-	-	11	73	60	69	31	8	-	-	-	-	-
		% of sample	-	-	4.0	28.7	23.6	27.0	12.9	3.0	-	-	-	-	-
		year-class			1964	1963	1962	1961	1960	1959					
1968	Loch Lomond near Balmaha	No. of fish	-	6	257	57	40	17	4	-	-	-	-	-	-
		% of sample	-	1.6	67.3	14.9	10.5	4.4	1.0	-	-	-	-	-	-
		year-class	-	1966	1965	1964	1963	1962	1961	-	-	-	-	-	-
1967	Loch Lomond fish of exceptionally large size	No. of fish	-	-	-	-	-	-	-	1	2	-	-	-	1
		year-class	-	-	-	-	-	-	-	1959	1958				195
1968	Loch Lomond fish of exceptionally large size	No. of fish	-	-	-	-	-	-	-	-	1	-	1	1	
		Year-class									1959		1957	1956	

Table 6. The final mean lengths (cm) of male and female perch from the Dubh Lochan at each age, calculated from the combined mean lengths; the weights (gm) were calculated from the final mean lengths.

Age (years)	1966-1967		1968		Final means	Calculated weight (gm)
Males						
1	5.1	(48)	5.0	(96)	5.05	1.1
2	7.6	(48)	7.5	(96)	7.55	4.5
3	9.3	(48)	9.2	(88)	9.25	9.3
4	10.6	(15)	10.7	(41)	10.65	15.2
5	12.0	(9)	12.0	(11)	12.00	23.0
6	13.0	(5)	13.2	(3)	13.10	31.3
7	13.9	(4)	14.9	(2)	14.40	43.7
8	14.7	(3)	15.9	(2)	15.30	54.0
9	15.5	(1)	17.1	(2)	16.30	67.4
10			18.2	(2)	18.20	99.1
11			19.1	(2)	19.10	117.5
Females						
1	5.3	(126)	5.1	(115)	5.20	1.4
2	7.8	(126)	7.7	(115)	7.75	5.4
3	9.7	(126)	9.5	(115)	9.60	10.9
4	11.0	(125)	10.9	(111)	10.95	16.8
5	12.0	(87)	12.1	(51)	12.05	23.0
6	13.0	(32)	13.2	(24)	13.10	30.4
7	14.0	(16)	14.2	(10)	14.10	38.7
8	15.2	(6)	15.1	(4)	15.15	49.1
9	16.6	(2)	16.5	(2)	16.55	65.6

Table 7. The final mean lengths (cm) of male and female perch from Loch Lomond at each age, calculated from the combined mean lengths; the weights (gm) were calculated from the final mean lengths.

Age (years)	Perch caught near Balmaha		Perch caught near Field Station	Perch of exceptionally large size	Final means	Calculated weights (gm)
	1967	1968	1966-67	1966-68		
Males						
1	6.2 (212)	5.6 (378)	7.2 (101)	6.5 (1)	6.4	2.4
2	10.8 (212)	9.9 (378)	11.3 (101)	10.4 (1)	10.6	13.3
3	14.0 (212)	13.5 (372)	13.7 (85)	15.2 (1)	14.1	35.2
4	16.0 (205)	15.9 (115)	15.6 (80)	17.7 (1)	16.3	57.5
5	17.5 (142)	17.5 (58)	17.0 (71)	20.9 (1)	18.2	83.7
6	18.7 (95)	18.6 (18)	18.3 (61)	23.9 (1)	19.9	113.3
7	19.9 (36)	19.7 (3)	19.5 (29)	26.7 (1)	21.4	145.1
8	20.9 (7)		20.6 (8)	28.4 (1)	23.3	193.7
9				29.4 (1)	29.4	338.5
Females						
1	6.5 (38)	7.0 (3)	7.0 (42)	7.3 (6)	7.0	3.1
2	11.5 (38)	11.2 (3)	11.0 (42)	11.2 (6)	11.2	15.7
3	14.7 (38)	13.7 (3)	13.8 (42)	14.7 (6)	14.4	37.8
4	16.9 (38)	15.9 (3)	16.0 (42)	17.3 (6)	16.7	63.5
5	18.5 (28)	17.8 (3)	17.6 (42)	20.3 (6)	18.9	97.8
6	19.9 (15)	19.3 (3)	19.0 (36)	23.0 (6)	20.9	136.7
7	21.1 (5)	20.6 (1)	20.2 (28)	25.3 (6)	22.5	179.9
8	22.8 (1)		21.5 (13)	27.4 (6)	24.8	252.8
9			23.2 (5)	29.3 (6)	27.3	353.6
10				31.4 (6)	31.4	544.2
11				34.0 (6)	34.0	761.0
12				36.0 (6)	36.1	938.4
13				37.5 (6)	37.5	1071.8

Table 8. Numbers in samples, mean lengths and standard deviations of four pairs of samples of female perch caught in traps in the Dubh Lochan. The first length in each case is obtained from the measurement of actual fish; the second by back-calculation from the same year-class a year later. The age group and the year caught are given in each case, as well as the value of P in a 't' test applied to the difference between the means of each year.

Age-group	IV	V	V	VI	VI	VII	VII	VIII
Year	1967	1968	1967	1968	1967	1968	1967	1968
Mean-length (cm)	11.06	10.93	12.00	11.90	12.97	13.13	13.64	13.80
Number	35	23	53	12	16	6	7	2
S.D.	0.3382	0.3146	0.2463	0.2429	0.2366	0.2607	0.2236	0.1414
P	> 0.10 not sign.		> 0.10 not sign.		> 0.10 not sign.		> 0.20 not sign.	

Table 9. Numbers in samples, mean lengths and standard deviations, of four pairs of samples of male perch caught in gill-nets in Loch Lomond. The first length in each case is obtained from the measurement of actual fish; the second by back-calculations from the same year-class in a year later. The age groups and the year caught are given in each case, as well as the value of P in a 't' test applied to the difference between the means of each pair.

Age-groups	III	IV	IV	V	V	VI	VI	VII
Year	1967	1968	1967	1968	1967	1968	1967	1968
Mean lengths (cm)	13.77	14.08	16.43	16.26	17.87	17.70	18.75	18.66
Number	7	57	62	35	47	15	44	3
S.D.	0.5971	0.7301	0.5649	0.4702	0.3464	0.4071	0.2903	0.0707
P	> 0.20 not sign.		> 0.90 not sign.		> 0.10 not sign.		> 0.10 not sign.	

Table 10. A comparison between recorded growth since tagging and back-calculations of growth from the opercular bones of recovered tagged fish of the Dubh Lochan.

