A study of minnow, Phoxinus phoxinus L. in the River Wear, County Durham, with special reference to feeding habits

A.S. Gee

How to cite:

Gee, A.S. (1978) A study of minnow, Phoxinus phoxinus L. in the River Wear, County Durham, with special reference to feeding habits. Masters thesis, Durham University.

CONTENTS.

A Study of the minnow, Phoxinus phoxinus L., in the River Wear, County Durham, with special reference to feeding habits. -

by A. S. Gee.

INTRODUCTION.

The factors which influence the size and structure of fish populations are very variable. They include most factors discussed in the many recent works on population ecology (Andrewartha & Birch, 1954; Lack, 1954; Le Cren & Holdgate, 1962; Wynne-Edwards, 1962.) Many features of fish population dymamics are, however, peculiar to this class, and greatly influence the resultant population structure. The variable size of adult fish is particularly important in this context. The size depends on growth rate, though survival rate may have some influence (Le Cren, 1965.). Important factors, too, are the labile nature of population numbers and mobility. Fecundity depends on size, and egg survival can be high when spawnin density is low. Adult mortality tends to be independent of age, predation being considered an important factor. Therefore, though at the limits of their range, physical factors may be important, it is generally considered that fish population density and structure are determined by biotic, density-dependent factors. Under experimental conditions, the growth of fish, particularly above 40°F., is directly proportional to the amount of food eaten (Pentelow, 1939.). Under natural conditions there is probably a direct association between food and growth rate (Smyly, 1955.). Wingfield (1940) also considers food a critical factor.

It is important, therefore, in the understanding of the ecology of any fish population, that the amount and type of food eaten is determined. This aspect of fish ecology has been studied extensively, although the work of Frost (1943) remains the only one dealing exclusively with the minnow (Phoxinus phoxinus L.) Other workers (Hartley, 1948, Maitland, 1965) have compared the food of minnows with other, coexisting species. The fish used in all these studies have come from one section of river where the species was known to be abundant. Comparison was often made between the food of fish caught in this area and those from another river or lake. No account is available on the feeding habits of minnows in different parts of one river system.

The original purpose of the investigation described here was to examine the food and population structure of minnows at selected sites in the River Wear, County Durham. Since no work had been done on the distribution or movement of this species within the river, the boundaries of the population(s) were not known.

Mann (1971) used the minnows within a specified 'reach' as his unit population, but encountered difficulties when, at various sampling times, all or part of a shoal would lie outside this 'reach'.

It was decided to take samples of up to 200 fish from each of the sampling stations, and to compare their structure. It was hoped that this might give some indication of the possible existence of discrete units of the River Wear minnow population. Gut analyses of fish from the sampling points, together with laboratory growth rate and predation tests were planned to give an indication of the feeding habits of the minnow. It was hoped to attempt an assessment of the importance of food on the size structure of the minnow samples obtained.

GENERAL FEATURES AND LIFE-HISTORY OF THE MINNOW.

The minnows is one of the smallest British freshwater fishes, rarely growing to a length of more than 3 or 4 inches, though occasionally specimens of 6 or 7 inches long have been found. Frost (1943) records most of the Lake District fish lying between 50 and 65 mm., the largest being 82 mm. Tack (1940) found minnows as large as 119 mm. The largest specimen found in this survey was 98 mm. long. The external features are very similar in all individuals, though slight differences do occur between sexes in fully mature fish, particularly in the breeding season.

They are found throughout Britain, apart from the Northern Highlands of Scotland, living in most areas of freshwater, though preferring clear streams where the bottom is composed of sand or gravel, (Regan, 1911). They swim in shoals, and, in larger rivers, tend to be found in regions of slack water. Regan describes shoals of minnows moving from one place to another 'in search of new feeding grounds'. In the winter, and on cloudy or rainy days, it has been noted during the course of this work that minnows retire to deeper water, and lie under stones or in holes in the banks.

Spawning occurs in the summer months, a fuller account of the reproductive behaviour being given in a later chapter.

THE SAMPLING STATIONS (See Table 1)

Information regarding the River Wear is given in Whitton & Buckmaster (1970) included in which are references to several papers on the hydrology and chemistry of the river. The Wear is formed at Wearhead, running 106.9 km. to Wearmouth Bridge, Sunderland. The fall in level from 336m. at Wearhead is gradual from source to mouth. Generally, the chemistry of the river can be described as a gradual increase in nutrient levels, though a number of sewage outflows do occur. Most effluents into the main river are in fairly good condition. The most important inflows being from Wadsworth sewage disposal works (Km. 39.6) and the River Gaunless which increases the hardness of the main river considerably. The lead and zinc contamination from mines occurs towards the head of the river, and many miles above the sampling stations chosen. Since 1966 the effects of mine water inflow have been only minor. The effects of any industrial chemical effluent is considered to have no marked effect on the ecology of the river. The May–June–July temperature variation between Stanhope, near the head of the river, and Sunderland Bridge lies within the range 10–17°C., (Smith, 1968).

POPULATION STRUCTURE

Methods

In any study of population structure it is important to obtain an adequate number and representative sample of the population. It will be explained later that in fact this was never truly achieved, due to the shoaling behaviour of the fish.

