Relationships Between Population Density, Feeding and Growth of the Roach (Rutilus rutilus, L. 1758) and other Coarse Fish in a Gravel-pit lake in Southern England

by

William James Barber BSc

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Contents

CHAPTER I

INTRODUCTION

I.1 Gravel-Pit Lakes

Gravel-pit lakes are an increasingly common feature of our landscape, particularly on the flood plains of rivers close to large urban or industrial areas e.g. the Thames Valley (see Fig. 1). When sand and gravel are removed from below the water table, lakes are produced by seepage into the excavation (wet diggings). At least 1600 hectares of land are being excavated in Britain each year for sand and gravel extraction of which ninety per cent are wet diggings (Hartwright, 1974). Filling with town or industrial refuse (back filling) is not common in wet diggings and the majority of the 1400 hectares dug each year remain as lakes.

These lakes provide areas for organised recreation such as sailing, water-skiing, angling and skin-diving. As open sites, frequently near suburban districts, the lakes and surrounding land can be pleasant amenity areas. Their value is increased if they are landscaped and planted with trees and shrubs (see page 26). Such areas are important for the conservation of a wide range of plants and animals, especially in view of the decline of naturally occurring wetland habitats.

Little is known of the biology of gravel-pit lakes; of their flora and fauna or of how these may change with time. Karim (1967) published a paper on the algae of Thames Valley gravel pits and concluded that the air carried the spores of many of the species of algae that colonised the lakes. Catchpole and Tydeman (1975) studied aspects of the bird faunas of several gravel-pit lakes and Harrison (1972) developed a complex of lakes in Kent as a bird reserve. All stress the value of the lakes as habitats for birds.

At the City of London Polytechnic a group is investigating the biology of gravel-pit lakes with particular reference to their fish faunas with the aim of establishing principles for managing the lakes as fisheries. The location of most of the pits being studied is shown in figure 1. They range in size from <1 to >100 hectares and in average depth from 1 to 5 metres. The age of these lakes is between 5 and 25 years (Powell, 1973). Apart from the work reported in this thesis, some of the aspects of the lakes' biology that this group has studied are:-

1. A survey of the mollusc fauna of 45 lakes (A.M. Powell and A. South in preparation).
2. Studies on the fish population structure of 6 selected lakes (Gee, 1976).
3. A survey of the growth rates of the fish in 36 lakes (Gee, 1976).
4. A survey of the parasite fauna of the fish in 36 lakes (A.M. Powell and R.A. Sweeting, in preparation).
5. A study of the relationships between water chemistry on the one hand and growth and standing crops of plants in several lakes on the other (F. Goodridge Ph.D. thesis, CNAA, in preparation).
6. A study of the relationships between fish population density and angler success in two lakes. (B. Howard, Ph.D. Thesis, CNAA, in preparation).
7. A study of the relationships between fish and zooplankton in selected lakes (M.P. Cook, Ph.D. Thesis, CNAA, in preparation).

The most popular recreation on gravel-pit lakes is angling. The lakes have many advantages as fisheries:-

1. They are often close to large urban areas.
2. They are often of a convenient size for the management of their fish stocks, with many between 0.5 and 10 hectares in size and 1 to 3 metres in depth.
3. As lakes that are moderately rich in nutrients (see table 2) but that rarely stratify, they are frequently biologically suitable for fisheries (Powell 1973).

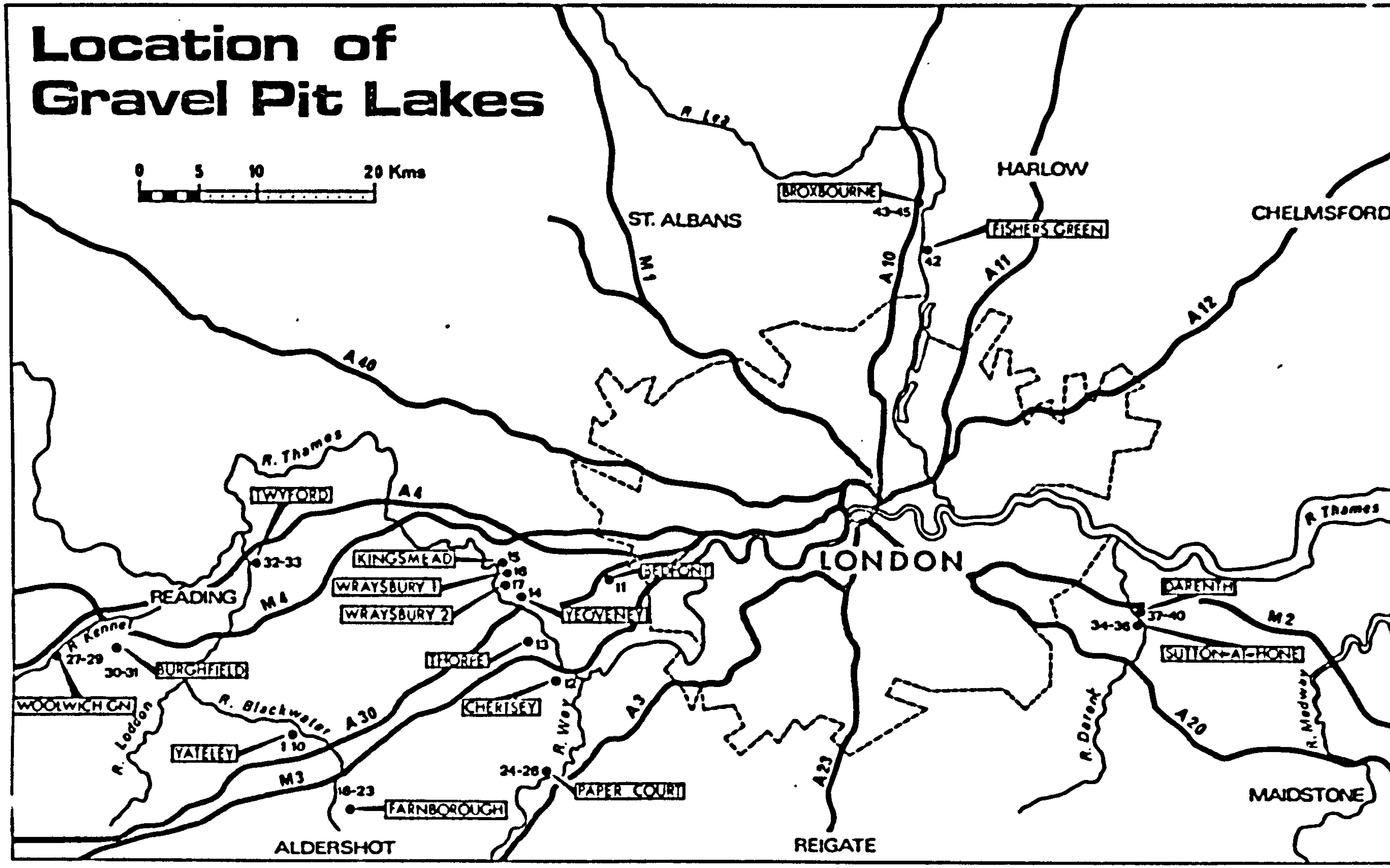

Location of
Gravel Pit Lakes
0 5 10 20 Kms
ST. ALBANS
BROXBOURNE
43-45
HARLOW
FISHERS GREEN
42
CHELMSFORD
R. Lea
M1
A10
A11
A12
A40
A4
M4
M3
M2
A30
A3
A23
A20
R. Thames
R. Kennet
R. Loddon
R. Blackwater
R. Wey
R. Darent
R. Medway
LONDON
TWYFORD
32-33
READING
27-29
30-31
BURGHFIELD
WOOLWICH GN
YATELEY
1 10
18-23
FARNBOROUGH
ALDERSHOT
KINGSMEAD
WRAYSBURY 1
WRAYSBURY 2
YEOVENEY
CHERTSEY
24-26
PAPER COURT
REIGATE
DARENTH
37-40
34-36
SUTTON-AT-HONE
MAIDSTONE

Figure 1

I.2 Fisheries Management

Fisheries management usually involves activities that attempt to maintain or improve anglers' success (catch-per-effort) for desired species of certain sizes. Such activities include modifying fisheries' banks, substratesand flora and manipulating fish stocks.

Some gravel-pit lakes have been managed to create specific fisheries e.g. trout and carp lakes by the introduction of these species. This is sometimes accompanied by attempts at removing unwanted species. More often chance fisheries develop following natural colonisation or stocking with the species that are most readily available. With more information fisheries could be better managed.

In the USA many aspects of fish-population manipulation have been studied, for example: the relationship between fish stocks and angler success (Bennet, 1954, Bennet and Childers, 1972, Buck and Thoits, 1970, Bird and Crance, 1965, Hensen, 1966 and Johnson 1972), the stability of different combinations of fish species in fisheries (Swingle, 1946), methods of controlling unwanted fish species (Lennon, Schrick and Burress, 1970 and Strand and Scidmore, 1970), the dynamics of fish-populations (Gerking, 1962, Rideout and Oatis, 1975, and Swingle and Swingle, 1968) and the influence of fertilisation and supplementary feeding (Bennet et al., 1973, Hensen et al., 1960). The papers listed above all refer to work on non-salmonid species. In many of these studies new stocks were added and the influences and survival of these introduced fish were recorded.

In the UK there have been few management studies on non-salmonid species. Despite the popularity of coarse fishing (National Anglers Survey, 1972), little work has been done on the relationships between angler success and fish population density; the stability of fish populations in small water bodies; the influence of piscivorous species such as pike and perch; and the effects of adding new stock to a fishery. There are two main factors responsible for the lack of information upon which management programs could be based. These are:-

1. The absence of facilities such as large drainable replicate ponds in which experiments e.g. stocking and monitoring angler success, might be conducted.

2. The lack of suitable fish, which are readily available, for such experiments. In the USA public hatcheries produce over 500 million fish (fingerlings and larger) and 1000 million fry (Burrows et al, 1975) each year. Thus experimental fish are always available.

Some studies of coarse fisheries have been carried out in Britain; Hunt (1971) and Moore (1971) studied the fish populations in popular coarse fisheries. Axford (1974) and Ayton (1976) found that introducing large numbers of fish into a river and a canal failed to improve anglers' catches. Despite these findings many River Authorities and angling clubs spend considerable sums on fish to restock river and canal fisheries.

Although, during this study, anglers were not allowed to fish the lake and therefore the relationship between stock density and angler-success was not investigated, the work was designed to provide information likely to be useful in managing lakes of this type.

I.3 The Roach

The roach (Rutilus rutilus L.) is widely distributed in England and is found in streams, lakes, rivers and ponds (Wheeler, 1969). It was the most commonly occurring species found in samples taken from 36 gravel-pit lakes in south-east England (A.S. Gee and R.A. Sweeting, personal communication), and the National Anglers Survey (1972) reported that the roach was the most popular non-salmonid fish.

For these reasons the roach was chosen as the main subject of this work. It has figured in many studies in Europe e.g. Kemp (1962), Volodin (1963), Hollick (1967a and b), Cabejsek and Frank (1968), Frank (1970), Sokolov (1970), Rudenco (1971) and Lyagina (1973). All these studies dealt with populations in large lakes and reservoirs. Hartley (1967), Healy (1958), Cragg-Hine (1964), Williams (1963, 1965), Mann, (1965), Cragg-Hine and Jones (1969), Mills (1969), Bray (1971), Mathews (1972), Hellawell (1972) and Mann (1973) all investigated river or canal populations of roach in the British Isles.

Of the few British standing-water populations investigated (Hartley 1947, Banks 1968 and 1970, Mills 1969, Wilson 1971 and Linfield 1973) only Mills included an estimate of the number of roach in the population. This prevents a valid comparison of the data produced in these different studies. None of these populations was sampled throughout the year and general conclusions about fish diets based on intermittent samples are unreliable.

Gerking (1962) stated that "Fish growth studies, as important as they are in their own right, have seldom been correlated with the kinds and qualities of food consumed and only occasionally have organisms found (in the fish stomachs) been related to their abundance in the same environment'. This statement applies to most of the past work on the roach in Britain; diets have not been compared with available food, and only rarely have growth rates and estimates of populations been considered together. It was unfortunate that while providing data on growth and population size, Mills (1969) did not give any information on the diet of the roach or the invertebrate fauna of the reservoir. Banks (1968), working on Rostherne Mere, concentrated upon the perch (Perca fluviatilis L.) and pike (Esox lucius L.). Few roach were caught and the samples were biased in favour of large fish. The zooplankton of the mere was sampled but these data are not yet available (M. Pugh-Thomas, personal communication). In the present work data on the diet, growth and population density of the roach and on the abundance of plants and animals likely to be important in the roach's diet were collected.

I.4 Interactions Between Fish and their Environment

Many workers have studied such interactions demonstrating a range of approaches which, for review purposes, can be placed into three broad categories:

(1) Observations made after unplanned changes in the environment.

(2) The longer-term monitoring of different trophic levels and aspects of the physical environment.

(3) Experimentation on natural or artificial communities.

(1) Single or short-term observations based on one or a few samples, without earlier data or control situations for comparisons, can be misleading. Two phenomena occurring together need not have a cause-and-effect relationship; Volodin (1963), for example, concluded that the improved growth rate and fecundity of roach in Rybinsk reservoir was due to the increased abundance of a food item, in this case Dreissena polymorpha (Pallas). The changes in the roach growth could have been caused by other factors such as a change in their population density. The relationship between two factors is more likely to be substantiated if many workers report the same factors occurring together, e.g. Reif and Tappa (1966), Wells (1970) and Hutchinson (1971) observed similar changes in zooplankton following increases in numbers of planktivorous fish. A. Duncan (personal communication) noted the increased abundance of Daphnia magna (Straus) in a Thames Water Authority reservoir following heavy perch mortalities. Kemp (1962) noticed improvements in roach growth rates following an increase in size of some reservoirs and the reduction of fish stocks in others.

(2) Long-term monitoring of a system can lead to an understanding of the interdependence between different trophic levels and the influence of the physical environment. Le Cren (1958) found a correlation between perch growth rate and 0+ year-class strength and temperature. Kipling and Frost (1970) concluded that temperature had a greater influence on the growth and abundance of 0+ pike than the biomass of adult pike, and Allen (1941) found that the biomass and production of brown trout (Salmo trutta L.) correlated with the standing crops of the invertebrates in different stretches of the Horokiwi stream.

(3) The experimental approach allows the individual testing of selected factors. It requires suitable sites, ideally a series of replicate lakes or ponds. Hall, Cooper and Werner (1970) used a series of 20 replicate

ponds to investigate the effects of stock density on fish production and the invertebrate fauna under three different nutrient regimes. The University of Auburn has a series of 17 experimental lakes, up to 10 hectares in size, and 300 concrete and earthen ponds which are all drainable and allow experiments on fish populations on a large scale (E.W. Shell, personal communication). R. White (personal communication) used a drainable sewage lagoon divided by plastic netting into quarters to study the influence of fish stocks on zooplankton. Alm (1946) transplanted fish from densely populated lakes to fishless lakes. These fish showed great improvements in their growth rates and Alm concluded that slow growth or 'stunting' was an environmental effect. Macan (1966) noted the abundance and distribution of corixids in a fish-free moorland pond. He then introduced trout into the pond and found that the abundance of and areas occupied by corixids were reduced.

Caution must be exercised when extrapolating from the results of experiments on artificial populations in small ponds to natural populations in large lakes.

Ball and Hayne (1952), Macan (1966), Straskraba (1965) and Lellak (1966) all record the effects of fish predation on the abundance and distribution of non-planktonic invertebrates. Other work has shown that zooplankton is similarly susceptible. Reif and Tappa (1966), Wells (1970) and Hutchinson (1971) all found that the introduction of, or increase in, numbers of obligatory planktivorous fish led to declines in the abundance of daphnids and Gymnomera in the zooplankton. Other workers (Hrbacek 1962 and Hrbacek et al, 1961 and 1965; Hillbrict Ilkowska, 1964; Grygierck, 1965; Gurzeda, 1965; Hall, Werner and Cooper, 1970; Mal'tyman, 1971 and White, 1975) all concluded from experimental manipulation of fish stocks that predation by omnivorous fish can cause quantitative and qualitative changes in the zooplankton.

The general conclusions that can be drawn from this literature are that:-

1. Fish predation on zooplankton is size-selective and therefore

the larger-size components of the zooplankton, e.g. Daphnia sp. and Gymnomera, are more vulnerable to predation than smaller zooplankters.

2. The effects of constant predation on zooplankton by fish can lead to the larger cladocerans, e.g. Daphnia sp., being replaced by the smaller Ceriodaphnia and Bosmina species.

3. The effects of predation from very high fish densities (>500 kgs/h) can lead to a total disappearance of crustaceans in the zooplankton, the largest-sized component of this modified zooplankton then being rotifers.

The consequences of such changes in the zooplankton would be most significant to fish that are dependent upon large Daphnia sp. as a source of food. If such fish are present in large numbers, it is possible that they could, by predation, modify the zooplankton in their environment and thus deprive themselves of a source of food.

Given a constant physical environment, fish growth rate is largely determined by the quantitative and qualitative nature of their diet (L. Orme, personal communication). The effect of quantitative changes in diet on fish growth rate is demonstrated constantly in hatcheries and fish farms and has been shown experimentally (Elliott, 1975). The different conversion rates that different hatchery diets achieve illustrate the importance of the qualitative nature of fish food. These same two factors must influence 'wild' populations. Volodin (1963), Williams (1963) and Britton (1968) suggested that the reasons for the differences in growth rates they observed were qualitative changes in the fish's diet. Both qualitative and quantitative improvement in fishes' diet causing increases in their growth rate were implied by the work of Alm (1946), Kemp (1962), Frank (1970) and Aldoori (1971).

Living conditions, including the quantity and quality of food, have been shown to influence the fecundity of many animals e.g. triclads (Reynoldson 1961), crustaceans (Ingle, Wood and Banta 1971), and birds (Chubb 1960). Bagenal (1969), Nikolsky (1963), Volodin (1963) and Mackay and Mann (1965) all considered that changes in fish fecundity were caused by changes in quantity or quality of the diet. Bagenal (1967) reviewed work which showed the influence of fish numbers and environmental conditions on fecundity and concluded, 'it is clear that overcrowding leading to food shortage results in lower fecundity'.

Literature concluding that facultative and obligatory planktivorous fish can modify zooplankton has been reviewed on the preceeding pages. The possible implications of this effect are:-

(i) The denial of a preferred food.
(ii) A quantitative and or qualitative deterioration in diet.
(iii) A decline in growth rate or fecundity or other parameters which reflect the fish's diet.

This chain of events has not been demonstrated by the study of a natural population. The examination of gut contents of roach and rudd taken from gravel-pit lakes in 1970 revealed that Daphnia longispina was commonly eaten by adult and juvenile fish. From this observation and the literature reviewed on the previous pages, two hypotheses were put forward:-

1. That Daphnia sp. are important food for fish in gravel-pit lakes.
2. That fish density and growth rate could be linked by the modification of the lake's flora or fauna which results from fish predation.

I.5 Outline of Work

Apart from collecting basic data on the biology of gravel-pits, this study attempts to test these two hypotheses. The growth, diet and population structure of the dominant fish species in a gravel-pit lake were monitored. Fecundity estimates were made on the roach. Simultaneous studies on the lake's flora and fauna were carried out to obtain data on seasonal changes in abundance and the fish population was estimated annually. After two years the population density of the fish was increased over five-fold by introducing new stock. The impact of this higher fish density on the diet, growth and fecundity of the fish and the flora and invertebrate fauna in the lake was monitored. The growth and survival rates of the resident roach were compared with those of the introduced stock. The growth rate of the introduced stock in their new environment was compared with their earlier growth rate achieved in their original environment. Several comparisons were planned between data collected in the third year and other data in an attempt to isolate the impact of the increased fish density. These were:-

1. Comparison between data collected in the first two years of the study with those collected in the third year.
2. Comparison between data collected from the study lake with those collected from a similar control lake. These 'control' data were mainly confined to the zooplankton.
3. Comparison between data collected from the main area of the study lake and those from a smaller fish-free area that was set up in the lake.
4. Comparison between data collected in this study and that gathered by other members of the group on fish populations in different gravel-pit lakes.

A limited amount of information on the physical environment was available to aid in interpreting the data.

I.6 Background to Methods

Many of the problems of monitoring the parameters discussed above arose because of the characteristics of the particular lake chosen for the study. The criteria used for selecting the site and the nature of the chosen lake are presented in the chapter on materials and methods (pages 22 - 28).

The initial observations of roach gut contents and reference to the literature, suggested that the roach might feed upon submerged macrophytes, zoobenthos, zooplankton and epilithic and epiphytic algae. Attempts were therefore made to monitor the abundance of these organisms. A fault of some of the earlier studies on the diet of fish has been the failure to obtain samples throughout the year. It was decided to sample the roach population at least monthly. These fish samples were analysed to provide information primarily on diet, growth of dominant year classes and seasonal development of the gonads. The annual population estimates gave additional information on the size-structure of the fish population within the lake. The methods used to monitor, sample and analyse the potential fish food organisms and the fish, are described in the methods chapter (pages 22-44).

Inevitably, conflict arose between the time required to give a comprehensive picture and the time available to give a maximum amount of information on any one aspect of the study, for example, the zooplankton. The final methods employed represent a compromise between these two requirements.

The macrophytes were monitored by direct mapping (page 28). Zooplankton is frequently sampled by a plankton net, vertical hauls avoiding errors because of uneven horizontal distribution of the plankton (Edumunson, 1971). Sampling the zooplankton by vertical hauls with a standard F.B.A. zooplankton tow net revealed two handicaps. Firstly the length of the net (0.7 m) compared with the average depth of the lake (1.7 m) meant that usually only a little over half the water column could be sampled without the risk of agitating the soft ooze of the substrate and including benthic forms in the plankton sample. Secondly, trials revealed that the numbers of cladocera per sample were very variable, so that a large number of replicate samples would be required to give a reliable estimate of the numbers present in the lake (see page 33). A pump sampler was therefore developed and used as described on page 33. This sampler also avoided the problem of assessing the variable efficiency of towed nets (Hall, Cooper and Werner, 1971 and Barnes and Tranter, 1965).

For sampling, the benthos was divided into that of the hard and soft substrates. Available methods for sampling the benthos of hard substrates in depths of water of 0.5-1.5 m fall into three categories:-

(1) Grabs such as the Petersen and Van Veen grabs have been traditionally used in many studies (Welch, 1948). They show several shortcomings, being prone to failure and generally poor at obtaining quantitative samples (Kajak, 1963 and 1971; Schwoerbel, 1966 and Flannagan, 1970).

(2) Artificial substrates have been used successfully in many situations (Moon, 1935; Mundie, 1957; Coleman and Hynes, 1970 and Crisp and Gledhill, 1970). They can be very successful and it is easy to collect the samples. However, they are time-consuming to set up and require areas of substrate to be left undisturbed. These two characteristics rendered artificial substrates unsuitable for this work.

(3) Pump and agitator systems have been recently developed. The Finnish IBP PF Group (1969) utilised a bell-shaped piece of apparatus which covered a known area of substrate. A diver kept the apparatus in place and stirred the substrate enclosed by the apparatus so that the water rising to the surface by a compressed-air air-lift carried with it the benthic animals. Operators in a boat on the surface filtered the animals out of this water before it was returned to the lake. This method seemed to provide the basis of a technique for the rapid collection of benthos samples from hard substrates and the sampler described on page 41 was developed and used in this work.

Schwoerbel (1966) and Welch (1948) discuss various methods for sampling soft substrates. The Ekman grab has certain disadvantages associated with the pressure wave which preceeds the grab and disturbs the substrate to be sampled; Burton and Flannagan (1973) have modified the grab to minimise this problem. Kajak (1963), Brinkhurst, Chua and Batoosingh (1969), and Paterson and Fernando (1971), all show corers to be more efficient than the Ekman grab. However, the Ekman grab was available, is reliable and takes a large sample, it was therefore used for this work.

Jonasson (1965) discusses the effect of mesh size on the efficiency and required time of sieving to reduce the bulk of mud samples. It was found that sieving time could be reduced by over 50% by using mesh bags rather than a conventional rigid sieve.

Standard methods have been employed in studying the fish fauna of the lake and these are described on pages 44-59. Fish population estimates were conducted by the mark, recapture technique (Ricker, 1958) using

Bailey's (1951) modification of the Lincoln Index.

Scale data were used to age the roach; roach scales have been described by Wallin (1957) and considered a reliable method of ageing roach in many studies (Hartley 1947, Jones 1953, Cragg-Hine 1964 and Hellawell 1972). Jones' (1953) nomenclature has been adopted to describe the features on scales. The presence of dominant year-classes in the regular samples allowed the period of check formation on the scales to be observed. The presence of apparent year-classes in the length frequency histograms were used to support estimates of age from fish scales in the manner of Peterson (Tesch, 1968). Fecundity is commonly defined as the number of oocytes developed in the fish's gonad that could be shed during spawning. It is often referred to as absolute fecundity (Bagenal, 1973) or individual absolute fecundity (Volodin 1963). In spring-spawning species such as the roach, this number is determined at the end of the previous summer (see page 56) and can easily be estimated as soon as the oocytes are large enough. Hence for this study fish captured during the winter months (December-April) have been used for fecundity estimates. Mann (1973) used roach caught between January and May.

There is usually a linear relationship between fish weight and fecundity (Bagenal, 1967) but this relationship is of doubtful usefulness because of the possibility of fish weight changing during the winter months (Le Cren, 1951). The relationship between fecundity and fish length is usually curvilinear (Bagenal, 1968 and Volodin, 1963) although Davis (1972) found a linear relationship for a small fish species with relatively low fecundity. Curvilinear relationships can be logarithmically transformed into linear relationships (Bagenal, 1967; Mackay and Mann, 1969; Mann, 1973 and Jones, 1974). This was the method used in this study for comparing different years. Raw data, supplied by R.H.K. Mann (personal communication) and gonads taken from a very slow-growing population in Kew lake provided additional material for comparative purposes. It was anticipated that the length, frequency regressions would reflect changes in the living conditions of the roach.

The use of stomach or gut contents to monitor the diet of fish is complicated by several problems:-

(1) It is usually difficult to quantify the mixture of semi-digested gut contents.

(2) Gut contents can only be used to determine true diet (i.e. the daily ration of different items) when the rates of digestion of the food and the feeding pattern of the fish are also known.

(3) Digestion rates not only change with temperature but can also vary for different components of the same meal (Elliott, 1972).

Various attempts have been made to estimate rates of feeding and digestion. Davis and Warren (1968) review some methods of estimating food consumption rates. Rosenthal and Paffenhofer (1972) used young garfish kept in aquaria which produced faeces convenient for examination. The rate of production of faeces and a comparison of the calorific content of faeces and diet were recorded. Kevern (1966) estimated the feeding rate of carp in a lake contaminated with radioactive waste by monitoring the accumulation of ^{137}Cs. Carline and Hall (1973) maintained fish in tanks that imitated their natural environment. The amount of food these fish required to achieve their usual growth rate was used as an estimate of 'usual' consumption.

Rates of feeding have been studied by taking samples of fish at regular intervals and measuring the accumulation of food in the guts, (Moriarty and Moriarty, 1973). Similarly fish may be fed in tanks or captured from the wild, retained without food and then killed at intervals. Analysis of their gut contents will provide information on rates of digestion, or more accurately, on rates of passage of food through the gut (Bajkov, 1935 and Kitchell and Windell, 1968). Elliott (1972) fed large invertebrates, of known weight, to estimate consumption. He then pumped out stomach contents after different intervals to determine rates of evacuation.

In an attempt to quantify mixed gut contents various methods have been used; these were reviewed by Cragg-Hine (1964). Hynes (1950) used a points system to overcome the bias which a purely numerical qualitative approach gives to small items. Hellawell (1971) developed a volumetric method which was handicapped by the large quantities of mucus he found in many of his samples. Many of the studies on cyprinid fish diets (Hartley, 1940; Cragg-Hine, 1964 ; Banks, 1968 and Hellawell, 1971) use only the first loop of the gut and often referred to this loop as a 'stomach'. Cyprinids have no true stomach (Al-Hussaini, 1949), and this practice seems only to deprive the investigator of two-thirds of his material. In this study the whole gut was used, the gut contents identified and the wet weight recorded; see page 54.

Some preliminary feeding experiments were carried out to assist in the interpretation of the observations made on the gut contents of the fish samples.

It was considered that this study would allow the opportunity of relating numbers, growth, fecundity and diet of fish to the invertebrate fauna and submerged macrophyte flora in a small lake.

CHAPTER II

Materials and Methods

II.1 The Site

The selection of the gravel-pit lake for study was made with the following criteria in mind:-

1. The lake should be one in which the roach was the dominant fish species.
2. It should have a roach population large enough to allow samples to be obtained easily.
3. The site should be physically suitable for convenient sampling of fish and invertebrates.
4. It should be physically and biologically typical of gravel-pit lakes.
5. It should not be prone to marked physical fluctuations, e.g. water-level changes.
6. It should be possible to put the site out-of-bounds to anglers. This was considered necessary to exclude the possibility of anglers' bait and ground bait providing additional food for the fish and to reduce the chances of anglers removing or introducing fish.

In 1971 little was known about the biology of the pits that were available for study. However, at Yateley Hampshire (OS ref. SU 823613) several lakes of a complex had been sampled for fish. Figure 2 shows a map of this complex. Yateley 7 was considered most suitable for the study. S. Bailey (personal communication) reported that it had a fish population dominated by roach which could be conveniently sampled. The water was of a suitable size and, being one of many lakes at one site, it could reasonably be put out-of-bounds. Fortunately, unlike some other gravel-pit lakes, for example those at Twyford (Berkshire) and Darenth (Kent), the water-levels of the lakes at Yateley were unaffected by the dry years 1971 and 1972.

The chosen lake lacked large areas of dense emergent or submerged

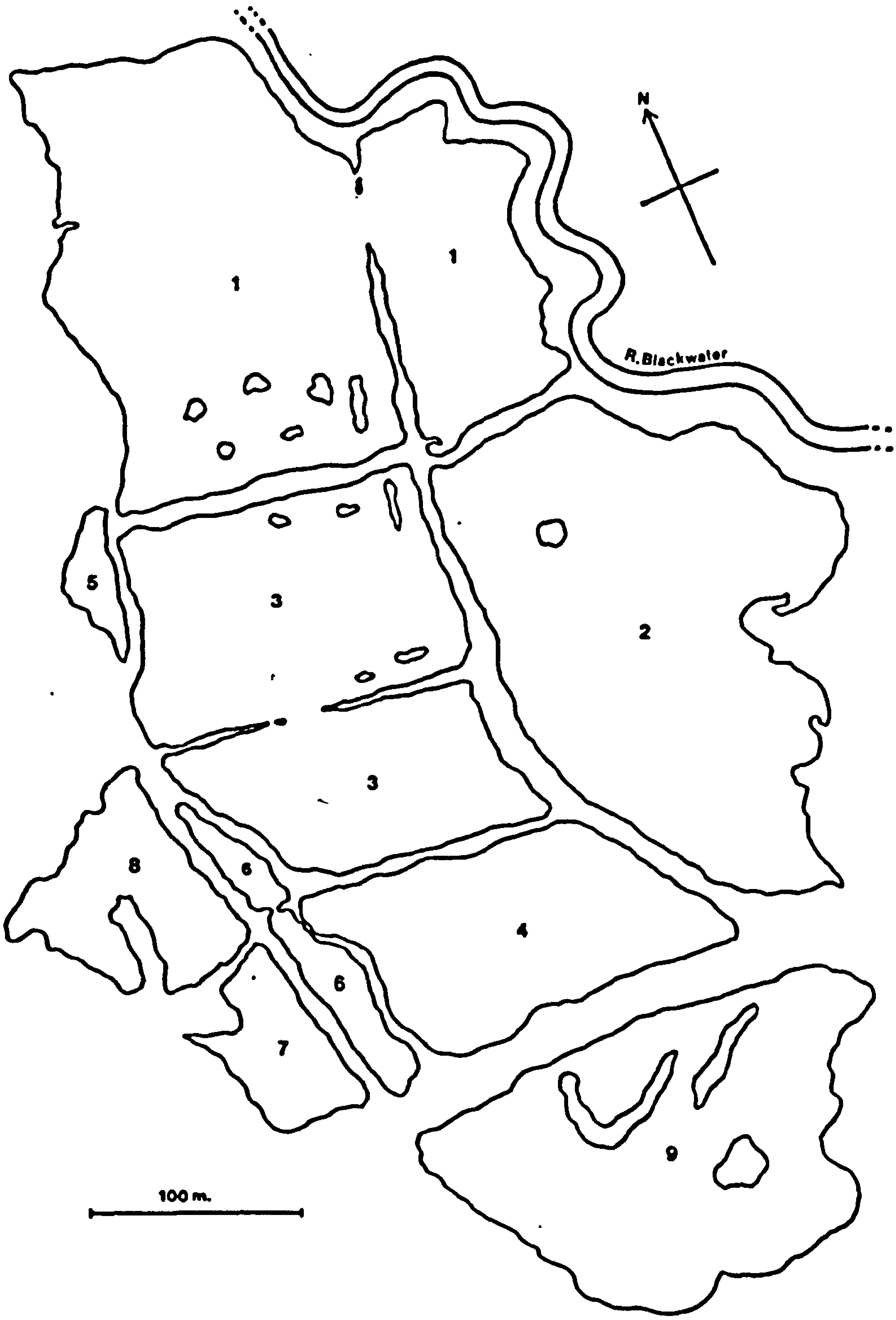


Figure 2   Map of lakes 1 - 9 at Yateley

macrophytes. Such areas might have hampered the study since they could have acted as reservoirs of fish food that would have been difficult to estimate.

Adjacent to lake 7 was a slightly larger lake more irregular in outline. This lake, number 8, was of a similar age to number 7. From catch-per-effort information, it was known to contain a similar fish population. Yateley 8 was used as a control lake.

The topography of lake 7 was surveyed at the beginning of the study. Right angles were projected from the straight eastern bank of the lake and a twine grid was formed. A three-metre pole, marked at 10 centimetre intervals, and a plumb line were used to find the depth and type of substrate The adjacent lake, number 8, was surveyed with an echo-sounder. The survey revealed that the lake was similar to 7.

Figure 3 shows the outline and contour map that was constructed from this survey. The area and average depth of lake 7 was found using a planimeter (Table 1).

TABLE 1 Area and Depth of Lake 7

Total area	:	4,500 m^2
mean depth	:	1.7 m
area of total < 1.5 m	:	27%
area of total > 1.5 m	:	63%

As can be seen from Figure 3 the slope of the banks exceed 45° around 70% of the margin of the lake. Shallow areas are limited and as a consequence, emergent vegetation such as Typha latifolia (L.) is restricted, in most places, to a narrow band around the margin of the lake. The flora of the lake is dealt with more fully on page 26 and Chapter III.1.

When conducting the survey it was found that the 1.5 m contour corresponded quite closely to the boundary between the hard gravel-and-clay substrate, typical of the shallow water, and the soft, silty substrate of the deeper water. As is seen from Table 1, this means that approximately

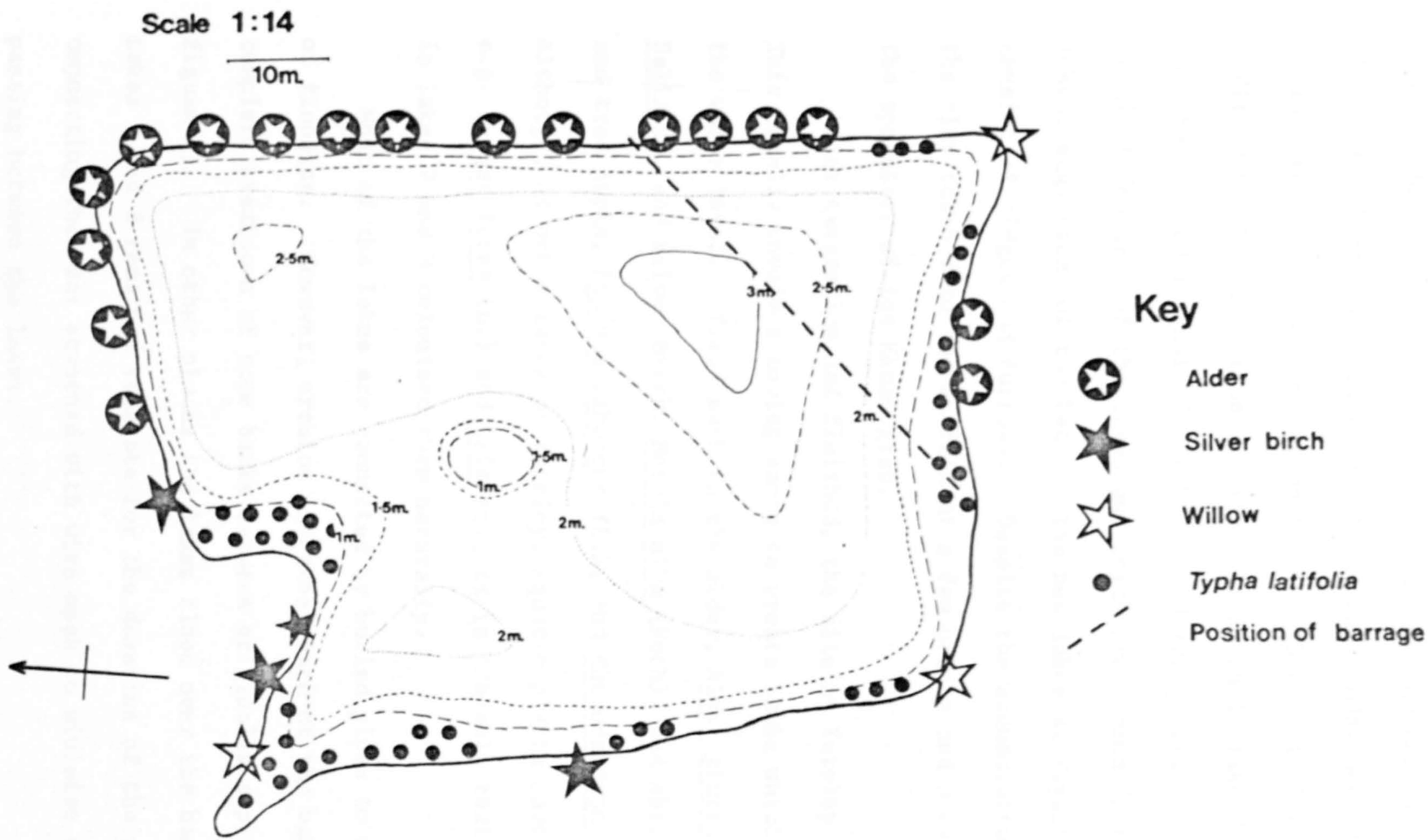


Figure 3 Depth contours and marginal vegetation of Yateley 7

63% of the area of the lake's substrate consists of soft silt.

The lakes at Yateley were excavated between 1950 and 1965, lakes 7 and 8 being the first dug. The gravel was removed down to the underlying clay which thus forms the initial substrate and tends, because of its impermeability, to isolate the lakes from one another. This initial substrate has been modified by the deposition of fine silt which in lake 7 is up to 0.5 m deep. This has filled in most of the holes and irregularities that presumably were original features of the lakes and which are common in the newer gravel-pit lakes, e.g. areas of the beds of the new lakes at Twyford in Berkshire consist of ridges and furrows. Despite the accumulation of silt at Yateley, the clay reached to the surface at a few points and occasionally prevented the operation of the Ekman grab.

After excavation had finished, the site at Yateley was landscaped. This usually involves moving earth to create banks which slope gently to the water level. Trees such as the alder, Alnus glutinosa (L.), willow, Salix sp. and silver birch, Betula alba (Roth), and shrubs such as Buddleia sp. and tree lupin, Lupinus arboreus (L.), and Rhododendron sp. were planted. Although, at other lakes at Yateley, aquatic plants have been introduced, e.g. Nuphar lutea (L.) and Iris sp., it is probable that the aquatic flora in lakes 7 and 8 colonised them naturally.

Most of the lakes are connected by buried pipes to minimise the risks of flooding. However, erosion and subsidence of the banks has led to complete breakdown of some banks between originally separate lakes (see figure 2). In other places the lakes flood over the banks only in winter. Lakes 7 and 8 remained separate for the duration of the study and the pipe connecting them was screened with wire mesh to minimise the chances of fish passing between the lakes.

During the first two years of the investigation the temperature profile of lake 7 was recorded at regular intervals using a Grant temperature recorder. These records are shown in Figure 4.

The phytoplankton of the lakes at the Yateley site have been studied

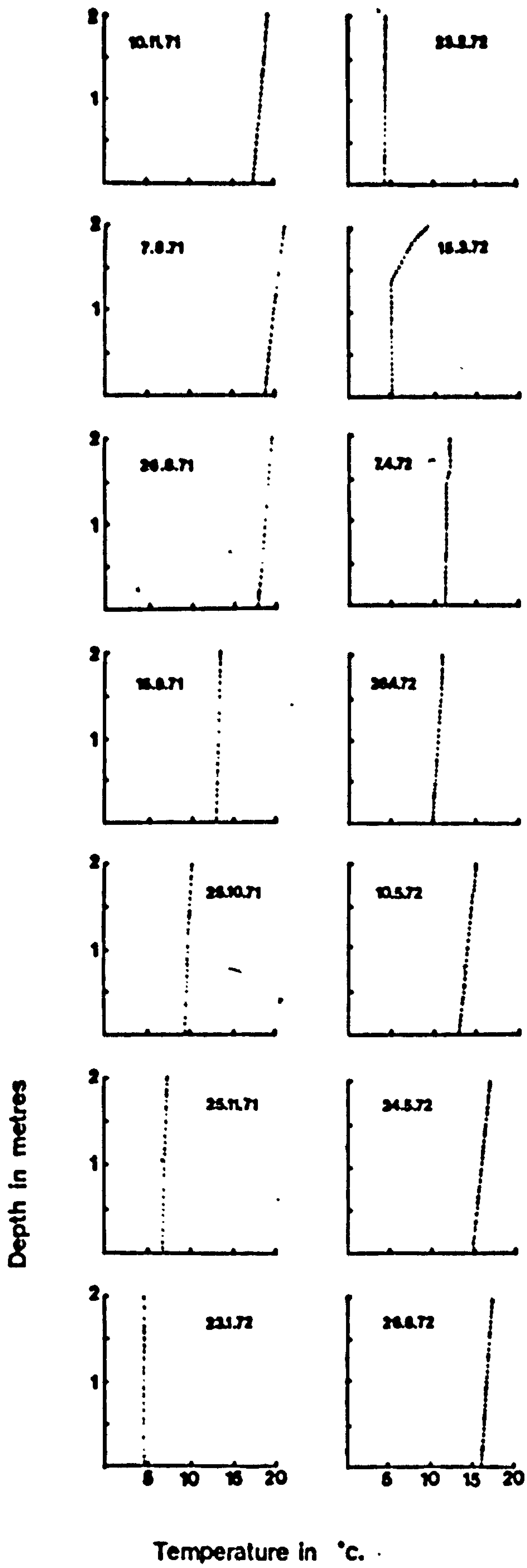


Figure 4 Temperature profiles in Yateley 7

(see page 7). This work included chemical analysis of water samples taken from many of the lakes including 7. A summary of the results of these analyses is presented in Table 2.

II.2 The Flora

Although divers (see acknowledgements) reported that filamentous algae and diatoms 'form a green cover over most of the bed of the lake' and these plants were found in the guts of roach, it was not possible to estimate their abundance.

The data on the phytoplankton (see Tables 3 and 4) were provided by A.M. Powell, B.R. Godfrey and F. Goodridge (unpublished data) from part of a general study on phytoplankton and water chemistry that was undertaken on lakes 1-9 at Yateley during 1972 and 1973.

Maps recording the occurrence and distribution of submerged macrophytes were prepared with the assistance of the divers. A diver moved around the littoral zone of the lake and on finding a plant, surfaced and reported the finding to a recorder who marked it on a map. If immediate identification was not possible, samples were taken and the species temporarily given a code letter. The extent of the plant's distribution was also recorded on the map. The positions of large trees were used as reference points.

The macrophytes were usually restricted to the hard substrate in shallow water. To check this, when plants were found, the diver investigated further out into deeper water. After circling the lake, several transects of the length and width of the lake were made. Finally the mound near the north bank (see Figure 3) was examined more thoroughly. The distribution of the different species of emergent macrophytes was also recorded on the maps.

The maps (see results) were made on the following dates: 20.6.71, 10.9.71, 3.7.72, 30.7.73 and 24.9.73.