No.	Date when tagged	Length (cm) when tagged	Back-calculated lengths (cm) at winter ring at the time of tagging	Length (cm) when recaptured	Date when recaptured	Tag no.
<u>Perch</u>						
1	23.4.67	13	13.1	13.4	7.5.68	Y172
2	23.4.67	12.7	12.9	13.1	14.5.68	Y173
3	27.4.67	12.3	12.3	12.6	30.4.68	Y 92
4	30.4.67	11.1	11.2	11.6	14.5.68	Y212
5	30.4.67	9.5	9.5	10.3	7.5.68	Y236
6	30.4.67	9.6	9.5	10.0	7.5.68	Y228
7	30.4.67	11.5	11.3	11.9	7.5.68	Y207
8	30.4.67	12.1	12.1	12.5	7.5.68	Y217
9	30.4.67	14.2	14.2	14.6	7.5.68	Y206
10	2.5.67	11.6	11.6	12.2	14.5.68	Y335
11	2.5.67	9.3	9.2	9.8	14.5.68	Y377
12	6.5.67	14.9	14.9	15.2	9.5.68	B260
13	6.5.67	10.2	10.0	10.9	7.5.68	B298
<u>Pike</u>						
1	8.6.67	36.4	36.8	40.3	29.5.68	129
2	15.5.67	44.4	44.6	48.0	26.4.68	118

Table 11. The growth in length of perch from the Dubh Lochan during 1967. The figures given are the mean lengths (cm) of male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes 1958	1959	1960	1961	1962	1963	1964	Combined means
Males								
1	5.4 (1)	5.2 (2)	5 (1)	4.7 (1)	5.4 (4)	5.3 (6)	5.1 (33)	5.1
2	7.4 (1)	7.8 (2)	7.5 (1)	7.7 (1)	7.8 (4)	7.6 (6)	7.3 (33)	7.6
3	8.7 (1)	9.6 (2)	9.8 (1)	9.5 (1)	9.5 (4)	9.2 (6)	8.8 (33)	9.3
4	10.1 (1)	11.0 (2)	11.0 (1)	10.6 (1)	10.9 (4)	10.3 (6)		10.6
5	11.8 (1)	12.1 (2)	12.2 (1)	11.7 (1)	12.1 (4)			12.0
6	13.0 (1)	13.0 (2)	13.2 (1)	12.8 (1)				13.0
7	14.2 (1)	13.9 (2)	13.7 (1)					13.9
8	14.9 (1)	14.6 (2)						14.7
9	15.5 (1)							15.5
Females								
1	6.0 (2)	5.9 (4)	5.1(10)	5.3 (16)	5.2 (55)	5.3 (38)	4.8 (1)	5.3
2	8.3 (2)	8.3 (4)	7.5(10)	7.9 (16)	7.9 (55)	7.9 (38)	7.2 (1)	7.8
3	10.5 (2)	9.9 (4)	9.2(10)	9.5 (16)	9.8 (55)	9.8 (38)	9.5 (1)	9.7
4	11.5 (2)	11.2 (4)	10.6(10)	10.8 (16)	11.1 (55)	11.0 (38)		11.0
5	12.5 (2)	12.3 (4)	11.6(10)	11.9 (16)	12.2 (55)			12.1
6	13.5 (2)	13.2 (4)	12.5(10)	12.9 (16)				13.0
7	14.6 (2)	14.0 (4)	13.3(10)					14.0
8	15.7 (2)	14.8 (4)						15.2
9	16.6 (2)							16.6

able 12. The growth in length of perch from the Dubh Lochan during 1968. The figures given are the mean lengths (cm) of the male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes 1957	1959	1960	1961	1962	1963	1964	1965	1966	Combined means
Males										
1	5.2 (2)				5.2 (1)	5.4 (8)	4.9 (30)	4.9 (47)	4.7 (8)	5.0
2	7.8 (2)				7.6 (1)	7.7 (8)	7.0 (30)	7.3 (47)	7.4 (8)	7.5
3	9.6 (2)				9.4 (1)	9.3 (8)	8.7 (30)	9.0 (47)		9.2
4	11.2 (2)				11.2 (1)	10.4 (8)	10.2 (30)			10.7
5	12.6 (2)				12.0 (1)	11.4 (8)				12.0
6	13.8 (2)				12.6 (1)					13.2
7	14.9 (2)									14.9
8	15.9 (2)									15.9
9	17.1 (2)									17.1
10	18.2 (2)									18.2
11	19.1 (2)									19.1
Females										
1		5.5 (2)	5.2 (2)	5.0 (6)	5.0 (14)	5.1 (27)	5.0 (60)	5.1 (4)		5.1
2		8.5 (2)	8.1 (2)	7.4 (6)	7.4 (14)	7.5 (27)	7.3 (60)	7.8 (4)		7.7
3		10.3 (2)	10.2 (2)	9.4 (6)	9.1 (14)	9.4 (27)	9.1 (60)	9.4 (4)		9.5
4		11.5 (2)	11.5 (2)	10.7 (6)	10.5 (14)	10.7 (27)	10.8 (60)			10.9
5		12.6 (2)	12.5 (2)	11.9 (6)	11.7 (14)	12.0 (27)				12.1
6		13.6 (2)	13.4 (2)	13.0 (6)	12.8 (14)					13.2
7		14.5 (2)	14.2 (2)	13.9 (6)						14.2
8		15.5 (2)	14.8 (2)							15.1
9		16.5 (2)								16.5

Table 13. The growth in length of perch from Loch Lomond near the Field Station during 1966-67. The figures given are the mean lengths (cm) of the male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes 1958	1959	1960	1961	1962	1963	1964	1965	Combined means
Males									
1		6.9 (8)	6.5 (21)	6.6 (32)	7 (10)	6.6 (9)	9 (5)	7.9 (16)	7.2
2		10.6 (8)	10.3 (21)	10.7 (32)	10.9 (10)	10.9 (9)	12.4 (5)	13.4 (16)	11.3
3		13.2 (8)	13.1 (21)	13.4 (32)	13.7 (10)	14.2 (9)	14.5 (5)		13.7
4		15.1 (8)	15.1 (21)	15.5 (32)	15.7 (10)	16.7 (9)			15.6
5		16.8 (8)	16.9 (21)	17.1 (32)	17.3 (10)				17.0
6		18.3 (8)	18.3 (21)	18.4 (32)					18.3
7		19.6 (8)	19.5 (21)						19.5
8		20.6 (8)							20.6
Females									
1	6.7 (5)	7.0 (8)	7.3 (15)	7.0 (8)	7.0 (6)				7.0
2	10.9 (5)	10.8 (8)	11.0 (15)	10.9 (8)	11.6 (6)				11.0
3	13.9 (5)	13.5 (8)	13.7 (15)	13.7 (8)	14.4 (6)				13.8
4	15.9 (5)	15.7 (8)	15.6 (15)	16.2 (8)	16.5 (6)				16.0
5	17.6 (5)	17.3 (8)	17.3 (15)	17.9 (8)	17.9 (6)				17.6
6	19.2 (5)	18.8 (8)	18.7 (15)	19.2 (8)					19.0
7	20.7 (5)	20.0 (8)	19.9 (15)						20.2
8	22.1 (5)	21.0 (8)							21.5
9	23.2 (5)								23.2