Many workers have used a wide variety of nets, traps and electric fishing apparatus for catching minnows. Electric apparatus was not available, so a number of nets and traps were tested. It was found that whenever a large shoal was present it was reasonably easy to catch large numbers in small hand nets, though a trap made from a large glass sweet jar with a funnel entrance was found most effective, especially when baited with bread. Many other traps made from a variety of bottles were tried without much success; these included a large trap made from nylon netting and wire, similar in design to that used by Hartley (1948.). Seine netting was considered unnecessary when using traps and to be unsuitable under conditions when traps would not function. No method was found of suitably sampling minnows in a stretch of river where they were either scarce or lying beneath stones. Possibly a combination of large seine net and electric stunner would have succeeded, but neither the apparatus nor the technical assistance was available. Such work would, in any case, have caused much disturbance, and would have been a considerable nuisance to local fishermen.

The stations chosen for study were sampled for minnows using the nets and traps. The fish were weighed and measured within a few hours of capture. Length was measured, to the nearest millimetre, from snout tip to tail fork. Filter-paper-dried fish were weighed to the nearest milligram on an electric balance. Guts were dissected out and the whole preserved in 70% alcohol for later examination.

An attempt was made to age the minnows using otoliths, but after many fish of different sizes were tried, it was found that little reliability could be placed in their interpretation.

Results and Discussion.

The data collected was grouped into 2mm. lengths and plotted against the numbers of fish caught from each length group. The resulting length frequency distributions, for all the sites studied, are shown in FIG 1a-g. Each frequency distribution is complex, most of the 'populations' sampled covering a wide range of lengths. The 3-point 'moving average' method for smoothing the histograms produced was employed, but in most cases the resulting curve was still very complex.

The Peterson Method for analysis of size frequency distributions is now standard in work on population structure. Basically, it requires a unimodel size distribution of all fish of the same age, but is therefore only easy to employ when there is no large overlap in the size of individuals in adjacent age-groups. It can generally be applied only to the youngest age-groups of a population (Tesch, 1968). It follows from the assumption of unimodal size distribution that the Peterson Method is best employed where modes are most pronounced. This occurs in fish with a short spawning season and rapid and uniform growth. Tesch believes that even when age determination is possible from scales and otoliths, this method of polymodal frequency analysis can make it possible to reduce greatly the amount of age determination needed. Again, Tesch states that close to the modes, all or nearly all of the fish can be expected to be of one age group. This latter statement is in fact the basis of the Peterson Method.

In many instances, and certainly in the case of the minnow, the spawning period is extended over several months. This results in considerable overlap in size between fish of adjacent year classes, especially in older fish. Buchanan-Wollaston & Hodgson (1929) devised a method of analysing such indistinct polymodal curves using the method of drawing 'curves of error'. 'Normal curves' are drawn about the modes, each of these is then treated as a distinct year-class. In some cases the necessary 'curves of error' are relatively simple to draw, but often, and the present curves for River Wear minnows are included here, this becomes very difficult, and it is impossible to determine which part of the curve is truly significant and which due to sampling error. When the frequency curves become complex the degree of speculation and 'judgement' necessary for resolving them detracts from their usefulness.

A better method for resolving frequency curves into component 'normal' curves is that of Harding (1949), Cassie (1954) and Tanaka (1962) using probability paper. Even with this method, however, the components become more difficult to distinguish as the compound curve becomes 'smoother'. Polymodal analysis of the frequency curves detained from the minnow samples was carried out to give an indication of the structure of the sampled fish (see. Fig. 2a-e). It is not, however, concluded that these resulting normal distributions necessarily relate to year-classes, as assumed in the Petersen Method. Neither must it be assumed that the structure of the sample is necessarily that of the minnow population at the sampling site, nor in the River Wear generally. Indeed, there is much circumstantial evidence to indicat that this is not the case.

The problem of relating length frequency distributions to year classes would be solved were the individual ages of the samples fish known. Various workers have employed scales and otoliths for this purpose with varying degrees of success. Frost (1943) found scales useful for ageing Windermere minnows, bu only those from the caudal peduncle are suitable, and interpretation of the ring structure is difficult. Most workers have preferred the use of otoliths. In this investigation many minnew otoliths were extracted. Although the sagitta is the largest of the three otoliths and easy to dissect out, it is still quite small. The very 'humpy' surface makes the reaching of the rings impossible, even when cleared with creosote oil according to the method of Jones and Hynes (1950). Various methods of grinding (Johnston, 1938) and burning (Christensen, 1964) are employable in these circumstances, but none were practicable during this study. Frost (1943) has recorded the range of lengths in minnows of different year classes, which, though differing slightly from one locality to another, can, I think, be taken as close approximations to the River Wear situation.

Analysis of the River Wear samples using the probability paper method gives mean lengths and associated S.D.s as shown in TABLE 2. As mentioned above, it is best to consider these values as descriptions of the structure of the shoals from which the samples were taken. Shoals of minnows were observed to change in composition with time and locality. It was common to see a choal comprising of large numbers of individuals of approximately the same size;c in a few occasions it was noted both by myself and others that two or more adjacent shoals would comprise of what could be described as distinct year classes, one year class per shoal. It was not possible in the time available to investigate the long-term nature of these shoals, to investigate the degree of exchange between shoals, nor to see whether or not a shoal is a distinct unit of the population, acting in any way separately from other neighbouring shoals. Because nothing is known about the shoaling behaviour, any conclusions resulting from analysis of a sample taken from the river cannot be extrapolated beyond the sample itself. However, in most instances, the sample can be regarded as representative of the shoal from which it was taken.