TABLE 2 Chemical analyses of samples taken from the Yateley Lakes

	Nitrate as mg/l of nitrogen		Silicate as mg/l silica		Calcium as mg/l calcium	
	in Lake 7	Range in Other Lakes	in Lake 7	Range in Other Lakes	in Lake 7	Range in Other Lakes
24. 1.72	0.47	0.25 to 2.3	1.5	1.5 to 15	132	71 to 132
21. 2.72	0.83	Trace to 1.85	-	- to 10	129	84 to 129
20. 3.72	1.92	0.2 to 1.92	2	<1 to 50	118	66 to 118
17. 4.72	0.29	0.03 to 0.87	1.5	<1 to 60	113	65 to 113
16. 5.72	0.23	Trace to 0.23	4.0	<1 to 50	111	74 to 111
13. 6.72	0.05	0.05 to 0.11	5.0	<1 to 90	129	70 to 129
10. 7.72	0.04	Trace to 0.19	10.0	<1 to 18		
21. 8.72	0.06	0.06 to 0.4	14	<1.5 to 18	113	51 to 113
18..9.72	0.02	0.02 to 0.4	14	<1 to 20	118	61 to 118
16.10.72	0.08	0.08 to 0.31	16	<1.5 to 24	124	59 to 124
13.11.72	0.08	0.05 to 0.21	16	<1.5 to 24	117	59 to 117
11.12.72	0.47	0.15 to 2.3	14	<1.5 to 16	105	63 to 112
15. 1.73	0.66	0.19 to 1.29	14	<2 to 16	109	65 to 110
26. 2.73	0.56	0.17 to 1.8	13	<1 to 13	119	69 to 121
25. 3.73	0.28	0.12 to 1.28	14	<1 to 14	112	65 to 114
24. 4.73	0.13	0.03 to 0.38	9	<1 to 11	113	71 to 113
21. 5.73	0.14	Trace to 0.8	9	<1 to 14	125	76 to 125
18. 6.73	Trace	Trace to 0.23	2	1 to 10	134	74 to 134
16. 7.73	0.08	0.03 to 1.3	8	1.5 to 12	125	82 to 125
15.10.73	0.07	0.02 to 0.75	12	1 to 20	99	55 to 99
12.11.73	0.01	- to 0.76	12	1 to 18	109	63 to 109

TABLE 2 Contd. Chemical analyses of samples taken from the Yateley Lakes

	Nitrate as mg/l nitrogen		Phosphate as mg/l ortho phosphate		Silicate as mg/l silica		Calcium as mg/l calcium	
	in lake 7	range in other lakes	in lake 7	range in other lakes	in lake 7	range in other lakes	in lake 7	range in other lakes
11.2.74	2.17	Trace to 2.17	0.027	0.022 to 0.027	11.0	<1 to 11.0	121	68 to 121
11.3 74	1.95	Trace to 1.95	0.029	0.006 to 0.127	12.0	<1 to 12.0	158	75 to 158
8.4.74	1.32	0.1 to 1.48	0.023	Trace to 0.152	8.0	<1 to 5.0	147	70 to 147
6.5.74	0.17	Trace to 1.90	0.002	0.002 to 0.07	7.0	<1 to 7.0	149	73 to 149
28.5.74	Trace	Trace to 1.83	0.032	Trace to 0.061	7.0	<1 to 10.0	144	75 to 144
18.6.74	Not determined		0.024	0.018 to 0.102	7.0	<1 to 12.0	139	85 to 139
15.7.74	Trace	Trace to 0.42	0.23	Trace to 0.03	11.0	2 to 12.0	137	77 to 137

TABLE 3 Levels of chlorophyll *a* in lakes 1-9 at Yateley

Date Samples Taken	Estimates of Chlorophyll *a* in Ugm / ℓ Lake 7	Range in all lakes	(Lake numbers)
17.11.71	18.8	0.8 - 31.2	(9 and 5)
28.11.71	16.3	2.1 - 19.8	(6 and 5)
13.12.71	13.1	1.0 - 14.6	(9 and 3/4)
10. 1.72	27.1	1.6 - 31.0	(1 and 3b)
24. 1.72	28.1	2.1 - 28.1	(4 and 7)
8. 2.72	20.8	1.0 - 20.9	(9 and 7)
21. 2.72	43.8	1.0 - 43.8	(9 and 7)
5. 3.72	15.6	4.1 - 30.8	(9 and 3a)
20. 3.72	17.7	2.1 - 41.2	(1 and 3a)
17. 4.72	44.8	31.6 - 41.2	(4 and 7)
1. 5.72	31.3	1.6 - 31.3	(1 and 7)
15. 5.72	17.7	1.6 - 23.9	(9 and 8)
30. 5.72	11.4	2.6 - 18.8	(4 and 5)
13. 6.72	29.7	4.7 - 34.9	(4 and 5)
26. 6.72	8.7	4.7 - 121.4	(1 and 5)
10. 7.72	43.4	5.2 - 43.4	(2 and 7)
24. 7.72	34.9	6.8 - 67.2	(9 and 2)
21. 8.72	20.9	4.7 - 43.3	(9 and 3b)
5. 9.72	38.1	4.1 - 54.2	(9 and 3a)
18. 9.72	71.9	5.7 - 175.1	(1 and 5)
2.10.72	22.9	2.1 - 68.8	(9 and 3a)
17.10.72	21.9	3.1 - 56.3	(6 and 3b)
30.10.72	8.7	0.5 - 41.2	(6 and 3a)
13.11.72	41.7	3.6 - 49.0	(9 and 3a)
27.11.72	34.4	3.1 - 38.6	(6 and 3b)
11.12.72	56.8	3.1 - 56.8	(2 and 7)
1. 1.73	12.5	1.3 - 12.5	(6 and 7)
15. 1.73	13.5	4.2 - 13.5	(6 and 7)

TABLE 4 Mean chlorophyll a levels in lakes 1-9 at Yateley for the Period 17.11.71 - 15.1.73

Lake Number	Mean Level of Chlorophyll a in Ugm / l
1	4.4
2	9.7
3a	23.7
3b	22.6
4	8.8
5	28.6
6	8.1
7	27.4
8	17.6
9	4.7

II.3 The Invertebrates

Samples were taken of the zooplankton and the zoobenthos.

A. The Zooplankton

The large Cladocera were considered to be a possible source of food for the roach, and other fish. The main objective in sampling the zooplankton was to monitor the fluctuating abundance of these Cladocera. The length-frequency distributions of Daphnia longispina in some of the 1973 samples were estimated. These aided the interpretation of trends in overall abundance and of the importance of their size to the predators (fish).

The sampler that was developed for the zooplankton consisted of a plastic tube 1.6 m long and 5.2 cm in diameter. The tube was sealed at one end and had a series of ten holes, 1.0 cm in diameter and approximately 14 cm apart, down its length. The open end was connected to a 10 m length of suction hose 2.6 cm in diameter. The zooplankton was sampled by lowering the tube vertically in the water and drawing water up out of it via the suction hose.

The sampler was designed to sample all depths of the water column simultaneously. Its performance was tested in a large aquarium. Water was pumped out of the tube at the same rate as that in the field. An OTT meter was at first used to measure the current at the inlet holes in the tubes but at no hole was the current sufficient to operate it. Dye was injected in front of each hole and the current estimated visually. The current was similar at all holes except near the sealed end, where it was slightly reduced. Before commencing the sampling program, field trials were conducted comparing samples taken with the pump sampler with those taken by vertical hauls with a standard F.B.A. zooplankton net. Table 5 shows that the dispersion and confidence limits were greater for the net replicates than for the pump replicates and that the means for net sample were less than those of the pump sample. The difference in the means of

TABLE 5 Estimates of numbers of animals found in replicates taken with the pump sampler and by vertical hauls with a zooplankton net - estimates converted to numbers per 100 l.

	Net Replicates							Pump Replicates						
	1	2	3	4	5	6	$\bar{x}$ and 95% limits	1	2	3	4	5	6	$\bar{x}$ and 95% limits
<u>Daphnia</u> <u>longispina</u>	1018	726	2010	297	759	916	954.3 ± 601.2	1673	1607	1697	969	1033	1214	1357.2 ± 334
Calanoid copepods	908	712	1813	288	682	893	882.7	1368	1611	1620	919	984	1189	1281.8
Cyclopoid copepods	137	123	238	47	88	162	132.5	213	153	208	119	174	185	175.3
<u>Chaoborus</u> sp.	3	2	12	6	10	4	6.2	5	4	7	8	4	6	5.7

Comparing means of <u>D.</u> <u>longispina</u>

	$\bar{x}$	s^2	t	p
net samples	954.3	328449	<1.0	>0.1
pump samples	1357.2	104965		

Using Logarithmic transformation

$\bar{x}$	s^2	t	p
2·91	0·27	1·36	>0.1
3·12	0·11		

D. longispina was significantly different (see table 5, page 34). This may well have been because no calibration was made for the net - it was assumed that the net filtered the maximum possible volume.

Pump samplers have been used successfully by other workers (Beers et al, 1967); Icanberg and Richardson (1973) could show no difference, at the 95% level, between samples obtained with a No. 10 plankton net and those pumped with a 0.25 h.p. motor. Using cyclopoids in a petri dish, Singarajak (1969) did demonstrate that zooplankters are capable of avoiding a siphon tube; however, avoidance of towed plankton nets has also been shown, (Fleminger and Clutter, 1965).

The pump sampler was assembled in a boat and used to extract 40 litres from each of five sites in both lakes 7 and 8. This gave a cumulative sample of 200 litres from each lake. The rigid plastic tube was lowered vertically into the water and water drawn through the apparatus to flush it out then, a square of 0.4 millimetre-mesh bolting silk was secured over the outlet pipe. The five 40 litre sub-samples were then taken from the successive sites. In this way the sample of zooplankton was filtered out of the water and retained in the mesh. The mesh was then carefully removed and placed in a labelled bottle containing 4% formalin. This procedure was repeated on the second lake.

Initially a 25 cc two-stroke motor was used to pump the water; this was unreliable and was replaced by a double-action bilge pump ('Whale Gusher') which delivered 40 litres for 50 full cycles of operation and required no priming.

During the study, all areas of lakes 7 and 8 were seined while sampling the fish; therefore it was not possible to set up bouys or stakes to mark fixed sampling points. On lake 7 four stations were regularly spaced at intervals down the long N-S axis of the lake approximately 20 m from the eastern bank. The fifth station was situated in the western part of the lake. In lake 8 in 1971 (in connection with other work) a vertical net barrier was set N-S across the narrow neck, dividing the lake into two.

The net was designed to separate the fish population into two. The zooplankton-sampling stations were confined to the eastern half and taken at approximately regular intervals down the N-S axis.

Because the lakes were always sampled in succession on the same day, great care was taken to flush out the apparatus before sampling the second lake.

As indicated by the samples taken by vertical hauls with a plankton net the Cladocera were contagiously distributed. These observations have been confirmed by other workers in gravel-pit lakes, (M.P. Cook, personal communication). Because the pump sampler took samples over a short period while the boat was drifting, rather than instantaneously at a fixed spot, it overcame some of the difficulties associated with sampling contagiously distributed animals. On one occasion in lake 7 the sample taken from the open water contained few individuals, large numbers were seen in the littoral region of the lake. On this and two other occasions when the littoral zone was sampled the samples differed from those taken from the open water (see page 70). However the volume of the littoral zone is very small compared with that of the open water. Hence differences in the abundance of zooplankton in the two regions were unlikely to invalidate the overall estimates of abundance which were based upon open water samples.

In the laboratory the animals were washed out of the mesh and re-suspended in a known volume of water. The volume of this water was varied from five to one hundred millilitres in an attempt to dilute the animals to a similar degree and allow the convenient counting of subsamples.

After thoroughly agitating the samples, the subsamples were taken with a wide-mouthed pipette and placed in an "Eel-worm' counting chamber for counting under a binocular microscope (x 10). This technique rendered the use of a device such as the Stempel pipette (Edmunson, 1971) unnecessary. The volume of water lying under the etched grid of the chamber was one millilitre and this enabled an estimate of the numbers of zooplankters in the whole sample to be calculated.

The dominant large cladoceran Daphnia longispina was counted separately. Other Cladocera were identified to genus and counted. The copepods were identified as either calanoids or cyclopoids and counted. The mesh size used on the sampler did not reliably retain rotifers or nauphii which were therefore not counted. The presence of other taxa was recorded.

Table 6 compares the counts made on replicate subsamples. This shows that by taking five replicates, the estimates of numbers of the more abundant animals have 95% confidence limits of ±10%. Wherever possible i.e. where the volume of the concentrated sample >10 ml at least 5 replicate subsamples were counted, elsewhere at least 30% of the whole sample was examined and counted (see discussion, page 148).

During 1973 the length-frequency distributions of D. longispina in the samples were determined. This was achieved by examining a subsample in the counting chamber and measuring the first 200 individuals seen using an eye-piece graticule. If necessary a further subsample was taken. The measurements of individuals were recorded against a list of size intervals which ranged from 0.45 to 2.45 mm in 0.1 mm intervals.

This method was checked by carrying out two analyses on one sample and comparing the results. The results (Table 7 and Figure 5) indicate that the measurement of 100-200 individuals gave reliable length-frequency distribution estimates.

To enable estimates of biomass to be made a length-weight relationship for D. longispina was determined. Six size categories were chosen to cover the range observed in the samples. These categories were: 0.7-0.8, 0.95-1.05, 1.2-1.3, 1.45-1.55, 1.7-1.8 and 1.95-2.05 (in mm). Twenty individuals were chosen that filtered into each of the first five categories; only four individuals of the largest size could be found. The individuals within the different categories were placed on aluminium boats and dehydrated for 24 hours in a desiccator. The dried Cladocera were then

TABLE 6 Counts on replicate subsamples taken from one sample
Counts are numbers /ml of the concentrated sample

	Replicates					
	1	2	3	4	5	$\bar{x}$ 95% confidence limits
SAMPLE 1 (taken on 25.11.71 from lake 7)						
Daphnia longispina	5	5	3	2	9	4.8 ± 3.1
Bosmina longirostris	286	297	308	318	332	308.2 ± 21.4
Calanoid Copepods	107	103	100	121	110	108.2 ± 9.3
Cyclopoid Copepods	27	21	22	34	37	28.2 ± 8.2
SAMPLE 2 (taken on 9.7.72 from lake 7)						
Daphnia longispina	430	452	492	418	469	452.2 ± 34.2
Bosmina longirostris	26	22	20	32	23	24.6 ± 5.4
Calanoid Copepods	8	6	4	6	7	6.2 ± 1.7
Cyclopoid Copepods	274	259	310	224	273	268 ± 34.7
Chaoborus sp.	1	1	-	1	2	1

TABLE 7 A comparison of two estimates of the mean length of *D. longispina* in the same sample

	$\bar{x}$	95% confidence limits	s^2	n
1st estimate	1.29	±0.04	0.05	122
2nd estimate	1.24	±0.04	0.04	107

t = 1.76 (no significant difference) at $p > 0{\cdot}05$

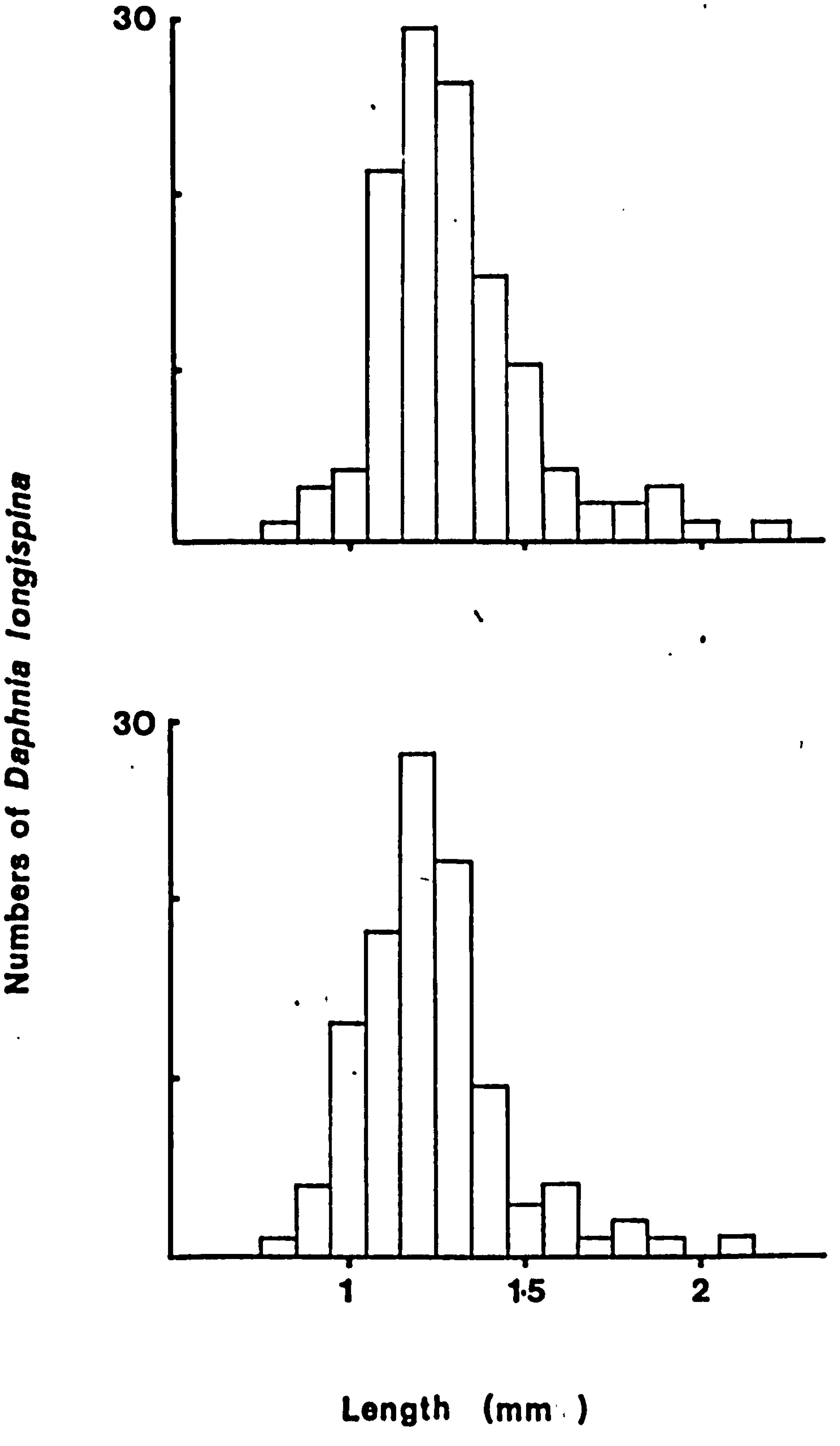


Figure 5 Daphnia longispina length-frequency distributions in two replicate sub-samples of the same sample

weighed on a Cahn balance by adding an animal, recording the weight, then adding another of the same size catagory and recording the cumulative weight. This procedure was repeated until all twenty of that size category had been added and repeated for each category. The average weight and confidence limits for each of the six sizes were then calculated. Using these estimates of weight for length the length, weight regression was calculated using the method of Bartlett (1949)* and a Fortran program provided by A.S. Gee. This method was used for calculating all the regressions where errors existed in the values of x and y.

B. The Zoobenthos

As mentioned in the introduction, different methods had to be employed for sampling the hard and soft substrates.

The sampler developed (see Fig. 6) for the hard substrate consisted of a brass cylinder 24.8 cm in diameter (484 cm^2 in area). The upper surface tapered to a central tube which had a bore of 2.6 cm and could be connected to a suction hose (as used on the plankton sampler). The present device had a polythene skirt around the outside, which overlapped the base, and four 2 cm holes in its sides. These holes were covered with 1 mm copper mesh and had short inlet pipes soldered to their insides pointing downwards. Angled 'fish-tail' jets were fixed to the ends of the pipes. To operate the sampler, it was lowered onto the substrate and water was pumped rapidly out via the suction hose. The weight of the brass sampler and the polythene skirt limits water entering the sampler from between the edge of the cylinder and the substrate so that most of the water is sucked into the sampler via the four mesh-covered inlet holes. The tubes and jets direct this water onto the substrate and create a scouring current. This current washes out the more buoyant components of the substrate including the animals; this material is raised up out of the sampler by the pump.

Here again a small two-stroke motor was used initially; however, its

*see appendix

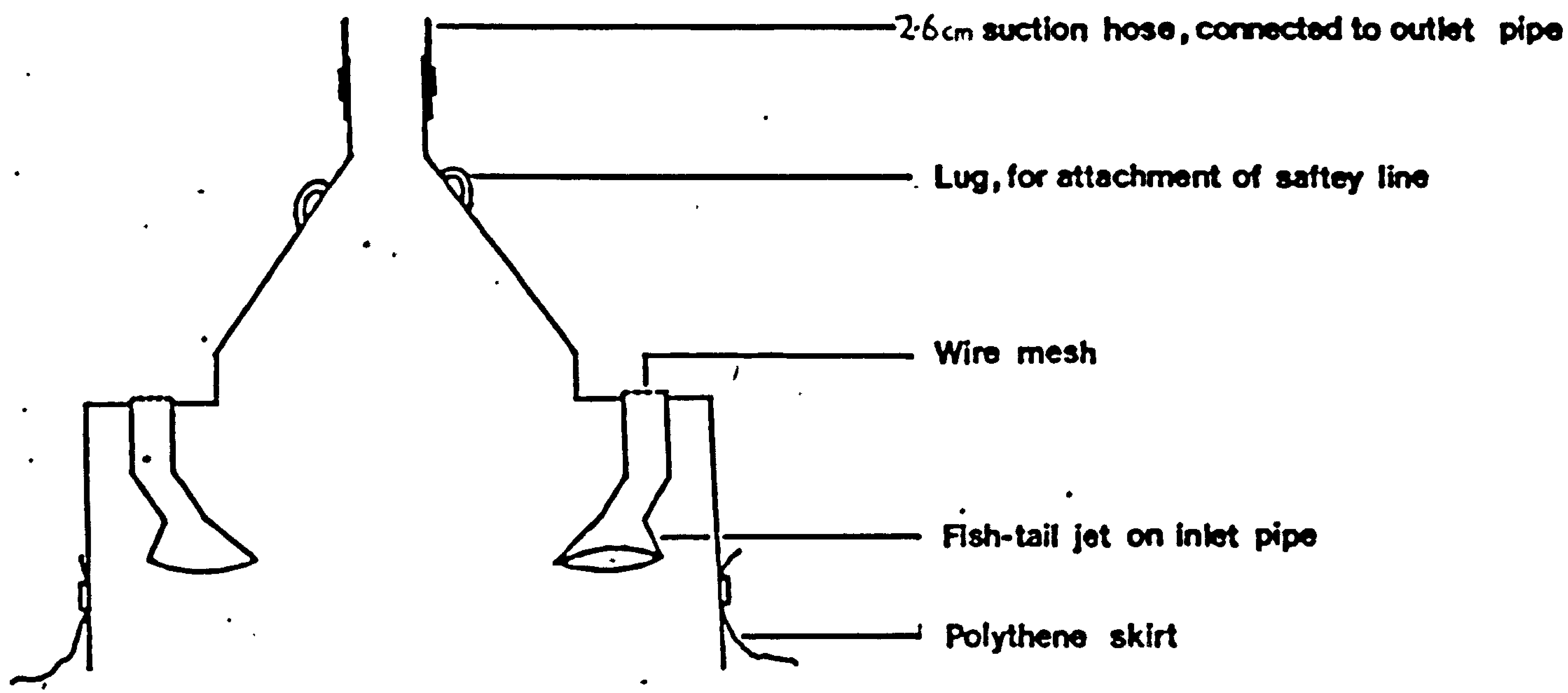


Figure 6 Diagram of the benthos suction sampler

basic unreliability was increased by small stones being carried up in the water and jamming the impeller. Further trials were carried out with the double-action bilge pump. The animals were collected by placing a mesh bag over the outlet from the pump. An attempt was also made to strain out the sample in front of the pump to prevent jamming of the impeller (see discussion, page 150).

Comparisons were made between a series of samples taken with the new device and those obtained with a brass corer (area 205 cm^2) and spade.

Some of these trials were carried out in Lake 3b at Yateley where extensive shallows allowed the convenient removal of replicate core and suction samples.

The volume of each core sample was reduced in the field using mesh bags made from heavy duty Nybolt bolting silk, ten meshes to the centimetre. The mesh bags saved sieving time and allowed the easy transference of the samples into plastic bags.

The samples were sorted in the laboratory using magnesium sulphate flotation (Schwoerbel 1966). Some workers comment upon problems arising from the dehydration of annelids in magnesium sulphate; this did not occur and therefore it was unnecessary to use Anderson's (1959) suggestion of sucrose instead of magnesium sulphate. The different taxa were identified as closely as possible and counted. The samples were always sorted before the animals died i.e. within two days of sampling.

By the time the sampler had been developed and tested, it had been found that the fauna characteristic of the hard substrate rarely occurred in the roach's guts. To allow more time for other aspects of the study, the plans to sample the benthos of the hard substrate were abandoned. However, as the trials showed (see results, page 75), the sampler proved an effective method for one-man sampling of the on-benthos of hard substrate (see discussion, page 150).

A messenger-operated Ekman grab (area 225 cm^2) was used to sample the soft substrate. Ten replicates were taken at four-monthly intervals. On one occasion the line to the grab parted and it was several weeks before a diver located and retrieved the grab. As a result, only six replicates were taken on that occasion.

Each replicate was sieved and sorted in the manner described for the core samples. The flotation process was carried out in one-litre plastic beakers. The animals were picked off and placed into separate tubes, one for each taxon. The beakers were sorted and stirred repeatedly until no more animals rose to the surface. Then the magnesium sulphate was decanted off and the remaining material tipped into a white tray. It was sorted by hand for any caddis fly larvae that might have remained in their cases, or molluscs that might not have floated to the surface. The numbers of individuals in each taxon were recorded.

II.4 The Fish

Table 8 lists the different species of fish caught in lakes 7 and 8 at Yateley during the study.

A. Field Methods

(a) Routine Sampling

Table 9 shows the dates when the fish were sampled and the numbers of fish retained. Most of the fish were caught with a seine net. In the first year the net used was fifty yards (approximately 45 m) long and nine feet deep (2.7 m). The stretched-mesh size of this net was 1 inch (2.6 cm) and there was a central bag approximately 15 feet (5 m deep). This net was replaced with a deeper net 12 feet (3.7 m) with a stretched-mesh size of ¾ inch (2 cm).

The 2-cm stretched-mesh net did not reliably catch fish until they were between 5 and 6 cm long. Samples taken containing year-classes of average length <5 cm could give false impressions of, for example:-

(1) Average size. Such samples may have a higher average length than the population.

TABLE 8 Fish species found in Lakes 7 and 8 (Yateley)

Cyprinidae	
roach	*Rutilus rutilus* (L.)
rudd	*Scardinius erythrophthalmus* (L.)
tench	*Tinca tinca* (L.)
common carp	*Cyprinus carpio* L.
crucian carp	*Carassius carassius* (L.)
dace	*Leuciscus leuciscus* (L.), lake 8 only
gudgeon	*Gobio gobio* (L.)
Esocidae	
pike	*Esox lucius* L.
Anguillidae	
eel	*Anguilla anguilla* (L.)
Percidae	
perch	*Perca fluviatilis* L.

TABLE 9 Numbers and dates of fish samples taken from Lake 7

Date of Samples	Numbers of Roach		Numbers of Rudd		Numbers of Perch	Other
	0+	1+ & Older	1+ & Older			
5. 6.70		12*	4*			10 tench*
15. 6.70		9*	9*			
21. 1.71		6	2			
19. 2.71		13				
11. 3.71		9				
1. 4.71		20	4			
5. 5.71		12	4			
26. 5.71		40	18			
25. 6.71	11	27	22			
13. 7.71		4	10			
29. 7.71	18	9	7			
28. 8.71	48	14	19			
15. 9.71		7	7			
25. 9.71		19	5			
25.10.71		10	7			November 1971
13. 3.72		15				1st population estimate
7. 4.72		7				
24. 4.72		7	no further			
10. 5.72		12	rudd taken			
24. 5.72		12	Total = 118			
11. 6.72		22				
26. 6.72		11	Extra roach			
9. 7.72		16	taken and			
6. 8.72		9	returned			
4. 9.72		10		Nos aged		
2.10.72		12		from		November 1972 2nd
8. 1.73		6	Total	Scales		population estimate, 6 pike
31. 1.73		110**	690**			
20. 2.73		35				
12. 3.73		18				
9. 4.73		11				
3. 5.73		19				
16. 5.73		20				
31. 5.73		21	775		65	
12. 6.73		14				1 pike
29. 6.73	31	20	100	86		
16. 7.73		21	71	56	100	
9. 8.73		12	178	77	186	
10. 9.73	49	23	756	86	32	
8.10.73		20	233	106	65	
13.11.73		23	1101		50	3rd population estimate
17.12.73		22	99	67	65	
Totals	***157	763	3903	478	543	

* - Preserved guts from fish collected by S. Bailey

** - Fish from lake 18b, sample of new stock

*** - 148 additional 0+ roach were taken on 4 additional dates in 1971 and 1973

(2) Sex ratio. In species such as the perch the males may mature in their first year when only 5 cm in length. Such 0+ males will have swollen abdomens and could become trapped in the net while the immature 0+ females escape.

(3) Parasite infection. It is common to record the incidence of such parasites as <u>Ligula intestinalis</u> (L.) as a percentage infection. This parasite causes a gross distension of the abdomen and, for fish between 4-6 cm in length, could easily account for infected fish being selectively netted.

All three factors occasionally applied to samples taken at Yateley 7. Small fish caught in the seine net were therefore only regarded as representative samples when the factors mentioned above did not apply.

There were considerable problems in catching fish during their first year of life. Unfortunately, this study pre-dated the paper by Bagenal (1974) which describes traps for catching 0+ fish. These traps have been used successfully on gravel-pit lakes in 1975 (M.P. Cook, personal communication). Perspex traps, to the design of Breeder (1960) were unsuccessful in Lake 7. Roach and rudd, up to two months old, were caught by using a standard FBA pond net and a larger-framed, long-handled net.

Although the study concentrated upon the roach, it was hoped to take fish samples that were representative of the entire fish community. Several factors precluded this. These were:-

(1) Some species e.g. tench and pike were present in low numbers in the lake (see population estimate results, page 85). If these species had been sampled regularly, in numbers sufficient to provide reliable data, the structure of the fish community in the lake would have been changed.

(2) The rudd were initially quite common and included in the routine sampling but by November 1972 their numbers had declined dramatically (see Table 16). From March 1972 they were rarely caught and it was no longer possible to take regular samples.

(3) Although 0+ perch were common in the catches at the end of summer, older perch were rare until 1973. Regular samples of perch were only taken during 1973.

As a result, the roach was the only species that was sampled throughout the entire duration of the study. Even this species was present in restricted numbers and this imposed limitations on the study.

As Table 9 shows, the samples were taken at approximately monthly intervals. Usually between 15 and 30 roach were retained for examination. In 1971 the fish were weighed and measured in the field; their guts and gonads were removed and placed in numbered bottles of 4% formalin. Key scales were taken and placed in envelopes. In 1972 and 1973 the fish were killed and abdomens slit and the whole fish placed in 4% formalin. Their guts, gonads and scales were removed and examined in the laboratory within a week (see page 52).

Attempts were made to identify the roach's diet, without killing the fish, by pipetting gut contents out of the anterior end of their guts. This proved unsuccessful. In June 1973 the collection of faeces to interpret the fish's diet was tested. Faeces were collected from fish and compared with gut contents of individuals caught at the same time. Results of this comparison did not warrant the continued adoption of this technique (see page 106).

(b) <u>Population Estimates</u>

Population estimates were carried out on the fish in lake 7 in November of 1971, 1972 and 1973. It was considered that the procedures involved in conducting the estimate would cause fewer mortalities when water temperatures were low.

Capture-recapture estimates may be biased by several factors, e.g. selectivity of sampling. Three of these factors are influenced by the interval between capture and recapture; these are:

(1) The possibility that the processes involved in capture and marking will increase the mortality rate of marked fish compared with unmarked fish.

(2) The possibility that these processes will influence the catchability of fish.

(3) The possibility that marked fish will fail to mix with the unmarked fish in the water (i.e. non-random distribution of marked fish).

The study lake was small; its entire area was fishable and would be covered several times with seine nets during the course of a day's fishing. It was concluded that factor (1) was most likely to bias the estimate. To reduce this to a minimum, the estimate was conducted on three consecutive days. The fish were given a different mark on each day and the lake was fished on a final occasion one week later. This was in an attempt to check on the possible influence of increasing the interval between capture and recapture.

The fish from each day's catch were counted, measured (fork length), checked for previous marks and marked. Fish under 10 cm long were fin clipped as follows:-

Day one - anal fin
Day two - left pelvic fin
Day three - right pelvic fin

The larger fish were marked with a panjet (Hart and Pitcher, 1969); Indian ink was used as the mark and the effectiveness was improved in the larger-scaled species (roach and rudd) by aiming the jet into scale pockets. A later model of panjet, the fish tattoo, with the washers modified to minimize clogging, proved more reliable than the first instruments used.

In 1972 the fish caught in each seine were counted and measured separately. During each estimate the fish were retained in 200-litre bins and two inflatable dinghies (filled with water), until the end of each day. Oxygen was available in 1973 and used when required. The cold water allowed the fish to be held at greater densities than would have been possible in summer; however, the lack of bottled oxygen in 1971 and 1972 necessitated changing the water in the bins at regular intervals.

In the first two years the fish were measured on a board and the lengths recorded; in 1973 the fish lengths were pricked on to waxed metric graph paper. The larger tench and pike were too big to be measured otherwise than on a board.

On the third and fourth days, samples of fish were retained for analysis of the fish's diet and age. Only unmarked fish were used. Mortalities occurring during the estimate were recorded, since the loss of marked fish in the population had to be considered when calculating the estimates.

Estimates were made using Bailey's (1951) modification of the Lincoln Index (Ricker, 1958).* The three different marks and three days of recaptures gave 16 possible permutations of estimates by Lincoln Index. These estimates were not independent and therefore estimates of means and confidence limits could not be calculated. Comparisons were made on the influence of time between marking and recapture on estimates and of estimates derived from recaptured fish marked once, twice and three times. In the light of the second comparison (see Table 18) the estimates used were based upon recaptured fish with only one mark.

(c) <u>Field Experiment</u>

The experiment consisted of increasing the density of roach in the lake while maintaining one area relatively fish free (see page 16). A barrage was set across the SE corner of the lake enclosing 750 m^2 of water, 16.6% of the lake's surface (see Figure 3). It was hoped to maintain this barrier for 8-9 months. Most of the fish were removed from the enclosed area by seining and setting gill nets; the stock density in the main part of the lake was increased.

The barrage was made of 1000 gauge polythene 70 m long and 3·5 m deep. Two 1-metre wide panels of 0.5 cm nylon mesh were set in the poly-

*This procedure minimises bias when the number of recaptures is low.

thene extending from top to bottom. These allowed a limited passage of water across the barrier and were designed to minimise the development of pressure on the structure. The polythene was further supported by being 'sandwiched' between 5·2 cm mesh 'netlon' garden netting.

Reinforced eyelets had been fitted every metre to the edges of the polythene and were used in its assembly. A wire cable was threaded through the eyelets along the top with one end attached to an angle-iron stake; the cable was drawn tight with a winch and then secured, leaving the barrage in position like a curtain hanging from a wire. The base was fixed to the lake's substrate by a diver fixing stakes into the bed of the lake through the eyelets in the polythene. In addition weights were placed on the surplus material. The structure was given further support by five stakes that were spaced along its length. One-inch galvanised iron barrel was driven through the fine silt and into the harder clay and the supporting wire was then attached to it.

A small pit approximately 5 miles from Yateley (Farnborough, 18b) was found to contain a large roach population. A sample was examined in December 1972 and indicated that the fish were healthy and suitable stock to introduce into lake 7. In January 1973 3,250 roach, ranging in size from 5 to 25 cm, were transferred to Yateley 7. Of these a sample of 700 was measured by pricking their fork lengths on waxed paper; an additional 111 fish from 18b were killed and processed in a similar way to the routine samples.

In February 1973, when the barrier had been in position for two months, the water level fell over 30 cm. Over 50 cm of the barrage was then exposed above the water and at this time a strong north-westerly gale blew. This was the only direction in which there was any fetch of water in front of the structure which had been deliberately set parallel to prevailing south-westerly winds (see Figure 3). The barrage was lifted and the polythene torn from the stakes and eyelets that were anchoring it to the substrate. Because these eyelets were torn out, the base could not be reanchored. It would have taken several months for a second structure to be made and this, together with the cost considerations, resulted in the abandonment of the idea of maintaining fish free area.

It was concluded that a better construction would have been to support the barrage on both sides with poles or to have used an inflatable tube to support the structure at the surface. The tube would have had the advantage of rising and falling with any fluctuations in the water level in the manner of the tubes in Blelham tarn (Gilson, 1971).

Examination of the scales taken from the sample of introduced fish revealed that these fish were slower growing than the native fish in Yateley 7. The dominant year-class in the introduced roach (2+ in January 1973, 1970 year-class) and the dominant year-class of the native roach stock (1+ in January 1973, 1971 year-class) were approximately the same length.

To provide better data on the growth rates of these two year classes, i.e. comparing the growth of native and introduced fish, larger numbers of fish were needed than those taken in the routine samples.

At monthly intervals from June to December 1973 larger samples of roach were taken. To maintain the high fish density in the lake these fish were not killed. Their lengths were recorded and 'key' scale samples were taken. The scales were placed into serially numbered glass vials which contained a small amount of water.

B. Laboratory Methods

(a) Treatment of Routine Samples

These samples were analysed to provide data on the following aspects of the fish's biology:-

(1) Growth rates.
(2) Relationship between growth and the appearance of checks on the scales.
(3) Diet.
(4) Intensity of feeding (as reflected by the amounts of food in the gut).

(5) Annual cycle of gonad development.
(6) Time of spawning.
(7) Fecundity.
(8) Relationship between spawning and the appearance of checks on the scales.

In examining the fish, the following procedures were adopted:

(1) Fork length was recorded to the nearest millimetre.
(2) Weight was recorded to the nearest gramme.
(3) Three key scales were taken from the 'shoulder' of the fish, three full rows below the anterior root of the dorsal fin.
(4) Gonads were removed, weighed wet to the nearest 0.1gm, assigned a state of maturity (see page 56) and stored in 4% formalin.
(5) The occurrence of conspicuous parasites was recorded.
(6) The entire gut was removed and stored in 4% formalin.

The roach and rudd were aged by examination of scales. The scales, if they had dried out, were soaked in hot water and cleaned between thumb and forefinger. They were mounted, dry, between microscope slides and examined on either a Reichart projector or a binocular microscope using the lower power (x 20).

The perch were aged from the examination of scales and opercular bones. Length, frequency histograms were used, wherever possible, to support age estimates based on the examination of bony tissues.

The growth of the fish was estimated from following individual year classes. Age-for-length analysis of catches was also undertaken. No significant growth was observed in the dominant year-classes during the winter months; it was concluded that no significant growth occurred during these months. Similar conclusions have been made by other workers studying temperate cyprinid populations (Mann, 1973 and Gee, 1976) .

The growth rates of the less commonly occurring year-classes were calculated by pooling the data collected during the months from October to April. No attempt was made to estimate separate growth rates for males and females.

Qualitative data were collected by categorising the gut contents. The following categories were used:-

(i) Daphnia sp.

(ii) Benthos - Detritus
Invertebrates

(iii) Plant material - Filamentous algae
Macrophytes

(iv) Other - included winged insects and zooplankton apart from Daphnia

The gut contents of each fish were assigned to one category or sub-category. Normally the gut of any one fish contained only one type of food (e.g. one species of animal) or items that fell into one category. Often when fish had benthic invertebrates in their guts, they contained detritus as well. However, both these items came under the same basic category. The only items difficult to categorise were filamentous algae and Chaoborus. The algae frequently occurred with detritus and estimating the relative proportions was sometimes difficult. Chaoborus larvae could have been eaten as benthos or plankton; it rarely occurred in the roach guts. A minority of the fish, approximately 25% were assigned to two or more categories based upon relative proportion. After all the fish in each sample had been examined, the numbers in each category were summed and, to enable samples to be compared, converted to percentages of the number of fish in a sample.

In 1973 the Daphnia longispina in several of the roach were entire. Length-frequency distributions were found using the same methods used in the zooplankton analysis but fewer individuals were measured. The length-frequency distributions of different-sized fish from the same samples were compared with those of the D. longispina in the zooplankton sample taken on the same day.

In preference to the complicated systems of Kestevan (1960) or Nikolsky (1963) a simplified system for assigning gonad states of maturity was used; this can be summarised as:-

	Male	Female
Immature	Gonad a thin strip Colour pinky white G.S.I. < 0.5%	Gonad thin strip Oocytes barely visible to naked eye G.S.I. < 1%
Maturing	Gonad compact and white in colour. Larger than thin strip. G.S.I. > 1%	Oocytes clearly visible to naked eye. G.S.I. > 2%
Atretic	Not seen	Oocytes variable in size Colour and texture of gonad patchy. G.S.I. variable
Ripe	Colour milky white Milt may be running from posterior end. G.S.I. 4-10%	Oocytes loose in gonad G.S.I. 20-30%

These criteria were checked by histological examination of selected gonads. The formalin fixed material was sectioned and stained with haemotoxylin and eosin.

The weights of the gonads were converted to gonad-somatic indices and these were averaged for the males and females separately within each sample. In 1971 and 1974 sufficient estimates of fecundities were made on females of different lengths to establish length-fecundity relationships. The fecundity estimates were constructed by blotting the whole gonad dry and removing and weighing a series of small subsamples. These sub-samples were broken up and the developing oocytes, within them, counted. By using gonads collected after October, there was no problem in distinguishing between maturing and undeveloped oocytes. Five separate estimates were made on one gonad and replicate estimates made on two others to check the methodology.

(b) Feeding Experiments

Experiment 1

The approach of Bajkov (1935) (see introduction, page 20) was rarely possible because large numbers of similar fish were not available. In August 1972, sixty roach were caught from lake 8 at Yateley, ranging in size from 8 to 14.5 cm. The fish were killed in batches of 10 and their guts were examined to determine the rate of passage of food. Unfortunately the fish were not maintained under ideal conditions during the course of the experiment. After the first two batches were killed, the remaining fish were transported back to the laboratory where they were placed in plastic bins, volume 200 litres. The temperature of the lake at the time of capture was 20°C. In the laboratory the fish were maintained at 18°C ± 2°C. The time intervals before killing that were used were 0 hrs, 3 hrs, 6 hrs, 9 hrs, 15 hrs and 24 hrs. Only four fish survived to comprise the final sample.

The gut contents of the experimental fish were analysed by cutting the length of the gut into six zones, each of the three main loops being cut in half. The wet weight of food in each zone and the length of each zone were measured. The fish were similar enough in size to allow the direct use of gut content weight. The distributions of food in the guts of each batch were expressed as averages (per batch) in milligrams per centimetre within each zone and as percentages, within each zone, of the total in the whole gut.

Experiment 2

It had been noticed that when roach were fed on maggots (the larvae of <u>Calliphora</u> sp.) their faeces consisted of the undigested chitinous skins which were easily seen in the water. Fish fed on pellet food tended to produce faeces which quickly broke up in the water.

An attempt was made to estimate the passage of food through the gut by feeding fish on maggots and observing the time taken to produce the characteristic faeces.

The experimental fish, roach of approximately 10 cm in length, were held in a 200 litre aquarium, kept in a room maintained at 12 ± 1°C. It was insulated with expanded polystyrene sheets, and black polythene shielded the top and front in an attempt to screen the fish from visual disturbance. In the tank were five 100-watt aquarium heaters connected to an external contact thermostat by which the aquarium water temperature could be regulated to the required level.

While the fish were being acclimatised, it was noticed that they were more nervous than fish in uncovered aquaria. The covering was removed from the experimental tank and the fish, presumably now aware of the constant slight disturbances in the room, became less timid and 'jumpy'. The fish were fed ad libitum on trout pellets until the experiments commenced.

At the beginning of the fourth and fifth trials and over a period of two days, the temperature was raised to 16°C. The fish were fed on pellets and their acceptance of this food was taken to indicate normality. The maggots were introduced and any uneaten or regurgitated were removed. The tanks filter system was turned off and the tank was visited every hour until the first maggot faeces were seen.

Experiment 3

It was hoped to overcome some of the shortcomings of the first two experiments by feeding the fish experimentally in the manner of Kitchell and Windell (1968) - see page 20 . At the same time, by feeding D. longispina, aspects of the roach's feeding on daphnids was observed. The experiment was designed to investigate the following:

(1) The rate of consumption of Daphnia.

(2) The degree of selectivity of the fish when feeding on Daphnia.

(3) The rate of passage of Daphnia through the fish's guts.

(4) The influence of further feeding on this rate.

Fifty-three roach, mean length 9.5 cm, were maintained in a 200 litre aquarium at 18°C ± 1°C. Before commencement of the experiment, the fish were starved for two days.

The D. longispina were collected from a gravel pit lake at Wraysbury (Bucks) where a dense population was found. The cladocerans were left to

CHAPTER III

Results

III.1 Macrophytes

The distributions and relative abundance of submerged and emergent macrophytes are shown in Figures 7-11. These maps show that except for a short period in 1973 (see Figure 10) submerged macrophytes were found mainly as isolated clumps in the shallow water (<1.5m). In general, these plants increased their abundance during the period of the study. Little change occurred in the distribution of emergent plants except that, because anglers were absent, many small gaps in the stands of Typha latifolia were quickly overgrown.

In some lakes at Yateley, e.g. numbers 4 and 6, considerable stands of Elodea canadensis developed in the summer of 1973. In previous years, despite lake 6 having characteristically clear water with good light penetration, Elodea had been restricted to sparse clumps. In 1973 an almost continuous stand developed covering the lake bed, growing approximately one metre high to within 50 cms of the surface.

Divers reported that lake 8 had a restricted submerged macrophyte flora in the years 1971, 1972 and 1973, similar to that of lake 7.

III.2 Invertebrates

A. Zooplankton

The estimates of the major components of the zooplankton in lakes 7 and 8 from June 1971 to December 1973 are shown in figures 12-15. Figure 12 shows the estimates of D. longispina, figure 13 those of Bosmina longirostris and figures 14 and 15 the numbers of calanoid and cyclopoid copepods respectively. The reliability of these estimates is discussed on page 148 Zooplankton was evidently similar, quantitatively and qualitatively, in the two lakes.