Table 14. The growth in length of perch from Loch Lomond near the Balmaha area during 1967. The figures given are the mean lengths (cm) of male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes 1959	1960	1961	1962	1963	1964	Combined means
Males							
1	6.3 (7)	6.5 (29)	6.1 (59)	6.3 (47)	5.8 (63)	6.4 (7)	6.2
2	10.5 (7)	11.0 (29)	10.8 (59)	11.0 (47)	10.5 (63)	10.8 (7)	10.8
3	13.4 (7)	13.9 (29)	13.9 (59)	14.3 (47)	14.0 (63)	14.5 (7)	14.0
4	15.4 (7)	15.9 (29)	15.9 (59)	16.4 (47)	16.4 (63)		16.0
5	17.1 (7)	17.5 (29)	17.5 (59)	17.8 (47)			17.5
6	18.6 (7)	18.8 (29)	18.7 (59)				18.7
7	19.9 (7)	19.9 (29)					19.9
8	20.9 (7)						20.9
Females							
1	8.5 (1)	5.7 (4)	7.0 (10)	5.9 (13)	5.6 (10)		6.5
2	14.2 (1)	10.1 (4)	12.0 (10)	10.9 (13)	10.4 (10)		11.5
3	16.2 (1)	13.5 (4)	15.0 (10)	14.4 (13)	14.3 (10)		14.7
4	18.0 (1)	16.0 (4)	17.0 (10)	16.6 (13)	16.9 (10)		16.9
5	19.4 (1)	18.0 (4)	18.5 (10)	18.2 (13)			18.5
6	20.6 (1)	19.4 (4)	19.7 (10)				19.9
7	21.8 (1)	20.5 (4)					21.1
8	22.8 (1)						22.8

Table 15. The growth in length of perch from Loch Lomond near Balmaha during 1968. The figures given are the mean lengths (cm) of male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes 1961	1962	1963	1964	1965	1966	Combined means
Males							
1	5.7 (3)	5.9 (15)	5.6 (40)	5.6 (57)	5.5 (257)	5.4 (6)	5.6
2	9.3 (3)	10.3 (15)	10.2 (40)	10.1 (57)	10.0 (257)	9.7 (6)	9.9
3	12.8 (3)	13.6 (15)	13.6 (40)	14.1 (57)	13.6 (257)		13.5
4	15.2 (3)	16.0 (15)	16.1 (40)	16.3 (57)			15.9
5	17.1 (3)	17.6 (15)	17.8 (40)				17.5
6	18.5 (3)	18.7 (15)					18.6
7	19.7 (3)						19.7
Females							
1	8.7 (1)	5.3 (2)					7.0
2	12.2 (1)	10.2 (2)					11.2
3	14.4 (1)	13.1 (2)					13.7
4	16.4 (1)	15.4 (2)					15.9
5	18.1 (1)	17.5 (2)					17.8
6	19.5 (1)	19.2 (2)					19.3
7	20.6 (1)						20.6

Table 16. Annual increments in length (cm) and weight (gm) of male and female perch from the Dubh Lochan and Loch Lomond (calculated from the tables of final mean lengths).

Year of growth	Length (cm) Dubh Lochan	Length (cm) Loch Lomond	Weights (gm) Dubh Lochan	Weights (gm) Loch Lomond
	Males		Males	
1	5.05	6.4	1.1	2.4
2	2.5	4.2	3.4	10.9
3	1.7	3.5	4.8	21.9
4	1.4	2.2	5.9	22.3
5	1.35	1.9	7.8	26.2
6	1.1	1.7	8.3	29.6
7	1.3	1.5	12.4	31.8
8	0.9	1.9	10.3	48.6
9	1.0	6.1	13.4	
10	1.9		31.7	
11	0.9		18.4	
	Females		Females	
1	5.2	7.0	1.4	3.1
2	2.55	4.2	4.0	12.6
3	1.85	3.2	5.5	22.1
4	1.35	2.3	5.9	25.7
5	1.1	2.2	6.2	34.0
6	1.05	2.0	7.4	38.9
7	1.0	1.6	8.3	43.2
8	1.05	2.3	10.4	72.9
9	1.4	2.5	16.5	100.8
10		4.1		190.6
11		2.6		216.8
12		2.1		177.4
13		1.4		133.4

Table 17. The growth in length of perch of exceptionally large size from Loch Lomond during 1966-68. The figures given are the mean lengths (cm) of male and female perch of successive year-classes at each age. (Figures in parentheses are the number of fish on which each mean is based.)

Age (years)	Year-Classes					Combined means
	1954	1956	1957	1958	1959	
Males						
1				6.5 (1)		6.5
2				10.4 (1)		10.4
3				15.2 (1)		15.2
4				17.7 (1)		17.7
5				20.9 (1)		20.9
6				23.9 (1)		23.9
7				26.7 (1)		26.7
8				28.4 (1)		28.4
Females						
1	6.5 (1)	8.6 (1)	8.4 (1)	6.8 (1)	6.9 (2)	7.3
2	10.2 (1)	11.7 (1)	13.4 (1)	10.6 (1)	10.8 (2)	11.2
3	14.4 (1)	14.9 (1)	16.3 (1)	14.8 (1)	14.1 (2)	14.7
4	16.7 (1)	17.4 (1)	19.1 (1)	18.1 (1)	16.4 (2)	17.3
5	19.4 (1)	19.5 (1)	21.5 (1)	22.5 (1)	19.5 (2)	20.3
6	21.4 (1)	22.6 (1)	23.6 (1)	26.0 (1)	22.3 (2)	23.0
7	23.6 (1)	25.0 (1)	25.3 (1)	28.9 (1)	24.6 (2)	25.3
8	25.6 (1)	27.4 (1)	27.7 (1)	30.3 (1)	26.8 (2)	27.4
9	28.4 (1)	29.3 (1)	29.5 (1)	31.5 (1)	27.6 (2)	29.3
10	31.3 (1)	31.7 (1)	31.3 (1)			31.4
11	34.7 (1)	34.0 (1)	32.7 (1)			34.0
12	36.5 (1)	35.8 (1)				36.1
13	37.5 (1)					37.5

Table 18. A comparison of the growth of perch in different countries which are not mentioned in Figure 24.