When the results expressed in TABLE 2 are compared with those for the River Brathay fish (Frost, 1943) it is difficult to resolve individual components into year classes. The Durham Sands 10.5.71 sample, for instance, seems to consist of two components of mean lengths 33.2 mm. and 41.9 mm., both of which could be fitted into Age Group 0 of River Brathay fish. In addition, one fully ripe female 71mm. long was caught. The above mentioned sample consists only of two main groups which have a fair degree of on overlap This contrasts greatly with a sample taken from exactly the same place on 24.6.71. Four days prior to taking the latter sample a fairly heavy flood had occured; the sample was taken as soon as the flood subsided and the river level dropped to its former level. A large number of very large minnows are seen to be represented. These larger minnows form a component distinct from the main mass of the 'population'l It is possible that the component curve of mean length 47.3mm. is composed of year classes 0 and I, whilst the larger one of mean length 71.3mm. represents year class II. An intermediate sample taken on 1.6.71, from the same pool, was unimodal, approximately normal, with a mean length of 38mm.

The Bishop Auckland sample has three components, giving the widest range of sizes within any shoal sampled. The fact that the mean values do not coincide with those at Durham Sands may be a function of real differences in size with age of the populations at the two sites. The sites are certainly different in chemical properties, and quite far removed in terms of distance from one another. Again, it is difficult to come to any definite conclusion because it is not known how much exchange of fish takes place between the two stations. It seems difficult to conceive of fish moving upstream from Durham as far as Bishop Auckland, especially since there are numerous weirs between, but it is possible for the reverse to occur, by active swimming or through being swept downstream. It is probable that a certain amount of downstream mixing of populations does occur. Minnows kept in aquaria were observed to swim against the current during changing of the tank water, but very quickly 'tired', and were swept backwards. The largest shoals of minnows occur in the classical 'minnow reach', that is, areas of slack, shallow water near the river bank. When disturbed in these pools the fish react immediately en masse by swimming into the main part of the river. At Durham Sands the current is fairly rapid in mid-stream such that fish could be swept away. Normally, minnows make for areas of slack water beneath or just downstream of stones. A few minutes after flight, the minnows return to the slack water pool, so that generally little displacement occurs in this way. The large flood between the two main sampling times at Durham Sands was probably a factor in the subsequent change in shoal structure described above.

The Witton-le-Wear station was visited on several occasions, but the only large sample obtained gave a normal distribution about a mean length of 50.4 mm. Those were probably Group I fish, On no occasion were larger fish of Group II size range seen.

The site furthest upstream was that at Wolsingham. Two visits here resulted in not one sighting of a minnow. Children playing in the area recalled the presence of minnows at Wolsingham from time to time, but none had been seen on the sampling days.

Many general conclusions can be drawn from observations made throughout the summer months in search of minnows. It was very common for minnows to be plentiful in a particular locality on one day, and to appear to be completely absent on a subsequent visit. There seemed to be quite a good correlation between the occurence of a shoal and of fine weather. On warm sunny days minnows congregate in the shallows, but this is rarely seen on close or cloudy days. The first two visits to Witton-le-Wear, for example, were on such cloudy days; no shoals were seen, but several minnows were disturbed from beneath stones, only to dart quickly away. Occasionally, some of these fleeing minnows were caught, but in insufficient numbers to make up a valid sample.

The Page Bank sample has mean values of 32.8 mm. and 44.7 mm., resembling, to some extent the Durham Sands sample taken on 10.5.71. This suggests that Group 0 and I fish in these parts of the Wear are considerably smaller than recorded for the River Brathay. It would, however, be unwise to consider this as more than a possibility. The Page Bank site was sampled downstream of the bridge, and upstream again on 30th May; both gave unimodal curves as shown in Fig. 1c.

The site at Sunderland Bridge was also visited on numerous occasions, and exceptionally small shoals of minnows were seen. On one occasion 34 fish were caught from one shoal, their length frequencies being displayed in Fig. 1d. Some of the fish were very small indeed, at 20mm., and it seems possible that within the sample, two age classes were represented. It seems unlikely that such a range in lengths would be represented with one age class.

Conclusions

It is obvious from the above remarks that shoals of minnows can differ very greatly in size structure. Two possible explanations can be considered; firstly, that the length frequency distributions are true representations of the structure of the minnow population at the sampling site. If the shoals are discrete units, then this would imply that the factors which govern individual size in minnows are very different in various parts of the Wear. Secondly, and more probably, the length-frequency distributions do not necessarily give accurate pictures of age structure, but result from mixtures of up to four year classes in different proportions. It has been concluded earlier that the samples are true representations of the shoals from which they were taken, so that it must be concluded that shoals can differ markedly in composition with time and locality. It is quite possible, of course, that both these factors are represented here. The question of available food as a factor in determining population structure is discussed in a later section.