Lakes 7 and 8 also showed similar trends in the numbers of D. longispina;

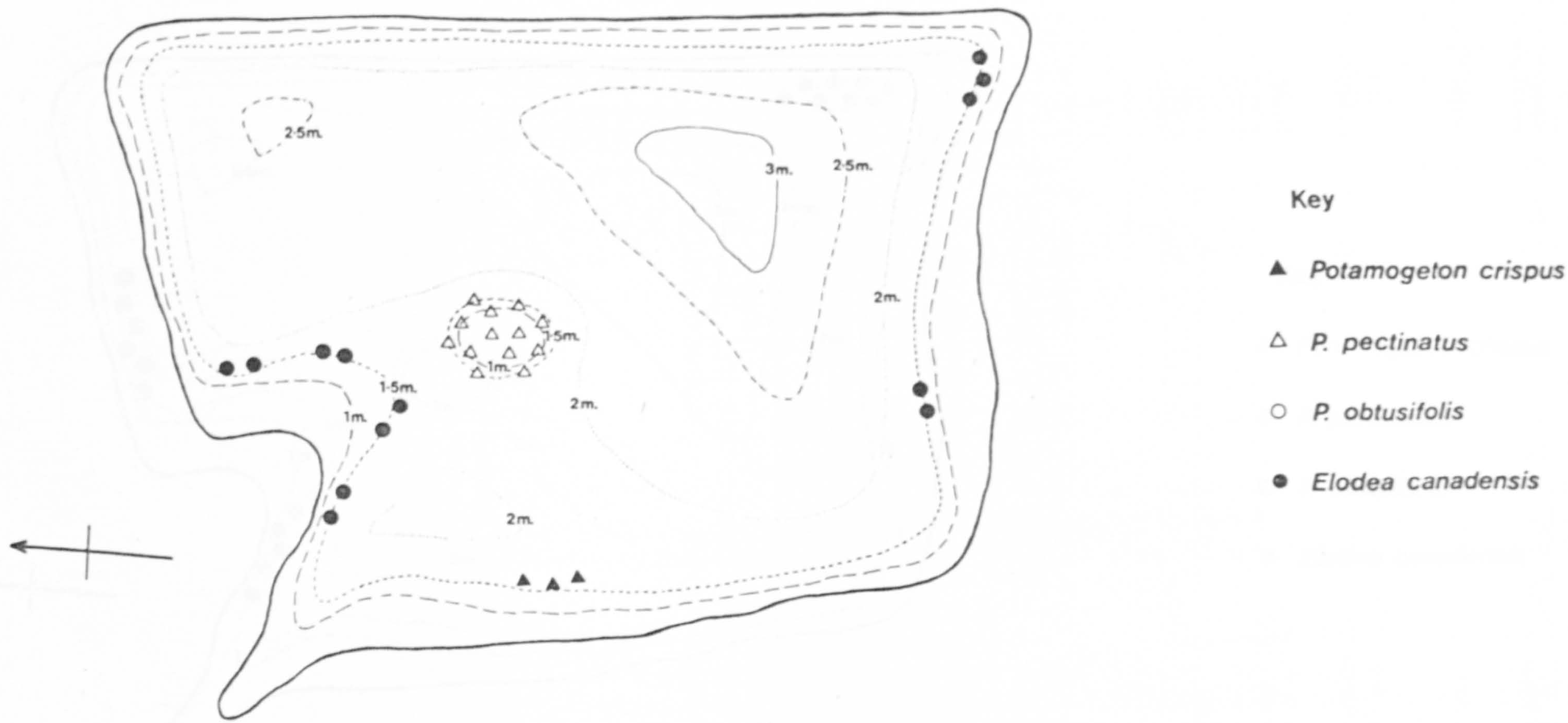


Figure 7 Distribution of submerged macrophytes in Yateley 7 on 20.6.71

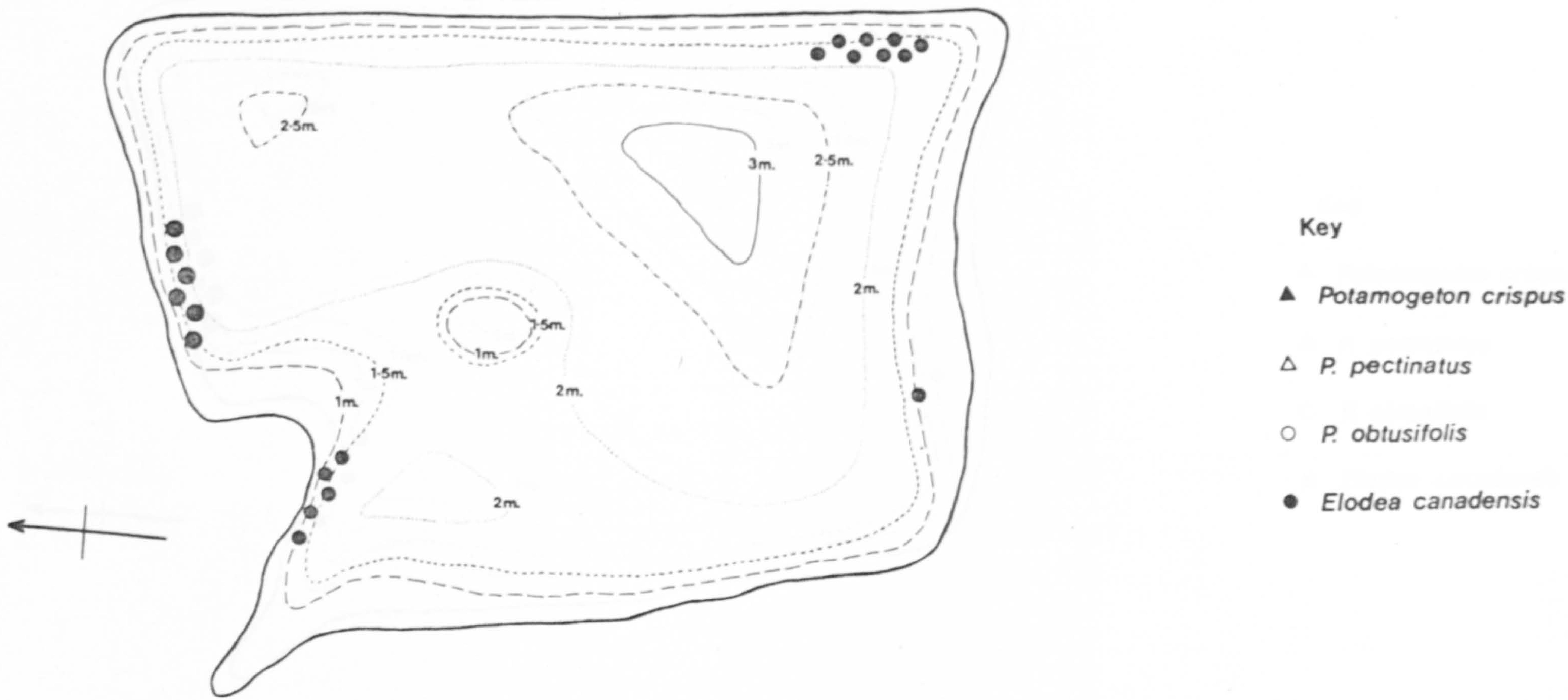


Figure 8 Distribution of submerged macrophytes in Yateley 7 on 10.9.71

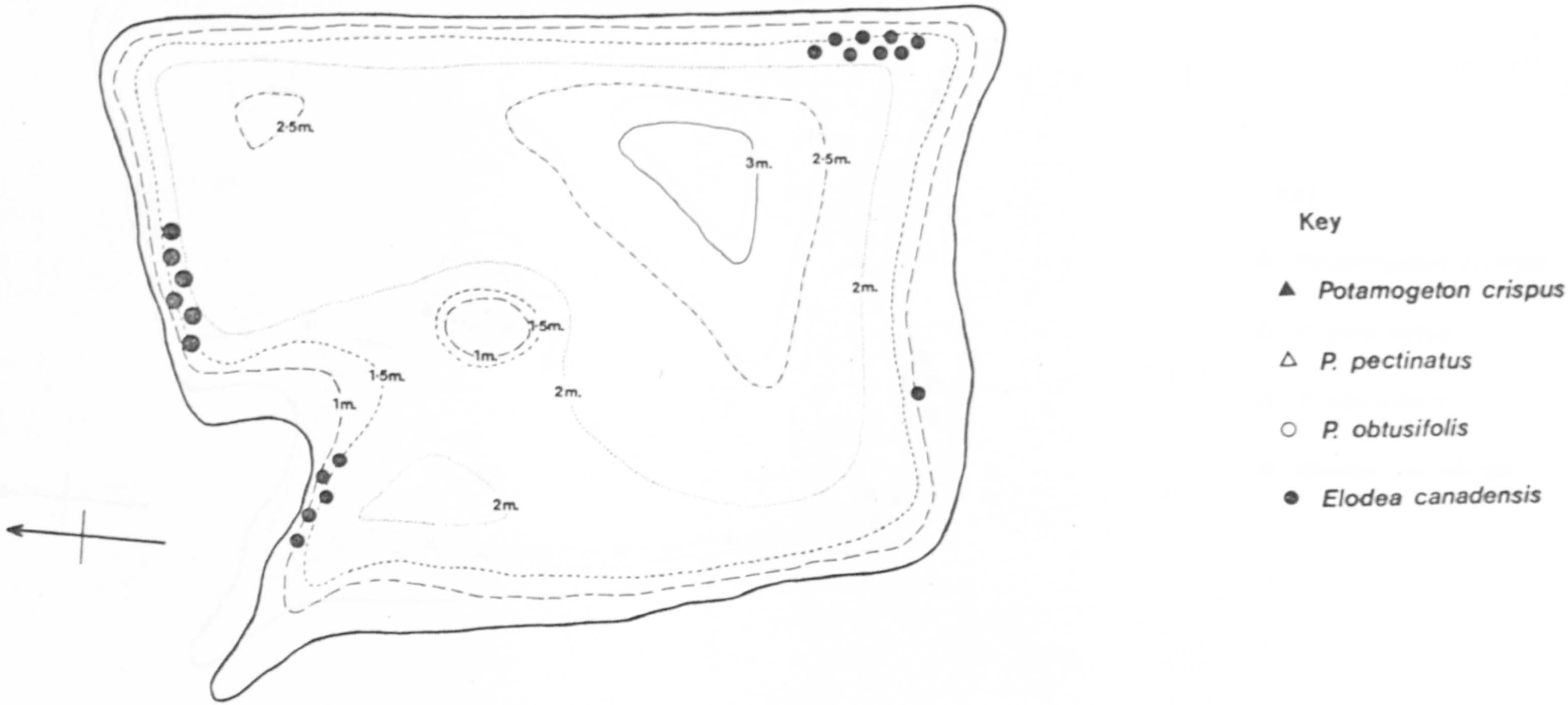


Figure 9 Distribution of submerged macrophytes in Yateley 7 on 3.7.72

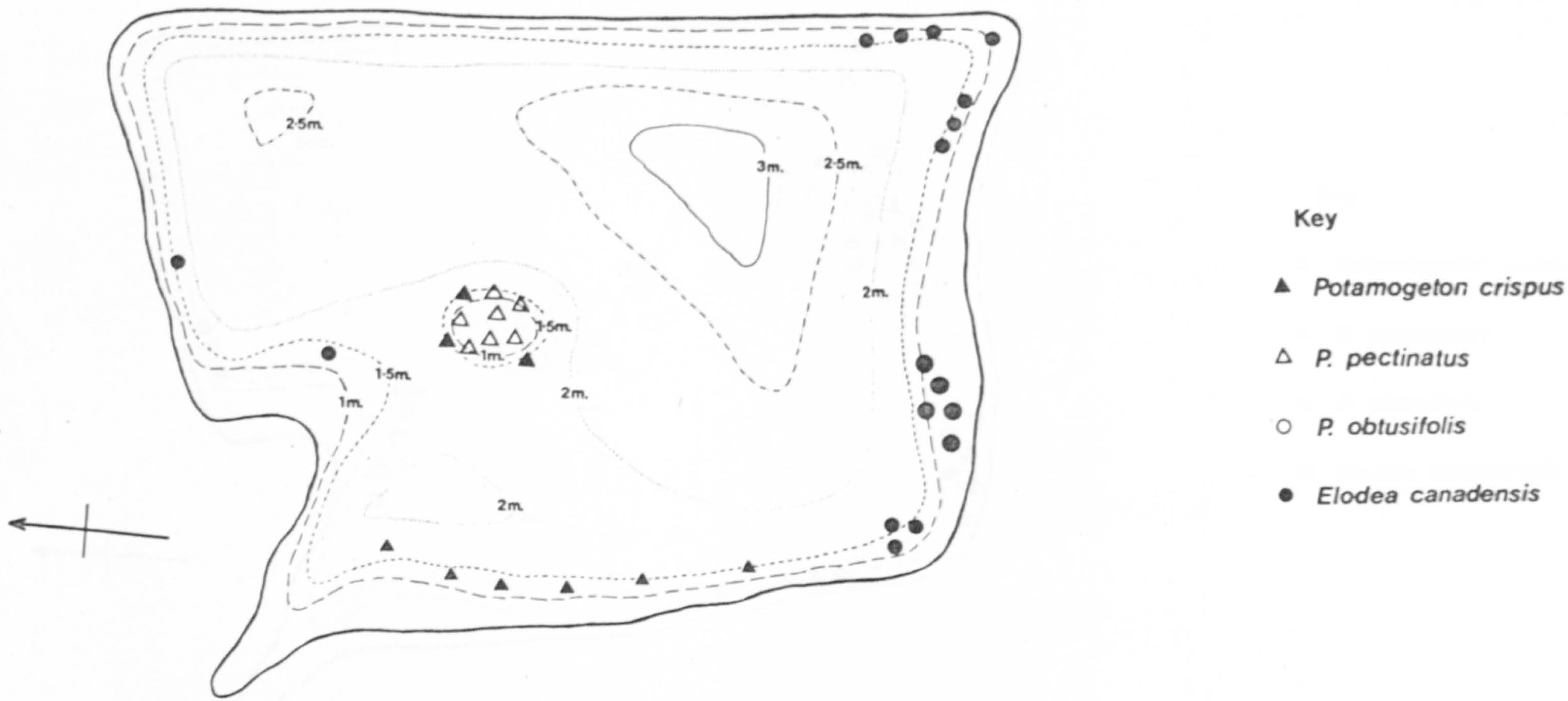


Figure 10 Distribution of submerged macrophytes in Yateley 7 on 30.7.73

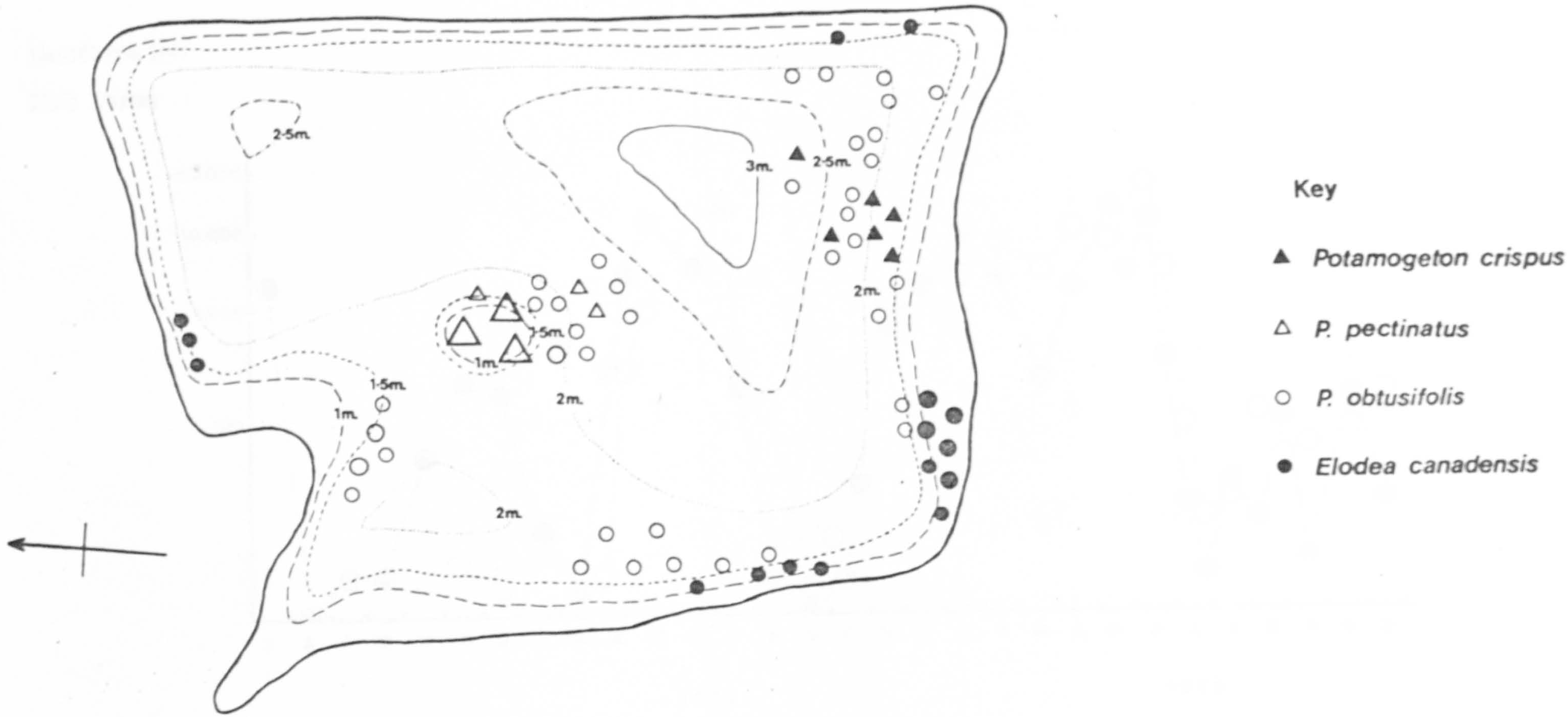


Figure 11 Distribution of submerged macrophytes in Yateley 7 on 24.9.73

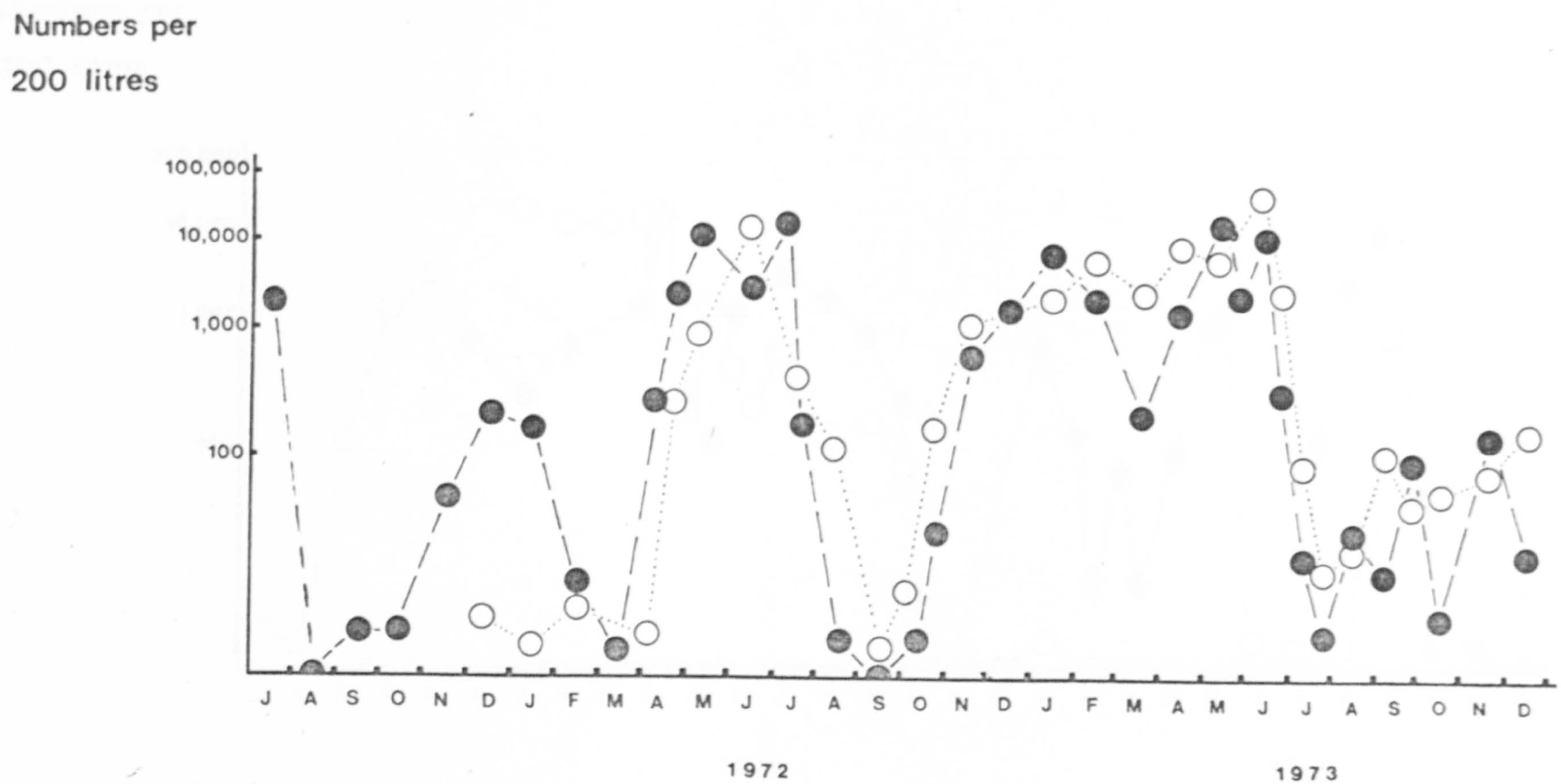


Figure 12 Estimated numbers of Daphnia longispina in lakes 7 (●) and 8 (○)

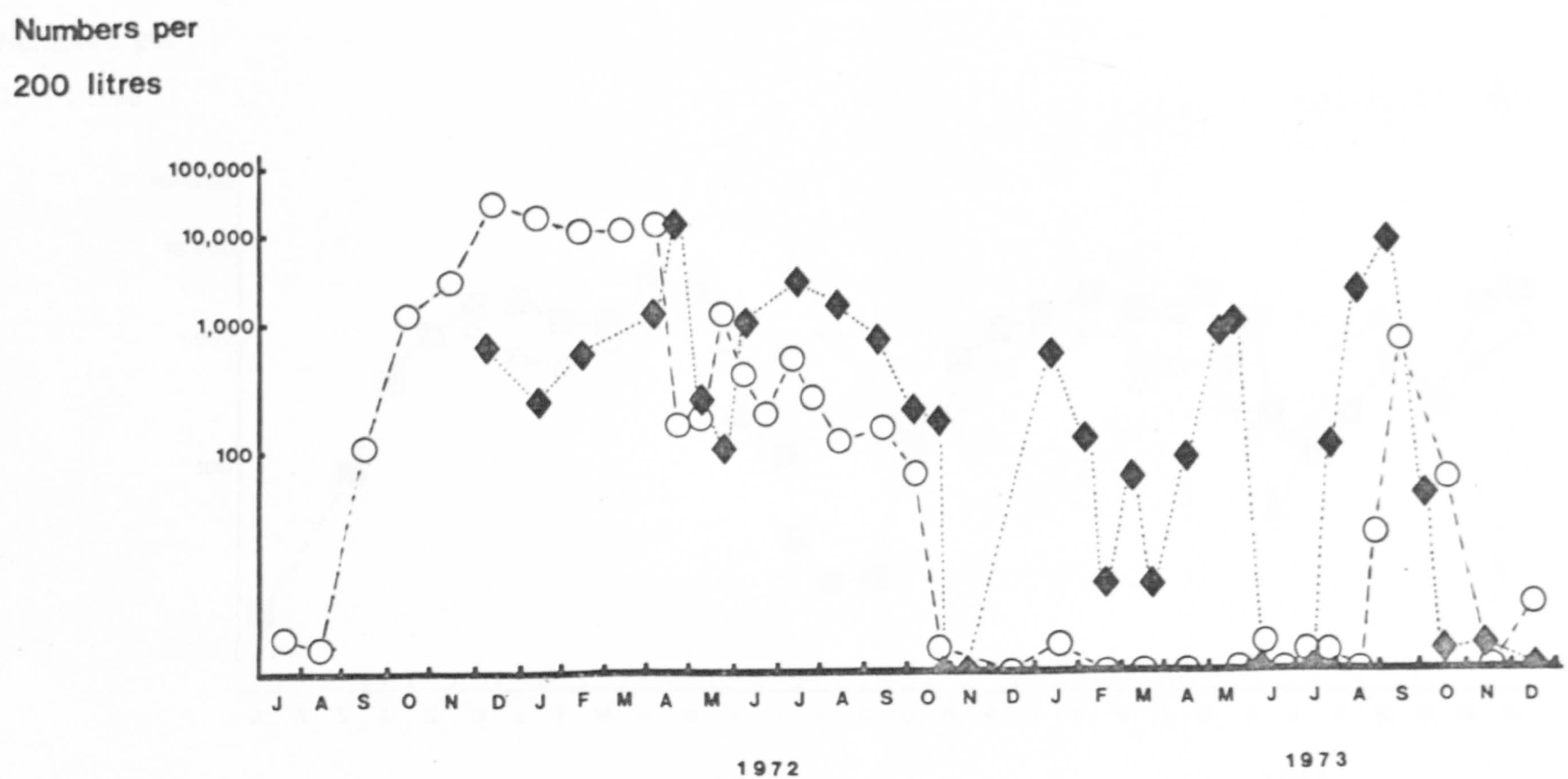


Figure 13 Estimated numbers of Bosmina longirostris in lakes 7 (○) and 8 (◆)

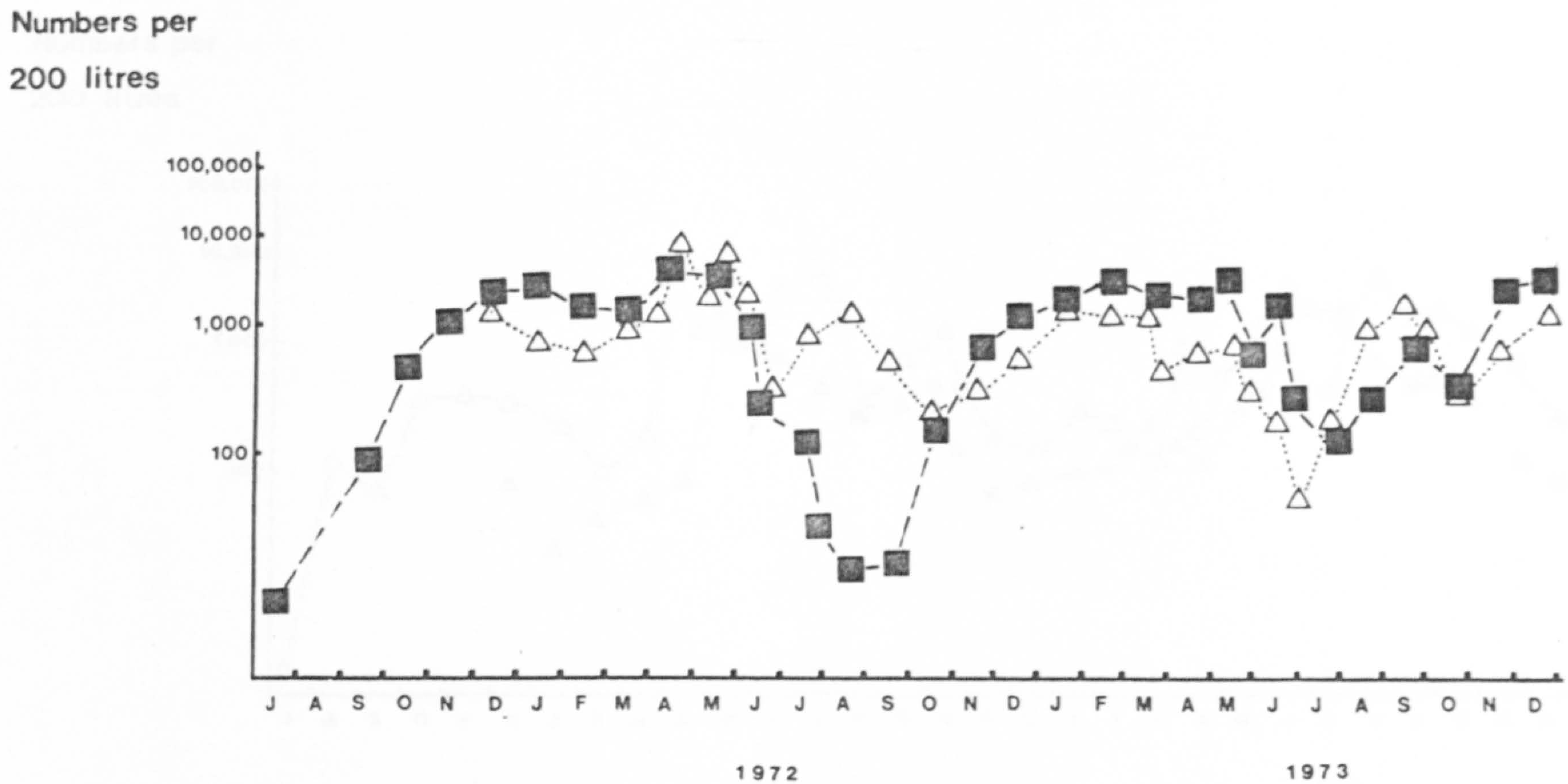


Figure 14 Estimated numbers of calanoid copepods in lakes 7 (■) and 8 (△)

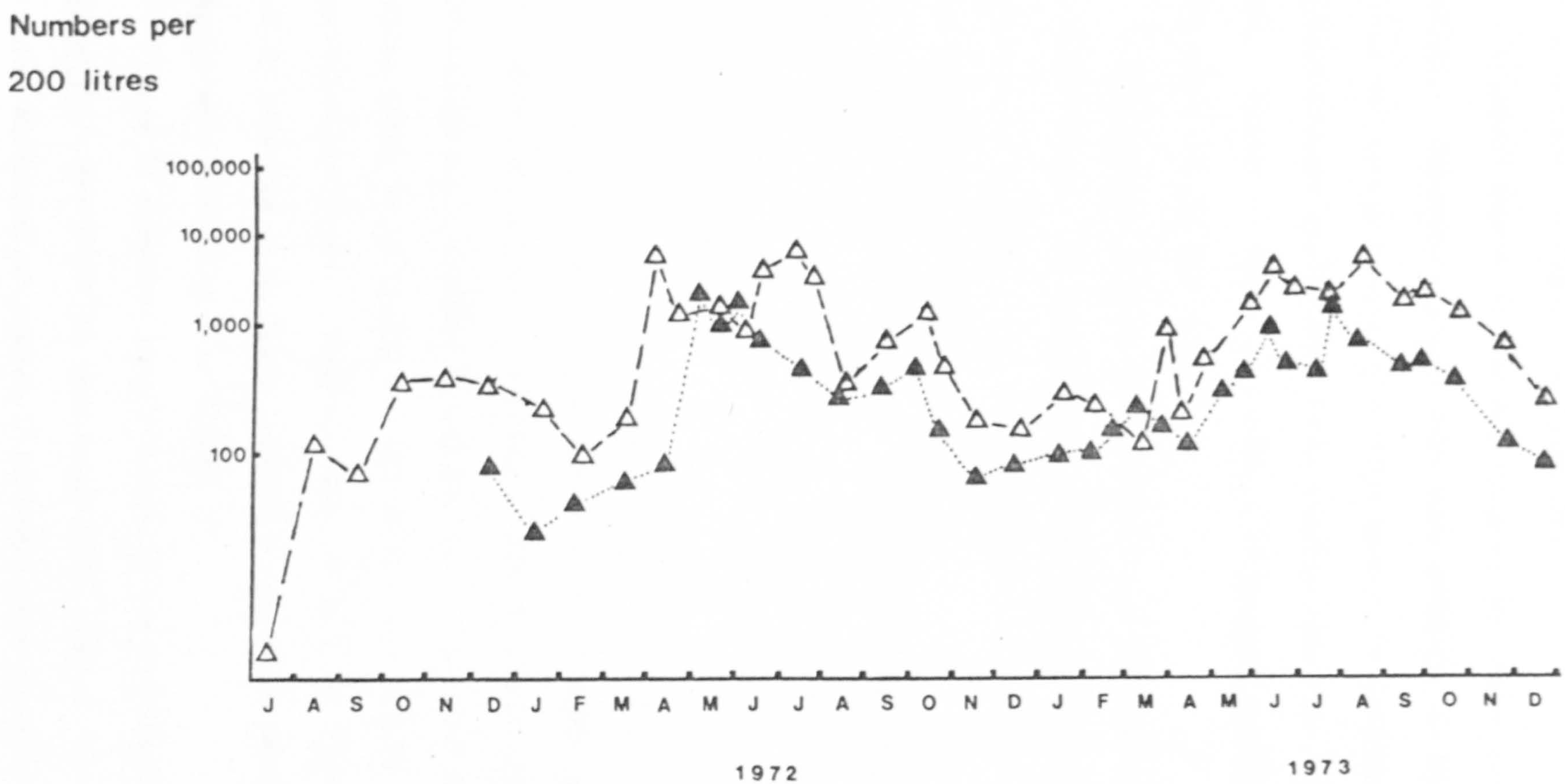


Figure 15 Estimated numbers of cyclopoid copepods in lakes 7 (△) and 8 (▲)

both showed peaks in April, May and June and lows in July, August or September. In the winter of 1972/73 fairly high numbers persisted through the winter months. The seasonal fluctuations of D. longispina in lake 7 are also shown in figure 28, page 107.

Seasonal trends in the abundance of the other zooplankters were less obvious. Calanoid copepods were more abundant, in both lakes, in the winter and spring samples i.e. from October to May/June. Cyclopoid copepod numbers experienced fewer fluctuations than did those of the other taxa. Figure 13 shows that numbers of Bosmina longirostris declined in both lakes during the study.

Ceriodaphnia cornuta (O.F. Müller) was the only other common zooplankter in either lake. On no occasion did C. cornuta exceed 10% of the samples' biomasses or numbers. On rare occasions low numbers of Chaoborus larvae were found in the plankton samples.

Figure 16 shows the length frequencies of D. longispina in 12 successive samples from 21.11.72 to 9.6.73. (This covered the period of the late spring and early summer which was the time when the numbers of Daphnia rose and fell most sharply).

Although the presence of large individuals (>2mm) in these samples does not necessarily mean that the large individuals are highly fecund, there is nevertheless a relationship between the presence of large individuals and increases in population. The large specimens present in samples taken on 19.12.73, 8.1.73, 24.4.73 and 3.5.73 are associated with population increases. Samples taken on 16.5.73, 22.5.73, 12.6.73 and 29.6.73 show few or no large individuals at times when the numbers in the samples were declining (see figure 16).

Figure 17 compares length-frequency distributions of Daphnia longispina taken from the open water with samples taken from the littoral on three different occasions. It shows that there is a tendency for larger individuals to be found in the littoral region of the lake. This was most marked in the sample taken on 16.5.73.

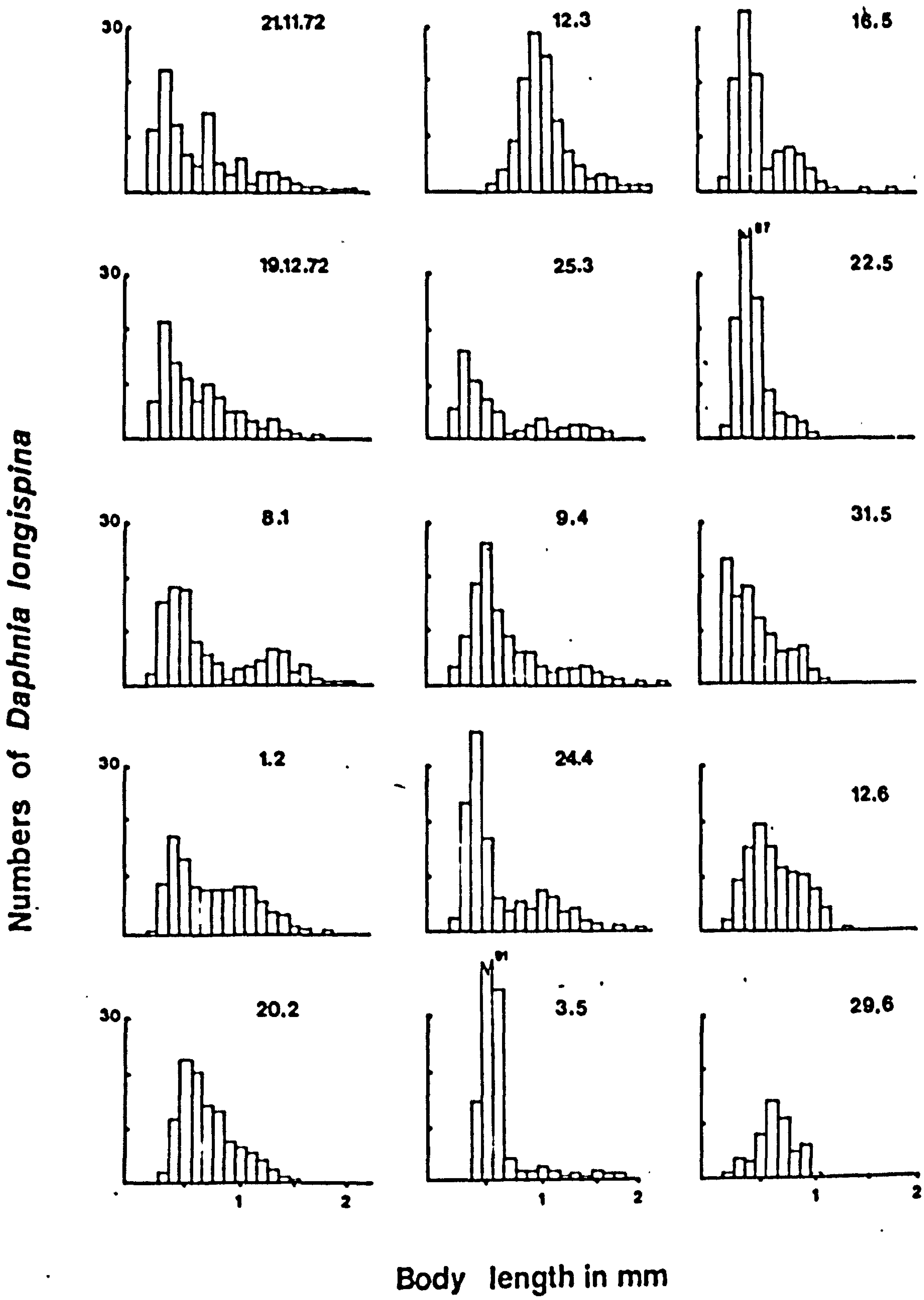


Figure 16 Length-frequency distributions of D. longispina in successive samples taken in 1972 and 1973

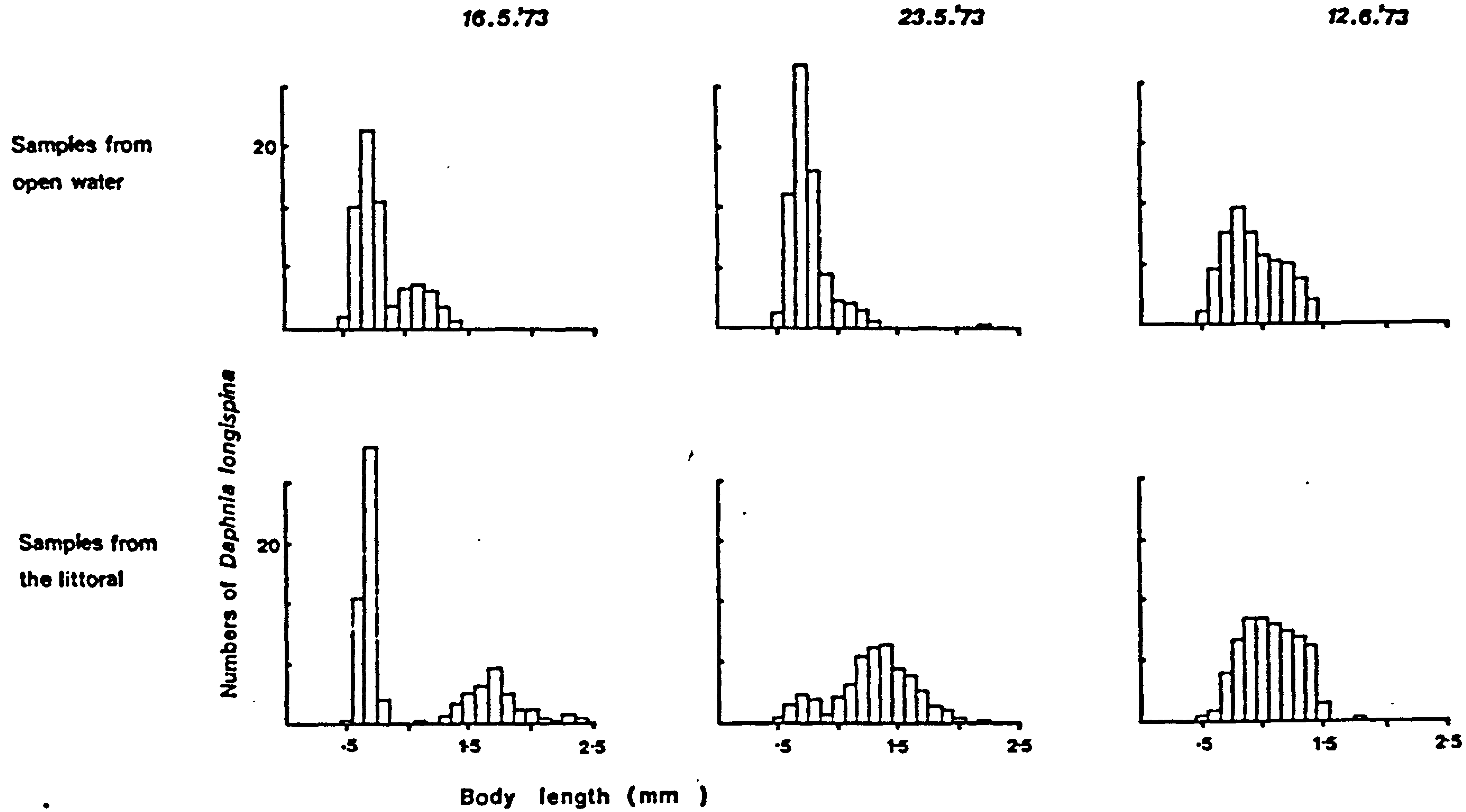


Figure 17 Comparisons of length-frequency distributions of D. longispina taken from the open water and the littoral region of lake 7 on three different occasions.

Figure 18 depicts the length-weight relationship for *D. longispina*. The length-weight regression was calculated (see page 41) as:

$$\log w = 2.907 \log l + 0.7936$$

where w = dry weight in micrograms and

l = length in millimetres

Table 10 shows the calculated mean dry weights for *D. longispina* of six different mean lengths.

TABLE 10 Mean Dry Weights and Confidence Limits for *D. longispina* of Different Lengths

Mean lengths (millimetres)	Mean dry weight (Micrograms)	95% confidence limits
0.75	2.8	±1.8
1.00	5.6	±0.6
1.25	10.9	±1.9
1.50	23.5	±3.4
1.75	31.5	±3.3
2.00	52.0	±9.4

The length-weight relationship has been used to calculate the standing crops of *D. longispina* in the lake on ten occasions. These estimates are shown in Table 11.

TABLE 11 Estimates of Biomass of *D. longispina* in Lake 7

Date	Numbers/l $\left(= \frac{\text{nos}/m^2}{1700}\right)$	Dry Wt. of *D. longispina* as gm/m^2 (= gm/1700ℓ)
8.1.73	48	0.554
1.2.73	42	0.527
20.2.73	15	0.080
25.3.73	1	0.008
9.4.73	7.8	0.006
3.5.73	178	1.85
16.5.73	16.8	0.006
31.5.73	23	0.0062
12.6.73	94	0.385
29.6.73	3	0.012

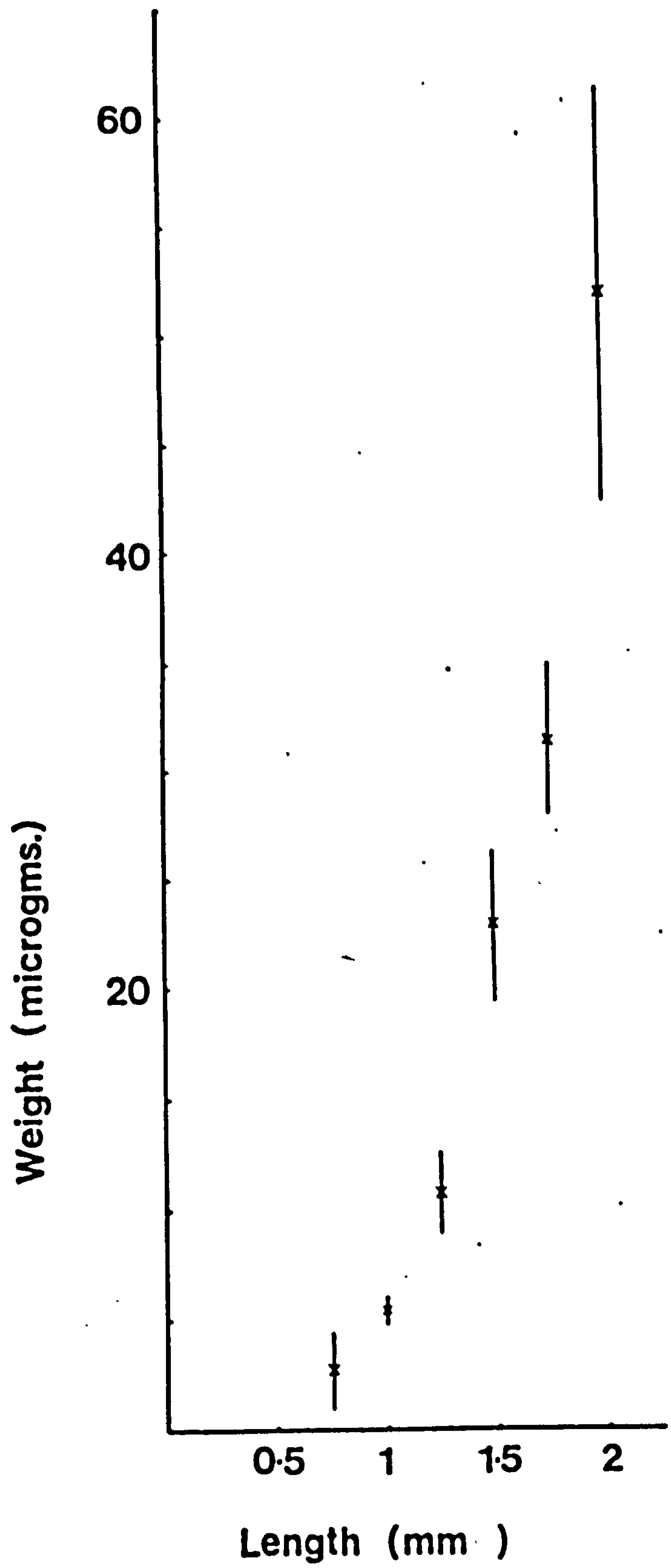


Figure 18 Length-weight relationship for D. longispina

B. The Zoobenthos

Table 12 shows the mean numbers of the different taxa sampled by the new sampler and corer. Table 13 shows the counts for each replicate taken by these two methods on 31.11.71. These could not be compared because the area sampled by the two devices was different (484 cm^2 and 205 cm^2) and the animals have a contagious distribution (Elliott 1971). Tables 12 and 13 do appear to show some differences in the performances of the two samplers. While the corer sampled more animals typical of the 'in-benthos' e.g. chironomids and oligochaetae, the pump sampler seemed more effective at sampling the 'on-benthos' e.g. Cragonyx and insect adults and nymphs.

The samples taken from the hard benthos and other pond net samples taken in the littoral region of lake 7 showed that this area had a rich, diverse fauna.

The results of the routine Ekman grab samples are shown in Table 14. When a comparison of these samples was made, no significant differences were found* even when the most apparently different samples were compared (see Table 15). Individual counts for replicates (Table 16), illustrate the differences that occurred between replicates. It was this variation within samples (Table 15) that obscured the demonstration of differences (if any) between samples.

Analysis of replicates (within samples) did reveal significant negative correlations between numbers of Chaoborus sp. on the one hand, and the totals of chironomids and ceratopogonids on the other (Table 17). Figure 19 shows the calculated regression for the counts of the 12 replicates taken on 12.4.72.

III.3 The Fish

A. Population and Biomass Estimates

A comparison of estimates based on recaptured fish marked once, twice and three times, is shown in Table 18. This table shows that estimates

* Except for the numbers of Chaoborus using logarithmic transformation

TABLE 12 A comparison of the means of the different taxa sampled from the hard substrate with the pump sampler and a corer. Area of pump sampler = 484 cm^2, area of corer = 205 cm^2, n = number of replicates, $\bar{x}_1$ = pump sample means, $\bar{x}_2$ = core sample means. Samples taken from lake 7.

		Samples taken on					
		1.4.71, n=5		18.6.71, n=3		30.11.71, n=7	
		x_1	x_2	x_1	x_2	x_1	x_2
Cordiacae		-	-	5.4	-	-	-
Polycelis sp.		1	-	-	-	-	-
Annelida	Oligochaeta	39	100.6	32	23	-	-
Hirudinae	*Helobdella stagnalis*	0.3	0.3	4	2	0.4	0.3
	Hemiclepsis marginata	-	-	0.3	-	0.7	0.7
	Erpobdella octoculata	-	-	-	-	0.7	0.7
Mollusca	*Pisidium/Sphaerium*	6.3	2.1	3.6	-	-	-
	Potamopyrgus jenkinsi	0.7	1.2	165.3	53.2	-	-
	planorbids	-	-	1.2	-	-	-
	Limnea peregra	0.2	1.0	-	0.3	-	-
Crustacea	*Cypris gigas*	-	-	9	2	-	-
	Eurycercus lamellatus	-	-	-	-	0.4	-
	Asellus aquaticus	0.3	-	0.6	0.3	0.3	-
	Crangonyx pseudogracilis	15.5	0.3	3.6	0.6	8.6	0.1
Insecta	chironomid larvae	90.8	54.6	8	7	24.6	76.1
	ceratopogonid larvae	14	3	11.6	3	9.7	1.1
	Chaoborus sp.	0.2	-	-	-	-	-
	tabanid larvea	-	-	0.7	-	3.1	0.9
	unidentified dipteran larvae	-	-	1.6	-	-	-
	dipteran pupae	-	-	0.3	-	-	-
	Caenis horaria	29	6.4	3.6	-	4.3	1.3
	Cloeon dipterum	2.7	-	-	-	4.9	-
	Corixa falleni	-	-	-	-	1	-
	Corixa nymphs	7.8		0.2	1	-	-
	Sialis lutaria	0.3	0.1	1.3	0.6	2	1.3
	Dytiscus semisulcatus	-	-	-	0.3	2	1.3
	Trichopteran larvae	7.1	3.8	2	0.3	-	-
	Zygopteran nymphs	2	-	-	-	0.1	0.1
Hydracarina		1.2	0.2	-	-	-	-

TABLE 13 A comparison of replicates taken from the hard substrate with the pump sampler and a corer. Samples taken on 30.11.71 in lake 3b.