Country and lake		Sex	I	II	III	IV	V	VI	VII	VIII
England: Eastern Midlands and East Anglia	Hartley, 1947	male + female	8.7	11.1	14.6	16.5	16.3			
Lake Ullswater	McCormack, 1965	male	6.9	11.4	16.0	17.7	18.7	19.2	19.9	20.7
		female	7.2	11.6	15.8	18.2	19.4	19.6	20.4	20.8
River Thames	Williams,1967	male	6.9	9.1	11.0	12.1	13.4	14.9	16.5	-
		female	6.9	9.2	11.3	12.4	14.0	16.0	17.2	-
Finland: Pellinge	Segerstråle, 1933	male + female	6.6	8.2	10.1	11.5	13.1	14.1	16.6	-
Germany: Prussian lakes	Röper, 1936	male + female	9.0	10.2	11.2	12.6	13.4	14.8	16.2	17.7
Sweden: Mälaren	Nilsson, 1921 (cf. Alm, 1946)	male + female	6.9	10.7	14.6	17.9	20.1	22.2	24.2	-
Switzerland: Lake of Constance	Nümann, 1947 (cf. Deelder, 1951)	male + female	-	-	-	13.5	15.6	-	20.6	21.4
Norway: St. Oivann	Olstad, 1919 (cf. Alm, 1946)	male + female	7.0	9.7	12.2	14.6	15.9	17.6	-	-

Table 19. The number and percentage of female perch caught in traps in the Dubh Lochan during 1967 and 1968.

	Total no. in traps	No. of female	% of female
1967			
April	2,996	248	8
May	3,200	395	12
June	61	12	19
	6,257	655	10.46
1968			
April	808	48	6
May	4,670	657	14
June	11	2	18
	5,489	707	13

Table 20. The ninety-five per cent fiducial limits of the regression coefficients (b) of the regressions of the logarithm of fecundity on the logarithm of age, length, weight and dry gonad weight.

Factor	'b'	95% fiducial limits		Remarks
		lower limit	upper limit	
DUBH LOCHAN 1967				
Age	1.2806	1.2373	1.3239	>linear
Length (cm)	3.1804	2.9117	3.4491	cubic
Weight (gm)	0.9426	0.8735	1.0117	linear
Dry gonad weight (gm)	0.7321	0.6607	0.8035	<linear
1968				
Age	1.3992	1.2097	1.5887	>linear
Length (cm)	2.9264	2.9024	2.9504	cubic
Weight (gm)	0.9158	0.8613	0.9703	linear
Dry gonad weight (gm)	0.7051	0.5806	0.8296	<linear
LOCH LOMOND 1967				
Age	0.7061	0.4862	0.9260	<linear
Length (cm)	2.2833	1.9753	2.5913	<cubic
Weight (gm)	0.7384	0.6459	0.8310	<linear
Dry gonad weight (gm)	0.4660	0.1566	0.7754	<linear

Table 21. The values of the coefficients for the regressions of log gonad weight on log length and log weight.

	Age-group	Length (cm) 'b'	Weight (gm) 'b'
Dubh Lochan 1967	total regression	3.8974	1.2706
	4th year	1.2200	0.3309
	5th year	1.4000	0.5366
	6th year	3.000	1.1538
	7th year	5.9500	2.0000
1968	total regression	4.1509	1.2894
	4th year	1.8000	0.7248
	5th year	2.8000	1.3544
	6th year	1.3000	0.9286
	7th year	3.9000	0.8800
Loch Lomond 1967	total regression	2.3529	0.7826
	5th year	2.9231	1.0255
	6th year	0.8000	0.8505

Table 22. The percentage of perch in size group which contained each of the food animals, for the period, October, 1966 to December, 1967, in the Dubh Lochan.

Size of perch in cm.	5-5.7	5.8-7.9	8-9.5	9.6-11.5	11.6-12.6	12.7-13.4	13.5-14.4	14.5-15.4	15.5 & over
Holopodium	42	25	3	19	18	-	18	-	-
Cyclops	42	37	10	19	16	-	-	-	-
Daphnia	25	-	-	-	-	-	-	-	-
Leptophlebia adults	-	-	-	2	-	-	9	20	50
Leptophlebia nymphs	-	12	14	12	24	31	18	40	50
Ephemeroptera unidentified	-	-	3	2	-	4	-	-	-
Sialis larvae	-	-	-	24	18	23	9	20	25
Chaoborus larvae	8	50	14	36	28	18	18	20	25
Chaoborus pupae	-	-	-	2	-	-	-	-	-
Chironomid larvae	25	50	31	29	18	14	9	20	-
Chironomid pupae	8	-	14	29	24	27	18	40	-
Trichoptera unidentified	-	-	7	2	2	9	-	20	-
Plectronemia larvae	-	-	-	2	-	-	9	-	-
Hydracarina	-	-	3	-	2	4	-	-	-
Corixa	-	-	-	-	-	-	-	20	-
Perch	-	-	-	-	4	-	-	-	-
No. of perch in each group	12	8	29	41	50	22	11	5	4

Table 23. The percentage of perch in size group which contained each of the food animals, for the period, April, 1968 to September, 1968, in the Dubh Lochan.

Size of perch in cm	5-6.5	6.6-7.9	8-9.5	9.6-11.5	11.6-12.6	12.7-13.4	13.5-14.4	14.5-15.4	15.5 & over
Holopedium	100	-	8	8	15	12	12	-	-
Cyclops	27	-	4	10	2	6	-	-	-
Daphnia	75	-	4	6	2	-	-	-	-
Eurycercus	-	-	2	3	-	-	-	-	-
Asellus	-	-	-	0.8	2	7	-	-	-
F. Leuctridae	-	-	-	0.8	-	6	12	-	-
Leptophlebia (emerging)	-	-	-	8	6	6	12	-	-
Leptophlebia nymphs	-	16	31	36	33	31	25	25	50
Sialis larvae	-	-	-	3	7	25	12	25	-
Chaoborus larvae	2	-	6	12	13	6	-	25	-
Chironomid pupae	2	-	4	21	2	6	12	-	-
Chironomid larvae	2	-	11	23	12	-	12	-	-
Trichoptera unidentified	-	-	-	-	2	6	12	-	-
Plectronemia larvae	-	-	4	6	14	27	-	-	-
Phrygamea larvae	-	-	-	-	-	7	12	-	-
Corixa		-	2	-	-	-	8	-	25
Perch		-	-	-	7	-	8	-	-
No. of perch in each group	52	6	48	123	45	16	8	4	4

Table 24. The percentage of empty stomachs in each size-group of perch of the Dubh Lochan and Loch Lomond.