Previous workers have relied very heavily on polymodal frequency analysis for resolving population structures (e.g. Smyly, 1957; Frost, 1943), but the present work indicates possible unreliability in some circumstances, depending greatly on social behaviour within the population being sampled. Otolith examination for age is often useful (Smyly, 1957) but in the case of the minnow even this method cannot be taken as very reliable. According to Frost '.....length frequency distributions threw much doubt on the otalith readings, which in many cases gave the age for any length either one or two yea greater than that attributed to it by the frequency curve.' Mann (1971), studying population structure of minnows and other coexisting species in Dorset, also found that shoaling behaviour made accurate estimates of survival difficult. Over 5-fold differences in numbers of fish per reach were estimated. Mann did not find any minnows which had survived longer than a few weeks after their third birthday.

FOOD AND GROWTH.

1. FOOD

GUT ANALYSES

The methods used to examine fish gut contents and quantify the results are very varied. Hynes (1950) has reviewed the commoner methods and has attempted to standardize the procedure. He concluded that when results are expressed comparably, i.e. when each food item is shown as a percentage of the total food eaten, all methods give substantially the same result. He rejects methods based on the numbers of organisms eaten and comparison of data so obtained with counts of the organisms found in samples of small areas of the subotratum. The best method, in his opinion, is based on the allocation of points on the basis of the estimated volume of each food item present. Hartley (1948) lists the numbers of organisms in the fish. He expresses the occurence of food as a percentage of the total number of prey organisms found. This is probably useful only when comparing foods of different species of fish, since the size of prey organisms will be important in determining the number eaten. Swynnerton & Worthington (1940) washed out the stomach contents, estimated the occurrence of prey organisms, designating them as 'very commod, 'common', 'frequent', 'rare' or 'very rare'. They report having taken the size of individual organisms into account. The contents of all stomachs, arranged in size groups for each species of fish, were tabulated, grouping occurrences in such a way that the resulting categories were 'common', 'frequent' and 'very rare', designated 3, 2 and 1 respectively. The integers in each section of the table were the summated and scaled down to a percentage. Smyly (1955) compared the fullness of stomachs of stone-loaches of different lengths. He allocated different scales of points depending on fish size for stomachs $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ and completely full. Frost (1943) used a method very similar to that described for Swynnerton & Worthington above. Each food category was given a number of points - 3, 2 or 1 - according to its abundance, the size of the individual organisms as well as their abundance being taken into account. This is an estimation of bulk, points representing absolute not relative values.

Methods.

The method employed here was similar to that of Frost's described above. A system of four points was used, 4 = completely filling gut; 3 = $\frac{3}{4}$ full; 2 = $\frac{1}{2}$ full, 1 = $\frac{1}{4}$ full. A number of points were then allocated to each category of food organism found according to the extent to which it filled the gut. It is thought that by using this method a fair comparison is made between the importance of various prey organisms in the diet of the minnow. The minnow has no stomach, so that food organisms tend to be swallowed as tiny fragments, the whole gut therefore being necessary for examination of food. It was often difficult to identify many of the small insect fragments found.

Using the length-frequency distributions, the main size groups represented in each sample were examined for gut contents. Results are expressed as the proportion of fish containing any of the prey categories, and as the proportionate number of points allocated to each food category. Direct comparison is therefore possible between each food category within a subsample, and between each size group of fish, though the differences in size of the subsamples makes direct comparison in the latter case less meaningful in a few instances.

Two visits were made to the Durham Sands site at 1-2 a.m. in an attempt to investigate the possibility of a diurnal feeding pattern. No minnows were caught on either occasion, though the traps used had been very successful at t same site during the day. The reason for this is not known.

Results.

The results of the gut analyses are summerized in Tables 3a and b., and in Fig. 3. The percentage of total fish examined which contained any of the food groups, and the percentage volume of gut occupied by the various food groups are shown.

Table 4 gives the percentage fullness of the guts of each size category of fish for each sample. Large differences between these fullness values are obvious between samples and between size groups within a sample. In all but the Sunderland Bridge Sample, the larger size groups had fuller guts than the smaller ones. This seems to indicate that larger fish spend more than a proportionate amount of time feeding, or are more efficient predators than smaller fish. It is not clear why larger fish should eat more than a proportion ately larger share of the food available.

i. Durham Sands 10.5.71.

This sample is a striking exception to all the others examined in its almost complete lack of any animal constituent of the diet. Ephemeroptera nympths and chironomid larvae are the only fauna represented, and contribute insignificantly to the volume of food eaten. It is interesting that Ephemeroptera are found in the two smaller size groups and none in the larger. This contrasts with the findings of Frost (1943), and Stankovitch (1921) who found that 'there was a tendency to an increase in the consumption of nymphal Ephemeroptera and larval Trichoptera with increasing length of the fish.'. However, the numbers of nymphs eaten within the sample are twoo small to be significant. Diatoms and debris occured in practically all the fish examined, but contributed very little to the bulk of food. Most of the diatoms were observed to have intact chloroplasts, and can therefore have been of mino nutritional importance. The proportional value of filamentous algae is very similar in all size groups. Frost records that '....filamentous algae and diatoms are eaten to an appreciable extent by all the minnows over one year old.