	Replicates taken with pump sampler Area = 484 cm^2								Replicates taken with brass corer Area = 205 cm^2							
	1	2	3	4	5	6	7	$\bar{x}$	1	2	3	4	5	6	7	$\bar{x}$
Hirudinae																
Helobdella stagnalis	1	-	1	-	-	1	-	0.4	-	-	-	1	-	-	1	0.3
Erpobdella otoculata	2	-	-	-	1	1	-	0.7	-	-	-	2	1	1	-	0.7
Crustacea																
Eurycercus lamellatus			1			1	1	0.4	-	-	-	-	-	-	-	-
Asellus aquaticus				1		1		0.3								
Crangonyx pseudogracilis	10	5	3	6	10	10	11	8.6	-	-	-	1	-	-	-	0.1
Insecta																
chironomid larvae	15	18	27	11	21	28	52	24.6	176	16	108	118	70	30	15	76.1
ceratopogonid larvae	2	17	15	9	11	9	5	9.7	-	2	1	-	-	5	-	1.1
tabanid larvae	-	2	-	4	13	1	2	3.1	2	-	-	2	-	-	2	0.9
Caenis horaria	-	7	3	1	11	4	4	4.3	1	-	1	-	3	2	4	1.3
Corixa falleni	6	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-
Cloeon dipterum	13	1	8	3	1	-	8	4.9	-	-	-	-	-	-	-	-
Sialis lutaria	6	2	1	3	1	3	3	2.7	3	-	3	1	2	1	-	1.3
Dytiscus semisulcatus	2	1	3	4	-	3	1	2	1	3	-	-	6	-	-	1.3
zygopteran nymphs	-	-	-	-	-	-	1	0.1	-	-	1	-	-	-	-	0.1

TABLE 14 Mean Numbers of Different Taxa Found in Ekman Grab Samples

Date	23.1.72	12.4.72	6.8.72	8.1.73	24.4.73	6.8.73	2.12.73
Number of Replicates	5	12	10	16	6	10	10
Chaoborus sp. larvae	13.8	63.9	103	97.4	53.2	194.4	305.4
Chaoborus sp. pupae	-	-	1.4	-	1	4.7	-
Chironomidae larvae	29.4	31.6	49.4	140.2	96.3	19.2	10.2
Chironomidae pupae	-	-	2.0	-	0.8	-	-
Ceratopogonidae	5	23.5	12.2	26.1	31.5	6.9	10.4
Oligochaetae	17	21.6	8.3	34.1	28	1	9.6
Hydracarina	1	-	0.1	-	2.2	-	-
Crangonyx pseudogracilis	-	-	-	0.1	-	-	-
Sialis lutaria	-	-	-	1.1	-	-	-

TABLE 15 Comparison of numbers of chironomids and *Chaoborus* from samples taken on 23.1.72 and 2.12.73

	23.1.72				2.12.73				t	P
	$\bar{x}$	95% Conf.	s^2	n	$\bar{x}$	95% Conf.	s^2	n		
Chaoborus larvae	13.8	±12.1	95.2	5	305.4	±170.4	56859	10	0.014	>0·1
Chironomid larvae	29.4	±31.6	644.8	5	10.2	±5.1	51.1	10	0.15	>0·1
Using logarithmic transformation										
Chaoborus larvae	1·05		0·3	5	2·3		0·5	10	8·93	<0·001
chironomid larvae	1·27		0·51	5	0·9		0·33	10	1·57	>0·1

TABLE 16 Animals found in each Ekman grab replicate taken on two sampling occasions

Animals Found	Replicates Taken on 12.4.72												Replicates Taken on 6.8.72									
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
Anellida																						
Oligochaeta	7	12	17	40	17	24	c60	c50	6	9	13	4	1	6	24	6	4	11	4	26	1	32
Piscicola geometra	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydracarina	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Insecta																						
Caenis sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae	60	19	48	42	6	29	48	45	3	10	38	31	108	74	89	4	4	33	87	23	7	65
Ceratopogonidae	21	6	59	40	7	33	25	34	2	2	27	27	12	4	7	3	3	40	26	11	9	7
Chaoborus sp.	28	81	28	33	68	101	46	15	70	143	95	59	92	130	169	102	127	16	82	62	115	140
Unidentified dipteran pupae																						

TABLE 17 Correlations between the numbers of Chaoborus and the total numbers of other diptera larvae in Ekman grab samples from Yateley 7

Date of Sample	N	r	P
12. 4.72	12	−0.67	<0.02 > 0.01
6. 8.72	10	−0.02	>0.05
8. 1.73	16	0.07	>0.05
24. 4.73	6	−0.64	>0.05
6. 8.73	10	−0.61	<0.05 > 0.02
2.12.73	10	−0.73	<0.02 > 0.01

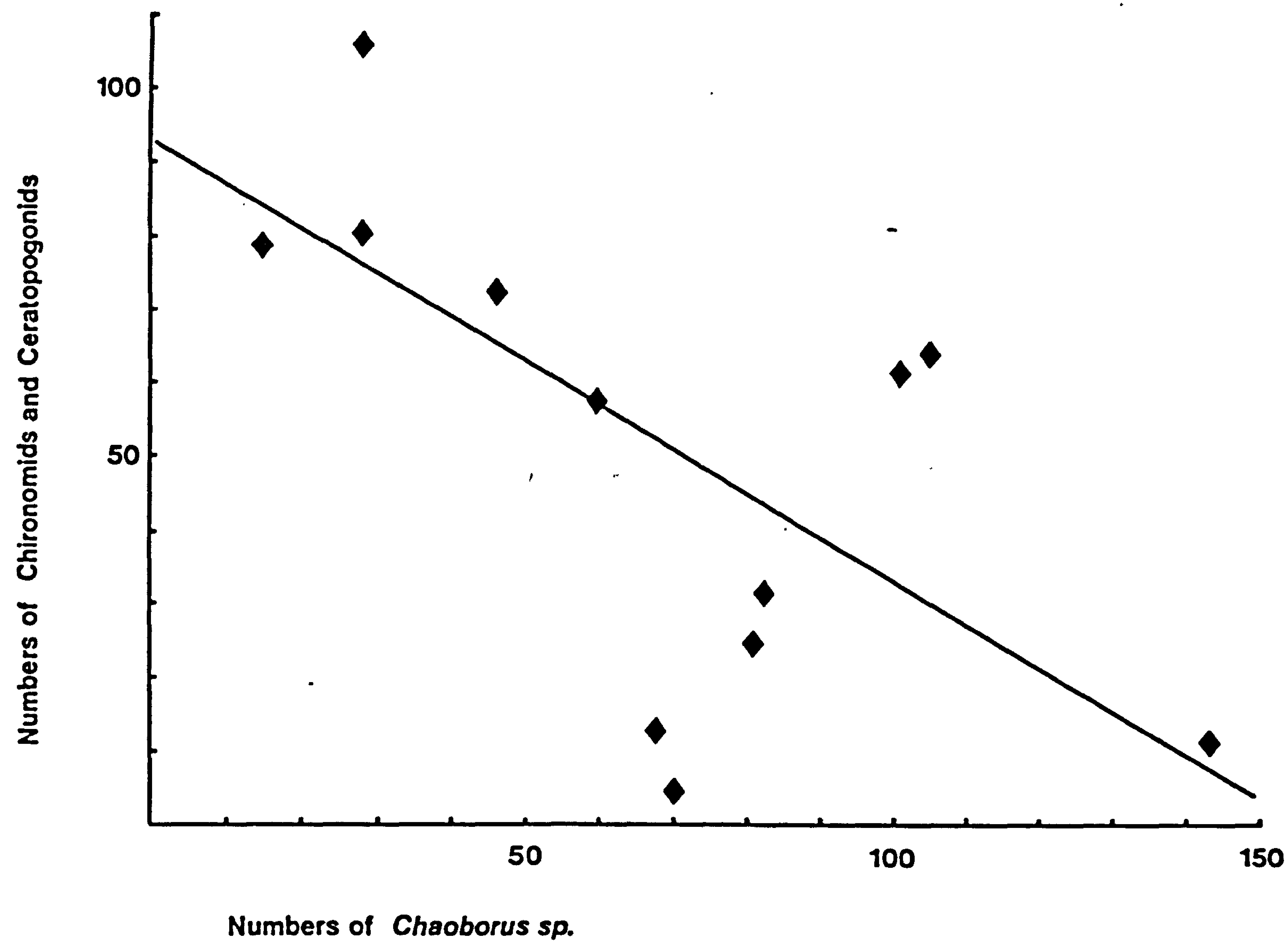


Figure 19 Relationship between numbers of Chaoborus and the totals of chironomids and ceratopogonids in the 16 replicates taken from Yateley 7 on 8.1.73

Table 18 Comparison of estimates derived from recaptures marked once, twice and three times using fin clip and panjet marks. Numbers of estimates (n) are given in brackets.

Species and age/size class	Estimates - means of n			Type of Mark
	1 mark	2 marks	3 marks	
1973				
Roach 2+ and 3+	736(6)	383(4)	271(1)	Panjet
Roach 4+ and older	157(6)	80(4)	56(1)	Panjet
Perch 0+	627(6)	709(4)	373(1)	Fin-clip
Perch 1+ and 2+	115(6)	64(4)	70(1)	Panjet
Tench 20 cms+	126(5)	45(3)	65(1)	Panjet
1972				
Roach 1+	556(4)	303(4)		Fin-clip
Roach 3+ and older	67(3)	36(2)	15(1)	Panjet
Perch 0+	1072(5)	429(1)		Fin-clip
1971				
Roach 11.5 - 17.9 cms	11(2)	6(1)		Panjet
Roach 18 cms+	31(4)	47(1)		Panjet
Perch 1+ and older	46(6)	35(3)		Panjet
Rudd 1+	325(3)	240(1)		Fin-clip
Rudd older	27(5)	24(2)		Panjet

based upon multiple-marked recaptures tended to be less than those based upon recaptures marked once. This was particularly so when the fish were marked with a panjet. This tendency even applied to the tench. Estimates based upon recaptures marked once are likely to be most accurate (see discussion, page 152). Table 19 presents these estimates of the different species and age/year-classes in 1971, 1972 and 1973. These estimates were based upon the means of a number (n) of estimates. Because each estimate was not independent of the others, confidence limits of these means were not calculated (see discussion, page 152).

The large catch of fish made on 17.12.73 enabled further estimates to be made. These were similar to the estimates made in the preceding November (see Table 20). Thus the increase in time between marking and recapture - from 1-7 days (in the November estimates) to one month - did not markedly affect the result.

Table 21 compares the vulnerability (catchability) of the different species and different year-classes of fish caught during the population estimates, expressed by the percentages of marked fish that were caught on the final day. Three trends were noticed when conducting the estimates and analysing the data and they can be seen in Table 21. Firstly, rudd seemed particularly vulnerable to capture and recapture; secondly, larger species seemed more vulnerable than smaller species; and finally, within any one species, older year-classes (larger fish) seemed more vulnerable than younger year-classes (smaller fish).

Table 22 records catch-per-effort during the 1972 population estimate as catch-per-day and number of seines-per-day. Table 22 shows how catch-per-effort declined during the course of the estimate. This pattern was seen on the other two occasions when the population was estimated at lake 7. Table 23 shows the catches made each day during the 1973 estimate.

Length-frequency distributions of unmarked fish caught during the estimates, and length-weight relationships, have been used to calculate

TABLE 19 Fish population estimates in Yateley 7 (based on the means of n estimates using only recaptures marked once)

Species and Year-Class		1971 Estimate (n)	1971 Range	1972 Estimate (n)	1972 Range	1973 Estimate (n)	1973 Range
Roach	0+	*		**		2134 (4)	1550-3703
	1+	99***		556 (4)	157-998	**	
	2+	11 (2)	8-14	67 (3)	44-86	736 (6)	408-1307
	3+						
	Older	31 (4)	20-50			157 (6)	104-204
Perch	0+	18 (1)		1072 (5)	252-2174	627 (6)	528-855
	1+	46 (6)	16-90	69 (2)	36-103	115 (6)	68-212
	2+			14 (2)	12-15	5 ****	
Rudd	0+	*		**		**	
	1+	325 (3)	298-366	3 (1)			
	2+	27 (5)	9-50	11 (2)	8-13	7 (3)	5-8
	3+			4 (3)	3-5		
	Older						
Tench all ages		16 (4)	8-20	95 (4)	51-122	126 (5)	86-174
Pike all ages		19 (4)	9-30	11 (2)	6-16	1 (1)	
Gudgeon all ages		38 (4)	4-77	-		-	
Crucian carp all ages		1 (1)		3 (1)		2 (1)	

* No estimate - Mesh of net used did not catch this year class
** No estimate - year class missing, or poorly represented
*** No recaptures, estimate by catch per effort comparison with 1+ rudd
**** No recaptures, estimate by catch per effort comparison with 2+ perch

TABLE 20 Comparison of estimates based upon fish recaptured after different time intervals i.e. on days 2, 3 and 4 of the 1973 population estimate and on the catch made one month later on 8.12.73. All estimates are based on recaptured fish marked once and are the means of the number of estimates given in brackets.

Species and Year Class	Estimates Based on Recaptures Made on Day 2 7.11.73	Day 3 8.11.73	Day 4 9.11.73	8.12.73
Roach				
2+ and 3+	565 (1)	902 (2)	682 (3)	1103 (3)
Older	129 (1)	147 (2)	173 (3)	171 (3)
Tench				
All ages	97.5(1)	150 (2)	116 (2)	115 (3)
Perch				
0+	640 (1)	621 (2)	716 (3)	853 (3)
1+	86 (1)	94.5 (2)	137 (3)	88 (3)

TABLE 21 Catchability of different species and year-classes of fish as expressed by the percentages of marked fish in the last days' catches during population estimates

		1971		1972		1973	
		Number Caught	% Marked	Number Caught	% Marked	Number Caught	% Marked
Roach	0+	-	-	-	-	28	4
	1+	2	0	23	24	)	
	2+	) 3	33	)		) 112	57
	3+	)		) 14	50	)	
	Older	8	40	)		36	58
Perch	0+	5	0	122	10	232	53
	1+	) 25	68	21	24	52	73
	2+	)		) 8	38	-	-
	Older	-	-	)		-	-
Rudd	0+	-	-	-	-	) 3	0
	1+	119	38	7	100	)	
	2+	) 6	83	)			
	3+	)		) 5	80	4	50
	Older	-	-	)			
Tench all ages		3	66	56	61	25	68
Pike	0+	8	36	) 7	43	-	-
	Older	2	100	)		-	-
Gudgeon all ages		8	75	-	-	-	-

TABLE 22 Catch-per-effort during the second population estimate, (1972). Each seine consisted of covering the whole area of the lake with two 50 m nets joined together.

		Catches					
		Roach	Rudd	Perch	Tench	Pike	Other
Day 1	1st seine	225	17	17	-	3	-
	2nd seine	277	3	96	51	1	-
	Total	502	20	113	51	4	-
Day 2	1st seine	82	5	12	23	7	-
	2nd seine	125	8	84	-	-	-
	Total	205	13	96	23	7	-
Day 3	1st seine	38	4	12	1	2	-
	2nd seine	38	7	13	2	1	-
	Total	76	11	25	3	3	-
Day 4	1st seine	13	4	46	15	2	
	2nd seine	2	2	19	4	-	
	3rd seine	15	5	24	-	2	
	4th seine	1		16	2	1	1 crucian carp
	5th seine	6	1	46	35	2	
	Total	37	12	151	56	7	1

TABLE 23 Catches of different species on each day of the third (1973) population estimate. Seines were made with one 50 yard net, long seines were made with two 50 m nets joined together and covered the entire area of the lake.

Effort	Catches				
	Total	Roach	Rudd	Perch	Tench
Day 1 9 seines	1068	714	4	298	52
Day 2 12 seines	576	338	8	186	44
Day 3 16 seines	364	164	27	162	11
Day 4 6 seines + 2 long seines	493	176	7	284	26

estimates of biomass of fish in the lake (see table 24). The relatively low rudd biomass was calculated from the roach length-weight relationship and that for the limited numbers of tench and pike from the weights of individual fish.

Figure 20 shows the length-weight relationship established for roach caught from lake 7 during 1973. The calculated regression was:-

$$\log w = 3.174 \log l - 1.989$$

where w = wet weight in gm and l = fork length in cm

Figure 21 shows the length-weight regression found for perch in lake 7. This was calculated as :-

$$\log w = 3.326 \log l - 2.026$$

where w = wet weight in gm and l = fork length in cm

Table 25 compares a range of estimates of roach biomass in different waters.

B. The Roach

(a) Ageing and Check Formation

As described on page 53, the roach were aged by examination of their scales. The results were supported by estimates derived from the presence of modes in length-frequency distributions (Petersen method), regular sampling and by observing the periods during which checks formed on fish's scales.

(i) The Petersen Method

In 1973 the length-frequency distribution of a subsample of the roach that were introduced into lake 7 from 18b showed three distinct modes (see Figure 38). Examination of fish scales from this population confirmed that these modes were equivalent to three year-classes (0+, 1+, 2+). Plate 1a, b and c show typical scales of the 1972 (0+), 1971 (1+) and 1970 (2+) year-classes.

(ii) Observation of Check Formation

In the Spring of 1973, the 1970 year-class of the introduced stock was

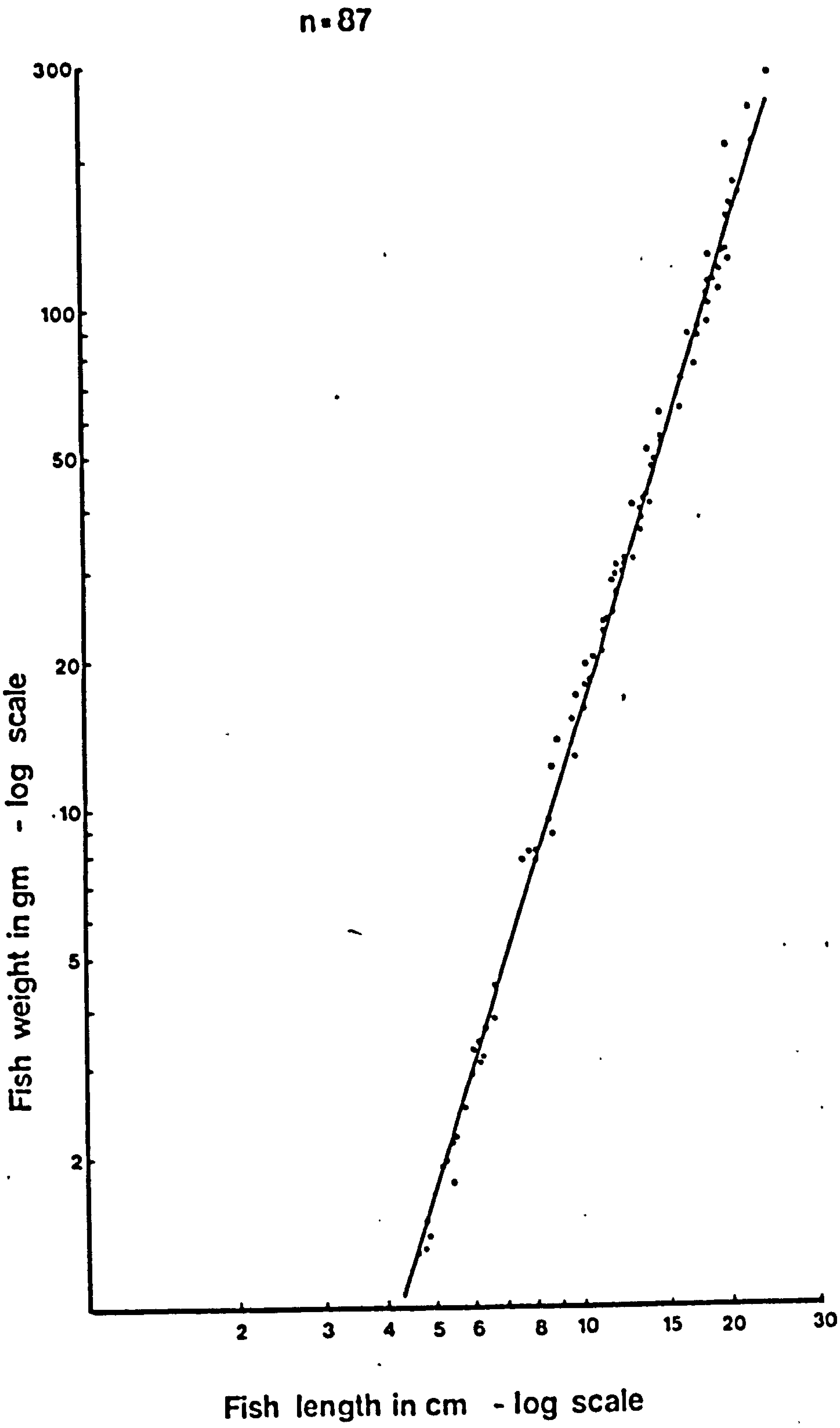


Figure 20 Length-weight regression for roach in Yateley 7

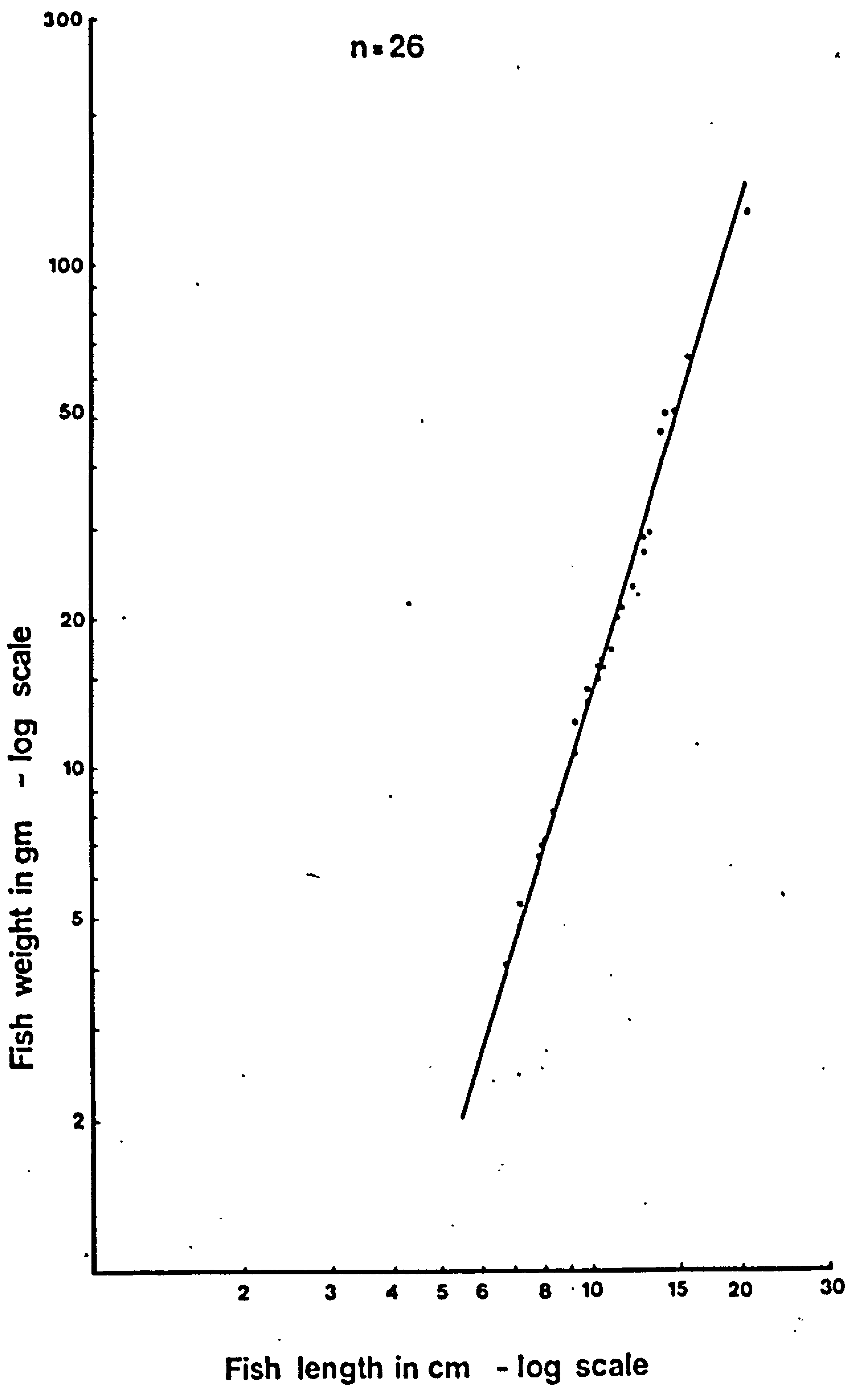


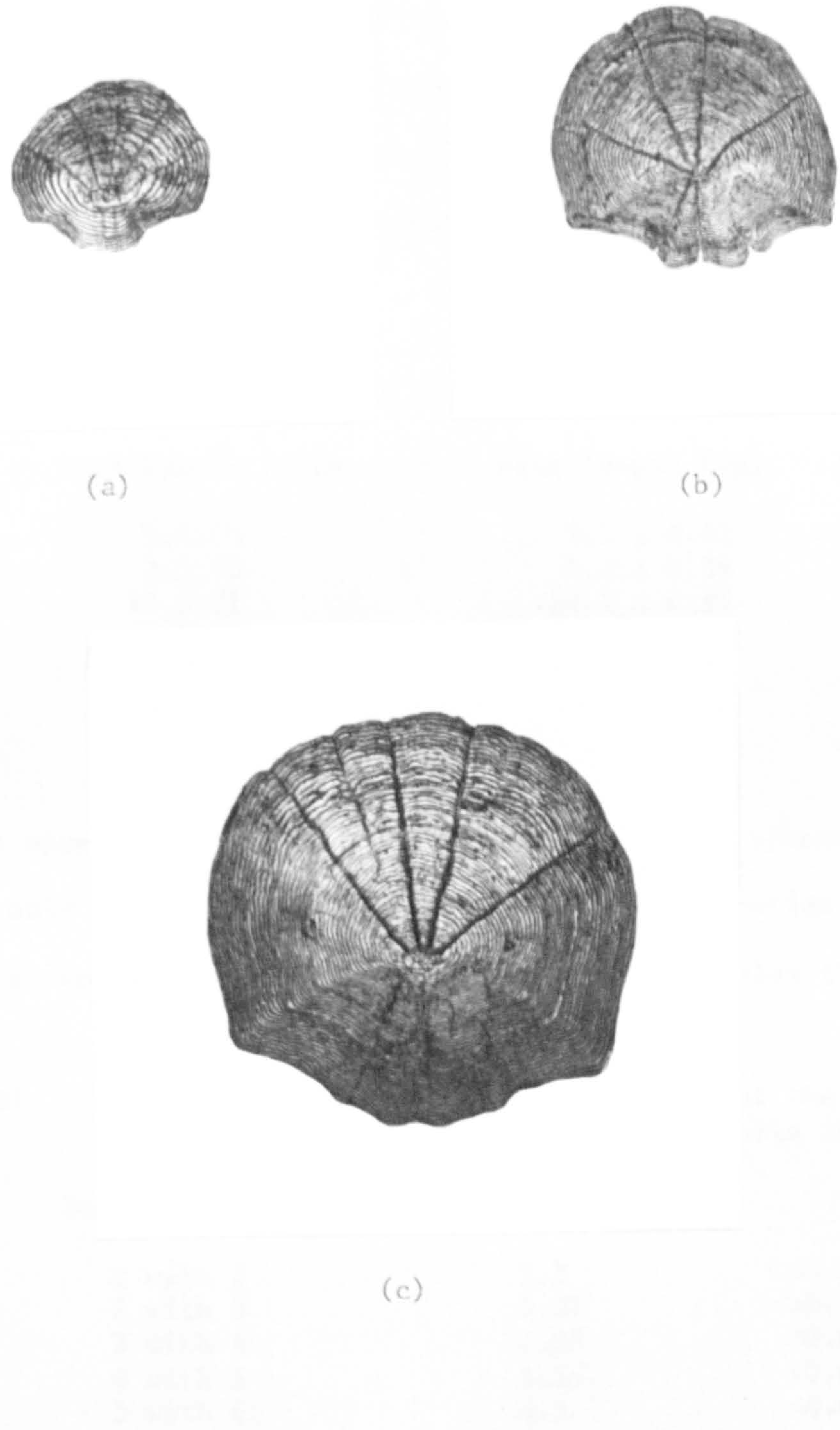
Figure 21 Length-weight regression for perch in Yateley 7

TABLE 24 Estimates of biomass of fish in lake 7

Date	Fish Species	Total Biomass (kg)	gm /m^2
November 1971	Roach	4.991	1.1
	Perch	1.397	0.3
	Rudd	c 4.0	0.9
	Tench	13.808	3.1
	Pike	c 4.2	0.9
	Total	28.4	6.3
November 1972	Roach	13.098	2.9
	Perch	3.6	0.8
	Rudd	<0.75	<0.2
	Tench	81.98	18.2
	Pike	c 4.0	0.9
	Total	103.43	23.0
Introduced fish (January 1973)	Roach	41.486	9.2
November 1973	Roach	54.259	12.1
	Perch	9.316	2.1
	Rudd	<0.4	<0.1
	Tench	108.738	24.2
	Pike	c 1.5	0.3
	Total	174.22	38.8

TABLE 25 A comparison of various estimates of roach biomass in different waters

Water (and source)	Biomass in Kg/hectare (= $gm/m^2 \times 10$)
Yateley 7 (this study)	10.8 - 120.6
Humbie reservoir (Mills, 1969)	416.0 (for fish over 4 years old, >12 cm)
River Thames (Mann, 1965)	212.0
Other gravel-pit lakes (Gee, 1976)	
Farnborough 18a	71.6
Twyford 32	5.7
Darenth 39	8.3
Darenth 40	115.1
Larkfield 41	14.9



(a) (b) (c)

Plate 1. Roach scales taken on 21.1.73 from fish introduced into Yateley 7 from Farnborough 18b; (a) - 0+, 1972 year-class fish, 3.8 cm; (b) - 1+, 1971 year-class fish, 7.6 cm and (c) - 2+, 1970 year-class fish, 10.0 cm. All scales ×5.

the dominant year-class in the regular samples of roach taken from lake 7. (see Table 35, page 126). Check formation was observed for this year-class. Samples taken on 9.4.73, 3.5.73 and 16.5.73 (numbers 1, 2, 3 in Table 26) showed the expected two checks and plus growth (additional circuli outside the second check). All fish sampled on 31.5.73 showed a new (third) check on the edge of the scale and fish taken on 16.7.73 showed the third check and plus growth. Table 26 presents these data together with the mean lengths of the samples.

TABLE 26 Growth and age of roach, introduced stock 1970 year-class

Sample	Date Sample Taken	n	Mean length (cm)	Age (from Scales)
1	9.4.73	7	9.3 ± 0.92	2+
2	3.5.73	12	9.8 ± 0.59	2+
3	16.5.73	9	10.1 ± 0.35	2+
4	31.5.73	5	10.5 ± 0.9	3
5	29.6.73	58	11.9 ± 0.2	3+
6	16.7.73	38	12.6 ± 0.28	3+

It appears from Table 26 that the third check becomes visible on the scales only after the commencement of growth. A series of 't' tests were conducted upon the mean lengths of consecutive samples (Table 27).

TABLE 27 't' tests comparing the mean lengths of the roach in consecutive samples (samples 1-6 in Table 26)

Test comparing	Value of t	p
1 with 2	1.2	>0.1
2 with 3	0.87	>0.1
3 with 4	2.25	<0.05 > 0.02
4 with 5	5.15	<0.01
5 with 6	4.5	<0.01

Table 27 shows that no significant difference occurred between the mean lengths of fish sampled on consecutive dates before 16.5.73 (sample 3). However, when the mean length of fish sampled on 16.5.73(3) is compared with that of the fish sampled on 31.5.73(4), a significant difference is found. This suggests that the fish grew between these dates (see also Figure 39, page 128) and as shown in Table 26 this was also the time when the new check appeared on the fish's scales. Figure 32 (page113) indicates that the roach in lake 7 spawned during the last weeks of May in 1973.

(b) <u>Growth</u>

Only the younger year-classes were caught in sufficient numbers to enable estimates of their growth throughout the year to be made. These data, showing the growth of the 1970, 1971 and 1973 (native) year-classes, are presented in Figure 22.

By pooling the lengths of each of the different year-classes of roach caught during the winter months (October to April) in 1970/71, 1971/72 and 1972/73, estimates of the growth of less abundant year-classes were made. These estimates are presented in Figure 23 and Table 28. Table 29 shows the overall average growth for native roach for all year-classes combined in Yateley 7.

TABLE 29 Average growth of native roach in Yateley 7

	1st Year	2nd Year	3rd Year	4th Year	5th Year	6th Year	7th Year
Average length (cm)	5.36	9.25	13.5	17.08	20.05	21.47	28.05
Average increment (cm)	5.36	3.89	4.25	3.58	2.97	1.42	6.58

(numbers of fish are given in Figure 23).

Figure 24 shows estimates of growth-rate by 'length-for-age' analysis on the pooled winter catches.

Figure 25 compares the average growth for native roach in lake 7 with that of roach in 18b ('length-for-age' analysis, see page 127) other gravel-pit lakes (Gee, 1976) and other published work.

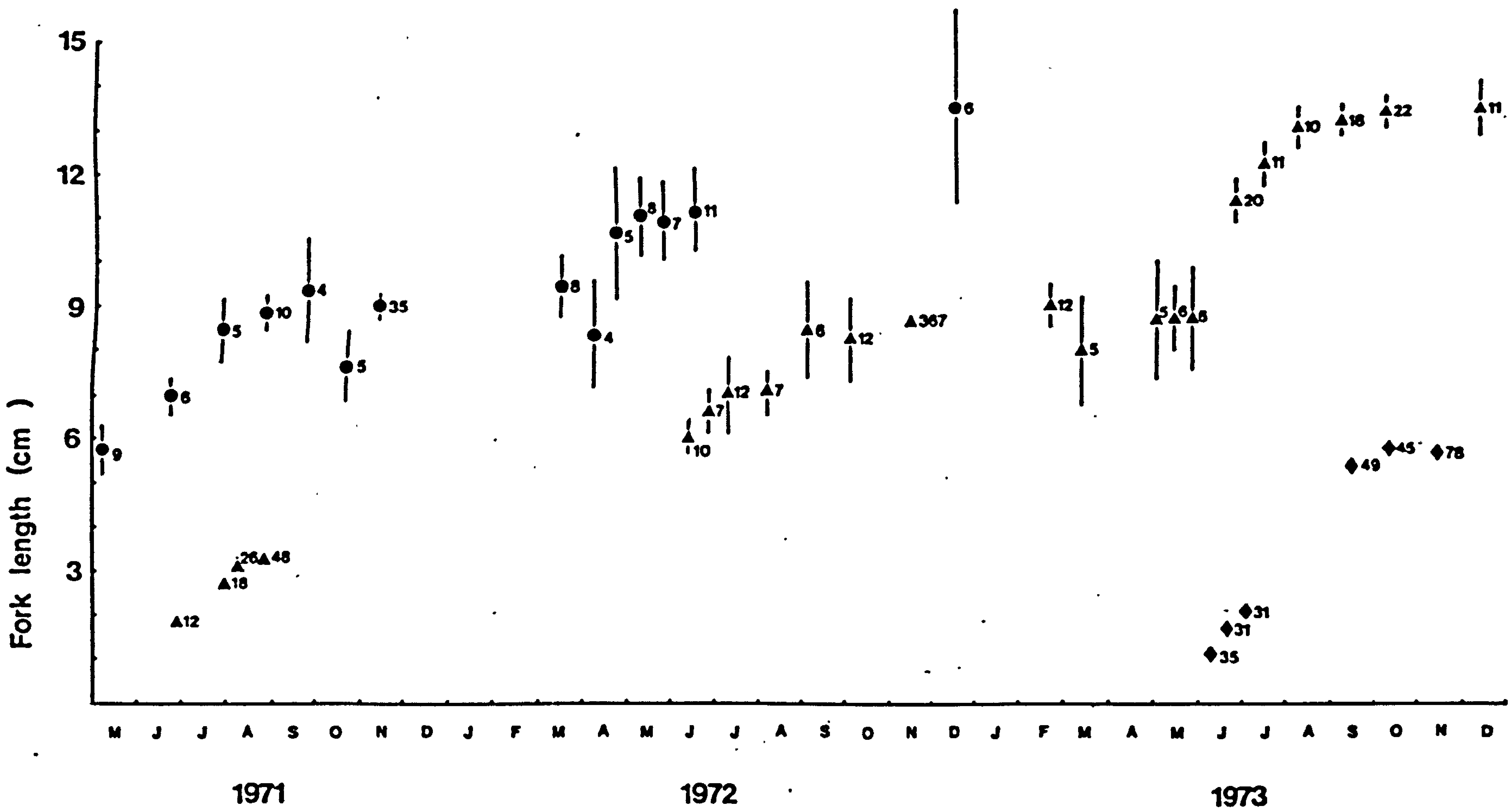


Figure 22 Growth of roach in Yateley 7; ● mean length and 95% confidence limits of 1970 year-class, ▲ mean length and 95% confidence limits of 1971 year-class, ◆ mean length of 1973 year-class, symbol covers 95% confidence limits.

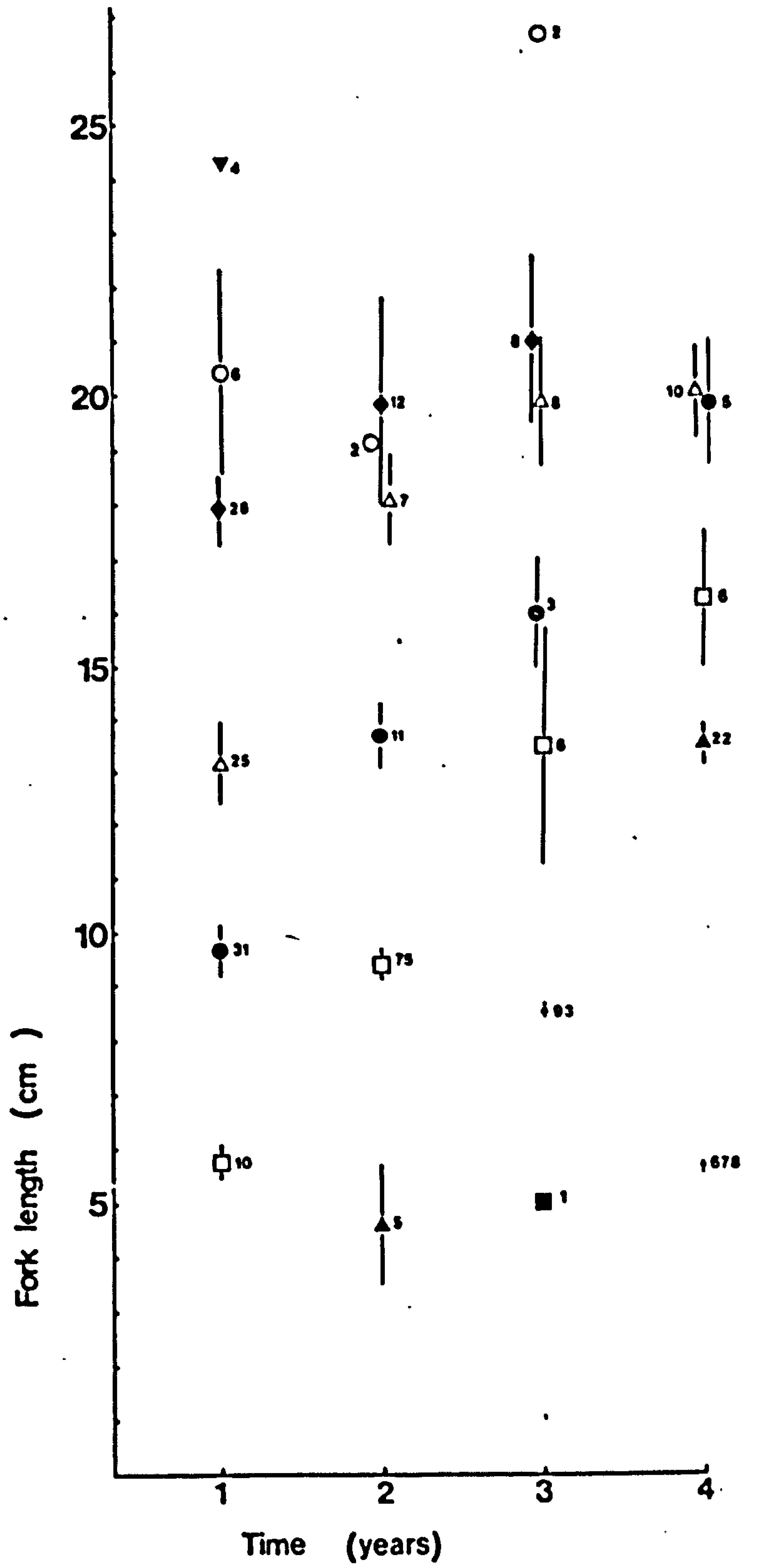


Figure 23 Growth of roach in Yateley 7. Mean lengths and 95% confidence limits of different year-classes of roach caught during winter months; ▾ - 1973 year-class, ■ - 1972 year-class, ▲ - 1971 year-class; □ - 1970 year-class, ● - 1969 year-class, △ - 1968 year-class, ♦ - 1967 year-class, ○ - 1966 year-class and ▼ - 1965 year-class.

TABLE 28 Mean fork-lengths for roach with 95% confidence limits, taken from fish caught during the months October - April in 1970/71, 1971/72, 1972/73 and 1973/74

Year-Class	Years								
	1	2	3	4	5	6	7	8	9
1965						25.34±6.78	No fish	No fish	No fish
1966					20.45±1.84	19.15±14.6	28.05±3.16	No fish	
1967				17.87±0.58	19.85±1.9	21.09±1.54	No fish		
1968			13.19±0.75	18.1 ±0.8	19.94±1.2	20.3±0.84			
1969		9.69±0.46	13.7 ±0.6	16.0 ±1.0	19.98±1.17				
1970	5.86±0.27	9.52±0.25	13.6 ±2.28	16.33±1.25					
1971	4.72±1.14	8.54±0.1	13.54±0.38						
1972	5.1 (1 Fish)	No fish							
1973	5.77 0.3								
Mean	5.36	9.25	13.5	17.08	20.05	21.47	28.05		

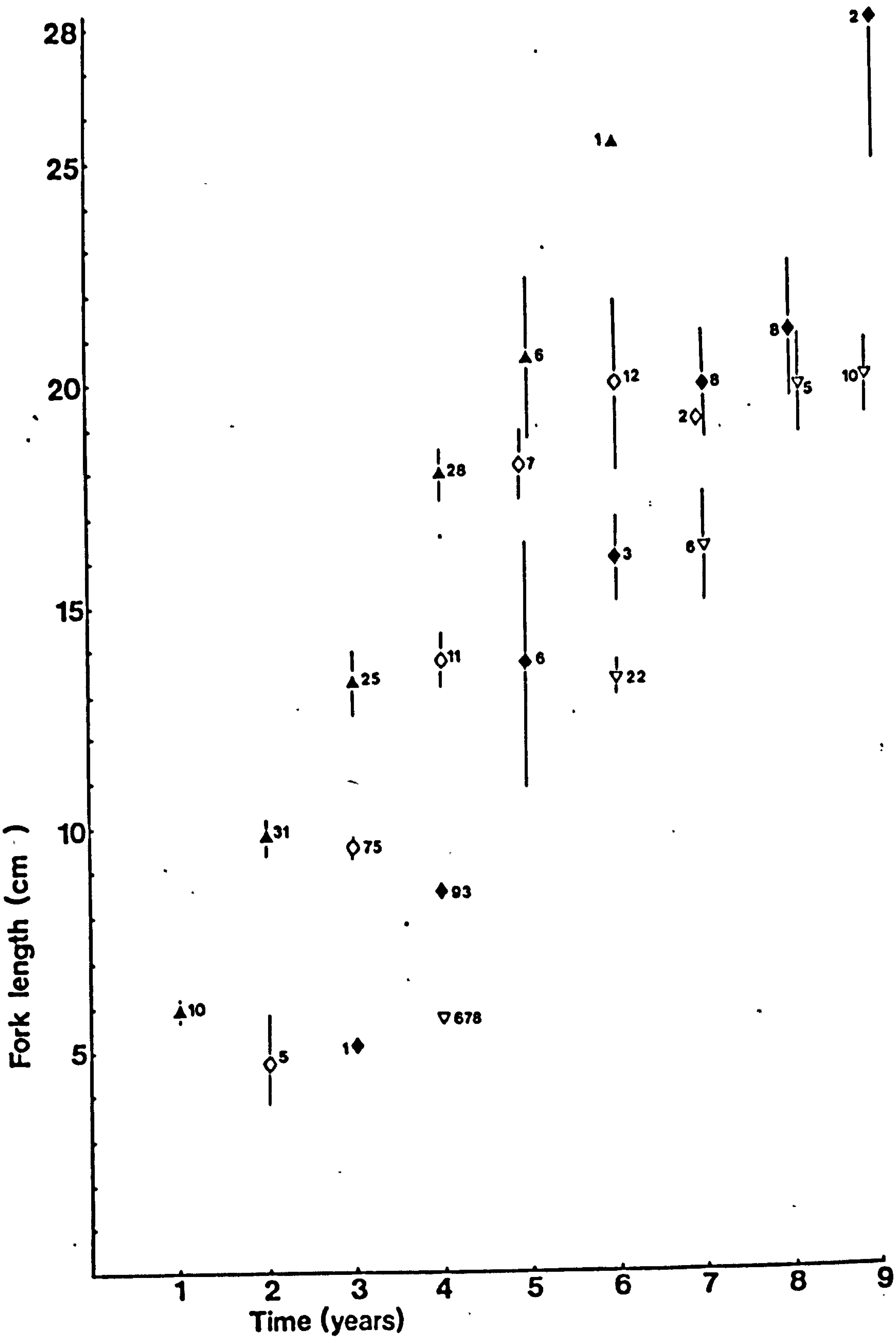


Figure 24 Growth of roach in Yateley 7 by age-for-length analyses of the catches made in the winters of; 1970/71 (▲), 1971/72 (◊), 1972/73 (♦) and 1973/74 (▽).