Dubh Lochan	Size of perch (cm)	5-9.5	9.6 and over
1966-67	winter	16	2
1967	summer	26	51
Number of perch in each group		49	133
1968	summer	29	39
Number of perch in each group		106	200
Loch Lomond	**Size of perch (cm)**	**5.2-12.8**	**12.9 and over**
At Field Station 1966-67	winter	-	47
	summer	3	23
Number of perch in each group		8	125
At Balmaha 1967	summer	-	19
Number of perch in each group		-	256
At Balmaha 1968	summer	30	35
Number of perch in each group		20	361

Table 25. The percentage of perch stomachs containing parasites from the Dubh Lochan and Loch Lomond.

	Parasites	Number present	Number of fish containing	% of fish containing
Dubh Lochan 1967	1. Nematoda: Camallanus lacustris (Zoega)	18	9	5
	2. Trematoda: Bunodera lucioperca (Müller)	5	1	0.5
1968	Nematoda: Camallanus lacustris (Zoega)	17	14	5
Loch Lomond At Field Station (1966-1967)	1. Acanthocephala: Acanthocephalus lucii (Müller)	4	3	2
	2. Nematoda: Camallanus lacustris (Zoega)	19	7	5
At Balmaha (1967)	1. Acanthocephala: Acanthocephalus lucii (Müller)	72	26	10
	2. Nematoda: Camallanus lacustris (Zoega)	30	19	7
	3. Trematoda: Bunodera lucioperea (Müller)	94	18	7
At Balmaha (1968)	1. Acanthocephala: Acanthocephalus lucii (Müller)	3	1	0.3
	2. Nematoda: Camallanus lacustris (Zoega)	2	2	0.5

Table 26. The number and percentage of food organisms and the number and percentage of perch containing each food organism in the Dubh Lochan during 1967 and 1968.

Food organisms	Number of individual organisms		% of individual organisms		Number of fish containing		% of fish containing	
	1967	1968	1967	1968	1967	1968	1967	1968
Holopedium	855	1258	36.2	32	19	13	12	6
Cyclops	221	554	9.4	14.4	19	14	12	6.4
Daphnia	-	187	-	4.8	-	6	-	2.7
Asellus	-	4	-	0.1	-	3	-	1.4
F. Leuetridae	2	5	0.1	0.1	1	3	0.6	1.4
Leptophlebia nymphs	479	1560	20.3	40.4	35	84	22	38
Sialis larvae	40	18	1.7	0.5	27	10	17	4.6
Chaoborus larvae	265	80	11.2	2.1	41	18	25.5	8.2
Chironomid pupae	224	80	9.5	2.1	37	23	23	10.5
Chironomid larvae	253	66	10.7	1.7	40	23	25	10.5
Trichoptera larvae	9	-	0.4	-	6	-	4	-
Plectrocnemia larvae	3	33	0.1	0.8	2	17	1.2	7.8
Phryganea larvae	-	2	-	0.05	-	2	-	0.9
Coleoptera	2	-	0.1	-	2	-	1.2	-
Hemiptera (unidentified)	1	-	0.05	-	1	-	0.6	-
Corixa	1	2	0.05	0.05	1	2	0.6	0.9
Hydracarina	3	-	0.1	-	3	-	2	-
Perch	3	-	0.1	-	3	-	2	-
Total	2361	3844	100.0	99.7				

Table 27. The percentage frequency of occurrence of each food organism in total stomachs of perch of the Dubh Lochan, examined for each month-group.

	March-May	June-Aug.	Sept.-Nov.	Dec.-Feb.
Holopedium	9.1	16	77.3	-
Cyclops	7	21.0	20	9.1
Daphnia	1.4	10.5	48	-
Eurycercus	1	16	-	-
Asellus	1	-	-	-
F. Leuctridae	1.4	-	-	-
Leptophlebia adult	4.4	-	-	-
Leptophlebia nymphs	26.9	-	1.1	9.1
Sialis larvae	11.3	-	2.3	-
Chaoborus larvae	18.1	26.3	8	-
Chironomid pupae	18.9	37	4.5	-
Chironomid larvae	17.8	42	9	-
Plectronemia larvae	5.2	5.3	1	-
Phryganea larvae	1.0	-	-	-
Trichoptera unidentified	2.0	-	1	-
Corixa	.5	-	-	-
Hydracarina	.5	-	-	-
Perch	.5	16	-	-
No. of fish examined	364	19	88	11

Table 28. The percentage of perch in each size group which contained each of the important food animals for the period, October, 1966 to May, 1967, in Loch Lomond at the Field Station.

Size of perch in cm	5.2-6.8	12.6-14.6	14.8-16.7	16.9-18	18.2-19.8	19.9-20.9	21-25	Over 25
Cyclops	50	6	20	-	-	-	-	-
Daphnia	75	6	20	-	-	-	-	-
Asellus	-	-	-	15	5	9	25	-
Gammarus	-	24	10	23	11	9	17	25
F. Leuctridae nymphs	-	-	10	-	-	-	8	-
Leptophlebia nymphs	-	-	-	-	2	4	8	-
Siphlonurus nymphs	-	-	10	-	6	4	8	-
Sialis larvae	-	6	-	8	-	-	-	-
Chaoborus larvae	-	-	20	-	-	4	-	-
Chironomid pupae	-	29	30	62	43	30	25	-
Chironomid larvae	12	12	-	15	11	13	-	-
Caddis fly	-	-	-	23	11	-	17	-
Hydracarina	-	-	-	-	-	4	8	-
Perch	-	-	-	-	2	-	-	-
Three-spined stickleback	-	-	-	8	9	26	25	75
Unidentified fish	-	12	30	8	-	-	-	-
No. of perch in each group	8	17	10	13	46	23	12	4

Table 29. The percentage of perch in each size group which contained each of the important food animals for the period, April, 1967 to February, 1968, in Loch Lomond at Balmaha.

Size of perch in cm	12.6-14.7	14.8-16.8	16.9-18	18.1-19.8	19.9-20.9	21-25	Over 25
Ostracods	-	2	-	2	-	-	-
Cyclops	14	-	1	-	-	-	-
Asellus	-	2	8	9	7	-	-
Gammarus	-	4	1	-	-	-	-
Leptophlebia nymphs	-	4	1	2	-	-	-
Siphlonurus nymphs	-	14	11	7	7	-	-
Ephemeroptera unidentified	-	2	3	2	-	11	-
Sialis larvae	-	2	-	1	-	-	-
Chironomid pupae	71	54	43	66	62	78	33
Chironomid larvae	43	18	22	23	17	22	-
Caddis fly	-	2	1	-	-	-	-
Phryganea larvae	-	-	-	1	-	11	-
Trichoptera larvae	-	-	3	-	-	22	-
Corixa	14	30	29	23	7	44	33
Perch	-	-	-	1	3	11	67
No. of perch in each group	7	50	65	92	29	9	3

Table 30. The percentage of total organisms, percentage occurrence and percentage composition by bulk (points) of food organisms from stomachs of perch of Loch Lomond at the Field Station during the spawning period in 1967.