ii. Durham Sands 24.6.71

No diatoms or filamentous algae were found in any of the 54 fish examined. The range of animal food eaten is quite large, the smallest minnows having the most restricted diet. In this sample, the guts of the largest minnows contained a proportionally greater volume of Ephemeroptera nymphs than the smaller fish, and in this respect agree with the findings of Frost and Stankovitch cited above. It must be noted that though the range of diet is large, the volume of food eaten in this sample is very small, appreciably less than in any of the other fish examined. This sample was taken subsequent to a flood, and the shoal structure, as described previously, changed dramatically from that prior to the flood. In the later section on reproduction, a note is made of the state of maturity of the fish occupying this pool. It is probable that these fish were late spawners, and were in the process of spawning at the time of capture. It is therefore not surprising that gut analyses showed little evidence of feeding behaviour. The practice of minnows to capture any small moving object in their field of vision suggests that the prey organisms found were caught in this non-selective manner, after having been disturbed during breeding behaviour. This speculation is in agreement with the observed behaviour of the fish. It would also explain why the guts contained so few prey belonging to so many categories. The eggs founds in minnows of 68-72 mm. size group were probably either minnow or stickleback eggs. Frost records minnow eggs in her category of 'Chance Food'.

iii. Bishop Auckland.

The data in Table 4 on percentage fullness shows these minnows from Bishop Auckland to have been feeding actively. Although plant material is present in a large proportion of the fish examined, it contributes little to the total volume of food eaten. Chironomid larvae becomes less important as the fish increase in size; the reverse is the case with Ephemeroptera nymphs. The latter are very well represented in the minnows greater than 70mm. The significance of this large figure for the largest group is not certain since only 5 fish were examined. However, these nymphs were found to be an important constituent in smaller fish examined, so that they probably are, in this group also, the most important food item. Adult Ephemeroptera are present in the smallest size group though absent from the other two. There is no doubt that all the minnows examined were physically capable of eating these emerging imagos, so that the difference found can only be attributed to chance encounter. Even within a shoal there is often subdivision according to size. The shoal sampled at Bishop Auckland was in fact much more dispersed than at Durham Sands, the larger fish moving in 'sub-shoals' of up to a dozen fish. Trichoptera larvae occur in small numbers in all size groups, though Trichaptera adults are absent from all.

An interesting 'chance food' in one 70-80 mm. minnow is the Gastropod <u>Ancylus fluviatilis</u>. P. S. Davis (1971), working on this mollusc, found that minnows did occasionally let the limpet if the latter was somehow dislodged from its stone. Limpets are rarely dislodged in this way, so that its rare occurence in gut samples is not unusual. This evidence also corraborates the frequent observation that minnows attempt to eat any small moving object.

Chironomid pupae are not as abundant in this sample as in some others, notably that from Page Bank.

It was unusual to find Coryxids in both the 50-62 mm. and 70-80 mm. groups; as these are quite large prey for minnows, the data only represents single individuals in both size groups.

Coleoptera larvae are recorded for all three size groups.

(iv) Witton-le-Wear.

From the large values for percentage fullness of the guts (Table 4), these minnows also seem to have been actively feeding. The algal cover at Witton-le-Wear was much less than at Durham Sands or Bishop Auckland, but the percentage occurence is still high. But, only in the smaller size group does plant material contribute significantly to the total volume. The guts of the larger fish contained very little plant material indeed. Ephemeroptera nympha , beetle larvae and chironomid pupae contribute most significantly to the diet. The single Isopod, the numerous very small mites, 'other Diptera' and Trichoptera are far less important, and may be taken as 'chance food'. The river bed at Witton-le-Wear consists of fairly clean large pebbles, having little algal or moss cover; Ephemeropteran nympha were noted as being quite abundant there.

(v) Sunderland Bridge.

Very few minnows were ever seen at Sunderland Bridge. The small values for gut fullness also suggests relative scarcity of suitable food. The river at this site differs from all the other sites in that the water is much deeper, and the river bed consists of mud and silt with little or no stony material. It has been mentioned previously that this site is considered an atypical minnow habitat. The food organisms found an analysis of the guts are also very different from other sites. Nowhere else do Ephemeroptera adults (subimagos) figure so predominantly in the sample. Chironomid pupae are also exceptionally abundant here.

The amphipod, Gammarus pulex, is an interesting item found in the smaller size group, whilst Plecopteran nymphs occur in the larger group.

(vi) Page Bank.

The most interesting outcome of analysis of this sample is the progressive increase in the contribution of the Chironomid pupae to the food. Chironomid pupae are quite small, so that the percentages shown in Fig. 36 represent large numbers of these animals. Ephemeropteran nymphs are absent from the smallest fish, but do occur in both the larger groups. Little significance should be placed on differences between size groups when small numbers of prey are represented.

Discussion.

Many of the more relevant points of interest arising from the results of the gut analyses have already been discussed. However, a few general points do arise. The data presented in Fig. 3 gives a good comparative picture of the relevance of the different food groups within any particular size category of minnows. The fact that the sample size varies between these categories makes absolute comparison difficult. It would have been possible to have carried out t-tests to compare the mean values for gut volume occupied by food for all food groups and minnow size categories. This would, however, have been a very lengthy process, the results of which would not be greatly different from deductions made using the displayed data, taking into consideration the sample size.

Comparison of the present data with that of Frost (1943) has been carried out extensively throughout the above account. She noted that filamentous algae diatoms, chironomid larvae and Ephemeroptera nymphs were the most important constituents of the food of River Brathay minnows. This contrasts with the large contribution by Copepoda and Cladocera in Lake Windermere fish. The River Wear data is very similar to that for the River Brathay, except that in the former Trichoptera larvae and Plecoptera nymphs are less important.