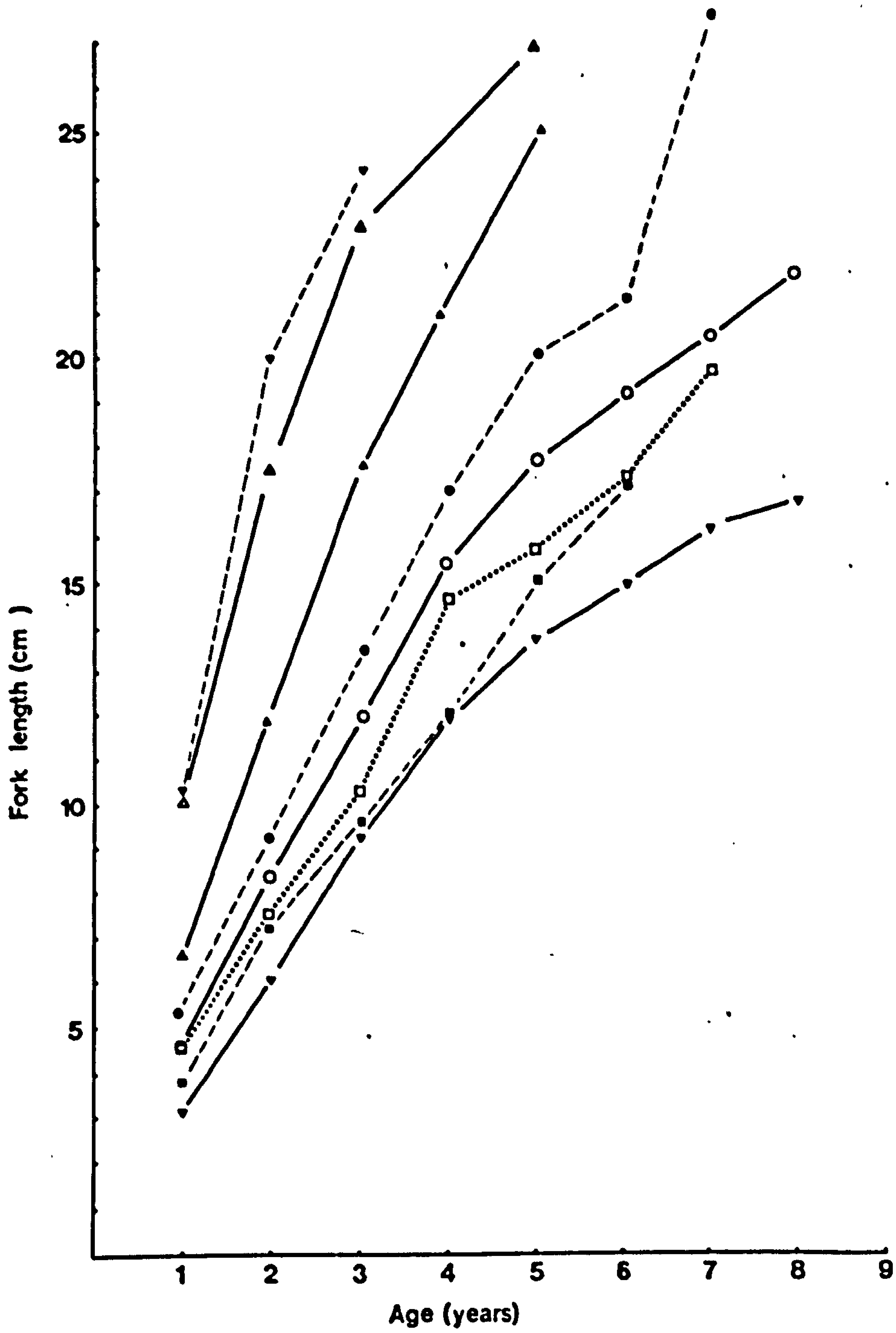


Figure 25 Growth of roach in various waters; ▼ - a carp pond (Hofstede, 1974a), △ - Chew (Wilson, 1971), ▲ — Yateley 3a (Gee, 1976), ● — Yateley 7, ○ - River Stour (Mann, 1974), □ — Larkfield 41 (Gee, 1976), ■ - Farnborough 18b and ▽ — Humbie Reservoir (Mills, 1969)

(c) Diet

The following items were all taken from guts of roach in Yateley 7 during the course of the study.

Detritus	-	plant and animal remains and silt (see below)
Plant material	-	epilithic/epiphytic diatoms filamentous algae *Elodea canadensis* *Potamogeton* sp. Alder seeds
Porifera	-	*Spongilla* sp.
Entomostraca	-	*Daphnia longispina* *Bosmina longirostris* *Chydorus* sp. *Simocephalus* sp. Calanoid copepods Cyclopoid copepods
Malacostraca	-	*Asellus aquaticus* *Cragonyx pseudogracilis*
Insecta	-	*Cloeon dipterum* nymphs *Corixa* sp. - nymphs and adults Trichoptera larvae *Sialis lutaria* nymphs *Chaoborus* sp. larvae Chironomid larvae Ceratopogonid larvae Dipteran pupae and adults
Mollusca	-	*Potamopyrgus jenkinsi* *Pisidium/Sphaerium*

Large quantities of silt, with epilithic algae and components of the zoobenthos, were frequently found suggesting that the fish often fed on the soft silt in an unselective way - this was classed as detritus. Most of the items listed above were rarely found in the fish; Figure 26 shows the major components found in the gut contents by percentage incidence. Figure 27 shows gut contents of the roach expressed as percentages of the fish's somatic weight. Because the few 0+ fish examined often showed a different diet to that of older fish, figures 26 and 27 were based on fish aged 1+ and older. Both these figures show seasonal changes in the importance of different components of the fish's diet. In particular they show a marked pattern in the importance of *D. longispina* in the fish's

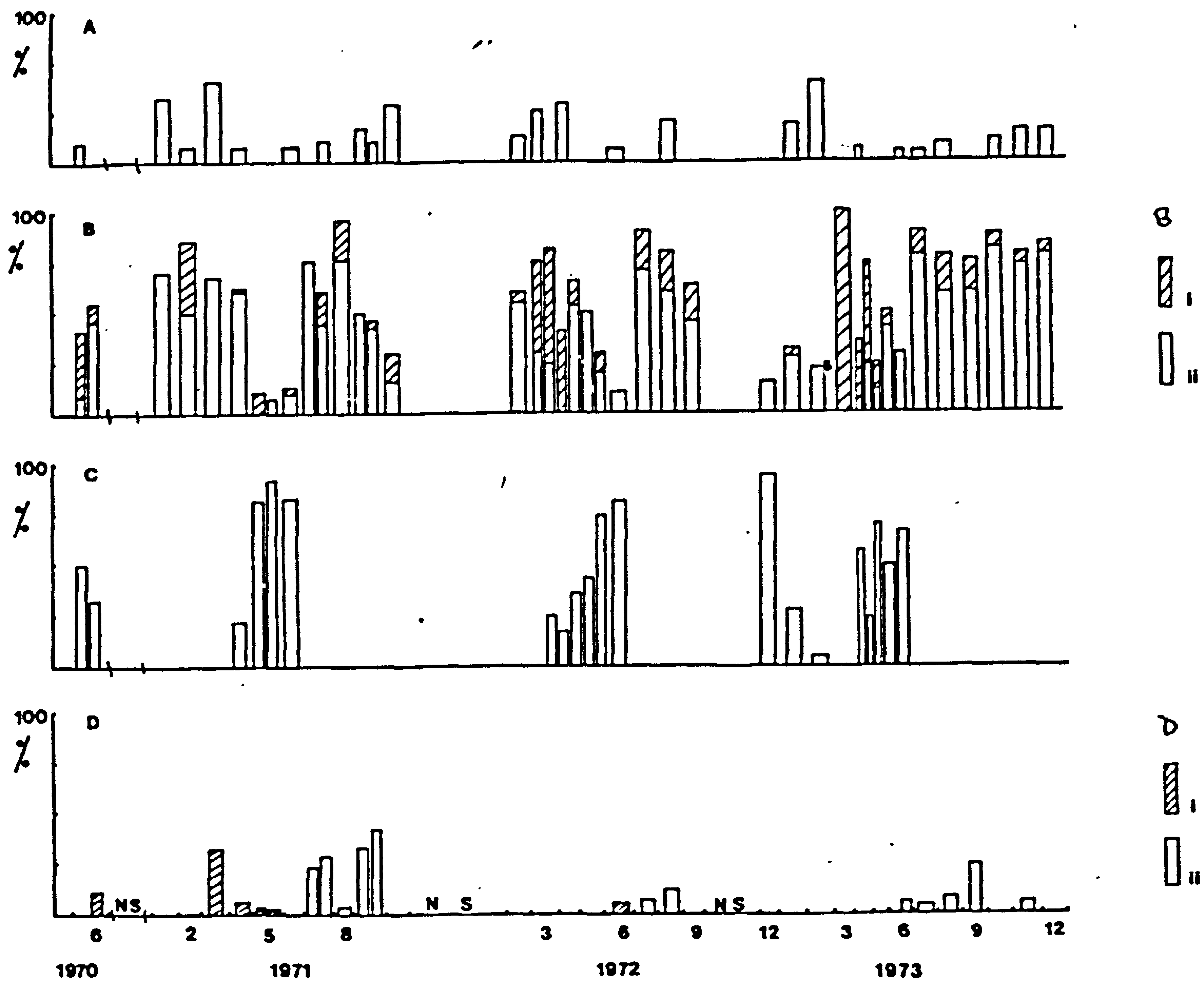


Figure 26 Diet of roach, by percentage of fish in each sample with empty guts (A), containing zoobenthos (B), Daphnia longispina (C) and vegetation (D); Bi - animals, Bii - detritus, Di - algae, Dii - macrophytes. NS - no sample. Numbers of fish in samples are shown in table 9.

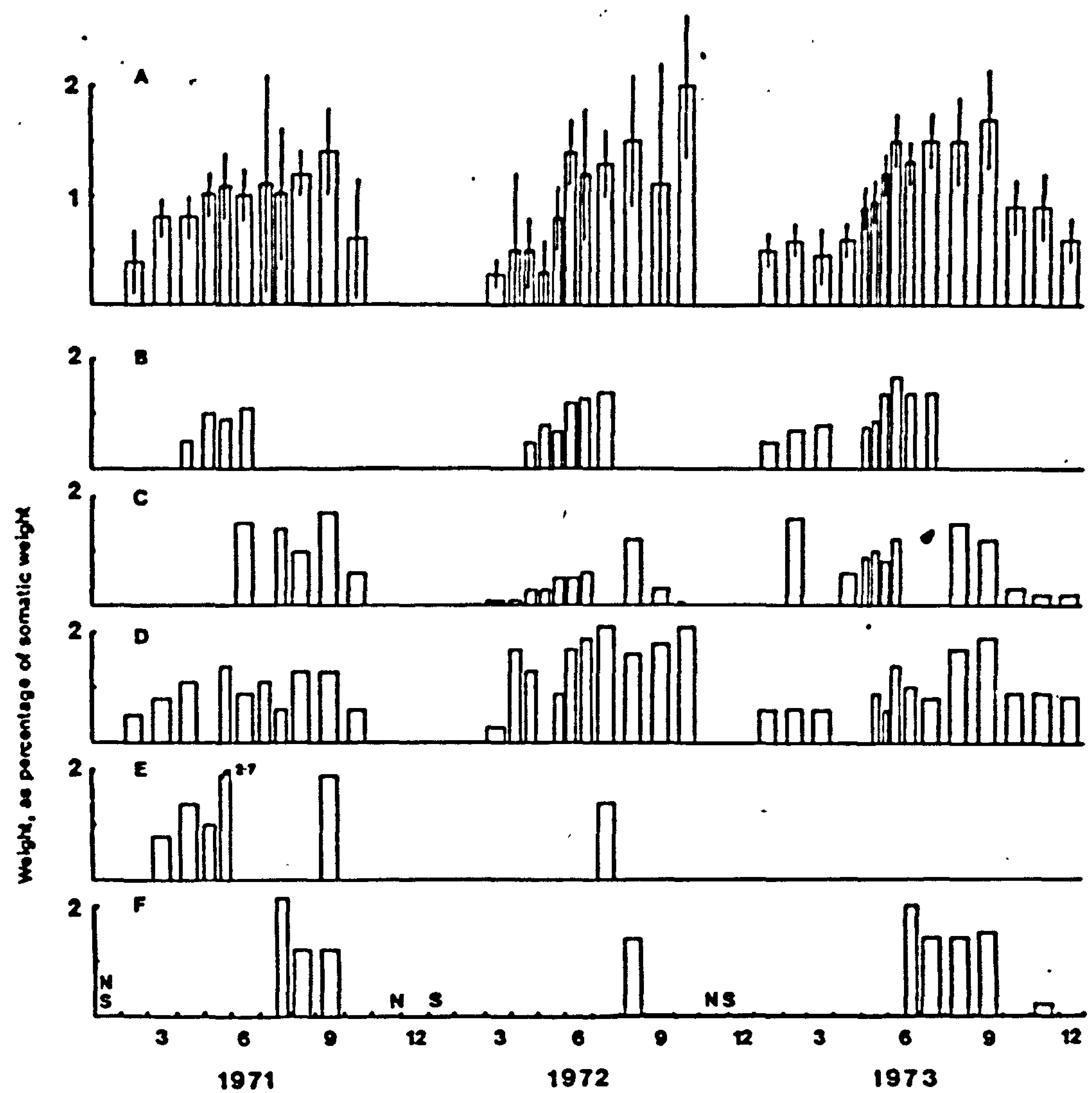


Figure 27 Wet weight of different items found in the guts of roach (expressed as percentages of somatic weight); A - overall average with 95% confidence limits, B - Daphnia longispina, C - insects, D - detritus, E - filamentous algae and F - macrophytes. NS - no samples. Numbers of fish in samples are shown in table 9.

diet. Figure 28 compares the abundance of D. longispina in the open water with the percentages of fish in the samples feeding upon D. longispina.

In Figure 27, in the graph of average weights of fish gut contents, there were sufficient numbers of fish for confidence limits to be calculated; seasonal trends can be seen in these weights of gut contents. They change from winter levels of 0.5% of the fish's somatic weights (December to February) to values of between 1 and 1.5% in summer and autumn (June to October).

Figure 29 compares length-frequency distributions of fish feeding on D. longispina with those of fish feeding on other food. It was constructed by pooling by lengths the fish in samples where at least some of the fish had been feeding on Daphnia. Although the largest fish tend not to feed on Daphnia while the smallest tend not to feed on 'other food', Figure 29 shows that Daphnia is important as food to roach over a wide range of sizes (<8 cm to >20 cm).

TABLE 30 A comparison between faeces analysis and gut analysis to assess roach diet

Number of Fish	Source of Data	Categories of Food (diet) D. longispina	Benthos
21	Gut contents of routine sample	13.5	7.5
63	Analysis of faeces	25.0	38.0

Table 30 compares the results of assessing roach diet by analysing the faeces of a large sample and the gut contents of some of the same fish. Taking the routine gut analysis as the expected result and the analysis of the faeces as the observed result, the value for χ^2 was

$$\chi^2 = 5.6$$

These results were significantly different ($0.02>p>0.01$). When the routine sample was examined traces of D. longispina were found in the extreme posterior end of the guts of four fish categorised as feeding on benthos.

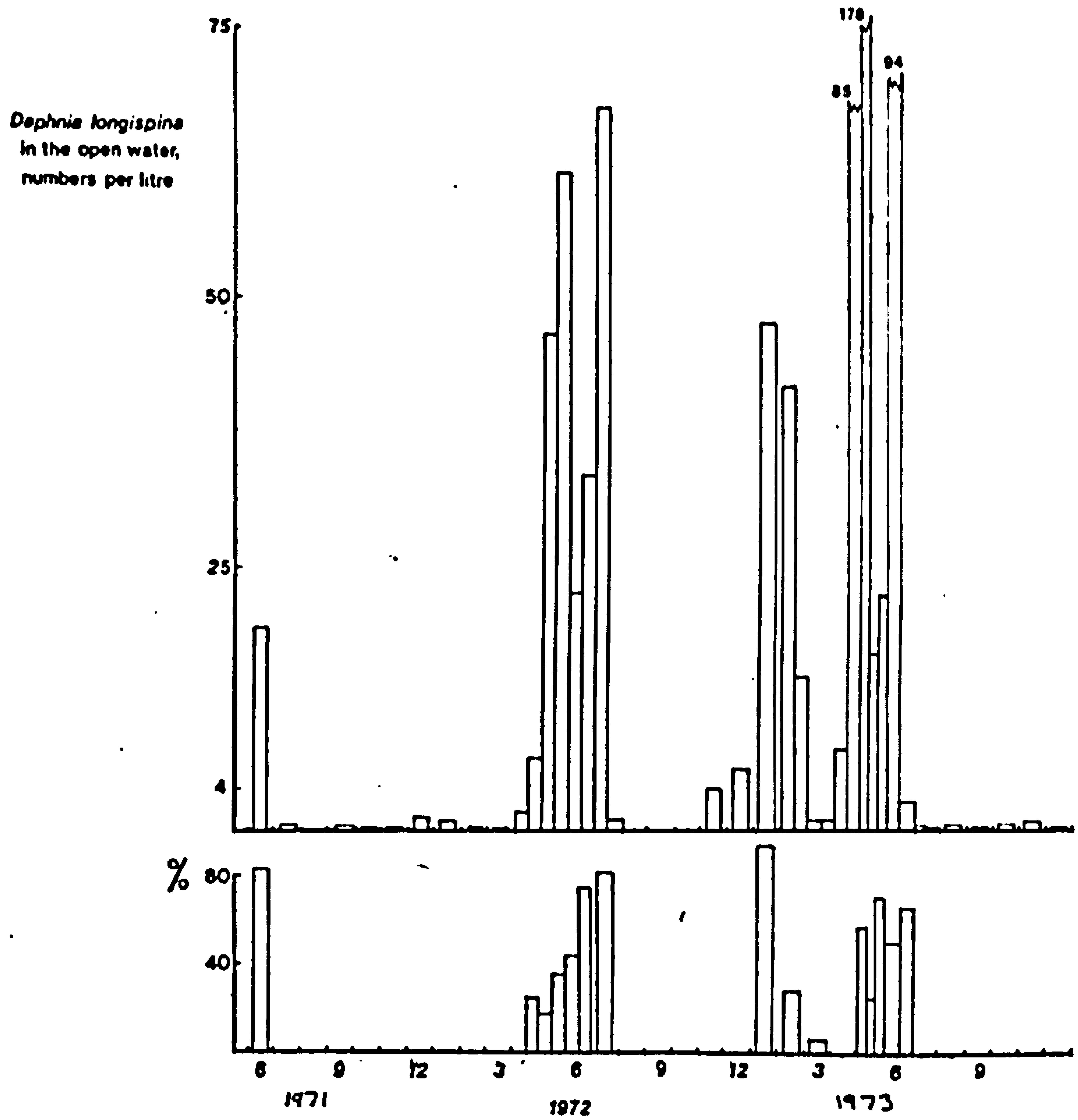


Figure 28 A comparison of the abundance of D. longispina in the open water (above) with the percentages of roach in the samples that were feeding on D. longispina (below). Samples cover the period June 1971 to December 1973. No fish samples were taken in November 1971 - January 1972 and November and December 1972.

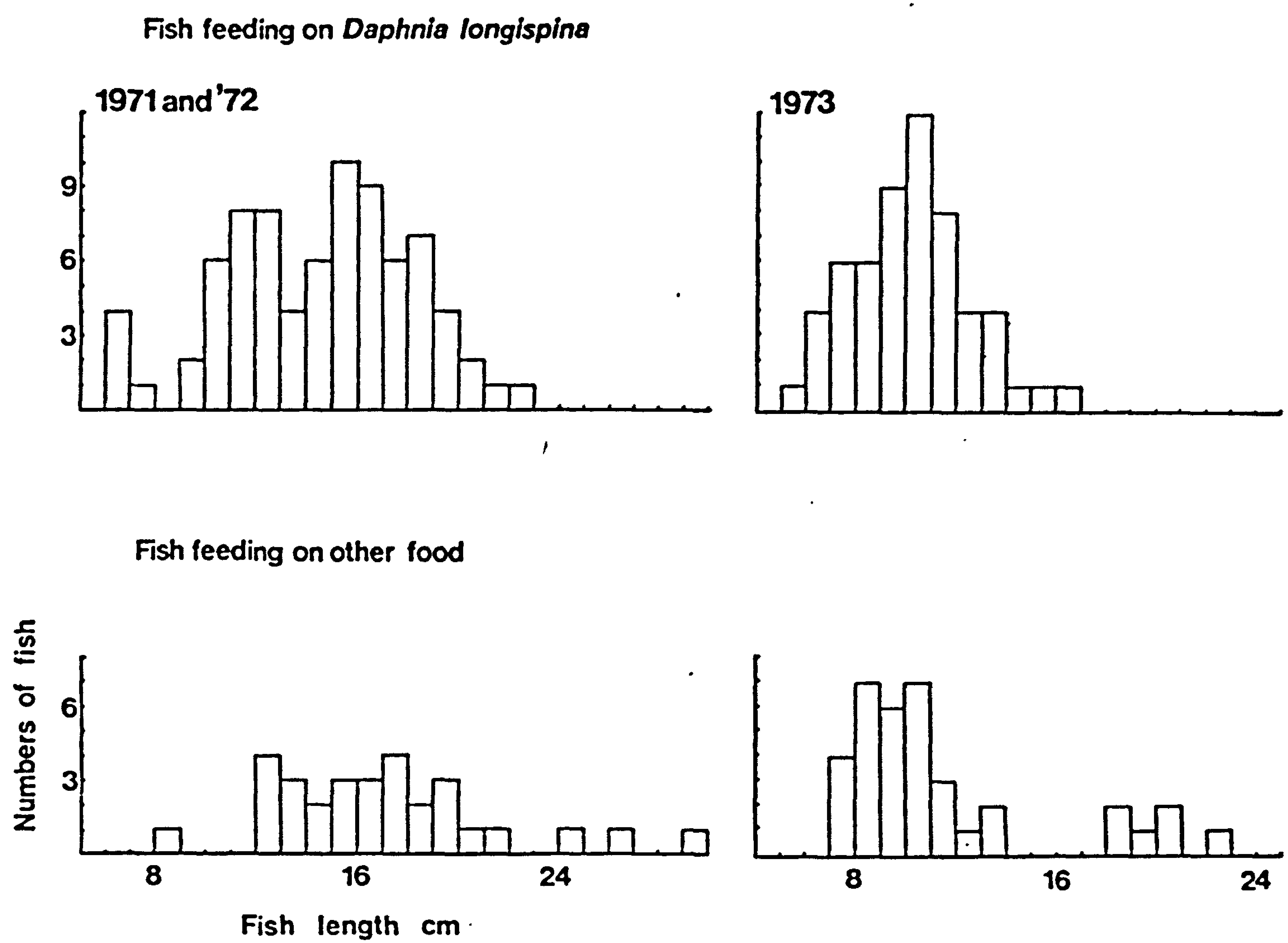


Figure 29 A comparison of the length-frequency distributions of roach feeding on <u>D. longispina</u> (above) with those of roach in the same samples feeding on other food (below)

Figures 30 and 31 show comparisons of length-frequency distributions of D. longispina taken from the open water, the littoral water and the guts of roach of different sizes. For the samples taken on 12.6.73 (Figure 30), where the distributions approach normality, a series of 't' tests were undertaken. These compare the mean lengths of the Cladocera taken from the littoral and the guts of five roach, with that of Cladocera taken from the open water (see Table 31). These results, Figures 30 and 31 and the results of the third feeding experiment (see page 136), show that roach select the larger D. longispina. Figures 30 and 31 suggest that larger fish are more selective than smaller fish. Table 31 shows that significant differences were found between the mean lengths of D. longispina found in fish guts and in plankton samples, for example, for the open water - Roach 691 comparison $p<0.001$

(d) Gonad Development and Fecundity

Figure 32 shows the annual cycle of gonad development; the only data used were those collected from fish old enough to be mature. Normally females matured in their third year i.e. had maturing gonads when 2+. Approximately half the males matured when 1+, the rest when 2+. Figure 32 shows that the average gonad-somatic index rose to 20% in females but only 8% in males. Some female fish had gonad-somatic indices of over 30%.

Ripeness in males, as indicated by sperm running from the vent, occurred over a period of 4-6 weeks from mid-April to mid-May. Fish caught during this time could be stripped of small amounts of milt and showed secondary sexual characteristics, with small (approximately 2mm in diameter) superficial, white warts in the epidermis on the centre of their scales and over the head. The gradual decline in male gonad-somatic index during April and May reflects this prolonged period of ripeness (see Figure 32).

In contrast to the males, no female fish were caught that could be stripped of ripe genital products. In 1971 and 1973 the gonad-somatic

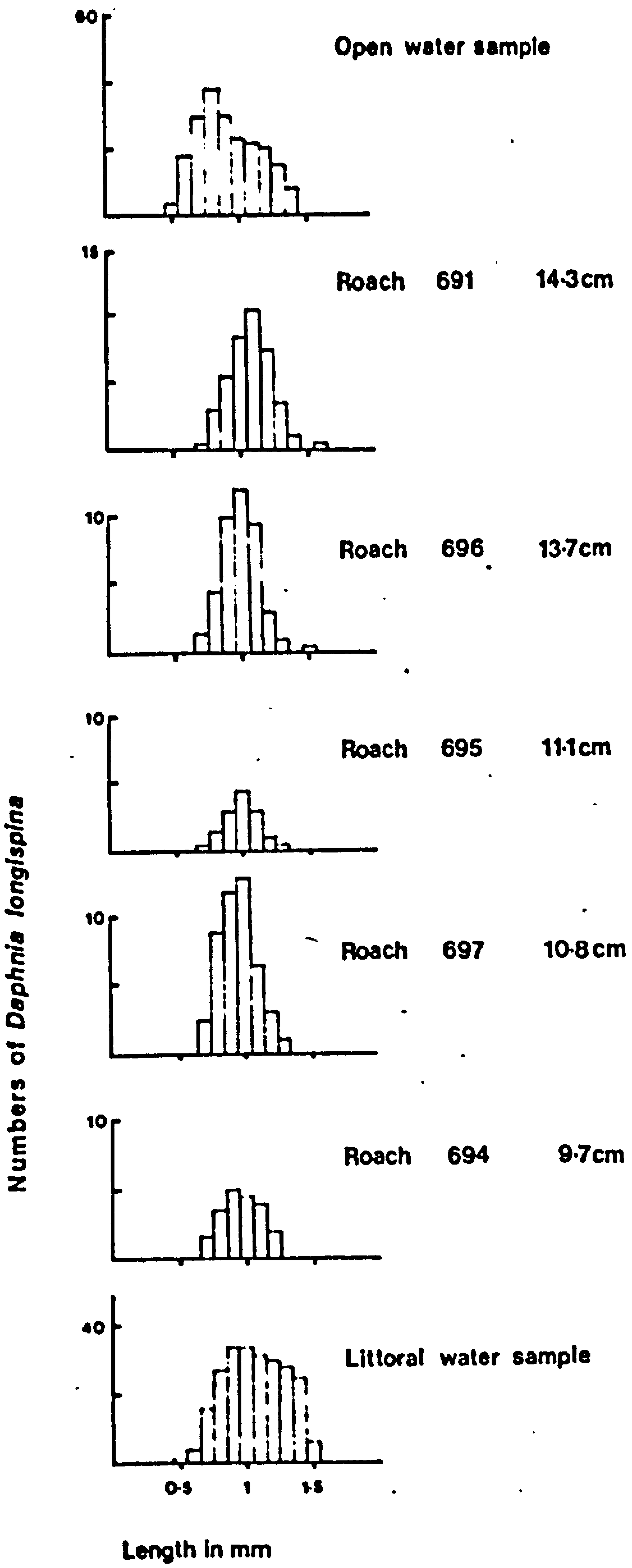


Figure 30 Length-frequency distributions of D. longispina taken from the open water, littoral water and the guts of 5 roach on 12.6.73

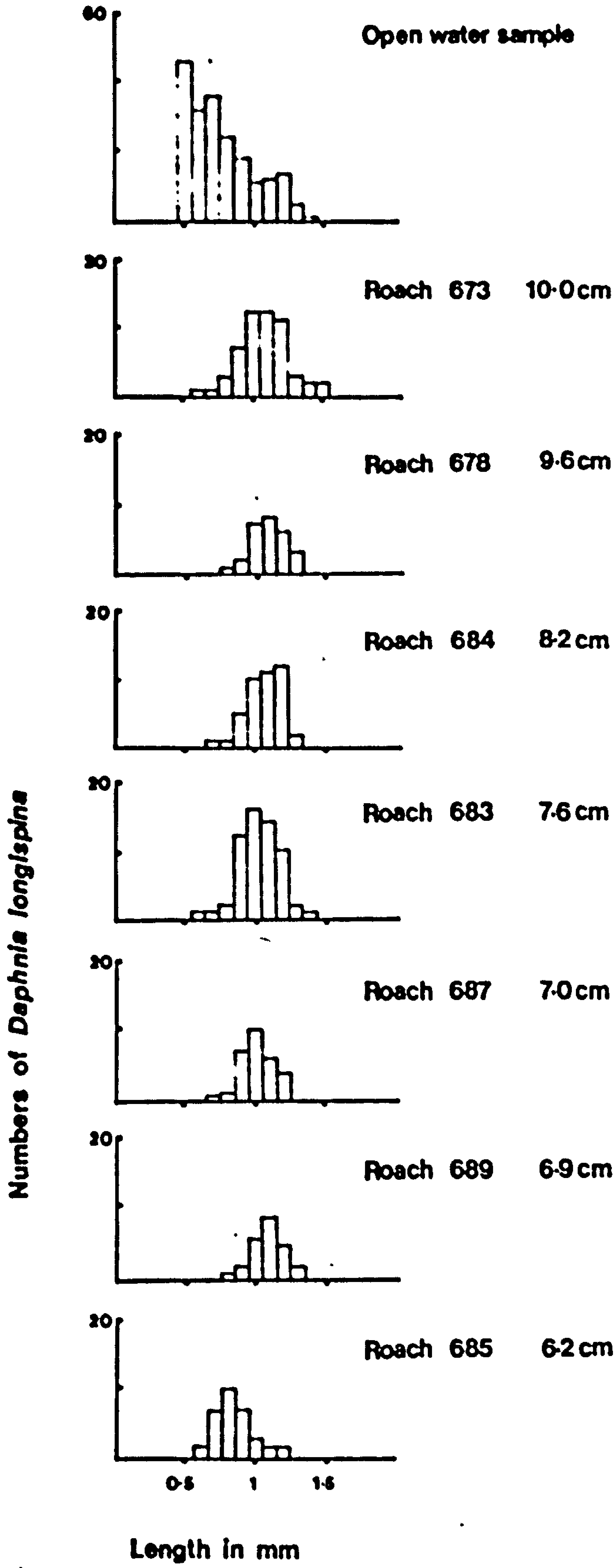


Figure 31 Length-frequency distributions of D. longispina taken from the open water and the guts of 7 roach on 31.5.73

TABLE 31 A comparison of mean lengths of <u>Daphnia longispina</u> sampled on 12.6.73

Source of *D. longispina*		n	mean length	s^2	't' compared to open water sample
Plankton Samples Open Water sample		208	0.93	0.055	
Littoral sample		239	1.07	0.048	6.25 ***
From Guts of Roach					
Fish number	length (cm)				
691	14.3	82	1.074	0.04	4.8 ***
696	13.7	84	0.998	0.02	2.41 *
695	11.1	28	0.993	0.019	1.45
697	10.8	89	0.945	0.019	0.57
694	9.7	41	0.958	0.021	0.7

* $p < 0.1 > 0.02$

*** $p < 0.001$

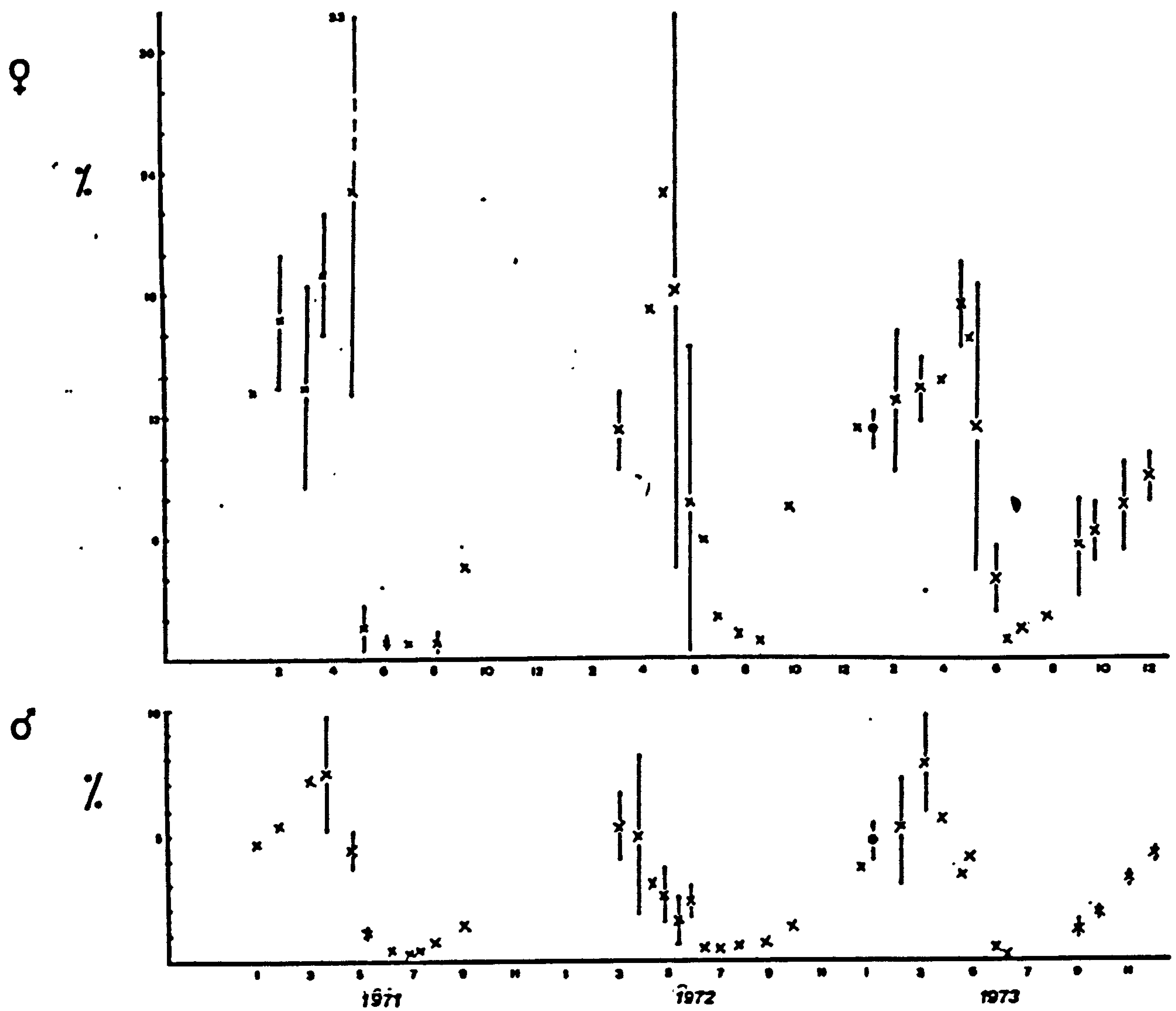


Figure 32 Changes in roach gonad-somatic index,
x̧ - mean and 95% confidence limits, x - mean of small sample and
ọ - sample from stock introduced from Farnborough 18b.

index dropped suddenly from a mid-May peak to a June low. This indication of the shortness of the spawning period was supported by the samples taken in 1971. In the sample taken on 15.5.71 none of the mature females had shed any eggs; however, in the sample taken ten days later, all the large mature fish had spent gonads. In 1972 very few spent female roach were seen; the drop in gonad-somatic index was slow and may have resulted from the resorption of unshed eggs. Consequently the lowest index in 1972 was delayed by three months compared to 1971 and 1972. Only two fish identified as belonging to the 1972 year-class were caught in 1972 and 1973.

The length-fecundity regressions for Yateley 7 roach which were going to spawn in 1971 and 1974, for Kew roach due to spawn in 1974, and for the river Stour roach due to spawn in 1970, are presented in Figure 33 and Table 32. Table 33 shows the results of 't' tests comparing the slopes and intercepts of these regressions. The only slopes of the regressions that were not significantly different from each other were those for the Stour roach and Yateley roach (both years).

C. Other Fish Species

The estimates of the population density and biomass of all the species found in lake 7 are shown in Tables 19 and 24 (pages 85 and 93).

Limited data were collected on the growth and diet of other species in the lake.

Tench

Figure 34 shows the length-frequency histogram for unmarked tench caught during the 1972 population estimate. This indicates that females tended to be larger than males.

Although tench were not sampled during the study, S. Bailey removed 10 tench from lake 7 in 1970. In their guts were found detritus and dipteran larvae (chironomids and ceratopogonids).

Pike

The guts of the four pike taken in November 1972 contained 1+ roach and 0+ perch.

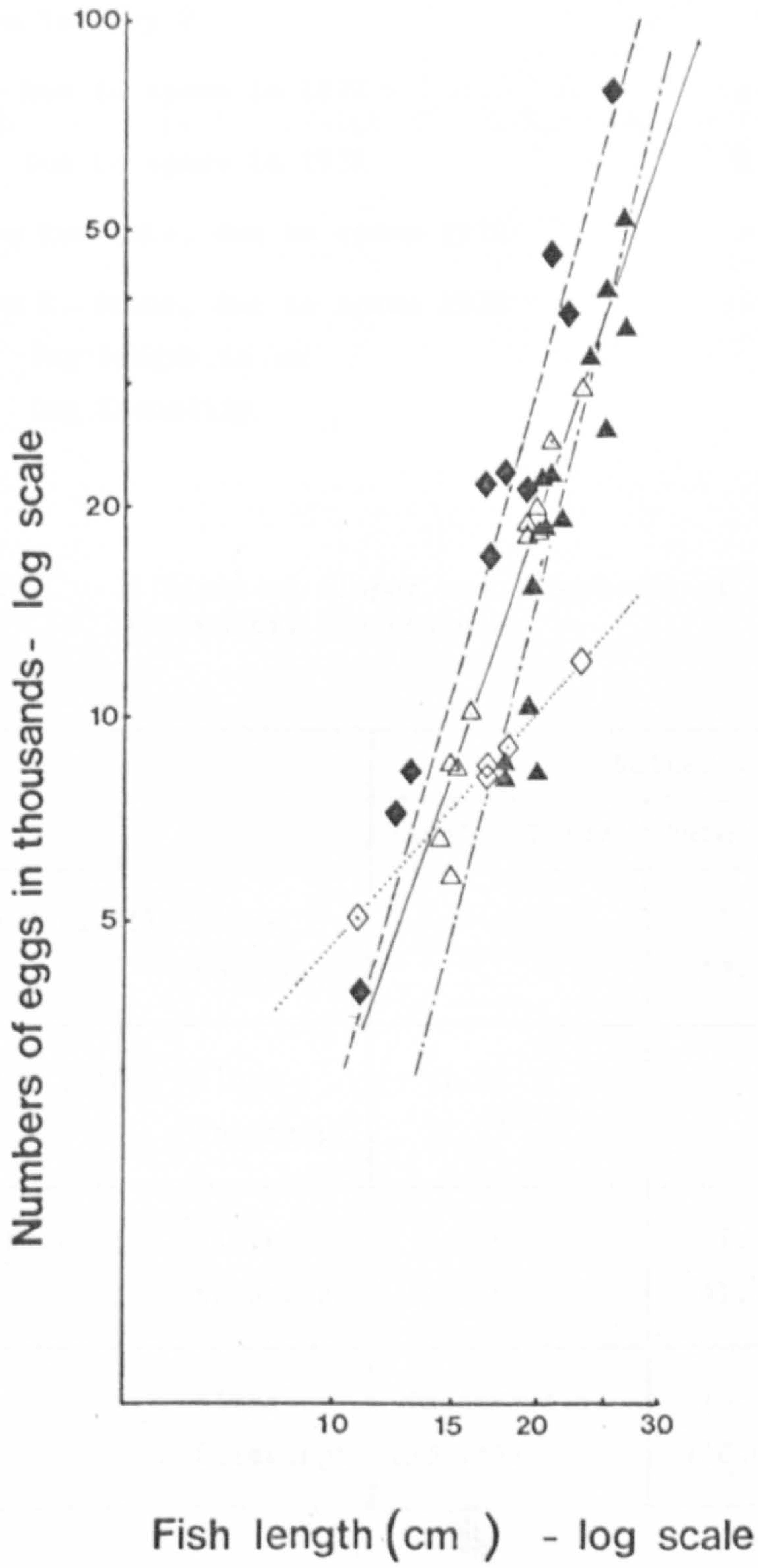


Figure 33 Length-fecundity regressions for roach from different waters.

◆ - Yateley 7 (due to spawn in 1971),
△ - Yateley 7 (due to spawn 1974),
▲ - River Stour and
◇ - Kew lake.

stand in a bucket and then live individuals only were decanted off into a second bucket. The contents of this bucket were agitated and 200 ml were removed as a sample for estimating size and abundance and a further 4 litres were then added to the experimental aquarium.

The air line, which supplied a 30-cm long air stone set at right angles to the long axis of the tank, was turned up at intervals of 30 minutes and 90 minutes. This thoroughly mixed the water in the tank. Two 2-litre water samples were taken from the tank after the water had been mixed. These samples containing D. longispina were analysed in the same way as the routine zooplankton samples to obtain estimates of numbers and length frequency-distribution.

After 90 minutes from the introduction of the Cladocera, the tank's filter was turned on. The pump had a filter rate of 200 l/m and quickly removed the remaining Cladocera from the water. Batches of five fish were removed at intervals of 30 minutes, 90 minutes, 5½ hrs, 9½ hrs, 13½ hrs, 17½ hrs, and 25½ hrs. When the second batch was removed and killed, ten extra fish were removed and placed in a different tank for the study of the effects of further feeding. These fish were fed trout pellets every hour which they took despite the disturbance they had suffered. Five of these fish were taken and killed with the next two batches of fish from the experimental tank.

The guts of these fish were examined in the same way as the routine samples taken from Yateley 7 (see page 54). The mean weights of cladocerans and 95% confidence limits were calculated for each batch. Length-frequency distributions of D. longispina were made on cladocerans taken from the guts of the fish in batches 1 and 2. An attempt was made to estimate the number of individual Cladocera in guts of the fishes in batches 1 and 2.

TABLE 32 Length - fecundity regressions for roach

Fish from Yateley 7	
Due to spawn in 1971	$x = 3.557y - 0.151$
Due to spawn in 1974	$x = 2.877y + 0.554$
Fish from Kew Lake, due to spawn 1974	$x = 1.179y + 2.467$
Fish from R. Stour, due to spawn 1970	$x = 3.868y - 0.871$

y = log length in cm

x = log fecundity

TABLE 33 t Tests on slopes and intercepts of length-fecundity, regressions

		Values for t		
		Yateley 7 1971	Yateley 7 1974	Kew
Yateley 7 (1971)	slope		1.3*	16.4***
	intercept		27.2***	130.9***
Yateley 7 (1974)	slope	1.3*		14.7***
	intercept	27.2***		110.6***
River Stour	slope	0.94*	1.8**	15.2***
	intercept	17.9***	41.2***	111.3***
Kew	slope	16.4***	14.7***	
	intercept	130.9***	110.6***	

* $p < 0.1 > 0.02$

** $p < 0.2 > 0.05$

*** $p < 0.001$

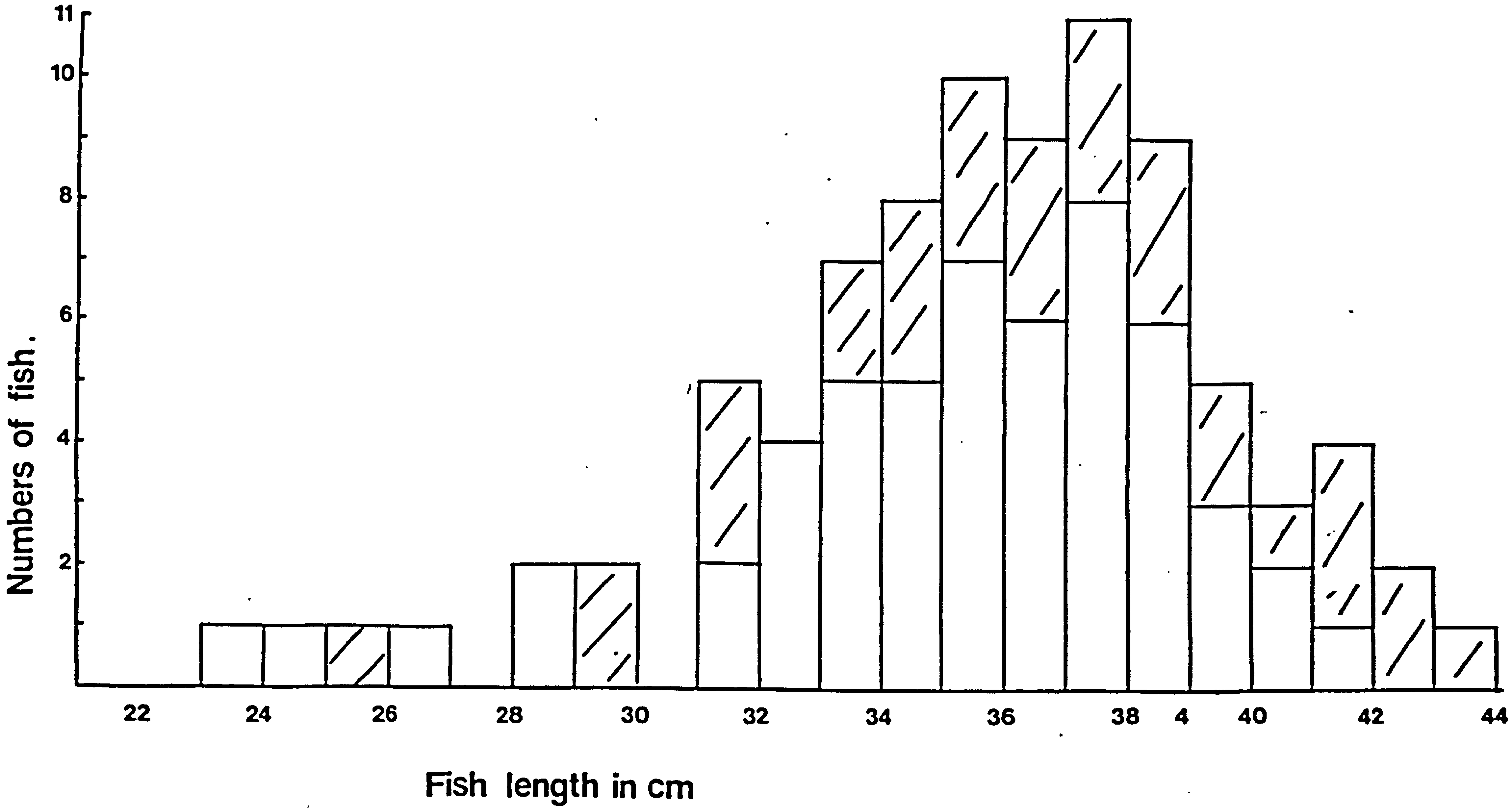


Figure 34 Length-frequency distribution for the unmarked tench caught during the third population estimate; □- males, ▨- females.