	Total organisms	% of total organisms	Fish containing	% of fish containing	Total points (bulk)	% of points (bulk)
Cyclops	240	42.1	1	1.3	37	1.6
Daphnia	40	7.0	1	1.3	7	.3
Asellus	23	4.0	4	5.1	25	1.1
Gammarus	111	19.5	11	13.9	420	19.0
F. Leuctridae	2	.3	2	2.6	13	.6
Leptophlebia nymphs	6	.9	4	5.1	54	2.3
Siphlonurus nymphs	13	2.3	3	3.9	51	2.2
Sialis larvae	2	.3	2	2.6	12	.5
Chironomid pupae	74	12.9	36	45.6	809	35.1
Chironomid larvae	8	1.4	8	10.1	94	4.1
Caddis fly	9	1.6	7	8.9	30	1.3
Three-spined sticklebacks	39	6.8	8	10.1	550	23.8
Unidentified fish	3	.4	3	3.9	205	8.9
Total	570	99.5			2307	
Empty stomach: 19%						

Table 31. The percentage frequency of occurrence of each food organism in total stomachs, of perch of Loch Lomond at the Field Station, examined for each month.

	Jan.	Feb.	Mar.	April	May	June	Sept.	Oct.	Dec.
Cyclops	-	20	-	-	1	-	50	-	-
Daphnia	-	20	-	-	1	-	75	-	-
Asellus	6	-	-	-	6	3	-	-	-
Gammarus	6	-	-	-	16	9	-	-	-
Siphlonurus nymphs	6	-	-	-	4	-	-	-	10
Sialis larvae	-	-	-	-	3	-	-	-	-
Chaoborus larvae	-	40	50	-		-	-	-	-
Chironomid pupae	-	-	-	-	49	31	-	-	-
Chironomid larvae	-	-	-	-	11	3	25	8	10
Caddis fly	-	-	-	-	10	-	-	-	-
Perch	-	-	-	-		3	-	-	10
Three-spined sticklebacks	19	-	-	-	7	12	-	25	20
Unidentified fish	6	-	-	-	4	6	-	-	-
No. of fish	16	5	2	3	70	32	8	12	10

Table 32. The data on population studies of perch in the Dubh Lochan during 1967 and 1968.

Date	A	Number marked and returned	B	AB	ΣAB	C	ΣC	P
1967								
31.3.67	28	28	0	0	0	0	0	0
16.4.67	88	81	28	2464	2464	0	0	0
20.4.67	202	176	109	22018	24482	0	0	0
23.4.67	452	441	285	128820	153302	9	9	17033.5
26.4.67	323	318	726	234498	387800	4	13	29830.7
27.4.67	222	170	1044	231768	619568	13	26	23829.5
29.4.67	1568	1283	1214	1903552	2523120	137	163	15479.2
30.4.67	138	104	2497	344586	2867706	7	170	16868.8
2.5.67	269	211	2601	699669	3567375	49	219	16289.3
3.5.67	581	384	2812	1633772	5201147	125	344	15119.6
4.5.67	492	292	3196	1572432	6773579	119	463	14629.7
6.5.67	161	101	3488	561568	7335147	58	521	14078.9
7.5.67	500	341	3589	1794500	9129647	159	680	13425.9
10.5.67	270	140	3930	1061100	10190747	118	798	12770.3
13.5.67	364	159	4070	1481480	11672227	173	971	12020.8
16.5.67	246	138	4229	1040334	12712564	108	1079	11781.8
21.5.67	285	137	4367	1244595	13957156	148	1227	11375.0
25.5.67	61	19	4504	274744	14231900	36	1263	11268.3
Total	6250	4523						
1968								
5.4.68	10	10	0	0	0	0	0	0
12.4.68	16	16	10	160	160	0	0	0
18.4.68	95	95	26	2470	2630	0	0	0
23.4.68	137	134	121	16577	19207	3	3	6402
26.4.68	190	187	255	48450	67657	3	6	11276
28.4.68	201	200	442	88842	156499	1	7	22357
30.4.68	170	166	642	109140	265639	4	11	24149
1.5.68	294	278	808	237552	503191	6	17	29599
4.5.68	321	282	1086	348606	851797	29	46	18517
6.5.68	582	470	1368	796176	1647973	79	125	13183
9.5.68	560	442	1838	1029280	2677253	86	211	12688
13.5.68	1455	1200	2280	3317400	5994653	211	422	14205
15.5.68	509	314	3480	1771320	7765973	195	617	12586
18.5.68	208	112	3794	789152	8555125	69	686	12471
20.5.68	409	202	3906	1597554	10512679	187	873	12042
22.5.68	283	120	4108	1162564	11675243	133	1006	11605
29.5.68	49	28	4228	207172	11882415	21	1027	11570
2.6.68	11	8	4256	46816	11929231	3	1030	11581
Total	5500	4264						

Table 34. A comparison of the growth of tagged and untagged perch in the Dubh Lochan.

Date when tagged	Length when tagged	Length when recaptured	Date when recaptured	Length of unmarked fish, caught along with the tagged fish (at the time of recapture)	Back-calculated length of unmarked fish one year before capture
30.4.1967	11.1	11.6	14.5.1968	12.0	11.0
"	9.5	10.3	7.5.1968	10.8	9.5
"	9.6	10.0	"	10.8	9.4
2.5.1967	11.6	12.2	14.5.1968	13.0	11.7
"	9.3	9.8	"	10.5	9.3
6.5.1967	10.2	10.9	7.5.1968	11.1	10.2

Table 35. Summary of estimates of perch and pike populations in the Dubh Lochan, with limits of ninety-five per cent confidence.

Year of experiments	Species	From trap recaptures			Approximate S.E. of population estimate	Estimated weights kg	Assumming that 100% of the marked fish present in the Dubh Lochan
		Estimate	Limits of Confidence				
			Lower limit	Upper limit			
1967	perch	11268	10691.4	11943.2	308.5	231	1649 fish/hectare or 33.9 kg/hectare
1968	perch	11581	10898.1	12326.1	360.8	269	1695 fish/hectare or 39.4 kg/hectare
1967	pike	89	51.3	173.4	38.80	53	7.76 kg or 17.1 lb/hectare
1968	pike	51	28.0	107.1	35.84	26.5	3.88 kg or 8.5 lb/hectare

Upper and lower limits of confidence calculated by taking recapture as a poison variable (Ricker, 1958); weights are computed from the average weight of mature fish during the spawning period.