Smyly (1955) notes that the Stone-Loach feeds extensively on invertebrates Chironomid larvae being the most important numerically and volumetrically. He includes a list of prey organisms which resemble very closely that for minnows.

It is interesting that in 'items of rare occurence' he includes Mollusca and Hemiptera, noting that the latter group was represented only twice, and on both occasions was a single Corixid . Stone-Loach seem to feed less extensively on plant material.

In a later paper (1957), Smyly includes data for the Bullhead. Here, the data again resembles that for the minnow and Stone-Loach, apart for the large contribution by Plecoptera nymphs. Ephemeroptera nymphs and Chironomid larvae are of major importance, though Trichoptera larvae are also more abundant here than it has been found for the minnow in the River Wear. Smyly' results are more closely akin to the original work of Frost, but since all samples for all three species came from the River Brathay, this is not surpris Smyly concludes that, in Bullheads, the food varies more with season and place than with size of fish. He also states that inferences regarding feeding activity could not be drawn from gut fullness data since nothing was known about the rate of digestion of food, the rate of feeding or the numbers of invertebrate bottom organisms.found. In the River Wear samples, observation during the predation tests showed that nymphs and larvae pass right through the gut within 1-1½ hours, so that any food found in the gut had probably been very recently eaten. The rate of passage of food did not very appreciably with availability.

The food of freshwater sticklebacks is discussed in the paper by Hynes (1950). Gasterosteus aculeatus feeds mainly on Crustaceans and Insects, with little change in diet either with season or size of fish. Hynes points out, however, that both sexes feed more sporadically than usual during the breeding season. Stickleback eggs were frequently found in the guts during the breeding season. The sampling pool at Durham Sands contained large numbers of 3-spined sticklebacks, which were in breeding condition at the time of first sampling in May. 20 of these fish were caught and their gut contents examined, with the following results:

Food Group	% volume of all food eaten.
Chironomid larvae	25
Chironomid pupae	20
Other Diptera	5
Ephemeroptera nymphs	15
Eggs	25
Debris and other material	10

65% of the food eaten was composed of Chironomid larvae and pupae and Ephemeroptera nymphs, which have been shown to be the main constituents of the diet of minnows also. The large number of eggs found agrees with Hynes' observation above. It is assumed that the eggs were those of the sticklebacks themselves since only one fully mature minnow was caught at this time. In fact, repeated minor samples taken at this site did not suggest the presence of breeding minnows until the end of June.

Comparison of the food of various fishes, including that of the minnow, has been made by Hartley (1948) and Maitland (1965). Hartley includes data for minnows, stone-loach and bullheads, concluding that the diet of each consists of generally the same species of invertebrate, except that the proportions of the different groups taken are slightly different. Loaches and bullheads took slightly more insects than did minnows; loaches and bullheads took considerably more crustaceans. Diatoms and filamentous algae contributed more to the diet of minnows than to that of either of the other tw species. Hartley found that there was a great overlap in feeding habits and food of many freshwater fishes, though there was a certain degree of preference, some groups not taken by various species. Between no two species was there any 'true identity of feeding habit'. Gudgeon and sticklebacks had the most similar diet, and, except for pike, there was 'a great degree of general competition.' Different species differed in the varying proportions in which they drew upon the constituents of a common food group. Hartley (194 also found that most coarse fish have great flexibility in their feeding behaviour. The great difference found between the diet of minnows caught at Durham Sands in May and in June certainly corraborates this.

COMPARISON OF THE OBSERVED GUT CONTENTS WITH THE NATURAL INVERTEBRATE FAUNA OF THE RIVER.

A survey of the invertebrate fauna of the River Wear was carried out by the Zoology and Botany Departments of the University of Durham as part of the extensive River Wear Project. A summary of the results of part of this work for the summer months May-July was made available to me.

(i) Witton-le-Wear.

Witton-le-Wear is dominated faunistically by Plecoptera and Ephemeroptera nymphs. Chironomid larvae are abundant, as are Helmid beetle larvae and adult *Simulium* larvae and Oligochaetes (including Tubificidae) are noted, with fair numbers of caddis larvae, including *Polycentropus*. None of the latter were, however, abundant.

The stone-flies are dominated by *Leuctra* sp. with *Perla* sp. present with few others. No stone flies were recognised in any of the minnow guts examined, though a few may have been present in a chewed form, making them indistinguishable from fragments of the more abundant mayfly nymphs. Not all the fragments of mayflies examined in gut smears could be identified to genus, though *Ephemerella* was considerably easier to identify due to the banding patterns on the limbs. It was noted that *Ephemerella* was not the dominant nymph in this sample. In the Wear, *Baetis* is listed as the most important genus, followed by *Ephemerella* and then by *Ecdyonurus*. *Caenis* sp. are present in small numbers only. This pattern closely resembles that observed in the gut samples. Fig. 3 shows Chironomid larvae and beetle larvae to be important food items, the latter being identified as belonging to the family Dystiscidae. Caddis larvae and adults are also recorded in the gut samples.

(ii) Bishop Auckland.