Perch

Samples of perch were taken in 1973 (see Table 9). These samples provided data on growth and diet which are presented in Figure 35 and Table 34 respectively. Figure 35 shows that perch reached 6-8 cm in their first year and 10-12 cm in their second year. Their gut contents showed that zooplankton was important to all year-classes examined. Larger invertebrates were eaten by larger fish and small fish were found in the guts of 1+ perch.

Rudd

During the study, rudd became less common in the lake (see Table 19) Samples taken in 1970/71 (see Table 9) provided data on diet. Figure 36 shows that rudd and roach diet were similar but that rudd have a greater dependence upon macrophytes and adult insects and a lesser dependence upon benthos.

III.4 Field Experiment

As described on page 51, the barrage failed to maintain a fish-free area within the lake. However, despite this failure, growth, diet and fecundity of the roach at the increased density during 1973 was studied together with the flora, zooplankton and zoobenthos. These data have been presented in Sections III.1, III.2A, III.2B and III.3B.

The ability to distinguish the introduced stock from the native stock in lake 7 during 1973 enabled comparisons of survival and growth of the two stocks to be made. This was achieved because the two stocks had characteristically different growth rates (before 1973) and as a consequence, different check patterns on their scales (see plates 2a and b, page 121).

A. Survival

From the estimate of numbers, age and size structure of the roach in lake 7 in November 1972 (see Table 19 and Figure 37) and the analysis of the size structure of the introduced stock (see Figure 38) an estimate of

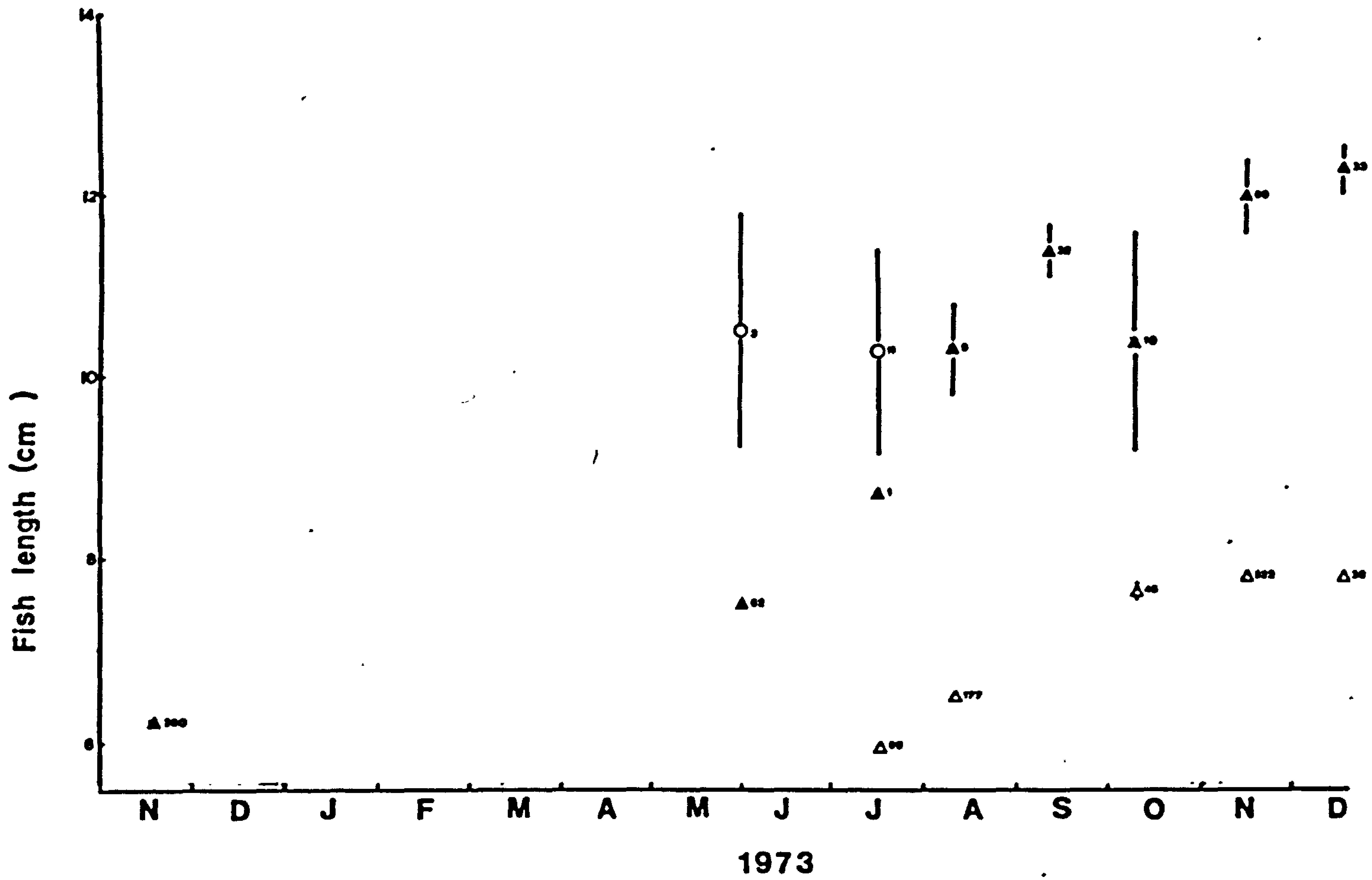


Figure 35 Growth of perch in Yateley 7

O mean and 95% confidence limits of 1971 year-class,
▲ mean and 95% confidence limits of 1972 year-class, and
Δ mean and 95% confidence limits of 1973 year-class

TABLE 34 Stomach contents of perch

Date of Sample	Year-class	Mean length (cm)	Numbers of Fish in Samples Containing Different Items								
			Daphnia longispina	Copepods	Chironomids	*Chaoborus* sp.	*Sialis* sp	Other Inverts.	Fish	Empty	Total
31.5.73	1+	7.5	12		1			1		1	15
	2+	10.5	2							1	3
29.6.73	0+	4.5	16								16
	1+	8.8	2		1			4		1	8
	3+	17.0	2								2
16.7.73	0+	5.9	4	11				3		2	20
	1+	8.7						1			1
	2+	10.3			2		6	3			11
9.8.73	0+	6.5		9			1				10
	1+	10.4			1		5	3			9
10.9.73	1+	11.4			3	5	13	5	5	1	32
	2+	15.6							1		1
8.10.73	0+	7.6		10							10
	1+	10.8			1	3	4	1		1	10
13.11.73	0+	7.7	4		2	1		1		2	10
	1+	11.7			4	4		1			9
											167

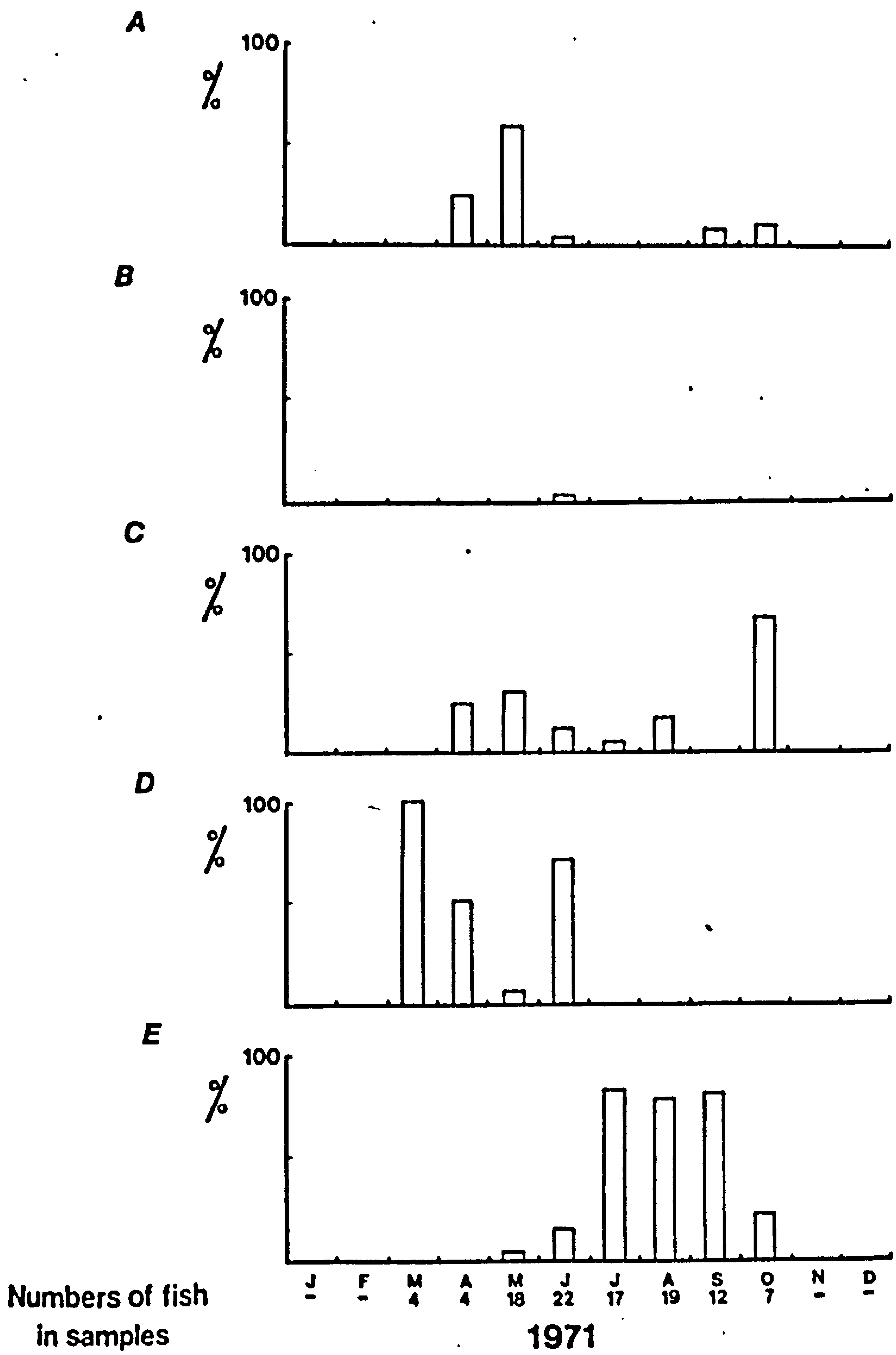
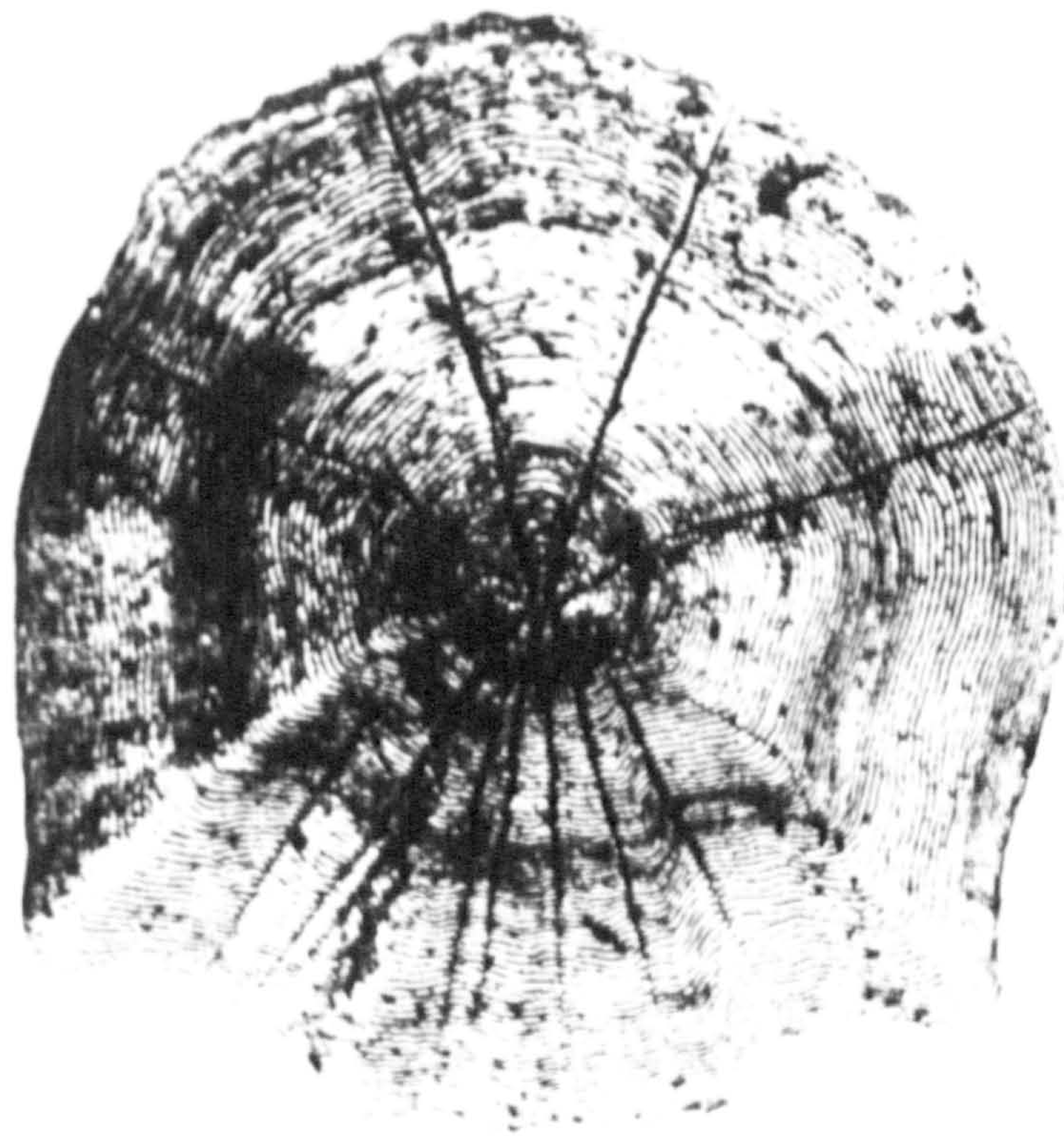
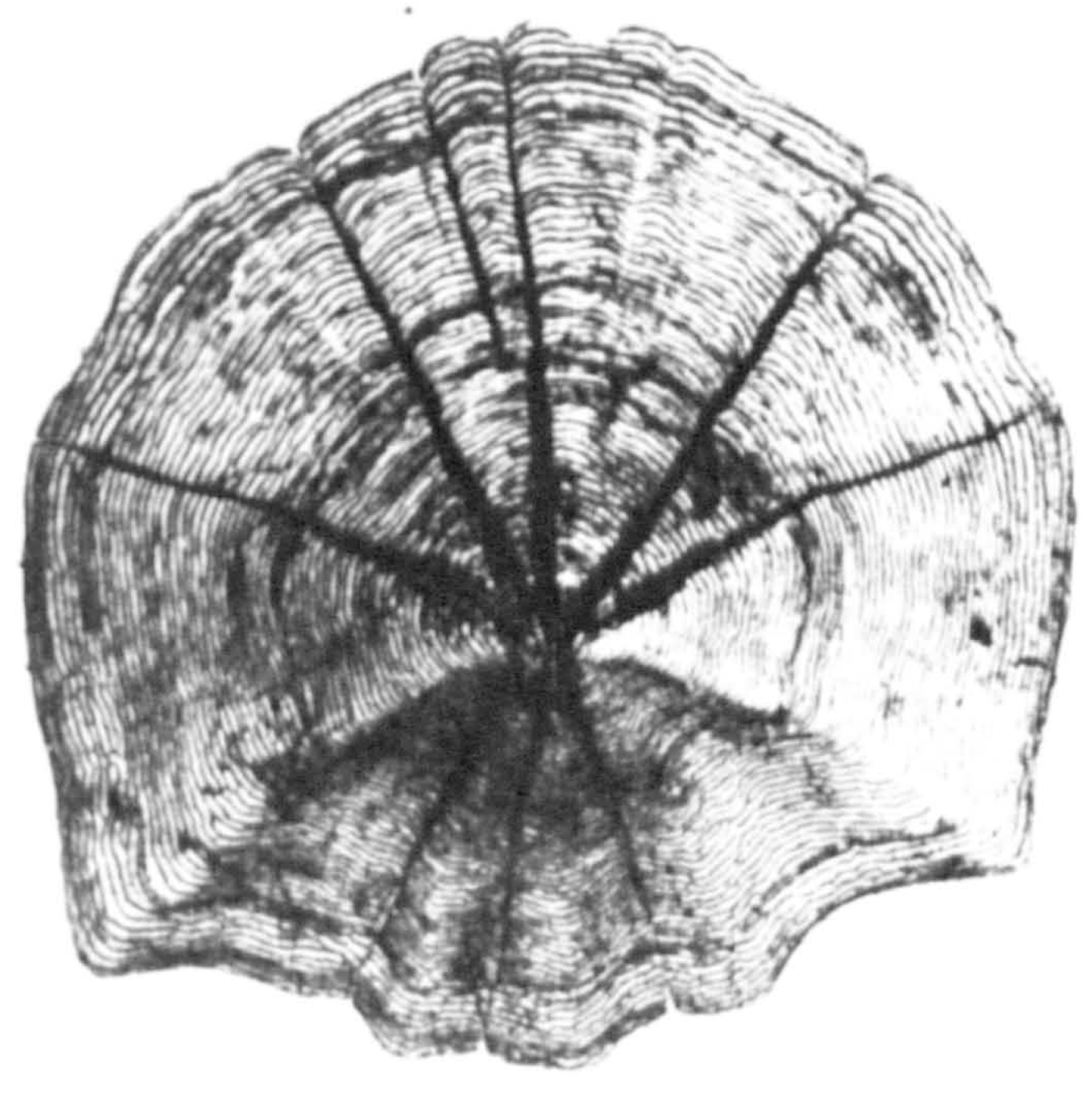


Figure 36 Diet of rudd in lake 7, by the percentages of fish in each sample with empty guts (A), containing detritus (B), insects (C), Daphnia longispina (D) and vegetation (E)



(a)



(b)

Plate 2 Typical scales from native (Yateley 7) and introduced (Farnborough 18b) roach taken on 29.6.73, (a) - 2+, 1971 year-class native fish, 12.1 cm and (b) - 3+, 1970 year-class introduced fish, 11.7 cm. Both scales x7.

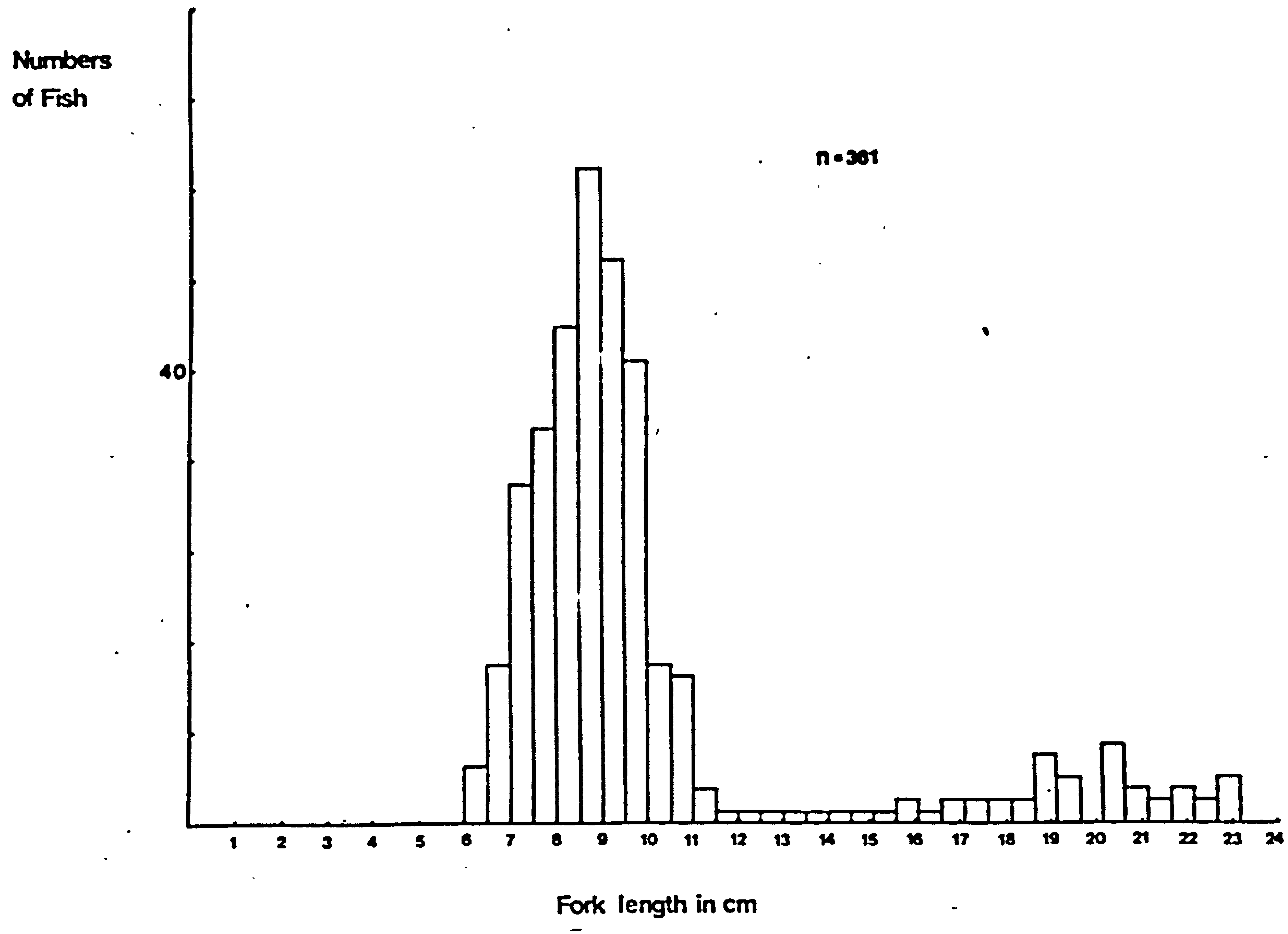


Figure 37 Length-frequency distribution of the unmarked roach caught during the second population estimate (November 1972)

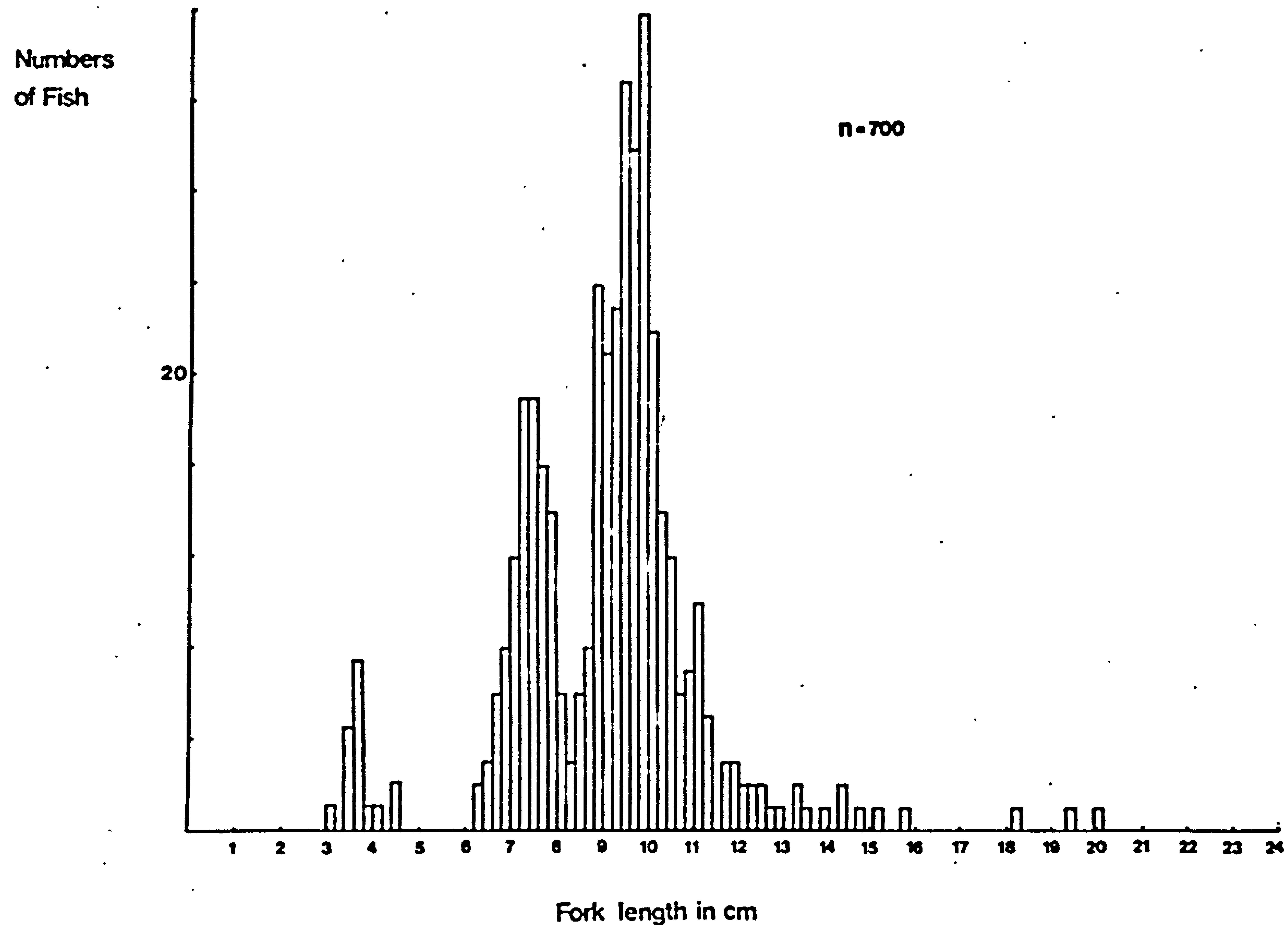


Figure 38 Length-frequency distribution of a sample of the roach introduced into lake 7 from lake 18b (taken in January 1973)

the relative percentages of the different year-classes in the lake in January 1973 was derived as :-

Native fish 1971 year-class	14.8%
Introduced fish 1970 year-class	58.6%
Introduced fish 1971 year-class	22.5%

This estimate assumes negligible mortality of the native stock between November 1972 and January 1973; and of the introduced stock, from transportation.

Table 35 compares the observed composition of the catches made in 1973 with those predicted from the above estimate. Only the smallest year-class, the introduced fish 1971 year-class was consistently under-represented in the catches. The numbers of 1971 year-class (native stock) and 1970 year-class (introduced stock) were consistently similar to those expected. The under-representation of the 1971 year-class introduced stock would account for the numbers of the other year-classes being slightly higher than expected. In fact the expected ratio of 1970 year-class (introduced fish) to 1971 year-class (native stock) remained consistently close to that expected (4:1) - see table 35.

B Growth

Despite the higher fish density (tables 19 and 24, pages 85 and 93) no change was observed in the growth of the native roach in lake 7 during 1973 (see figures 22 and 23). However, differences were observed when the growth of the native and introduced stocks were compared and when the growth of the introduced stock in lake 7 was compared to the previous growth achieved in its native water i.e. lake 18b (Farnborough).

The growth of the two stocks was compared by monitoring the mean lengths of the introduced 1970 year-class and the native 1971 year-class. The results are shown in Figure 39. The differences between samples taken in May and June were tested by 't' tests (see Table 36).

TABLE 35

Composition of large samples taken in 1973, comparing the numbers of native fish (1971 year class) with introduced fish (1970 and 1971 year classes).

From the 1972 population estimate and the analysis of age structure of the introduced fish the expected composition was:-

Native fish (1971 year-class) 14.8%; Introduced fish (1970 year-class) 58.7%;
Introduced fish (1971 year-class) 22.5%

Date of Sample	Total number of Roach in sample	Native stock 1971 year class		Introduced stock (from Farnbrough)			
				1970 year class		1971 year class	
		Expected	Observed	Expected	Observed	Expected	Observed
29. 6.73	86	12.7	16	50.4	58	19.4	7
16. 7.73	56	8.2	12	32.9	38	12.7	3
9. 8.73	77	11.4	10	45.2	57	17.4	5
10. 9.73	86	12.7	18	50.2	60	19.4	3
8.10.73	106	15.7	22	62.2	66	23.9	2
17.12.73	67	8.6	11	34.1	40	13.1	3

TABLE 36 Values for 't' comparing the mean lengths of the native fish (1971 year-class) with introduced fish (1970 year class).

Date sample taken	Fish lengths 1970 year-class	1971 year-class	t	p
16.5.73	10.1 ±0.35	8.9 ±0.5	4.1	$p>0.001$
29.6.73	11.92 ±0.2	11.49 ±0.48	2.3	$p<0.05>0.02$

Table 36 and figure 39 show how these two year-classes started (in May) with significantly different mean lengths but that the native fish grew faster and that by August the two year-classes had similar means. The length-frequency histograms (figures 40 to 46) also reflect the growth of the roach in the lake during 1973.

Because the population in 18b had been dramatically reduced (fish were also removed for other research), no comparison was made between the growth of the fish from 18b in lake 7 and that of those remaining in the lake.

Table 37 shows the 'age-for-length' estimate of the growth rate of roach in 18b based on the sample taken on 31.1.73; compared with this the increment of 4.1 cm achieved by the 1970 year-class, 18b fish in lake 7 was much greater than the average increment of 3.2 cm achieved in lake 18b.

TABLE 37 Growth-rate of roach in lake 18b from 'age-for-length' analyses of the sample taken on 31.1.73

Year Class	Average length (cm)	95% Confidence Limits	n	Increment (cm)
0+	3.8	0.2	13	3.8
1+	7.2	0.2	17	3.4
2+	9.6	0.2	62	2.4
3+	12.1	0.8	10	2.5
4+	15.1	2.5	2	3.0
5+	17.2	2.7	5	2.1
				$\bar{x}$ 3.2

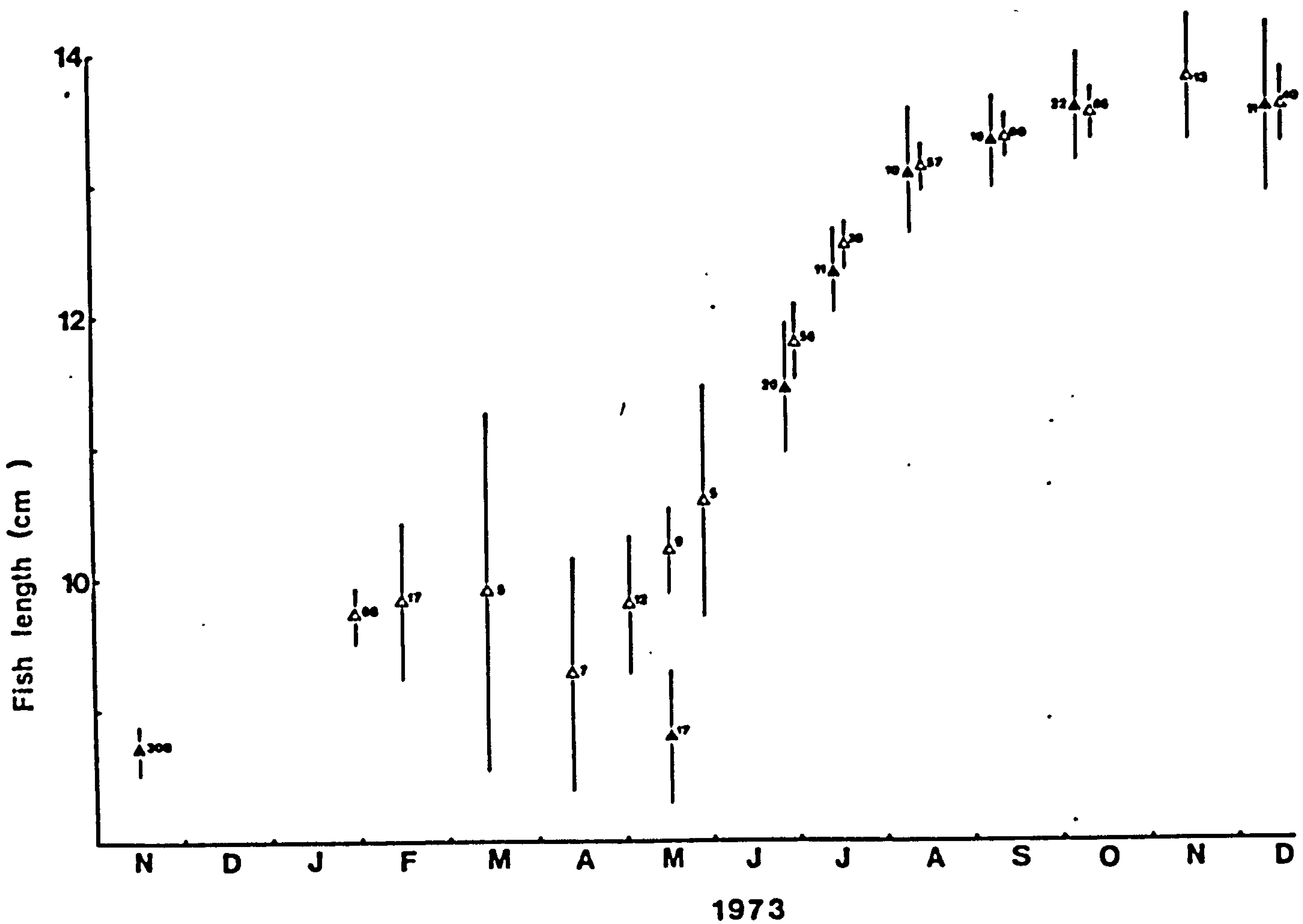


Figure 39 Mean lengths and 95% confidence limits of roach sampled from Yateley 7; ▲ - 1971 year-class - native stock, △ - 1970 year-class introduced from Farnborough 18b.

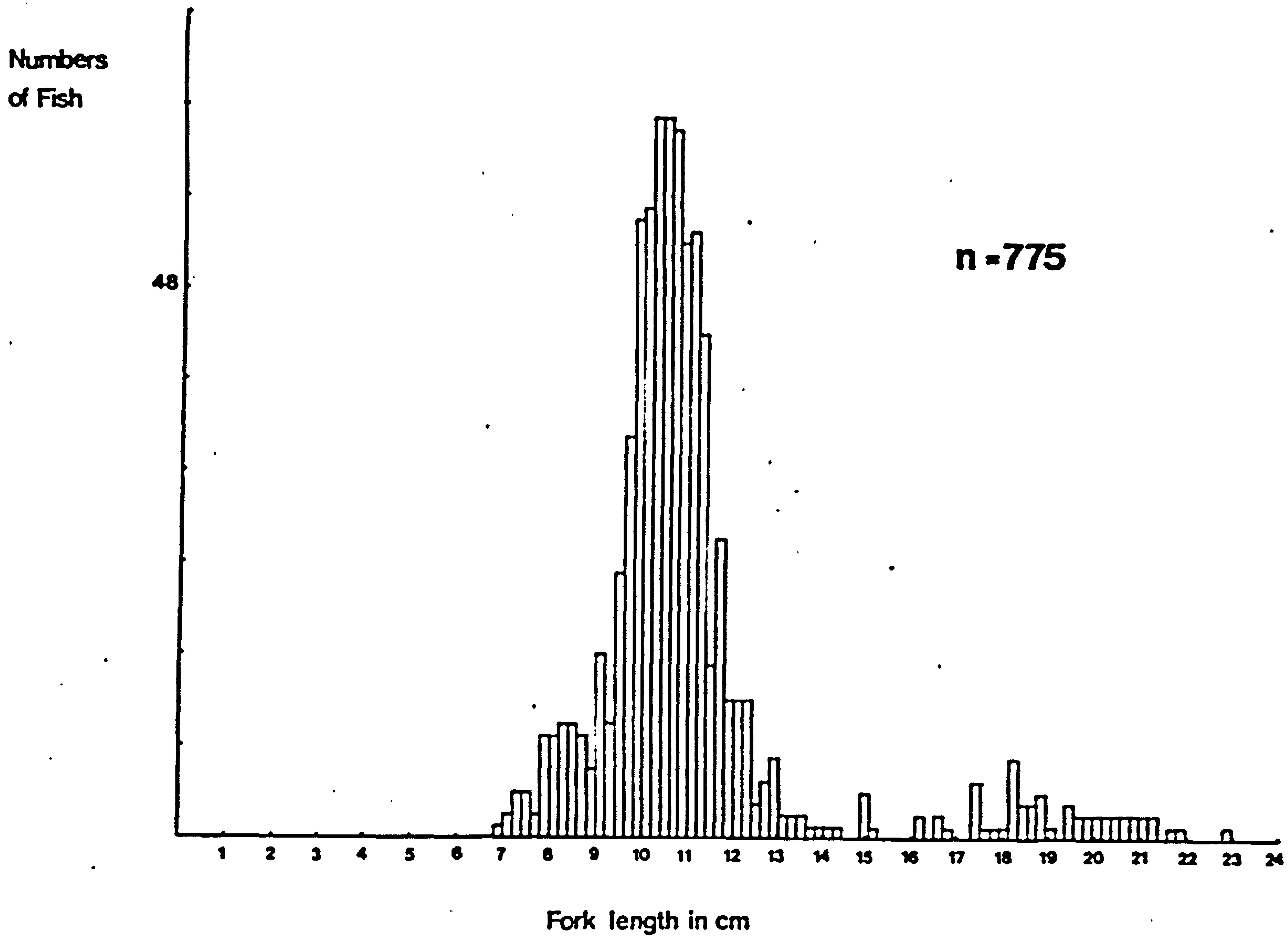


Figure 40 Length-frequency distribution of the roach caught in Yateley 7 on 31.5.73

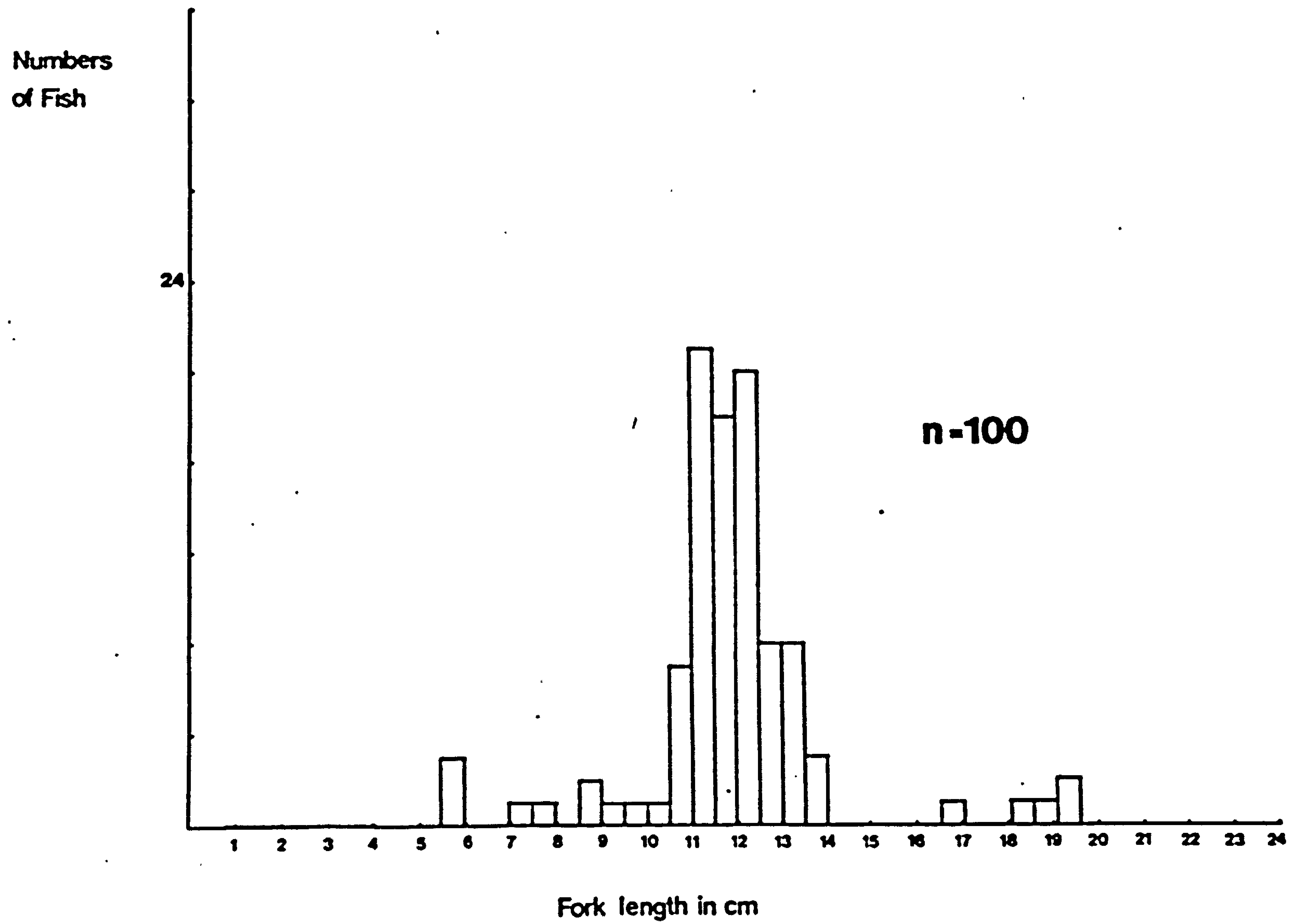


Figure 41 Length-frequency distribution of the roach caught in Yateley 7 on 29.6.73

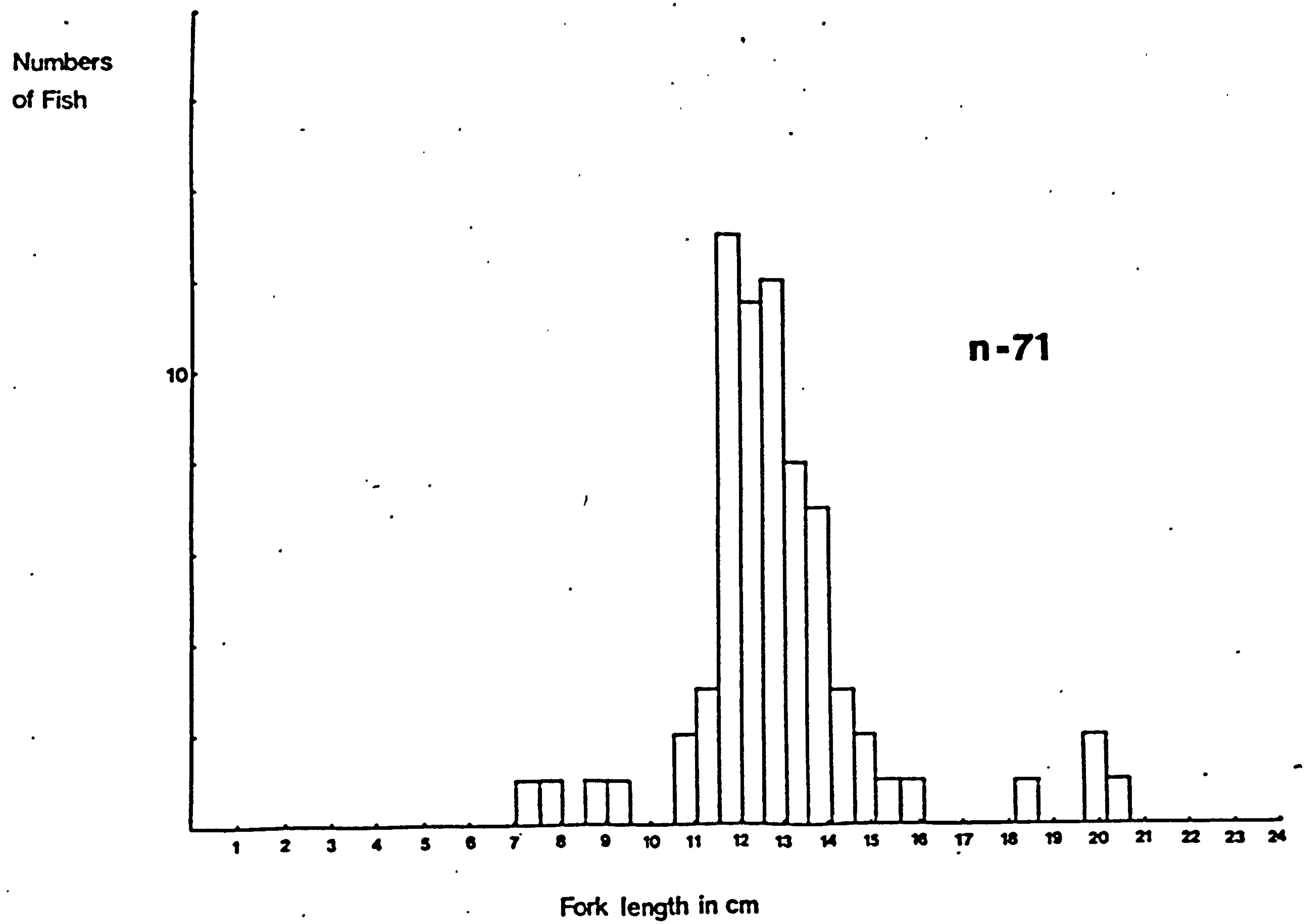


Figure 42 Length-frequency distribution of the roach caught in Yateley 7 on 16.7.73

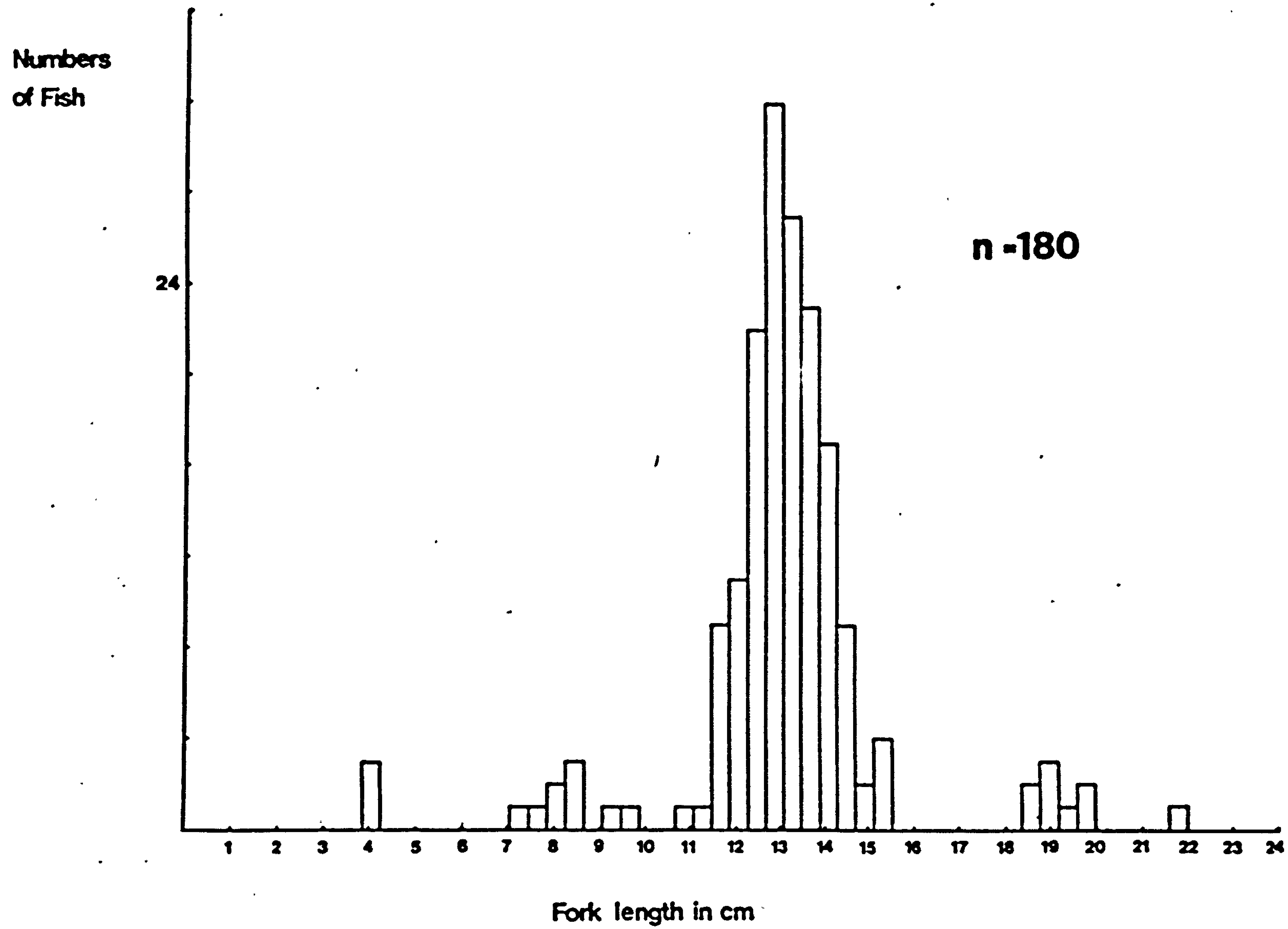


Figure 43 Length-frequency distribution of the roach caught in Yateley 7 on 9.8.73