Table 36. Growth and mortality data for successive age groups of perch in the Dubh Lochan. (For explanation of calculation of biomass, see text, page .)

Age	Estimated no. of fish	Length (cm)	Weight (gm)	Instantaneous growth rate (G)	Annual survival rate (S)	Instantaneous mortality rate (Z)	G-Z	Biomass of year-class
Male perch, 1967								
III	5445	9.3	9.3					1000
				0.491	0.460	0.776	0.752	
IV	2562	10.6	15.2					752
				0.414	0.449	0.801	.679	
V	480	12.0	23.0					511
				0.308	0.768	0.264	1.045	
VI	160	13.0	31.3					533
				0.207	0.900	0.105	1.107	
VII	961	13.9	38.5					591
				0.197	0.336	1.091	.409	
VIII	480	14.7	46.9					241
Female perch, 1967								
IV	289	11.0	16.8					125
				0.314	0.245	1.406	0.336	
V	623	12.0	23.0					42
				0.279	0.700	0.357	0.925	
VI	178	13.0	30.4					39
				0.241	0.668	0.403	0.851	
VII	56	14.0	38.7					33
				0.238	0.627	0.467	0.795	
VIII	33	15.2	49.1					26
Male perch, 1968								
III	4786	9.2	9.2					1000
				0.509	0.525	0.644	0.874	
IV	4091	10.7	15.3					874
				0.408	0.227	1.483	0.341	
V	997	12.0	23.0					298
				0.314	0.168	1.784	0.230	
VI	101	13.0	31.5					68
VII	101	14.9	44.5					48

Table 36 (Continued)

Age	Estimated no. of fish	Length (cm)	Weight (gm)	Instantaneous growth rate (G)	Annual survival rate (S)	Instantaneous mortality rate (Z)	G–Z	Biomass of year-class
Female perch, 1968								
III	45	9.5	10.85					10
				0.434	0.970	0.030	1.497	
IV	737	10.9	16.75					15
				0.319	0.495	0.703	0.681	
V	376	12.1	23.05					10
				0.278	0.479	0.736	0.633	
VI	210	13.2	30.45					6
				0.241	0.391	0.939	0.497	
VII	90	14.2	38.75					3
				0.238	0.333	1.099	0.423	
VIII	15	15.1	49.15					1
				0.289	0.667	0.405	0.890	
IX	30	16.5	65.6					0.5

Table 37. The number of tagged perch in the Dubh Lochan in 1967 and 1968 and the percentage of recovery in different length-groups and the percentage of tagged, clipped and combined recoveries and the percentage of recoveries of tagged pike in the Dubh Lochan.

1967	Length when tagged in cm						
	8-9.5	9.6-1.5	11.6-12.6	12.7-13.4	13.5-14.4	14.5-15.4	15.5 & over
No. of tagged perch	97	244	85	37	19	6	12
No. of recaptured perch	24	69	22	13	5	1	2
% of recaptured perch	25	28	26	35	26	17	17
1968	**Length when tagged in cm**						
No. of tagged perch	20	56	13	5	2	2	2
No. of recaptured perch	1	10	2	1	0	0	0
% of recaptured perch	1	18	15	20	-	-	-

Perch:	1967	percentage	of	tagged	recoveries:	24
	"	"	"	clipped	" :	28
	"	"	"	combined	" :	28
	1968	"	"	tagged	" :	14
	"	"	"	clipped	" :	25
	"	"	"	combined	" :	24
Pike:	1967	"	"	tagged	" :	30.7
	1968	"	"	"	" :	38.4

Table 38. Decline in recoveries of marked perch in the Dubh Lochan during 1967 (see Figure 36).

Expected number of tagged recoveries:	100 (= anti log 3.00)
Actual number of tagged recoveries:	119 (1967)
Expected number of clipped recoveries:	1288 (= anti log 3.11)
Actual number of clipped recoveries:	1144 (1967)
Expected number of all recoveries:	1549 (= anti log 3.19)
Actual number of all recoveries:	1263 (1967)

Table 39. The effect of tags upon the rate of recapture of perch, based on fish tagged and clipped from March 31 to May 25, 1967 and April 5 to June 2, 1968. Column 3 is column 2 divided by column 1, expressed as percentage; similarly column 6 is column 5 divided by column 4. Column 7 is column 6 divided by column 3, again as percentage.

From traps:	Clipped			Tagged			
	1	2	3	4	5	6	7
	Average no. at large	Recaptures	Ratio	Average no. at large	Recaptures	Ratio	Ratio of Ratios
Perch (1967)	4038	1144	28.3	500	119	23.8	81.3
Perch (1968)	4164	1030	24.7	100	14	14.0	56.7

Table 40. The catch of perch in traps per month at different depths in the Dubh Lochan during 1967 and 1968, and in Loch Lomond during 1967.

Depth (m)	(a) Jan.-March; July to Dec. Catch	(a) % Catch per month	(b) April to June Catch	(b) % Catch per month
Dubh Lochan, 1967				
2-3	5	0.8	506	84
3-4	1	0.1	785	130
4-5	5	0.8	630	105
5-6	12	2	1788	298
6-7	3	0.5	1814	302
7-8	0	0	443	74
8-9	0	0	343	57
Depth (m)	(a) Jan.-March; July to Dec. Catch	(a) % Catch per month	(b) April to June Catch	(b) % Catch per month
Dubh Lochan, 1968				
2-3	0	0	640	107
3-4	0	0	938	156
4-5	0	0	980	163
5-6	0	0	1360	226
6-7	0	0	1248	208
7-8	0	0	97	16
8-9	0	0	226	38
Depth (m)	Jan.-March; Aug. to Dec. Catch	% Catch per month	April to July Catch	% Catch per month
Loch Lomond, 1967				
2-3	3	1.4	32	15.1
4-5	0	0	43	20.3
6-7	2	1.0	74	34.9
8-9	0	0	40	18.9
10-11	1	.5	17	8.0

Table 41. A comparison of the coefficients 'b' in the length-weight regression equations of pike of different waters.

Waters	Sex	'b'	Statistically significant from 3
Dubh Lochan	male	3.3471	yes
Dubh Lochan	female	3.2400	no
Loch Lomond	male	3.2951	no
Loch Lomond	female	3.1147	no
Windermere (Frost, 1967)	male	3.18	yes
Windermere (Frost, 1967)	female	3.27	yes
Loch Choin (Munro, 1957)	male + female	3.0773	-
Michigan pike (Beckman, 1945)	male + female	3.0665	-
Canadian pike (Miller & Kennedy, 1948)	male + female	3.17	-

Table 42. The mean back-calculated lengths of male and female pike of successive year-classes at each age caught in the Dubh Lochan, during 1967-68.