Above the railway viaduct at Bishop Auckland, at the point of minnow sampling, Leuctra is the only Plecopteran found, and is described as being abundant. However, none were identified in the gut smears. The Ephemeropteran nymph population is very similar in generic composition and abundance to that at Witton-le-Wear. Baetis and Ephemerella were very abundant in the guts examined, whilst some emerging adults were also recorded in the smallest size groups. The remainder of the invertebrate fauna is very similar to that at Witton-le-Wear, apart from the more abundant Caddis larvae at Bishop Auckland. Polycentopus is described as considerably more abundant, with Hydropsyche also important. Both these species were found in the guts examined, two cases of vegetable matter being found, possible being those of Polycentropus.

(iii) Page Bank.

No faunistic data was available for this station, though its close proximity to Willington Bridge allows the use of data for the latter to be used in this case. The dominant groups found in the gut samples were Chironomid larvae and pupae, followed by Ephemeroptera nymphs. Trichoptera larvae were absent from the smallest minnows, but did occur, though occupying a small percentage volume, in the larger fish. Caleaptera larvae were found in the larger fish. No Plecopteran nymphs were found. This compares well with the recorded low abundance of Plecoptera in this region of the river below the entry of the River Gaunless into the Wear. Leuctra is recorded as being much less abundant than upstream, whilst other stonefly larvae are rare. Ephemerella is the dominant mayfly, with Ecdyonurus and Baetis also occuring in large numbers. Caenis is less abundant than these. Chironomid larvae are very abundant, as well as Helmid beetle adults and larvae Oligochaetes are described but were not found in the guts. The tendency for food to be ground into small fragments, together with the rapid digestion of soft parts, make the discovery of such food items less likely than for those groups with hard exoskeletons. The Caddis larvae Ryacophila, Polycentropus and Hydropsyche are fairly numerous here, though forming but a small proportion of the observed food of the minnows.

(iv) Sunderland Bridge.

Sunderland Bridge lies midway between Willington Bridge and Shincliffe Bridge, and about one mile upstream of the confluence of the River Deerness. Faunistic data is available for Willington and Shincliffe, though not for Sunderland Bridge. Comparison of the two sets of data shows broad similarities in faunal composition, particularly regarding the Plecoptera, for which Leuctra is the only one recorded, and is much less abundant than at the other stations upstream. The Ephemeroptera are very similar in species composition and relative abundance at both stations; the only great difference is in the rarity of caddis larvae and Helmid beetles at Shincliffe. Chironomid larvae are recorded as being very abundant at both. Fig. 3 shows the high percentage of Chironomidae in the guts, but the numbers of beetle larvae found suggest that the fauna at Sunderland Bridge resembles far more closely that upstream of the confluence of the Deerness than at Shincliffe.

(v) Durham Sands.

The fauna at Durham Sands is exceptional in its almost complete lack of stoneflies. A few Leuctra sp. are recorded, but only about one-tenth the numbers at Bishop Auckland. No other species are found during the summer months, Amphinemura occuring only in winter. Vast numbers of Ephemerella occur, as at Shincliffe, but Baetis and, to a lesser extent, Ecdyonurus are also numerous. Caenis, as is common throughout the Wear, is rare. Hydropsyche and Polycentropus are numerous here, with very large numbers of Chironomid larvae and Tubificids amongst the mud and plant material. The minnow guts contained an invertebrate fauna very similar to that described above.

PREDATION BY MINNOWS OF DIFFERENT LENGTHS ON VARIOUS PREY ORGANISMS.

Methods.

Following the method of Davies and Reynoldson (1969) minnows were starved for 7 days prior to the experiment. One starved minnow was placed in a 1000 ml. beaker of clean tap water in which had been placed 10 individuals of a prey species. In all but one case, no shelter was provided. When a prey organism was eaten it was replaced by another of the same size and species. Note was made, usually every 15 minutes, of the numbers eaten, which were then replaced. For the first 15 minutes the minnows were observed continuously. This procedure was repeated for all the prey organisms listed in Table 5, and for each of the three sizes of minnows over an observation period of 8 hours. Two replicates were run concurrently, and the whole was repeated.three times. The mean values of the results are shown in Table 5 as the number of prey taken per minnow per 8 hour period.

Results.

By nature of the test material, the results are only semi-quantitative, but are useful when considered in relation to the gut analyses described above.

The first, most obvious result of feeding minnows with natural prey organisms is in agreement with what has been described many times in the earlier part of this chapter. A prey organism left in the bottom of a 1000 ml. beaker of water swims or crawls about, usually quite vigorously. This seems to attract the minnow, which then seizes the animal. A repeated pattern of ingestion and ejection was observed.

Davies and Reynoldson (1969) record that the stickleback, Gasterosteus aculeatus, often rejected food after ingestion. When rejection did occur the prey organism was often subsequently ingested and rejected again several times before being finally swallowed or rejected. Such behaviour was often observed in minnows kept in aquaria. The combination of this selection process, together with the initial, non-selective attack on any 'potential prey' seems to account, to a large extent, for the feeding behaviour of the minnow. During swimming activity in the shoal minnows almost certainly disturb prey into flight movement, and the roaming nature of the shoal adds to the possibility of coming across moving larvae or emerging adults.

The occurence of the repeated ingestion-rejection process increased with the duration of the experiment. The rate of predation an Ephemeroptera nymphs shown in Fig. 4 is a function of this behaviour pattern.