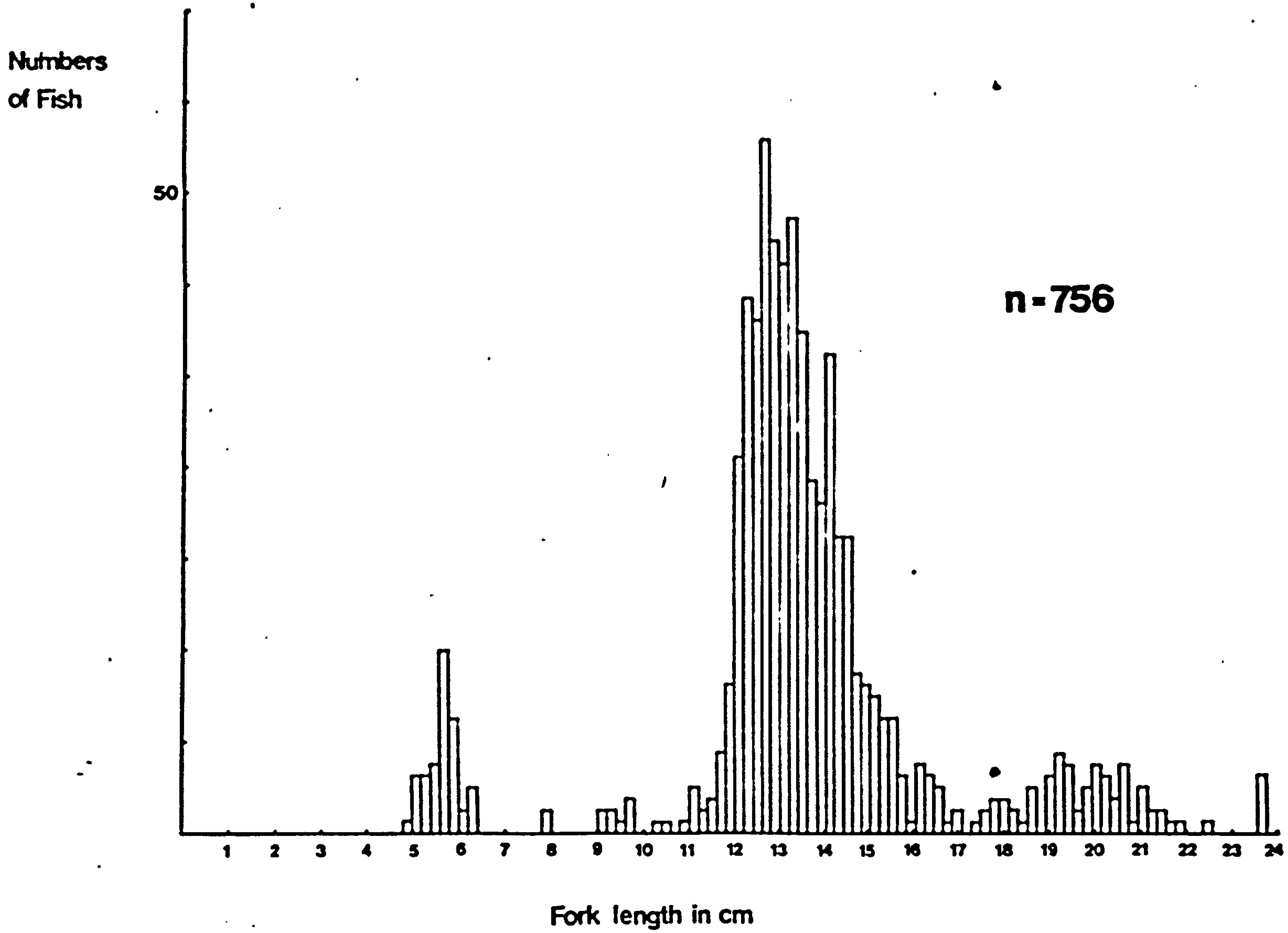


Figure 44 Length-frequency distribution of the roach caught in Yateley 7 on 10.9.73

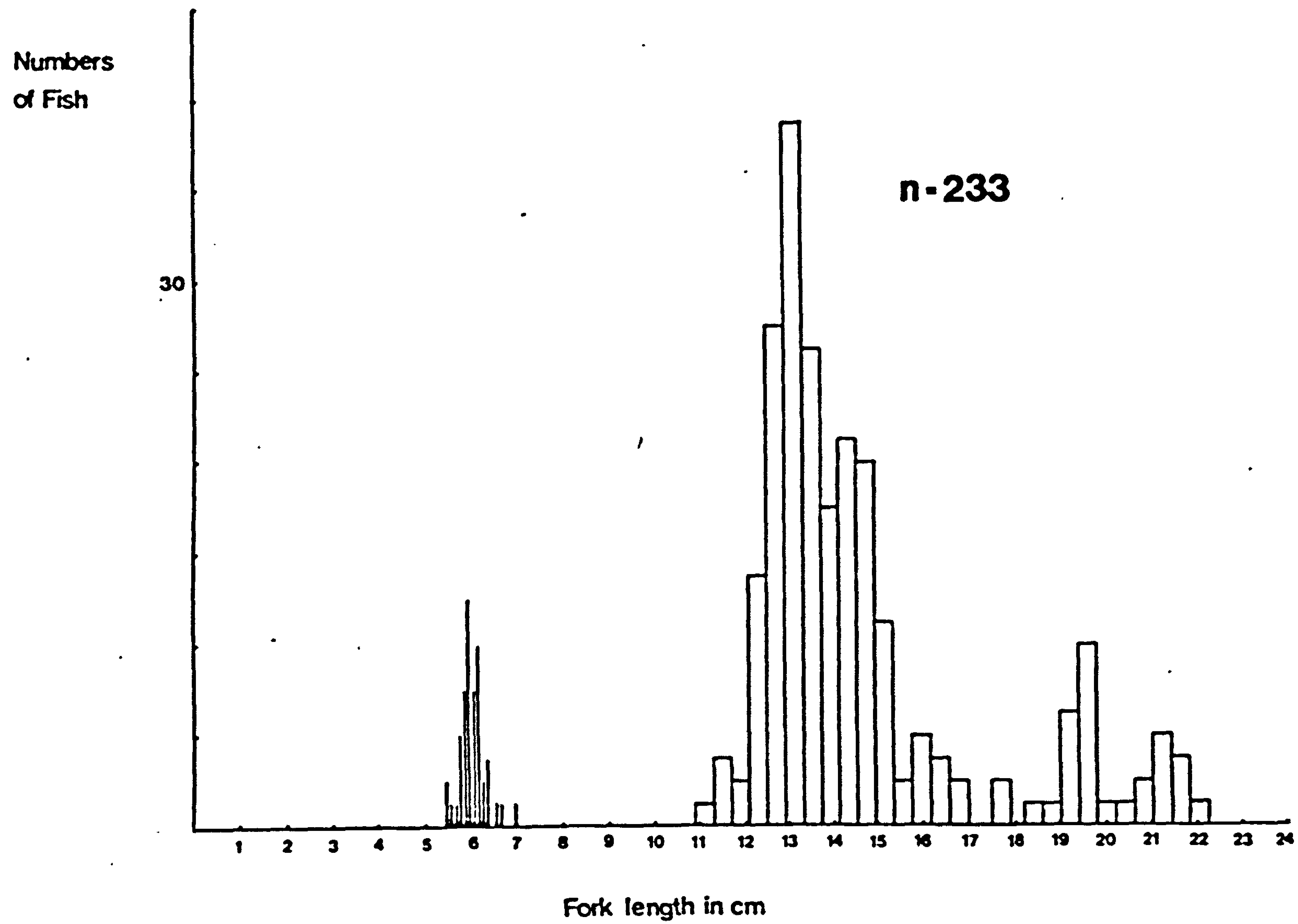


Figure 45 Length-frequency distribution for roach caught in Yateley 7 on 8.10.75

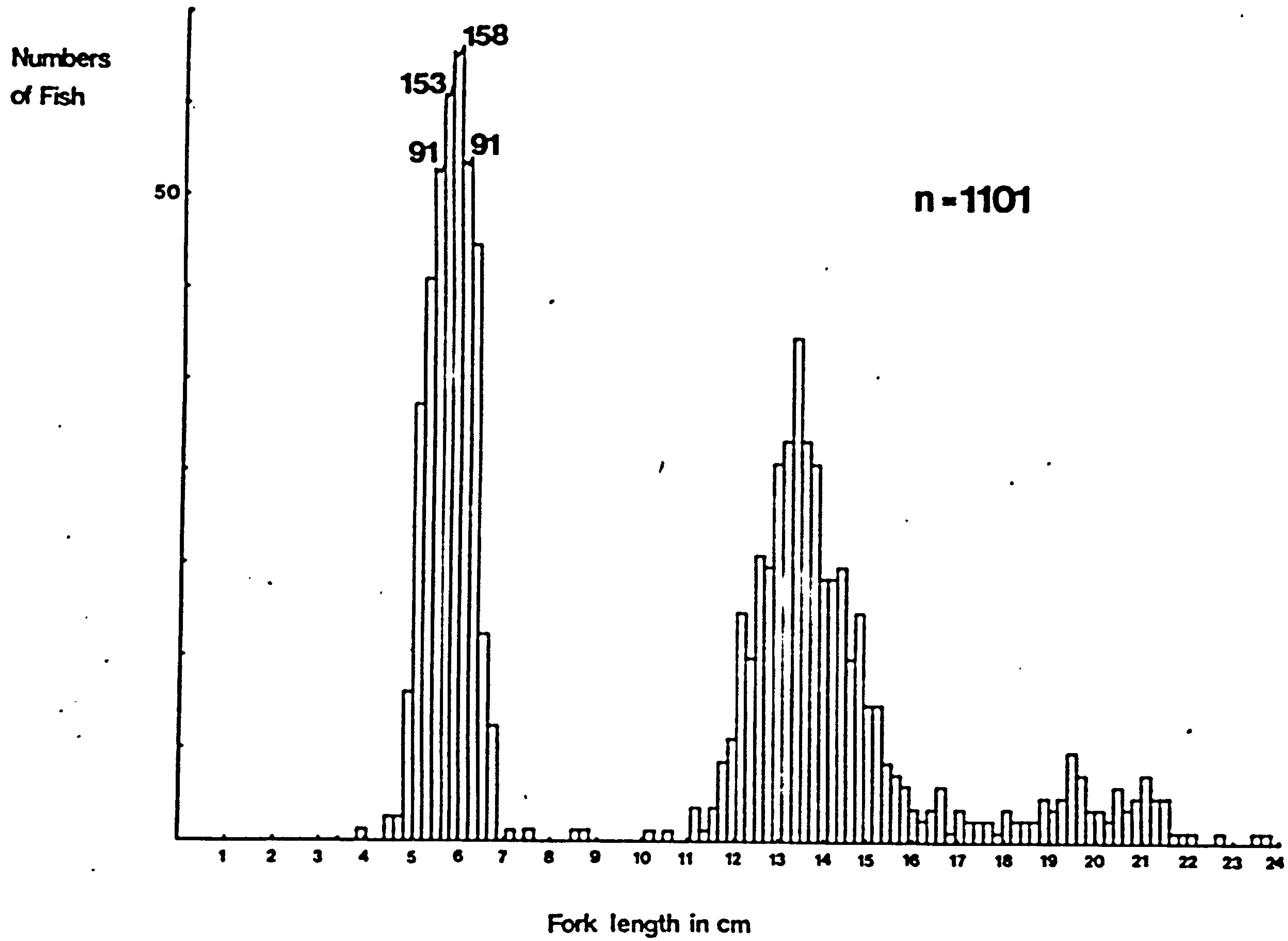


Figure 46 Length-frequency distribution of unmarked roach caught in Yateley 7 during the third population estimate (November 1973)

III.5 Feeding Experiments

Experiment 1

The mean wet weights of food in the guts of the roach are shown in Figure 47. This shows that after 9 hours (in batch 4) the amount of food in the first two regions of the gut had fallen by over 50%. This was true in regions 3 and 4 after 15 hours. Regions 5 and 6 showed little change in weight of contents per unit length throughout the 24 hrs.

Experiment 2

The results of the five trials (Table 38) give some indication of the time an unnatural diet (Calliphora) takes to pass through the alimentary canal of the roach.

TABLE 38 Time taken for maggots to pass through the alimentary canal of the roach (passage time)

Trial Number	Time and date of feeding	Time and date maggot skins first seen in faeces	Temp-erature	'Passage' time
1	8.1.74, 17.00 hrs	9.1.74, 12.30 hrs	12°C	19½ hrs
2	14.1.74, 12.00 hrs	15.1.74, 09.20 hrs	12°C	21 hrs 20 mins
3	21.1.74, 12.00 hrs	22.1.74, 08.30 hrs	12°C	20½ hrs
4	28.1.74, 18.00 hrs	29.1.74, 10.30 hrs	16°C	16½ hrs
5	31.1.74, 18.30 hrs	1.2.74, 08.30 hrs	16°C	14 hrs

Experiment 3

This experiment was designed to provide information on the rate of passage of food (cladocera) through the roach's gut, the rate of consumption of Daphnia by roach, the selectivity of this feeding and the influence of further feeding on the rate of passage of the initial meal.

Figure 48 shows the gut contents (wet weight) of the different batches of fish killed after different intervals following a single meal. Batches 3b and 4b were given further food and contained less Daphnia than batches 3 and 4, suggesting that further feeding increased the rate of passage of the first meal. Batch 3 shows that faeces were produced after 8 hours.

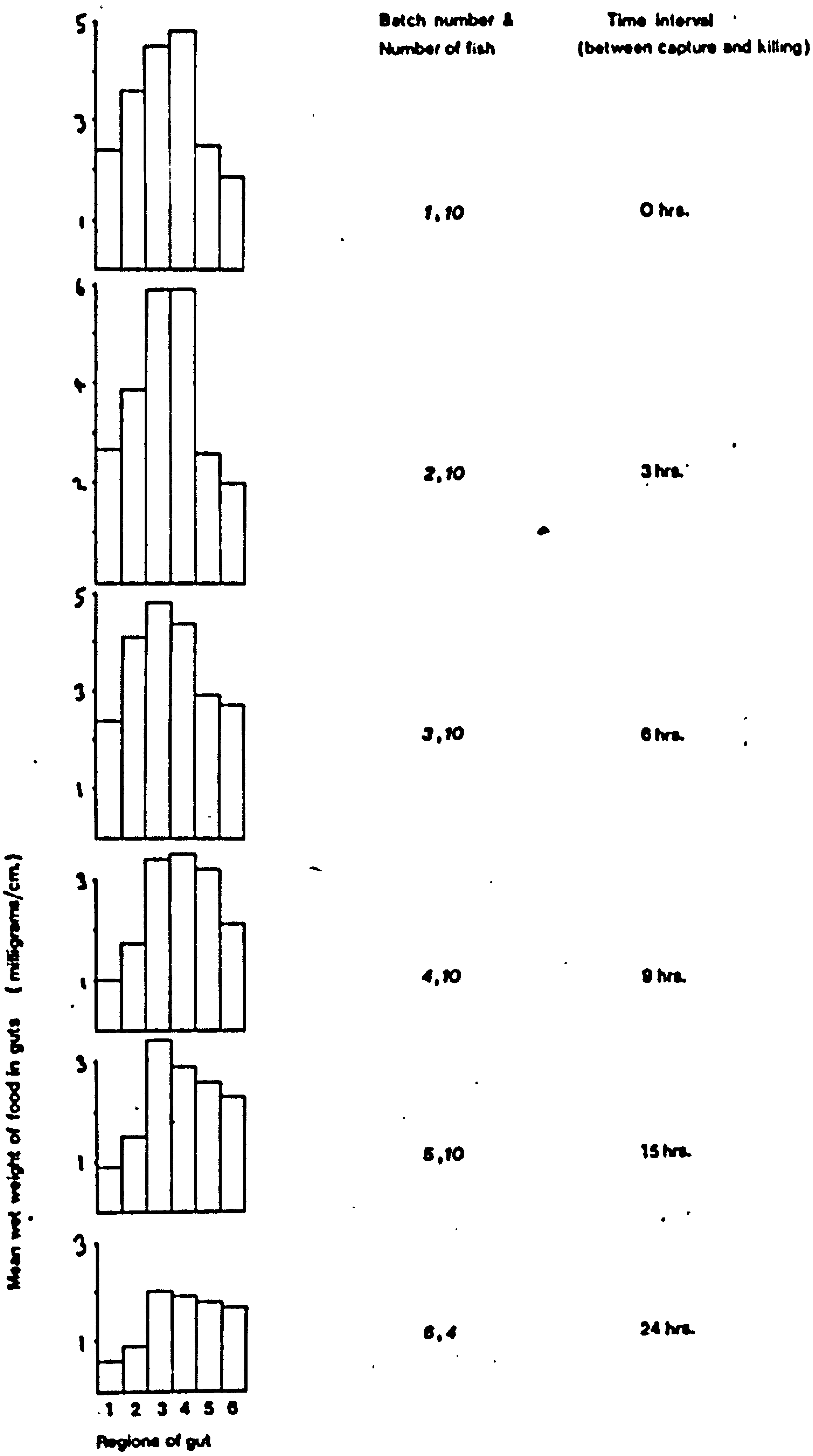


Figure 47 Distribution of food (by weight) in the guts of the roach killed in experiment 1.

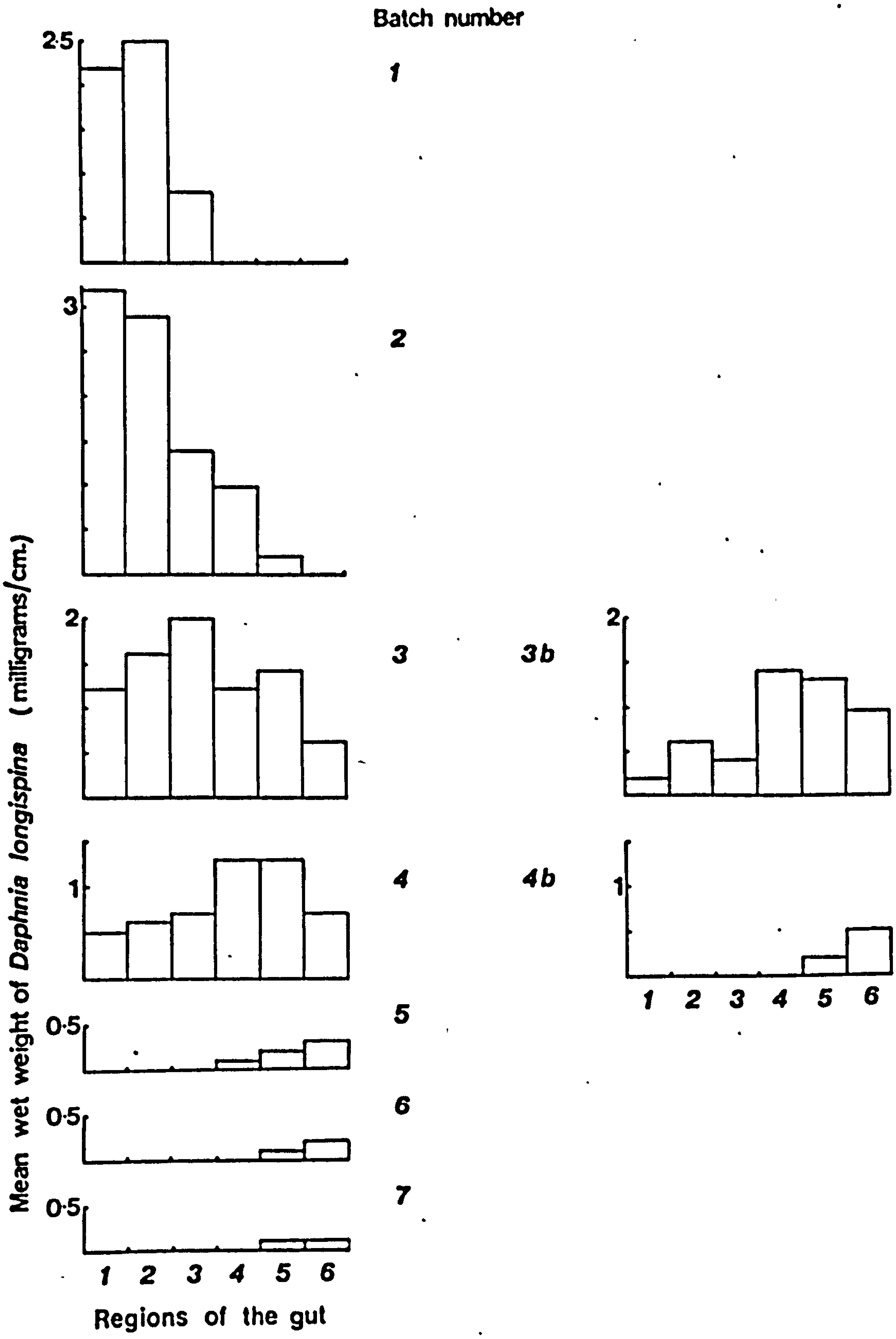


Figure 48 Distribution of food (Daphnia) in the guts of the roach killed in experiment 3. The fish were given the opportunity to feed on Daphnia from -90 min to 0 hrs and killed at intervals of -60 mins (1), 0 hrs (2), 4 hrs (3), 8 hrs (4), 12 hrs (5), 16 hrs (6) and 24 hrs (7). The batches in series b were removed from the experimental tank at 0 hrs and given further meals of trout pellets.

Figure 49 presents the results as the mean wet weights of D. longispina found in the roach guts in the different batches.

Figure 50 shows the length-frequency distributions of Daphnia taken from the experimental tank before the roach started to feed and after fifteen and a further thirty minutes feeding respectively. This shows that the fish fed on the larger Cladocera (>0.75 mm). Because very few entire Cladocera were found in the roach-guts, this observation was not confirmed by measuring the lengths of the Daphnia in the fish guts.

Table 39 shows the estimates of the numbers of D. longispina in the experimental tank at the beginning of the experiment and after the fish had been feeding for 30 and 90 minutes. Since the fish were at a density of 0·25/litre their rate of consumption must have been 125/minute during the first 30 minutes and 19/minute during the next 60 minutes.

TABLE 39 Extimates of numbers of D. longispina in the experimental tank at the beginning of Experiment 3

Time interval	Nos. of D. longispina/litre
0	3160
30 minutes	2220
90 minutes	1930

Estimates of numbers and rate of consumption of Daphnia can also be made from the weights found in the guts of roach in the first two batches. Figure 50 shows that the average weight found in these batches was approximately 100 milligrams and 130 milligrams after 30 minutes and 90 minutes respectively, from the introduction of the Daphnia. Assuming (from Figure 50) the approximate average length of Daphnia longispina consumed by the fish was 1.4 mm, the estimated rate of feeding would be 40.4/minute during the first 30 minutes and 6/minute during the subsequent 60 minutes.

Differences in these two estimates are most likely due to errors in the abundance estimates and to the assumed average size (and therefore weight) being incorrect.

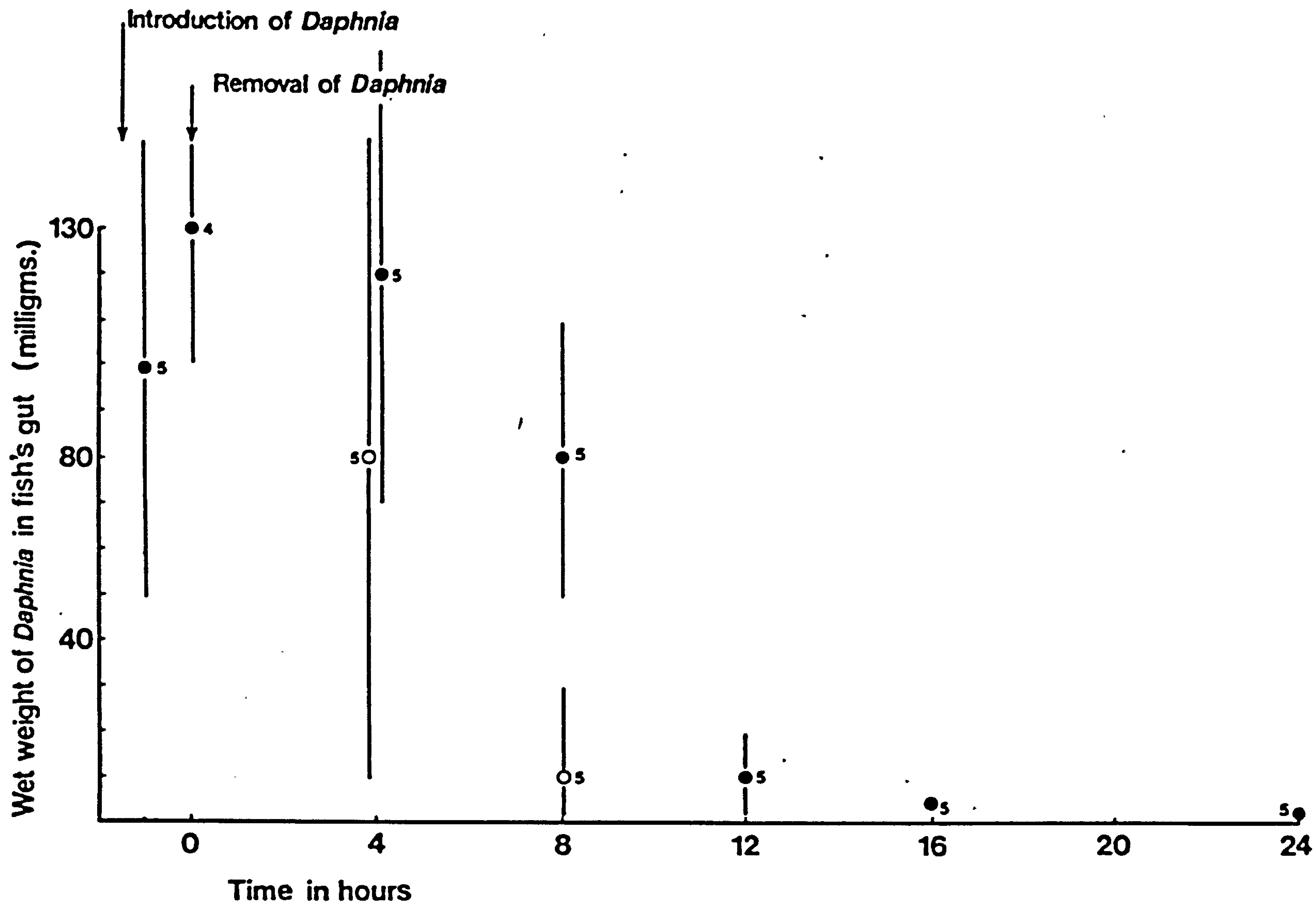


Figure 49 Mean wet weight and 95% confidence limits of *Daphnia longispina* in the guts of roach killed during experiment three; ● - batches 1-7, ○ series b batches (see figure 48 and text).

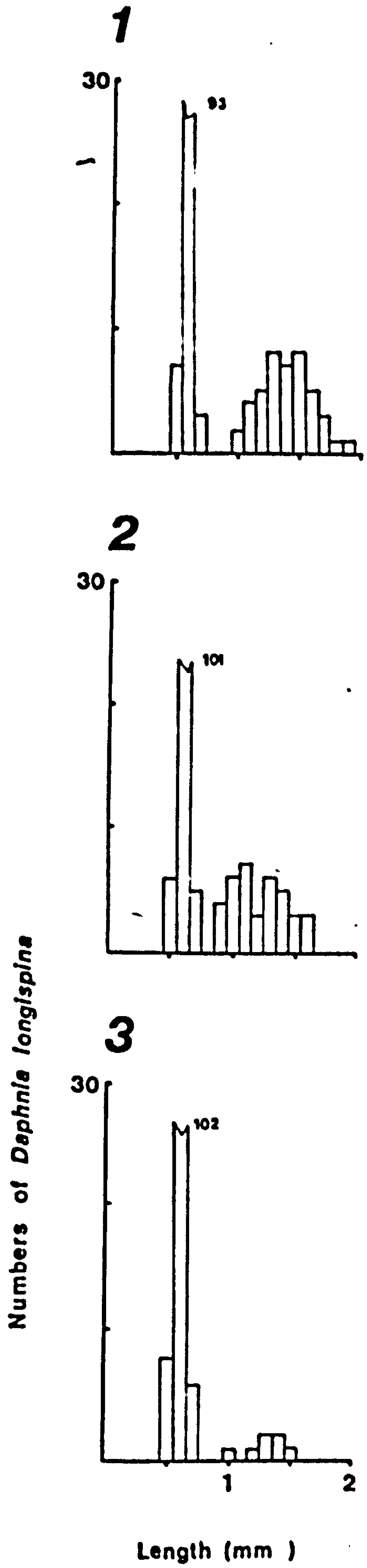


Figure 50 Length-frequency distribution of Daphnia longispina in the experimental chamber during experiment 3.
1 - before any fish predation, 2 - after 15 minutes fish predation and 3 after 45 minutes fish predation.

III.6 Consumption of D. longispina by the Roach

Estimates have been made of the quantities of *Daphnia longispina* consumed by the roach in the lake. These are based on the results of feeding activity studies, together with values for fish and *Daphnia* biomass. Figures 26 and 27 (page 104) show the percentages of fish, within each sample, feeding upon *Daphnia* and the weights of *Daphnia* found in the roach guts. These weights are expressed as percentages of the fish's somatic weight and used as an estimate of daily ration, could be converted, using a fish biomass figure, to give a consumption estimate for the whole population.

To calculate roach biomass during 1973 it has been assumed that mortality rates were constant. Thus the biomass dropped until May as mortalities reduced numbers. By June growth was more than compensating for loss of biomass by mortality and the biomass rose.

Table 40 shows the estimates of consumption of *D. longispina* by roach. The figures for 20.2.73 show that the rate of the fish predation was increased dramatically by the introduction of approximately 41.3 kgs of roach in January. These figures indicate that the roach can consume a significant percentage of the daphnid population. It is likely that the consumption was underestimated because the daily ration was probably greater than the average gut contents (see next page). Selective predation would also increase the impact of the fish's predation (see page 169).

The estimates of roach biomass in Table 40 exclude the 1972 and 1973 year-classes of fish. The 1972 year-class was virtually absent and the 1973 year-class, in June 1973, was too small to feed on *D. longispina* (see Figure 22). Perch were present in the lake and fed upon *Daphnia* (see Table 34). Table 24 shows that perch at their most abundant, formed only 20% of the total perch/roach biomass (in November 1972) and since little data were collected on the perch diet, their additional consumption

TABLE 40 Estimates of consumption of D. longispina by the roach

	Biomass of Daphnia (10 x dry weight) gm /m^2 From table 11.	Biomass of roach gm /m^2	% of Roach in samples Feeding on Daphnia From Fig. 26.	Average wet weight of Daphnia in guts of samples as % of fish somatic weight From Fig. 27.	Consumption	
					gm /m^2	% of biomass of Daphnia
8.1.73	5.54	2.9	94.5	0.5	0.014	0.25
20.2.73	0.81	11.7	27.9	0.7	0.023	2.8
25.3.73	0.08	11.0	6.0	0.7	0.005	5.8
9.4.73	0.06	No fish feeding on D. longispina in sample				
3.5.73	18.5	10.2 (3.5.73 – 31.5.73)	33.0	0.8	0.026	0.15
16.5.73	0.67		25.5	0.9	0.02	3.5
31.5.73	0.62		71.0	1.4	0.1	16.0
12.6.73	3.85	13.2	51.0	1.7	0.094	2.4
29.6.73	0.12	13.2	66.0	1.4	0.12	100.0

of *Daphnia* was not included in Table 40.

The feeding experiments showed that food may remain from 8 to over 24 hrs in roach guts and thus the contents of guts in roach samples may represent more than a day's feeding or only a fraction of the daily ration (see figures 47 and 48 and Table 38). However, experiment 3 demonstrated that the majority of a meal of *D. longispina* might pass through the gut in 12 hours or even less if more food is consumed (see Figures 48 and 49). Thus gut contents may sometimes represent only one third to one half of the fish's daily ration and therefore the estimates for consumption of *Daphnia* by the roach population in lake 7 presented in Table 40 may well underestimate daily rations. The third laboratory feeding experiment (see page 136) does demonstrate that roach can consume *Daphnia* at a rate sufficient to achieve the consumption rates made for roach in the lake.

CHAPTER IV

Discussion

As mentioned in the introduction, little work has been carried out on gravel-pit lakes; similarly the fish populations of small lakes have rarely been studied in Europe. Consequently, there are few suitable data available with which to compare the results of this study, and consequently, comparisons have been made with N. American data. The implications of the differences in fish species and species diversity found in N. American waters are recognized.

The study was planned on two main fronts. Firstly, to gain basic biological information on gravel-pit lakes and secondly to obtain data on the factors which influence fish populations. Much of the information gathered in this study and by City of London Polytechnic personnel, demonstrates the unstable nature of gravel-pit lakes - this is further discussed on page 173 . Chemical, algological, macrophyte and invertebrate data quoted in this thesis all provide evidence of this instability that is not easily explained. These results together with those concerning the fish fauna, the relationships between the fish and zooplankton and fish growth and population density are discussed, together with the implications of the results on the management of gravel-pit lakes as fisheries.

IV.1 The Water Chemistry and Flora

Table 2 (page 29) illustrates the very different nutrient levels in adjacent lakes at Yateley. Although the lakes were excavated from the same seam of gravel, the passage of water between the lakes is limited; not only are there bands of clay in river gravels which restrict the flow of ground water, but the deposition of silt in the lakes affords a degree of self-sealing. The limited movement of ground water was illustrated by water-level differences of over 1 metre in adjacent lakes (e.g. lakes 3A and 1). Quantifying the rate of movement of ground water and the degree of isolation of any one lake was not possible.

Various factors could have been responsible for the differing nutrient regimes in the different lakes. Drainage ditches enter some lakes and springs reputedly enter others, thus the nutrient inputs into the lakes may vary. A biological activity, e.g. the levels of primary production, may also be responsible for differences in nutrient levels between lakes.

Only the silica levels showed regular annual patterns; these were believed to be linked to the growth of benthic and planktonic diatoms (F. Goodridge, personal communication).

As table 2 shows, lake 7 was one of the chemically richer lakes at Yateley but there was no increase in nutrient levels after the increase in the density of the fish stock in January 1973. This conflicts with the results of Hrbacek _et al._ (1961), Hillbricht-Ilkowska (1964), Grygierek _et al._ (1966) and Kajak _et al._ (1972). However, in contrast with their studies above, the total fish biomass in lake 7 was only slightly increased (see Table 19).

The studies by A.M. Powell, B.R. Godfrey and F. Goodridge on the phytoplankton of the Yateley pits have found that the lakes lack obvious annual patterns other than a tendency for blue-green algae to appear in late summer. (F. Goodridge, personal communication). The chlorophyll '_a_' estimates indicate that although the standing crops of phytoplankton did not fluctuate over extreme ranges as for example in Esthwaite (Talling, 1968) they were unstable and unpredictable; for example No. 9, which typically had the lowest chlorophyll '_a_' levels, occasionally had the highest.

The observations on the submerged macrophytes in lake 7 (see page 28) and less detailed observations on other lakes, showed that the distributions and abundance of these plants changed considerably with time. The repeated seining which took place in lake 7 could have affected aquatic macrophytes in two ways:-

(i) Disturbance of the fine sediments could have increased the turbidity and therefore reduced light penetration thus influencing the growth of plants.

(ii) Occasionally the seine net swept up large quantities of submerged macrophytes. Thus repeated seining in this small lake is likely to have reduced the standing crops of these plants.

However, the macrophyte surveys in lake 7 (figures 7-11) indicate that in 1973, despite the intensive seining, there was a dramatic increase in the abundance of Potamogeton species. There is no obvious explanation for this increase in 7 or for similar increases observed at Yateley and elsewhere in other years. Possibly periods of improved light penetration allowed the colonization of the deeper water by plants. A possible alternative explanation is that such increases are linked to the release of nutrients or trace elements which might have recycling periods of several years.

As part of a lake community, macrophytes are important in all waters. In smaller lakes, such as gravel-pits, they may play an important part in the uptake and release of nutrients. They also provide habitats for other plants and animals and contribute to the accumulation of silt and organic debris. In gravel-pit lakes used for recreation, they may fulfil additional roles:-

(i) Some forms e.g. Typha latifolia and Phragmites communis are important in stabilizing banks against wave action which can cause erosion.

(ii) The leaves and fruits of many emergent and submerged forms are important as food for wild fowl (Harrison, 1971).

(iii) In fisheries, large stands of macrophytes can create access problems for anglers while in one gravel-pit lake summer growths of Elodea canadensis caused problems for water skiers.

(iv) Macrophytes are important to fish since they can provide a direct source of food, a reservoir for potential food, spawning sites, a sanctuary for fish from predators and a sanctuary for large invertebrates which may prey upon small fish.

(v) Macrophytes can cause fish kills if large growths die off and deoxygenate the water.

For these reasons a better understanding of the factors regulating macrophyte growth and distribution in gravel-pit lakes is required.

IV/2 The Invertebrate Fauna

Because, on each occasion, only one, cumulative, zooplankton sample was taken from the lake, rather than a series of replicates, it was not possible to calculate confidence limits for the estimates of abundance. However, there was good evidence to support the assumption that the sampling method gave reliable estimates of the zooplankton populations. This evidence was:

(1) The consistent estimates obtained from replicates, which, on one occasion, were kept separate (see Table 5, page 34).

(2) The regular annual patterns especially for D. longispina revealed by the sampling technique.

(3) The similarities, especially for D. longispina, between these annual patterns in lakes 7 and 8 suggested that they were genuine (i.e. not a product of sampling) and therefore that the sampling method was either reliable or consistently biased.

(4) The absence of freak high- or low-abundance estimates for either lake on any one occasion.

(5) The similarity between the estimates of D. longispina biomass in lake 7 (based upon abundance estimates) and those of other workers (Lewkowicz 1971; M. Cook, personal communication).

(6) Similarities between the annual patterns found for D. longispina abundance and those found for similar species by other workers.

It is also to be noted that Ravera (1969) and Duncan (1975) monitored zooplankton biomass or numbers using single and cumulated replicates on the grounds that differences between replicates were insignificant compared with differences between samples.

Hall (1964) studying Daphnia galeata, Ravera (1969) with D. hyalina, Angino and Armitage (1973) with D. pulex and Duncan (1975) with D. magna.

D. pulex and D. hyalina, found annual patterns in abundance similar to those found for D. longispina in lakes 7 and 8. Hall, Duncan and this study recorded the presence of large, highly fecund individuals preceding the late spring increase in numbers. However, the use of 4% formalin to fix plankton samples in this study caused the shedding of eggs and young and prevented any determination of daphnid fecundity. Since the commencement of this study, Haney and Hall (1973) have recommended the use of sucrose (40 gm/l) to prevent egg-shedding.

Ingle, Banta and Wood (1937) demonstrated experimentally that improved food supply increased growth-rate and fecundity and hence recruitment and total numbers of D. longispina. Angino and Armitage's (1973) study of a field population of D. ambigua attempted, statistically, to correlate total numbers, clutch size and the numbers of egg-bearing females with 27 different variables. Tests were carried out using simultaneous data and lag times of one, two, three and four weeks. They found that calcium concentration in the water had a higher correlation with the cladoceran parameters than did available food. The latter was estimated by chlorophyll 'a' levels. Although recognized as a standard and reliable way of estimating standing crops of algae (Vollenweider, 1969) chlorophyll 'a' estimates may give false impressions of the food available to Cladocera: Burns (1968, 1969) demonstrated that Cladocera are size selective in their feeding; thus large species of algae may be responsible for high chlorophyll 'a' levels but be too big for Cladocera to consume. A. Duncan (personal communication) considers small flagellates to be very important as food for daphnids but that because of their size and fragility they may be poorly represented by chlorophyll 'a' estimations following certain sampling and treatment techniques. An alternative explanation is that a non-plant food, e.g. suspended detritus, was important to the Cladocera (Duncan, 1975). There was no obvious relationship between abundance of zooplankton and chlorophyll 'a' levels in lakes 7 and 8.

The annual cycle in D. longispina populations in lakes 7 and 8 resulted in lows in August/September. Such declines must have been caused by changes in their rates of recruitment and/or mortality. A change from parthenogenesis to sexual reproduction and the production of ephippia might explain these annual declines in the populations. However, although seen, ephippia were never found in plankton samples in numbers sufficient to explain the population declines.

As seen in Figures 26, 27 and 36 (pages 104, 105 and 121) and Table 34 (page 120), D. longispina was a common component in the fish's diet. The population declines could have been the result of reduced recruitment aggravated by fish predation. The differences observed in numbers and size-structure of D. longispina in the littoral and open-water regions indicate that the littoral region of the lakes may support a reservoir of daphnids.

The implications of fish predation on zooplankton are further discussed in Section IV.4.

The results of the trials with the benthos sampler indicated that although it was not as effective at sampling the in-benthos (e.g. chironomid larvae and oligochaeta) as was a corer, greater numbers of on-benthos animals were sampled. Thus the sampler would seem to be a promising device for one-man sampling of animals such as gammarids, insect nymphs and coroxids on hard substrates. Possibly its efficiency could be improved by using a reliable self-priming motor-pump and by filtering the sample from the water infront of the pump.

Samples taken from lake 7 and other pits indicate the presence of diverse invertebrate fauna with many species of Diptera, Hemiptera, Coleoptera, Odonata, Ephemeroptera and Trichoptera and with less common genera such as Ranatra, Nepa and Ilyocoris.* The mollusc survey (A.M. Powell and A. South in preparation) revealed that a total of 20 different species were found in the 45 gravel-pit lakes examined. The highest number of species in any one lake was 11.

* see appendix, page xi.

Gravel-pit lakes usually occur in river valleys and are close to existing lakes, therefore colonization by many invertebrates is rapid. At a Yateley site where gravel was still being extracted, chironomid larvae, Corixa sp. and Notonecta sp. were found in the shallow pools of the otherwise dry pit. It is also likely that the activities of anglers and yachtsmen will lead to the accidental and intentional introduction of various plants and animals.

There are three possible explanations for the existence of the negative correlations found between the numbers of Chaoborus and other dipteran larvae within the replicate samples taken by the Ekman grab. These are:-

(1) Substrate preference. Although the soft silt appeared homogeneous it may have been that Chaoborus preferred one area while other dipteran larvae preferred another. Such preference may have been based upon such factors as particle size, oxygen concentration or the distribution of epilithic algae.

(2) Spatial inhibition, ie high numbers of Chaoborus in one area inhibiting chironomids and ceratopogonids from settling in the same area or vice versa.

(3) Predation. Chaoborus is a carnivore; its facultative predation upon other components of the zoobenthos might explain the negative correlations.

Chaoborus is said to be a benthic invertebrate that enters the plankton at night to prey upon zooplankton (Goldspink and Scott, 1971). However, La Row (1970) demonstrated that the change from benthos to plankton is not always a simple diurnal rhythm but can be initiated by low oxygen concentration. Thus in gravel-pit lakes such as Yateley 7, where there is no great depletion in oxygen levels, Chaoborus may remain as a benthis carnivore. Consequently the negative correlations may be explained by direct predation. Oligochaeta have been found in the guts of Chaoborus by Popchenko (1971).

Of the above interpretations it would seem unlikely that the phenomenon is explained by competition for space since dipteran larvae are known to live at extremely high densities (Mundie, 1957 and Hynes 1963). In addition, although negative correlations occurred for replicates with high counts, they were also found where numbers were quite low. There was no way of determining whether substrate selectivity was the responsible factor.

IV.3 The Fish Fauna

The finding that multiple-marked recaptures, especially when marked by panjet, gave rise to lower estimates (Table 18) was not expected. The trend, shown in Table 18, can be explained by either the fish having a vulnerability to recapture that increases with the number of times they are caught and marked or the single-marked fish having a higher mortality rate than the multiple-marked fish. The latter possibility seems more unlikely and the former was accepted. It was also considered that single-marked fish behaved more like unmarked fish than did multiple-marked fish. The estimates used were all based on single-marked recaptures. The results in Table 18 suggest that the panjet mark has a greater effect on fish than fin-clips although the data were not suitable to compare statistically the effects of the different marks on similar size classes of the same species. It is possible that the effects of being caught and handled were as significant as the effects of the marks, therefore fish were given multiple marks simply to enable the fish caught more than once to be recognized and discounted.

Although confidence limits were not found for the estimates, those given can be considered as reliable since they were usually based upon the average of several estimates, with a relatively narrow range (see table 19 page 85) and because they were based on estimates where the percentages of recaptures were high - as is shown in Table 21, page 87 (Ricker, 1958).

Table 21 shows that a greater percentage of large fish were marked, as compared with small fish. Although more small fish, especially those aged 0+, died from handling and marking than large fish, the mortalities observed were subtracted from the totals of marked fish; therefore the continued mortalities of smaller fish, after their return to the lake, must have been very high to account for their low percentages of recapture. A more likely explanation of the apparent size-dependent catchability is simply that larger fish were more easily caught; this may be partly explained by the possibility of small fish having a greater tendency to escape the seine net through the inevitable small tears.