Sex	Age	Year - Classes 1957	1960	1961	1962	1963	1964	Mean	Calculated weights (gm)
♂	1		11.3(2)	10.1(6)	12.3(6)	11.8(1)	10.4(1)	11.2	9
	2		20.2(2)	18.9(6)	20.6(6)	18.0(1)	15.8(1)	18.7	47
	3		28.3(2)	25.6(6)	28.1(6)	24.0(1)	20.0(1)	25.2	124
	4		34.7(2)	32.3(6)	33.8(6)	28.4(1)		32.3	277
	5		41.0(2)	37.7(6)	38.1(6)	31.0(1)		36.9	427
	6		46.2(2)	41.6(6)	38.9(2)			42.2	659
	7		49.2(2)	45.1(2)				47.1	942
♀	1	13.6(1)			11.9(3)		12.1(2)	12.5	10
	2	24.0(1)			21.2(3)		20.9(2)	22.0	68
	3	31.8(1)			27.7(3)		27.1(2)	28.5	163
	4	39.0(1)			33.4(3)		33.0(1)	35.1	328
	5	45.2(1)			37.7(3)			41.4	570
	6	50.4(1)			46.0(1)			48.2	948
	7	56.8(1)						56.8	1641
	8	60.8(1)						60.8	2061
	9	65.0(1)						65.0	2576
	10	68.0(1)						68.0	2999

Table 43. The mean back-calculated lengths of the male and female pike of successive year-classes at each age, caught in Loch Lomond, during 1966-68.

Sex	Age	Year - Classes 1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	Mean	Calculated weights (gm)
Male														
	1			19.8(2)	16.0(2)	14.0(1)	20.4(4)	26.3(2)	20.5(1)			22.2(4)	19.9	46
	2			36.0(2)	28.9(2)	26.0(1)	35.1(4)	42.1(2)	36.6(1)			34.7(4)	34.2	276
	3			47.3(2)	39.5(2)	36.0(1)	46.8(4)	52.5(2)	49.7(1)			36.5(1)	44.0	632
	4			53.2(2)	47.6(2)	44.2(1)	55.5(4)	61.1(2)	60.0(1)				53.6	1213
	5			60.9(2)	54.9(2)	51.5(1)	61.0(4)	66.6(2)	65.5(1)				60.1	1766
	6			64.7(2)	59.7(2)	60.4(1)	66.8(4)	69.8(2)					64.3	2208
	7			69.4(2)	64.7(2)	65.5(1)	69.6(4)						67.3	2564
	8			72.3(2)	68.8(2)	69.5(1)							70.2	2951
	9			74.2(2)	71.5(2)								72.8	3327
	10			76.4(2)									76.4	3899
	11			83.6(1)									83.6	5248
Female														
	1	21.4(1)	17 (1)		14.4(1)	26.2(2)	19.5(1)	27.7(2)	23.2(2)	41.6(1)	40.1(2)	24.3(2)	25.5	145
	2	39.0(1)	31.4(1)		26.6(1)	44.0(2)	34.0(1)	47.5(2)	40.6(2)	63.6(1)	59.6(2)	36.1(2)	42.4	697
	3	53.0(1)	43 (1)		37.4(1)	56.2(2)	45.0(1)	61.7(2)	53.9(2)	74.8(1)	68.7(2)		54.8	1570
	4	65.0(1)	53.4(1)		46.6(1)	64.6(2)	54.3(1)	71.9(2)	63.4(2)	81.4(1)			62.5	2366
	5	75.0(1)	62.4(1)		54.6(1)	71.8(2)	60.2(1)	79.2(2)	68.0(2)				67.3	2978
	6	83.2(1)	74.6(1)		63.0(1)	77.2(2)	65.5(1)	84.3(2)					74.6	4102
	7	90.0(1)	82.5(1)		68.5(1)	81.8(2)	70.0(1)						78.6	4831
	8	95.4(1)	88.0(1)		73.7(1)	85.8(2)							85.7	6324
	9	99.5(1)	91.4(1)		77.5(1)								89.5	7244
	10	103 (1)	94.3(1)										98.6	9795
	11	105.5(1)	96.5(1)										101.0	11143
	12	108 (1)											108.0	13002

Table 44. The data on population studies of pike in the Dubh Lochan during 1967 and 1968.

Date	A	No. marked & returned	B	AB	ΣAB	C	ΣC	P
1967								
15.4.67	4	4	0	0	0	0	0	0
29.4.67	4	4	4	16	16	0	0	0
3.5.67	7	6	8	56	72	1	1	72
11.5.67	2	2	14	28	100	0	1	100
13.5.67	4	4	16	64	164	0	1	164
15.5.67	3	2	20	60	224	1	2	112
19.5.67	2	2	22	44	268	0	2	134
21.5.67	5	4	24	120	388	1	3	129
23.5.67	6	5	28	168	556	1	4	139
24.5.67	7	6	33	231	787	1	5	157
26.5.67	2	0	39	78	865	2	7	123
29.5.67	2	0	37	74	939	1	8	117
8.6.67	2	0	35	70	1009	2	10	100
15.6.67	2	0	33	66	1075	2	12	89
1968								
12.4.68	5	5	0	0	0	0	0	0
18.4.68	3	3	5	15	15	0	0	0
21.4.68	4	3	8	32	47	1	1	47
25.4.68	5	5	11	55	102	0	1	102
29.4.68	3	3	16	48	150	0	1	150
4.5.68	3	3	19	57	207	0	1	207
8.5.68	2	1	22	44	251	1	2	125
12.5.68	3	2	23	69	320	1	3	106
17.5.68	2	1	25	50	370	1	4	92
23.5.68	1	0	26	26	396	1	5	79
30.5.68	2	0	25	50	446	2	7	63
2.6.68	2	0	23	46	492	2	9	54
8.6.68	1	0	21	21	513	1	10	51

Table 45. The number and percentages of pike containing each food organism and the number and percentage of food organisms in stomachs of pike in Loch Lomond, caught during 1955-1967.

Food organisms	No. of fish containing	% of fish containing	No. of food organisms	% of food organisms
Asellus	2	1	29	20
Perca fluviatilis	5	2.6	6	4.2
Coregonus clupeoides	54	28	62	43
Gasterosteus aculeatus	5	2.6	5	4
Rutilus rutilus	4	2	4	3.5
Salmo trutta	19	9.8	23	16.1
Salmo salar	2	1	6	4.2
Phoxinus phoxinus	1	0.5	1	0.7
Anguilla anguilla	1	0.5	1	0.7
Esox lucius	1	0.5	1	0.7
Empty stomachs	91	47		