The trend of declining catch-per-effort during the course of the estimates (shown in Tables 22 and 23) is puzzling. Hunter and Wisby (1964) demonstrated that carp in tanks could escape capture in nets and their ability to escape improved with experience and when they were in shoals. Table 22 shows that catch-per-effort did not decline during any one day thus it was not general disturbance during the day's fishing which modified the behaviour of the fish in the lake and made them harder to catch. Apart from a longer time lag (12-15 hours) the only difference from the last seines on one day and the first seines of the next, was that marked fish had been returned to the lake after the last seine of each day. Presumably it must have been a factor linked with the return of these marked fish that led to the reduced catch per effort on the succeeding days. Possibly the marked fish, mixing with the other fish, modified their behaviour in a way not associated with deliberate net-avoidance that made them harder to catch. Or, in the manner of Hunter and Wisby, the marked fish may have mixed with the unmarked fish and, with their earlier experience of being caught, tended to avoid recapture themselves and led to the increase in escape rate of unmarked fish. The catches did suggest that marked fish mixed with unmarked fish.

Little data are available to compare the estimates of numbers and biomass in 7. The results of Gee (1976) and this study, do show that the biomass of fish in gravel-pit lakes vary considerably (<10 to >300 kg/h). In the USA many fish populations in lakes and ponds have been studied primarily because of the importance of such waters as fisheries. Jenkins (1975) reviewed biomass estimates in 73 reservoirs. Though large (average size was 6250 hectares), the reservoirs were relatively shallow - average depth was 8.2 metres. The estimates were made by applying rotenone to coves and bays (Hayne et al., 1968; Hall, 1974), and the average fish biomass found was 201.6 kg /hectare, the maximum 998.8 kg / hectare. Over 50 species occurred in more than 20 of the reservoirs. Jenkins suggested that a ratio of 4:3:1 existed between bottom feeders, planktitrophs and predators. Hackney (1975) found the biomass of an artificial population of largemouth bass (Micropteris salmoides Lacépède), bluegills (Lepomis macrochirus Rafinesque), redear sunfish (Lepomis microlophis Rafinesque) and green sunfish (Lepomis cyanellus Rafinesque) established ten years earlier was 306.1 kg /hectare. These results tend to be higher than those for the gravel-pit lakes; the greater species diversity of fish communities in the USA may be a contributory factor.

Compared to the estimates quoted above and those of other workers in the UK (e.g. Mill's estimate of 416 kg /hectare for roach over 4 years old in Humbie Reservoir) the fish biomasses in gravel-pit lakes tended to be low. This must be the product of high mortality rates and/or poor recruitment.

Mortalities can be caused by predation, disease or starvation. The good growth rates and condition of the fish in lake 7 makes starvation an unlikely explanation of mortalities of fish other than fry (see page 170). The chief predators in lake 7 were the perch, pike and great crested grebe (Podiceps cristatus L.). In one lake at Twyford, the fish biomass consisted mainly of pike (A.S. Gee, personal communication). The pike were in very poor condition and small invertebrates were found in their guts. In lake 7 the initial high number of pike (19 in November 1971) must have been responsible for considerable mortalities on the fish <20 cm in length (their likely prey). Perch did feed on 0+ fish in their second year of life but were not common in lake 7 during the course of the study. However, in 1973, when pike were effectively missing from the lake and perch were still few in number, high mortality rates still occurred.

In the summer of 1973 one adult and two immature great crested grebe stayed on the lake for at least three weeks. During one period of observation the adult was seen to catch and feed to her young many roach between 10 and 15 cm in length.

During the course of the study a bacterial disease was affecting many perch populations in S.E. England. Anglers and bailiffs at Yateley reported that catches of perch and sightings of large shoals of fish over 10 cm in length declined in the late 1960s. In all the years of the study the lesions believed to be symptomatic of the disease, were observed on perch of all year-classes caught. In August 1973 approximately 10% of the roach caught had dermal lesions. None of the fish caught in September was similarly affected; apart from a few fish killed by population estimation procedures, only a few fish, mostly small perch, were ever found dead in the lake. It seems unlikely therefore that disease caused sudden high fish mortalities, especially among larger, more conspicuous fish. Although population estimates caused mortalities and sampling reduced numbers, these activities could not have been responsible for the low estimates made early in the study in 1971. The effects of sampling were also not enough to prevent the production of the strong 1971 year-class.

Figure 22 shows the almost total absence of the 1972 roach year-class. Only two of the roach caught in 1972 and 1973 were assigned to that year-class despite the presence of healthy mature roach in lake 7 in the spring of 1972. This was thought to be because of poor spawning (see page 109). The absence of year-classes and the presence of poor and very strong year-classes have been reported for many fish species (Nikolsky, 1966) including the roach (Hellawell, 1972; Banks, 1970 and Mann 1973) and has been found in other gravel-pit lakes (Gee, 1976 and M.P. Cook, personal communication). The parasite *Ligula intestinalis* has been implicated with poor roach recruitment and declining populations (Wilson, 1971). Over 90% of the roach taken from Yateley 3a in 1971 were found to be infected with *Ligula* but a strong 0+ year-class was produced in that lake in 1971. In lake 7, where no sample of roach was ever taken in which Ligula infected more than 10% of the fish, it is reasonable to discount Ligula as a factor influencing recruitment.

It would seem that the low biomass of fish, other than tench, in lake 7 was the product of high mortalities, primarily from the predation by pike and grebe. Avian predation has been shown to have a considerable effect on fish survival (Hyamana et al., 1960). The low biomass of roach and perch must have been aggravated by the occasional failure of the roach to spawn and by 'bacterial perch disease' affecting perch survival. The direct and indirect effects of sampling and population estimates added to these 'natural' causes. The decline of the unsampled 1970 year-class of rudd (fish that were not included in the routine samples) from an estimated 325 to 11 (97%) between November 1971 and November 1972 illustrates the levels of mortality occurring in the lake. The consistent level of the tench population, as reflected by the estimates in 1972 and 1973, demonstrates the more stable nature of the population of these larger fish (average length was approximately 35 cm), which were presumably less vulnerable to predation.

The estimates for tench in lake 7 were consistent in 1972 and 1973 and have stayed consistent in 1974, 1975 and 1976 (M.P. Cook, personal communication). The low estimate of 1971 cannot be explained. Although the few tench examined could not be accurately aged, examination of operculae indicated that the fish of average lengths were between 4 and 6 years old. Thus the increase in tench population, indicated by the 1972 estimate, could not be explained by recruitment within the lake. Since over 50 tench were caught in one seine in 1972, the 1971 estimate was either a chance underestimate or numerous large tench were surreptitiously introduced into the lake shortly after November 1971.

The structure of the tench population was similar to that in other gravel-pit lakes (Gee, 1976) and those studied by other workers (Kennedy and Fitzmaurice, 1969). In several lakes at Yateley, tench were seen spawning in mid-June, and in lake 7 and other lakes 0+ tench were caught in hand nets in weedy littoral areas, indicating that successful spawning was common. However, very few tench between 5 and 15 cm were ever caught. Assuming this size group was not just avoiding capture, it appears that the tench suffered a high mortality in their first few years of life.

It would seem that the stability of the tench population is the result of high mortality of small fish resulting in poor recruitment to the population of large fish which suffer a low mortality rate. The tench is a very popular fish with anglers and at Yateley, was the most sought-after species in summer. A greater understanding of the growth-rate, longevity and population dynamics of tench and the relationship between fish density and angler success would enable tench fisheries to be better managed. In this context the Floy anchor tag has proved an effective method of individually marking small-scaled species such as trout (Carline and Brynaldson, 1972) perch (Stobo, 1972) and pike (Koshinsky, 1972). In preliminary laboratory trials the tag was found to be successful for tench.

Few of the studies of still water populations of roach in Britain have included investigations of the fish's diets. Banks (1970) sampled roach from Rostherne Mere throughout the year. However, he found that the grinding of food by the pharyngeal teeth made it difficult to identify gut contents. He reported molluscs, macrophytes and algae as the most important food, with Asellus and Gammarus commonly occurring and Trichoptera larvae, Sialis lutaria and large Cyclops sp. occasionally seen.

These results are very different from those found for lake 7 where, as Figures 26 and 27 show, Daphnia longispina was the most important item for several months each year. Hartley (1947) found daphnids to be a very important item in roach diet for the fish taken from the only lake in his study. However, he dismissed these results as being biased by the small size of the fish in the sample. Hartley concluded that zooplankton is only eaten by roach in their first two years of life. As Figure 29, (page 108) shows this was not true for roach in Yateley 7.

Aldoori (1971) found Daphnia in the guts of roach taken from Duddingstone loch. Stangenberg (1958) did not report Daphnia as important in the diet of roach in either Lake Wigry or Lake Suchar Wielki although Ceriodaphnia were important in the diet of roach in Suchar Wielki. The results of Stangenberg and many others are difficult to interpret since they are based upon single or few samples of fish. In waters where the abundance of potential food organisms such as Daphnia can change considerably, fish dietary studies are inconclusive unless samples of fish are taken throughout the year.

River populations do not necessarily have the same range of food from which to select as do standing water populations, thus the results of dietary studies in rivers are not necessarily relevant to this study. Hartley (1947) found macrophytes, molluscs, detritus and to a lesser extent, invertebrates were important in the roach's diet. These results have been confirmed by other workers (Healy, 1956; Williams 1965; Britton 1968; Hellawell, 1972; Cragg-Hine, 1964 and Mann, 1973).

Hellawell, Hartley, Williams and Mann found that samples contained more fish with empty guts in winter than in summer. Hellawell found that the volume of gut contents declined in winter. Hartley described some roach populations as undergoing a winter fast. In Yateley 7 the roach caught in summer and autumn had significantly more food in their guts than those caught in the winter (see figure 27, page 105).

Kemp (1962), Volodin (1963), Mackay and Mann (1965), Williams (1965), Aldoori (1971) and Lyagina (1973) all relate the quantitative and qualitative nature of roach diet to growth rate. Aldoori and Volodin thought that improvements of this kind lead to increased growth rates while Britton, Mackay and Mann and Williams considered the poor qualitative nature of the diet of the roach they studied was the cause of their poor rate of growth. In these latter roach studies detritus formed a major component of the diet. Detritus also formed a large part of the diet in Lake 7 yet the roach in 7 had a good rate of growth. If, as is suggested by Britton and others, roach can obtain little of nutritional value from detritus the other items of diet of lake 7's fish must be largely responsible for their good rate of growth. The most important other item was D. longispina and it would seem that the 2-3 month period of feeding on Daphnia was very important for the roach in lake 7.

While many studies (Stagenberg, 1956 and Banks, 1970) have shown the common occurrence of aquatic insects and Malacostraca in roach diets, such animals, though common in lake 7, were rarely found in roach guts. The roach in lake 7 appeared to feed mainly in the open water (on D. longispina) and on the bottom in deep water (on detritus, epilithic algae and dipteran larvae). As was seen from the perch gut contents (Table 34), a varied littoral fauna was available to fish, but these larger invertebrates were rarely found in the guts of lake 7 roach.

Hartley (1947) found that rudd consumed a similar diet to roach but depended more upon adult diptera and macrophytes. The limited amount of data on the diet of rudd in lake 7 supported these findings. Hartley concluded that the prognathous jaw of the rudd is adapted to aid feeding on the surface, e.g. adult diptera taken as emerging, egg-laying or spent individuals.

Unlike some species e.g. the mullets (Family Mugilidae) and the grass carp (Ctenopharyngodon idella), the rudd (and roach) do not possess any adaptations in their digestive tract to deal with plant food other than their pharyngeal teeth and slightly increased gut length (Al-Hussaini, 1949). Although Banks reported problems in identifying gut contents because of grinding by these teeth, this has not always been reported elsewhere. Roach and rudd taken from Yateley 7 occasionally had fragile items such as Daphnia in an entire state in their guts and the plant material always appeared to be little affected by pharyngeal grinding or digestion. The absence of any adaptations and the undigested appearance casts considerable doubt on the direct value of plant material as food for rudd and roach.

Perch in lakes have been found to feed mainly upon zooplankton in their first year gradually changing to larger invertebrates and a fish diet (Allen, 1935; Healy, 1954 and Banks, 1970). Fish consumption commences in the perch's second year when they feed upon 0+ perch and cyprinids. A similar pattern was seen for the perch in lake 7. Unlike the roach and rudd in that lake the perch, especially 0+ fish, continued to feed upon zooplankton after the decline of Daphnia, and fed upon copepods. Copepods were rarely found in the guts of roach and rudd over one year old. Also unlike roach, the perch exploited the littoral invertebrate fauna; corixids, larval Sialis lutaria, Asellus aquaticus and Cragonyx pseudogracilis were all commonly found in their guts.

Banks (1970) reported 1+ perch feeding on 0+ fish including perch. Similar findings were made in lake 7. Among the perch examined, a 12.3 cm fish contained a 5.7 cm 0+ perch, a 12.1 cm fish contained two 5.5 cm roach, and a 15.6 cm, 2+ fish contained a 7.5 cm 1+ perch. As suggested on page 154 , had older perch been more common in lake 7 they might have had a considerable influence on the survival of 0+ fish.

The monitoring of individual year-classes confirmed the reliability of ageing roach from scales. The occurrence of two checks in one year has been found in cyprinid fish e.g. Linfield (1974) in roach and Hofstede (1974a) with rudd. This did not happen with the Yateley 7 fish.

Jones (1953) and Holcik (1967a) interpreted conspicuous checks on roach scales as erosional marks resulting from spawning i.e. as spawning checks. Such marks were only occasionally seen on lake 7 roach scales and then on the outer margins of scales from older fish. The timing of the appearance of checks did not assist in determining the cause since both spawning and the onset of growth occurred at the same time as the appearance of new checks on scales (see Figures 22 and 32). However, the presence of typical checks on the mature roach in 1972, when very few roach spawned, supports the argument that check formation is associated with growth rather than spawning. The presence of normal checks on the scales of immature fish and of roach castrated by the parasite Ligula intestinalis does not support the possibility that checks are the product of physiological changes associated with gonad maturation. So-called 'spawning' checks with erosion marks were more common on the scales from the slower-growing fish in Farnborough 18b. Check resulting from growth after periods of no-growth have been demonstrated experimentally by Bilton and Robins (1972a and 1972b) and Bilton (1974) on several species of pacific salmon (Oncorhynchus sp.). The same explanation was used to account for the formation of false or winter checks on roach scales (Linfield 1974). All this evidence is taken to confirm that checks are a growth phenomenon and that poor growth perhaps combined with the effects of spawning cause exaggerated checks with erosion marks.

It will be recalled that the roach growth rates were estimated by conducting length-for-age analyses on pooled winter catches and by following the growth of individual year-classes. If the roach had grown at a different rate before the onset of the study, e.g. slower, then the large fish caught at the beginning of the study would have been much older than the large fish caught at the end of the study. The presence of these slower-growing, older fish, would have influenced the age-for-length growth-rate estimates. That made from the first winter catch (1970/71) would have been different from that made from the last winter catch (1973/74) and also from growth-rate estimates derived from following individual year-classes. The similarity of all growth-rate estimates (See Figures 23 and 24, page 100) suggest that growth-rate has remained unchanged during the course of the study and was probably the same in the years immediately prior to the commencement of the work.

As Figure 25 (page 102) shows, the growth of roach can be very variable; many studies have shown a negative correlation between fish growth and population density (Alm, 1946; Kemp, 1962; Hall, Cooper and Werner, 1970; Aldoori, 1971 and Gee, 1976). Since the population density in Yateley 7 was relatively low (see page 85) a better than average growth rate may be anticipated. It was surprising that a change in roach growth rate did not occur in 1973 after the biomass of roach in the lake had been artificially increased over fourfold. The results of Gee (1976) may explain this. He found a negative relationship between total fish biomass and growth rate in a range of gravel-pit lakes that was independent of species composition. Although the roach biomass in lake 7 was increased by over 400%, the large biomass of tench in the lake reduced the overall increase, due to the addition of roach, to only 50%. Gee's results suggest that a dramatic decrease in fish growth-rates including that of the roach, would not be expected from such a moderate increase in total fish biomass. This is further discussed on pages 165 and 166.

It is difficult to relate growth of natural populations to the quantitative and qualitative nature of their diet (see pages 158 and 159). Estimations of total gut contents (Figure 27) suggest that more food is consumed in the summer months. The interpretation of daily ration from gut contents is complicated by various factors (see page 20)including the dependence of the fish's metabolism on temperature. Experiment 2 (see page 136)indicated that increased temperature influenced the rate of passage of food through the digestive tract. This rate was also increased by repeated meals (experiment 3, page 136).

The correlation between fish growth rate and temperature was demonstrated in a natural population by Le Cren (1958) who showed that the strength and size of 0+ perch year-class in Windermere correlated with degree days above 14°C and experimentally on brown trout by Elliott (1975). Other aspects of fish metabolism have been shown to be closely dependent upon temperature e.g. gonad development (Huisman, 1974) and antibody production (Bisset, 1948). It is therefore possible that because of the fish's basic metabolism, growth is unlikely to occur below a certain species-specific temperature whatever the qualitative or quantitative nature of the diet.

This hypothesis is supported by observations that thermal pollution extends growing seasons (W. Larimore, personal communication and Boytsov,

1971) while the presence of abundant food supply only improves growth-rate during the typical season i.e. it does not extend the season (Hofstede, 1974a). Roach in lake 7 grew mainly between June and September (see Figure 22); reference to Figure 4, which shows temperature profiles in lake 7, suggests that a critical temperature for roach growth lies between 10-15°C.

The June-to-September growth period for roach in lake 7 was similar to that found for other populations e.g. lake 4 at Yateley (Gee) and the river Stour (Mann). In the River Thames, Williams (1965) did report a longer growing season (April to October) for roach.

The small amount of information gathered on the growth of other species in lake 7 supports the conclusions reached for the roach, i.e. that the fish in lake 7 had better than average growth-rates. 0+ perch were seen as 1-2 cm fry in mid-May in lake 7 (and other lakes at Yateley) indicating earlier spawning and a longer growing season for perch compared to roach.

The annual increment of 0+ perch of between 6 and 8 cm was better than that observed by Banks (1970), Healy (1954), Alm (1946), Williams (1965) and Le Cren (1958), on natural populations. Alm demonstrated that at very low population densities perch could achieve annual increments greater than 6 cm.

Length-fecundity regressions were estimated in an attempt to find a sensitive measure of fish's living conditions. The results in Tables 32 and 33 and Figure 33 show that the regressions for three different roach populations and one population in two different years all had significantly different intercepts and only three, the river Stour fish and Yateley 7, 1971 and 1974 fish, had slopes that were not significantly different.

These results and the less comparable data of Volodin (1963) show that slower-growing fish have fecundity-length regressions with a less steep slope and higher values for the intercept than fast-growing fish. Thus the fecundity of slow-growing fish increases with length much more slowly than does that of fast-growing fish. While the intercepts of the length-fecundity regressions of different populations e.g. R. Stour and Yateley 7 were significantly different, growth-rate differences between these two populations were less obvious (see figure 25, page 102).

Evidence supporting the hypothesis that a fish's absolute fecundity is the product of the quantity and quality of its food, was reviewed on page 14. Diet is also largely responsible for determining the growth increment achieved, therefore the relationship between growth-rate and length, fecundity regression was to be expected.

Growth-rate estimates are frequently used as an indication of the general living conditions of fish (Hofstede 1974b) when contemplating restocking or depleting stock in a fishery. The results of the length-fecundity regressions show that determining this relationship might be an easier and more sensitive technique to ascertain a fish population's living condition than is growth rate. It is possible that the decline in roach fecundity in 7 in 1974 was a consequence of the higher population density, i.e. a slight decline in quantity and quality of available food that was too slight to affect the fish's growth rate. More data on roach length-fecundity regressions for comparison would assist in the interpretation of results from lake 7 fish.

The use of length-fecundity regressions to indicate the condition of fish stocks would have the additonal advantage of reflecting recent changes in the fish's living condition i.e. the nine months before spawning (Scott, 1962 and Persov, 1973). This would not necessarily be true of growth-rate studies, especially those found by 'length-for-age' analyses.

Restocking is a common treatment applied to an ailing fishery. In the UK restocking with non-salmonids does not always improve anglers' catch per effort (Axford, 1974 and Ayton 1976). Timmermans (1967) did find that up to 50% of newly stocked roach were caught by anglers but concluded that restocking with catchable roach only improved anglers' catches in poorly stocked waters and then only temporarily. The analysis of the scales of large monthly samples of roach in the summer of 1973 indicated that all but the smallest of the fish introduced survived as well as the native roach (see Table 35). Survival of introduced stock is a prequisite of any stocking operation and it has been shown by other workers that survival of many species increased with the size of the introduced fish e.g. T. Osborn (personal communication), walleye (Stizostedion vitreum Mitchill) and Johnson (1973) rainbow trout (Salmo gairdneri Gibbons). Where hatchery fish are used for restocking, because the cost of the fish is by weight, it may on some occasions, be more economic to stock with many small fish rather than fewer larger ones.

The improved growth-rate of the Farnborough roach in lake 7 confirms the observations of Aldoori (1971) and Alm (1946) that previously slow-growing fish can show an accelerated growth rate when transferred to another water. The studies on Yateley 7 confirmed this and showed that this improved growth-rate was similar to that of the native fish (see Figure 39), thus indicating that slow-growing fish can be used to restock waters with low populations with the expectation of their achieving a better growth-rate. The introduction of roach into Yateley 7 has shown that the density of roach in a gravel-pit lake can be increased by stocking. Mortalities associated with handling and moving the fish were probably minimised by carrying out the operation in winter when temperatures were low. The better survival of the larger fish (>8 cm) was probably associated with their greater resistance to the effects of handling and the size-selective mortality rates which generally favoured the survival of the larger fish in lake 7.

Many studies have shown an inverse relationship between fish growth rate and population density especially for single-species populations. This relationship is thought to exist because of competition for food (see page 170).

Gee (1976) found that this relationship also occurred in mixed-species populations. He concluded that his results were a reflection of the importance (in numbers and biomass) of small fish, <20 cm, in the populations.

The few larger fish present in the population tended to show independent growth-rates. The differences in the growth rates of large, older fish compared with young, smaller fish of the same species, may be related to senescence, if the growth-rate is slowing down. Improved growth-rates in older fish have been explained by the ability of older fish to feed on food items too large for smaller fish (Williams, 1967 and Buck and Thoits 1970). Thus small slow-growing perch may grow slowly because they are abundant and competing for a limited supply of small invertebrates, while larger perch in the same population may grow quickly, feeding on small fish and large invertebrates. Thus the suggestion of Gee, that average growth-rate ($\bar{G}$) of fish is inversely related to the total biomass of the population, is unlikely to be true for small fish if they live in a population whose high biomass is due mainly to large fish. As demonstrated by Yateley 7, the large tench biomass gave an overall high fish biomass; yet the relatively low roach and perch biomass present achieved good growth-rate. Unfortunately, the only population studied by Gee that had a high biomass of large fish also had a high biomass of small fish (i.e. Farnborough 18a).

Studies on lake 7 and examination of fish guts taken from other pits (R.A. Sweeting, personal communication) show that zooplankton, especially Daphnia, sp. is an important part of the diet of many cyprinids and perch <20 cm (see page 150). The vulnerability of Daphnia to fish predation (see page 169) suggests a simple mechanism by which the relationship between fish density and growth-rate can operate. High fish stocks would not only compete for food, they would ultimately be deprived of an important component of their diet. Thus dense fish stocks would not just have a smaller share or use more energy to find food, they would have to feed on different, nutritionally poorer items.

The continued good growth rate of roach in lake 7 would be anticipated from the results of the gut contents studies. In 1973 the roach fed on similar items to those of 1971 and 1972 and similar quantities of food were found in their guts (see Figures 26 and 27, page 104). Presumably the population was not high enough for the increased level of predation to result in an obviously different, poorer diet (either quantitatively or qualitatively), such as would produce a decrease in their growth rate; though it might well have caused the reduced fecundity (see page 114). Climate favouring primary, secondary and hence fish production in any one year was suggested by Gee to account for some better than average growth and recruitment rates for roach in 1973. Had 1973 been a 'good' year for roach in lake 7 then this factor may explain why the impact of the high roach stocks was not more apparent.

IV.4 Fish Zooplankton Relationships

Figure 28 shows that there was a close relationship between the abundance of *Daphnia* in the open water and the percentages of roach guts containing *Daphnia*. On only one occasion when *D. longispina* were more abundant than 4/litre did a sample not contain fish feeding on these Cladocera. When *D. longispina* was as abundant as 50/litre, between 70 and 90% of the fish in the samples were found to be feeding primarily upon these animals. Ware (1972) found a similar relationship between feeding and prey density in the rainbow trout (*Salmo gaidneri*, Gibbons). He considered that a certain minimum prey density was required to initiate feeding behaviour and that the fish needed the reward of a good rate of success for the behaviour to be maintained. Ware also found that food had to be above minimum size. This seemed true for the roach in lake 7 since they consumed the larger *Daphnia* and since fish, older than 1+, rarely fed on copepods. Archibald's (1975) observations of 10 cm goldfish feeding on zooplankton and small *Daphnia* may be explained by the fact that the fish, confined in cages, had no other source of food than zooplankton.

The experimental increase in the roach population of lake 7 did not affect the dynamics of *D. longispina* in 1973. However, the estimates of daphnid consumption by roach in lake 7 (see Table 40) shows that once the biomass of *Daphnia* had fallen to $<5\,gm/m^2$ it was possible for the fish to consume a considerable percentage of the standing crop. It was also likely that the figures for consumption were underestimates of the daily ration. This was indicated by the results of the feeding experiments, i.e. experiment 3 suggested that if feeding is continuous the daily ration may equal 2 or 3 times the gut contents. It was therefore likely that fish predation accelerated the rate of decline of the D. longispina population in lake 7.

The effects of high fish-population density in lakes were first reported by Cahn (1929). Work showing the influence of fish on zooplankton was reviewed on pages 13 and 14. This work shows that as fish predation on zooplankton increases with increasing fish stocks, the larger species are selectively consumed. Thus the larger cladoceran species such as Daphnia sp. and Leptodora sp. disappear and the smaller genera e.g. Bosmina and Ceriodaphnia become dominant. Only Gliwicz (1969) argues that this change is not the result of predation, but that increases in fish stocks change the water chemistry as more nutrients are recycled. In this enriched water changes now occur in the phytoplankton i.e. smaller algae are replaced by colonial green and blue-green forms and there are increases in the numbers of suspended bacteria. It is argued that these changes lead to changes in zooplankton because the larger Cladocera are too small to filter-feed on the new large algae and too large to feed efficiently on the bacteria. However, small Cladocera are more efficient feeders on bacteria and these then become the dominant species.

There are several arguments against Gliwicz's explanation:-

(1) Fish predation has been shown to affect zooplankton where no great increase in fish stocks has occurred e.g. following the introduction of planktivores (Rief and Tappa, 1966; Galbraith, 1967 and Brooks, 1968).

(2) Daphnia sp. can in fact feed on large algae and bacteria associated with suspended detritus (A. Duncan, personal communication).

(3) The same kinds of effect of fish predation on zooplankton have been

demonstrated in the nutrient-rich environment of sewage lagoons where there were no differences in the nutrient regimes of the experimental populations (White, 1975).

(4) Using conservative estimates of cladoceran consumption by fish and various data available on Daphnia biomass and production and fish biomass, it is possible to show that daphnid populations cannot support the predation of a high fish biomass (see below).

If fish consume 1% of their body weight/day (see page 142), a high fish population e.g. 40 gm/m^2 (Humbie reservoir, Mills, 1969) would consume 0.4 gm/m^2/day. As gm/m^3 the estimates for Daphnia biomass in lake 7 were comparable to those of Ravera (1969) for D. hyalina in Lake Maggiore, and of Duncan (1975) for Daphnia sp. in Queen Elizabeth II reservoir (<15 gm/m^3). Expressed as gm/m^2 the 17 m deep, artificially circulated, nutrient rich Q.E. II reservoir had mean, annual, wet weight, Daphnia biomass estimates of 15-73 gm/m^2 and a maximum production of 28.9 gm/m^2. However, the mean production for Daphnia sp. in Q.E. II was only 0.68 gm/m^2 (wet weight). Thus, even in Q.E. II, a high fish population could consume over 50% of the Daphnia production.

That predation on zooplankton is size-selective was demonstrated in this study for roach in lake 7 and in aquaria. Similar selectivity has been shown for other fish species (Lindstrom, 1955; Gurzeda, 1965; Brooks and Dodson, 1965: Grygierck, 1965, 1973; Rief and Tappa, 1966; Galbraith, 1967; Brooks, 1968; Mitrovic and Mihajlovic, 1968; Zaret, 1969; Hall, Cooper and Werner, 1970; Dodson, 1970; Wells, 1970; Hutchinson 1971; Mal'tyman, 1971; Hakkari, 1972; Kajak et al., 1972 and Archibald, 1975).

The effect of selective predation is that the larger egg- and young-bearing individuals are consumed, and a population's recruitment is impaired. Thus even the high daphnid production in Q.E. II is probably not immune from the effects of fish predation from a high fish stock. The population of Daphnia in lake 7 (one-tenth to one-twentieth that of Q.E. II, see page 73) would be extemely vulnerable to a predation rate of .4 gm/m^2/day.

As reviewed on pages 13 and 14 the effects of fish predation are not observed as mere declines in numbers of individuals of large species but as their replacement by small forms e.g. Bosmina and Ceriodaphnia. Thus the possibility exists that certain zooplankton communities reflect fish populations e.g. a zooplankton lacking Daphnia sp. but dominated by Bosmina sp. may reflect a high fish biomass. Samples of zooplankton taken from Farnborough 18a and b and Larkfield 41 were found to be dominated by the small cladoceran genera. Later examination of their fish faunas showed that they consisted of large numbers of relatively slow-growing tench, roach, bream and perch; the estimated biomass in 18a was 36.7 gm/m^2 and 41 was 27.5 gm/m^2 (Gee, 1976). No gravel-pit yet studied has had a low fish population combined with small open-water zooplankton species or conversely, a high fish population combined with large zooplankton species. As the results of the abundance of cladocera in lakes 7 and 8 show (see Figures 12 and 13) numbers are extremely seasonal and single or few zooplankton samples could be misleading. Nevertheless, monitoring zooplankton is much easier than conducting fish population estimates especially in large lakes. Thus zooplankton studies may become a valuable technique for reflecting fish population parameters.

Smyly (1952) considered fry mortalities could be the product of starvation due to the absence of vital, small components in the zooplankton. Tsunikova (1973) described experiments conducted on the survival of roach larvae subjected to periods of starvation and this work supports the idea that starvation may be an important factor determining fry mortalities and hence recruitment. Such starvation would be more likely where the zooplankton was of the type typically associated with low fish populations (i.e. few individuals of large types such as Daphnia), and less likely where the zooplankton was of the type typically associated with high fish biomasses (i.e. large numbers of small types such as Ceriodaphnia and rotifers). Thus there could be a positive feed-back mechanism assisting recruitment in waters which already have a high fish population and tending to impair recruitment in sparsely populated waters. This mechanism may explain the extremes of high and low population densities observed by Gee (1976).

IV.5 The Management of Gravel-pit Lakes as Fisheries

A successful fishery provides anglers with good catches in terms of catch/effort of the required size and species. Bennet, Adkins and Childers (1969) found in Ridge Lake, Illinois, that although anglers sometimes achieved good catches when stocks were low and poor catches when stocks were high, there was a link between angler success and stock density. In general 1000-2000 catchable fish/hectare gave catch rates of 0.5-1.5 fish/ man hour and stock densities of 200-500 fish/hectare gave catch rates of 0.1 to 0.5 fish/man hour.

Thus the management of fish populations in fisheries invariably involves attempting to maintain fish stocks at levels high enough to ensure good catch-rates but not so high as to impair fish growth-rate to the point where only small fish are caught. In the USA many attempts have been made to manage fisheries i.e. create stable, balance populations in lakes and ponds by stocking with various combinations of different predator and prey species. Ideally these balanced populations then provide high rates of catch-per-effort and good yields to anglers (>1 fish/ man hour). Swingle (1946, 1950) considers that predator and prey species e.g. largemouth bass and sunfish, can be stocked into fisheries at ratios based upon certain formulae. G.W. Bennet (personal communication) considers that this is not possible and that universal formulae cannot be applied because of the biological differences that occur between different waters. In Europe attempts at manipulating predator prey ratios to maintain desirable fish populations in fisheries have been few and largely confined to stocking or removing pike. (Hofsted 1974b).

Although suited in many ways for use as fisheries, gravel-pit lakes seem to be relatively unstable (see pages 145 and 172) and this is especially reflected in the populations of smaller fish species e.g. roach, rudd and perch. Instability is a major disadvantage for the managing of fisheries. The relatively small size of pits may be largely responsible for this instability. Large variations have been found in fish populations of other small water bodies e.g. the fish population in Ridge Lake, Illinois was found to be very changeable (Bennet, Adkins and Childers, 1969; again, the yield of smallmouth bass (Micropterus dolomieu Lacépède) from a 0.5 hectare gravel-pit lake was found to vary between 30.1 and 104.8 kg/hectare/ year (Bennet and Childers, 1972); finally, fish biomass in similar, New York, farm ponds five years after stocking ranged from 62-563 lb/a (Regier, 1962).

As small, shallow, well-mixed water boties, gravel-pit lakes may be unstable because of their sensitivity to the climate. With a greater bank-length/open-water area ratio than large lakes, small shallow lakes are also more influenced by possible edge effects e.g. changes in the abundance of littoral macrophytes; and fish predators such as great crested grebe can live at much higher densities during spring and summer in small lakes than in large open lakes. Thus the maximum effect these predators can have is greater in small lakes than in large lakes. A final factor that may be contributing to the instability of gravel pits is their age; as young water bodies, fluctuations in aspects of their biology may be a consequence of the impact of newly colonizing species or of the lake's maturing.

Whatever the cause, the instability of gravel pits is not conducive to their management as successful, stable fisheries, especially for small species. The introduction of fish into lake 7 showed that roach populations could be increased. By 1975, however, the roach biomass had fallen to 1971/72 levels and pike were again found in the lake (M.P. Cook, personal communication). Gee (1976) found that the pits with the highest fish biomasses had few or no pike. It would seem that efforts to increase the biomass of small fish species should include attempts to reduce the numbers of predators. While it was relatively easy to remove pike from lake 7, grebe would be difficult to control.

However, Gee found that there were pits where fish were so abundant that their growth-rate was very poor, i.e. where predation was low and recruitment high (see page 170). Although high fish stocks with consequent high catch rates are desired for some forms of angling most anglers prefer to catch larger fish produced in faster-growing populations. There are three possible ways of preventing 'over-recruitment'. These are:-

(1) Removing small fish as numbers increase by selective netting, electric fishing or poisoning.

(2) Encouraging anglers to remove fish i.e. harvest the fishery. This may be more successful with species other than cyprinids.

(3) Introducing predators that are selective on small fish. This could be achieved with pike; if anglers were encourage to remove those above the size at which they can prey upon the more desirable stock in the fishery. Alternatively species could be used that are more selective on small fish than pike e.g. perch, zander (Lucioperca lucioperca L.) or a N. American centrarchid.

If the second or third option was adopted then fisheries could yield significant quantities of highly palatable animal protein.

An alternative management policy would be to use species that grow to be relatively invulnerable to predation. In this context tench and carp grow to a large size and are popular fish with coarse fishermen. Results already reviewed indicate that typical gravel-pit lakes could 'support' these fish at a density of 200-300 kgs/hectare. More information on the relationship between fish density and angler's catch-per-effort would assist in formulating stocking programs.

The relatively small size (0.5-50 hectares) and shallow depth (<5 metres) of gravel-pit lakes, although possibly responsible for their instability, allows their fish stocks to be studied using conventional methods e.g. capture-recapture population estimates and to be manipulated by organisations with modest budgets. The fish stocks of larger waters

(>50 hectares) could be assessed by zooplankton studies (see page 171), fecundity studies (see page 164) or using rotenone. Estimating the fish populations of large lakes by applying rotenone to bays and coves sealed off with stop nets is becoming a standard technique in the USA (Hayne et al., 1964; Hall, 1974). This method would be made more effective if, during the final phase of their construction, small bays were formed around the margin of the pits. This technique would also be suitable for application to large, flooded-valley reservoirs.

Volodin (1963) attributed the increased growth rate of roach in Rybinsk reservoir to the increased abundance of the freshwater mussel (Dreissensia polymorpha). As stated on page 150 the mollusc faunas of different pits were very variable. It is possible that the introduction of new invertebrate species, such as molluscs, into lakes could have beneficial effects on the lakes' fish fauna, providing them with a wider range of food. This technique has been used in new reservoirs in the U.S.S.R. (Karpevitch and Lukonina, 1971) and alpine lakes in the U.S.A. (Johnson, 1972).

The abundance and sizes of gravel-pit lakes means that not only can different waters be set aside for different activities but that of those used as fisheries, some could be intensively managed to create specific fisheries, while others are left alone for anglers who prefer to fish more 'natural' populations.

CHAPTER V

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APPENDIX

Ricker (1973) discussed and compared the results of various methods for conducting linear regressions. He considered that functional regressions tend to be more reliable than the predictive method especially when dealing with biological data which is subject to both error and variability. Predictive regressions also imply that one parameter depends upon another; in a length, weight regression, weight depends upon length no more than does length upon weight.

Gee (1976) found that Bartlett's (1949) arithmetic mean functional regression gave reliable results. This method was adopted in this thesis. The text and this appendix contains the raw data used in calculating these regressions thus enabling alternative methods to be employed. Similarly the raw data on the fish population estimates are included.

Raw data as used for fish length fecundity regressions (page 116)

1974 Kew fish

length (cm)	fecundity	length (cm)	fecundity
17.1	8226	11.0	5050
23.2	11945	17.1	8150

1970 River Stour (data from R.H.K. Mann)

length (cm)	fecundity	length (cm)	fecundity
15.6	8594	19.7	16150
25.3	40576	19.4	10176
20.5	18464	26.9	36800
25.2	25760	17.9	8080
21.2	22240	19.9	8368
24.1	32160		
20.5	22208		
27.5	50784		
21.7	19040		

Raw data as used for fish length fecundity regressions (page 116)

1974 Kew fish

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21.2	22240	19.9	8368
24.1	32160		
20.5	22208		
27.5	50784		
21.7	19040		

1971 Yateley 7

length (cm)	fecundity
10.9	3880
12.4	7100
12.9	8300
17.0	17100
17.2	21900
17.7	22100
21.9	38200
21.1	46700
26.8	80500

1974 Yateley 7

length (cm)	fecundity
15.0	5800
14.4	6610
15.2	8350
14.8	8430
16.8	10200
15.2	10800
19.5	18400
20.0	18500
19.6	19100
19.8	19800
20.0	20100
21.1	24900
23.3	29500

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1971 cont.	c	r	M1	M2	M3	M1M2	M1M3	M2M3	M1M2M3
Perch (1+)									
Day 1	8								
" 2	7	3	3	-	-	-	-	-	-
" 3	3	1	-	1	-	-	-	-	-
" 4	8	6	1	3	1	1	-	-	-
Perch (2+ & older)									
Day 1	26								
" 2	15	6	6						
" 3	8	6	1	4	-	1	-	-	-
" 4	25	17	7	4	1	4	-	1	-
Rudd (1+)									
Day 1	-								
" 2	21	-	-	-	-	-	-	-	-
" 3	127	8	-	8	-	-	-	-	-
" 4	119	45	-	4	38	-	-	9	-
Rudd (2+ & older)									
Day 1	13								
" 2	16	8	8						
" 3	19	12	1	6		5			
" 4	6	5	2		1			2	
1972									
Tench (all ages)									
Day 1	51								
"	15	6	6						
"	3	3	1	2					
" 4	57	37	20	7		8		1	
Pike (all ages)									
Day 1	4								
" 2	7	1	1						
" 3	3	3	-	3					
" 4	7	3	-	-	-	1	-	2	-
Rudd (1+)									
Day 1	3								
" 2	2	2	2						
" 3	-								
" 4	-								
Rudd (2+)									
Day 1	11								
" 2	9	8	8						
" 3	7	6	2	-		4	-	-	
" 4	7	7	1	1	-	-	1	-	4
Rudd (3+ & older)									
Day 1	3								
" 2	2	1	1						
" 3	4	4	2	1		1			
" 4	5	2	-	-	-	1	-	-	1
Perch (0+)									
Day 1	85								
" 2	93	9	9						
" 3	17	5		5					
"	142	14	4	6	2	2			

1972 Cont.

		c	r	M1	M2	M3	M1M2	M1M3	M2M3	M1M2M3
Perch (1+)										
	Day 1	14								
	" 2	2	-							
	" 3	5	-							
	" 4	21	4	2	-	2				
Perch (older)										
	Day 1	5								
	" 2	1	-							
	" 3	3	-							
	" 4	8	5	2	-	3				
Roach (1+)										
	Day 1	260								
	" 2	115	79	79						
	" 3	60	45	15	13	-	17			
	" 4	17	5	2	1	1	1			
Roach (2+)										
	Day 1	5								
	" 2	2	1	1						
	" 3	3	3	2	-	1				
	" 4	-								
Roach (older)										
	Day 1	35								
	" 2	9	7	7						
	" 3	14	7	5			2			
	" 4	14	8	3	1	1		1	1	1

1973

		c	r	M1	M2	M3	M1M2	M1M3	M2M3	M1M2M3
Tench (all ages)										
	Day 1	52								
	" 2	44	23	23						
	" 3	11	7	1	1		5			
	" 4	25	18	4	5		7		1	1
Rudd (2+ & older)										
	Day 1	4								
	" 2	7	2	2						
	" 3	4	3	1	-	-	2			
	" 4	4	2	-	1	-	-	-	-	1
Perch (0+)										
	Day 1	247								
	" 2	150	55	55						
	" 3	140	68	35	24		9			
	" 4	232	114	43	18	27	13	10	9	4
Perch (1+)										
	Day 1	50								
	" 2	35	19	19						
	" 3	22	13	5	4		4			
	" 4	52	38	9	2	6	12	4	3	2

1973 Cont.

		c	r	M1	M2	M3	M1M2	M1M3	M2M3	M1M2M3
Roach (0+)										
	Day 1	393								
	" 2	124	9	9						
	" 3	160	13	4	8		1			
	" 4	28	1	-	1	-				
Roach (2+ & 3+)										
	Day 1	271								
	" 2	172	82	82						
	" 3	82	52	11	14		27			
	" 4	112	64	20	11	4	13	1	5	10
Roach (older)										
	Day 1	48								
	" 2	42	15	15						
	" 3	22	11	3	5		3			
	" 4	36	21	9	3	1	3	3	1	1

Plankton Counts Yateley 7 (Nos/200ℓ

	Daphnia longispina	Bosmina longirostris	Ceriodaphnia quadrangula	Calanoid copepods	Cyclopoid copepods
29. 7.71	8	-		28	5
26. 8.71	-	8		60	112
29. 9.71	16	120		104	96
25.10.71	17	2,078		723	510
25.11.71	77	4,931		1,731	419
29.12.71	300	51,080		4,690	370
23. 1.72	204	31,248		4,656	228
23. 2.71	35	16,290		2,525	95
15. 3.72	8	16,472		1,940	236
7. 4.72	284	1,952		5,696	7,554
26. 4.72	1,385	210		8,315	2,065
10. 5.72	9,360	293		6,081	2,076
14. 5.72	12,312	2,992		5,040	1,010
13. 6.72	4,680	605		250	1,125
26. 6.72	6,755	370		380	6,340
9. 7.72	13,566	732		136	8,040
24. 7.72	220	305	100	60	5,235
6. 8.72	13	113	16	37	500
4. 9.72	-	206	13	40	937
2.10.72	10	90		125	1,875
30.10.72	57	7		353	678
21.11.72	857	-		807	227
19.12.72	1,210	-		1,675	190
8. 1.73	9,490	10		2,730	460
1. 2.73	8,310	-		1,860	410
20. 2.73	2,933			5,073	193
12. 3.73	252			3,474	132
25. 3.73	240			2,853	1,253
9. 4.73	1,633			1,747	333
24. 4.73	17,025			3,105	855
3. 5.73	35,633			4,866	666
16. 5.73	3,793			1,594	2,360
23. 5.73	3,075			645	1,073
31. 5.73	4,580			1,100	2,846
12. 6.73	18,825	10		1,980	7,430
29. 6.73	533			340	5,667
16. 7.73	45		5	265	5,100
30. 7.73	15		5	175	4,050
14. 8.73	-	60		350	10,270
10. 9.73	40	995		465	3,890
24. 9.73	135	83		1,088	4,313
8.10.73	20			380	2,110
13.11.73	270	23		3,720	968
10.12.73	53	-		4,223	450

Plankton counts Yateley 8 (Nos/200l)

	Daphnia longispina	Bosmina longirostris	Ceriodaphnia quadrangula	Calanoid Copepods	Cyclopoid Copepods
29.12.71	18	908		2,138	462
23. 1.72	10	403		883	93
23. 2.72	25	768		708	118
7. 4.72	14	1,403		1,102	368
26. 4.72	380	29,290		8,990	14,770
10. 5.72	1,086	426		2,592	8,004
24. 5.72	2,565	112		7,179	11,106
13. 6.72	21,980	1,120		2,460	1,800
26. 6.72	18,670	1,040		370	5,850
24. 7.72	665	515	4,630	950	2,160
6, 8.72	180	1,915	1,690	1,415	1,090
4. 9.72	10	20	910	635	1,316
2.10.72	33	-	353	393	3,793
30.10.72	233	-	-	243	683
21.11.72	2,935	-	-	470	370
8. 1.73	3,885	785	-	2,075	510
1. 2.73	8,172	125	-	1,025	500
20. 2.73	8,220	30	-	1,200	720
12. 3.73	3,983	88	-	1,116	995
25. 3.73	5,630	30	-	670	760
24. 4.73	10,370	110	-	760	590
3. 5.73	9,135	1,140	-	885	1,950
16. 5.73	7,620	1,670	-	420	2,310
12. 6.73	18,700	-	-	216	7,800
29. 6.73	4,450	-	-	70	3,140
16. 7.73	98	-	-	293	2,453
30. 7.73	38	63	100	213	12,930
14. 8.73	50	4,370	220	1,040	6,900
10. 9.73	165	12,353	440	3,311	3,619
24. 9.73	75	533	23	938	3,750
8.10.73	80	5	10	385	1,810
13.11.73	95	10	-	855	605
10.12.73	234	-	-	1,452	402

List of macroinvertebrates found in Lake 7, Yateley

Spongillidae
Hydra sp.
Polycelis sp.

Mollusca

Potamopyrgus jenkinsi
Planorbus sp.
Limnea peregra
Limnea stagnalis
Pisidium sp.
Sphaerium sp.

Annelida

Helobdella stagnalis
Epobdella octoculata
Hemiclepsis marginata
Piscicola geometra
Tubificidae

Arachnida

Hydracarina

Crustacea

Cyclops sp.
Diaptomus gracilis
Daphnia longispina
Bosmina longirostris
Eurycercus lamellatus
Sida crystalina
Simocephalis vetulis
Chidorus ovalis
Polyphemus pediculus
Cypris gigas
Argulus foliaceus
Asellus aquaticus
Crangonyx pseudogracilis

Insecta

Caenis horaria
Cloeon dipterum
Coenagrion sp.
Aeshna sp.
Sialis lutaria
Molanna sp.
Limnephilus sp.
Dytiocus semisulcatus
Hydrometra stagnorum
Gerris sp.
Corixa falleni
Cymatia bonsdorffi
Nepa cinerea
Ranatra linearis
Ilyocoris cimicoides
Notonecta glauca
Chaoborus sp.
Dixinae
Chironomidae
Ceratopogonidae