In the case of predation on Ephemeraptera larvae, with or without the presence of a stone, there is a significant difference between the numbers taken by 38mm. minnows and fish of 45 mm. or 52mm. There is no significant difference between values for the two larger sizes ($P = 0.05$).

Chironomid larvae were readily and easily swallowed by all sizes of minnow

There seemed to be no limit to the number of larvae which could be eaten. The algal covering of the stones in the Wear contains a vast population of small chironomid larvae readily available to the minnows.

It is interesting that no caddis larvae of any species was taken when introduced in its case. Hydropsyche larvae, although large, were swallowed by all three sizes of fish. All seemed to have difficulty in swallowing the prey, the larger fish expectedly succeeding more often than the smaller ones.

Gammarus pulex were also apparently difficult for the minnows tested to swallow. By vigorous swimming action most amphipods were able to escape, even after being seized between the fish's jaws.

Herpobdella is a very common leech in the minnow pool at Durham Sands, though no leeches were eaten, probably due to their large size and slimy surface. Many attempts were made at capture, but none were successful.

The predation on Ancylus fluviatilis followed very closely that described in the previous section, namely that, of the many test aquaria set up, most limpets dislodged by the swimming action of the minnow were left alone, and only rarely were any eaten. One exceptional minnow ate 4 limpets in 2 days (see Davis, 1971).

The food of minnows - Conclusions.

The results of this series of predation tests confirm the mode of feeding of minnows deduced from examination of gut contents. Many organisms which do form an important constituent of the minnow's diet were not tested;

the main reason for this in all cases was the difficulty of obtaining sufficient individuals of approximately the same size for all the replicate tests. Hydropsyche was difficult in this respect.

The logarithmic rate of predation on Ephemeroptera nymphs is interesting in that it shows that minnows do not, at least under experimental conditions, feed mechanically. It is not known whether or not this progressively decreasing rate of predation is due to 'saturation', i.e. satisfaction of the predatory drive, or due to some factor akin to monotony. In the growth tests carried out with minced liver, excess food had the same result. Should this phenomena occur under natural conditions it would tend to obscure any differences in size due to food availability.

There is a good correlation between the food of minnows and that potentially available. Ephemerella and Baetis, followed by Ecdyonurus are dominant in the gut and river analyses, as are Chironomid larvae and pupae. Trichopteran larvae are less abundant in the guts than would be expected, but this is probably due to their more sedentary behaviour and protective case. Movement on the part of the potential prey in attracting the attention of the minnow is very important. The medation tests showed that minnows apparently found difficulty in eating caddis larvae. Some of the common animals, such as Oligochaetes, are not recorded in the diet of minnows, probably due to the rapid rate of digestion and absence of large indigestable skeletal structures to aid in identification.

It is therefore to be concluded that minnows are probably largely non-selective in their feeding behaviour. Evidence from the predation tests suggest that diet consists of small moving objects, which, on swallowing, prov to be palatable. Selection is relatively unimportant until the potential prey has been swallowed.

Allen (1942) concluded that the availability of naturally occuring food organisms changes with the size of a fish, and that, within the Salmonidae, size was more important than species. He found that the Ephemeroptera and Chironomidae decreased in availability as the size of the fish increased, but the availability of Trichoptera and Mallusca increased. In a previous paper (Allen, 1941) it was found that, for the salmon, definite selection is exercised by most of the fish which have more than a few animals in their stomachs, and that the effect of selection is to increase the apparent availability factors of those animals most abundant in the available fauna. It is therefore probable that initial feeding is fairly non selective, but the possibility of action of some kind of 'searching image' cannot be overruled. Ephemeroptera nymphs or Chironomid pupae and adults usually occured in large numbers, to the exclusion of most other food items, in the larger minnows with full guts. This certainly suggests some form of conditioning to a food item, but differs from the specific example of change i availability as the size of the fish increased, but the availability of Trichoptera and Mallusca increased. In a previous paper (Allen, 1941) it was found that, for the salmon, definite selection is exercised by most of the fish which have more than a few animals in their stomachs, and that the effect of selection is to increase the apparent availability factors of those animals most abundant in the available fauna. It is therefore probab that initial feeding is fairly non selective, but the possibility of action of some kind of 'searching image' cannot be overruled. Ephemeroptera nymphs or Chironomid pupae and adults usually occured in large numbers, to the exclusion of most other food items, in the larger minnows with full guts. This certainly suggests some form of conditioning to a food item, but differs from the specific example of change in availability described above for the Salmonidae. The relatively small size of even 3-year old minnows probably accounts for this.

2. GROWTH

Pentelow (1939) gives a good account of the relation between food and growth in fish, particularly in the case of Salmo trutta L. He fed a number of trout on live Gammarus pulex, estimating the weight of food actually eaten by the fish each week. The duration of the experiment allowed for estimation of the maintenance requirement of the fish. He showed that it was impossible to foretell exactly how much food would be required for this purpose. A number of fish were kept at maintenance ration whilst others were given more in series up to an excess of food. Pentelow was fortunate that facilities allowed for monitoring the individual growth of the trout. He found a decrease in growth rate of all fully fed fish due partly to low efficiency of food consumption and decline in appetite. Growth in weight was variable, but generally it increased with increasing size of fish. The food source proved to be very efficient in that 5 gm. produced a 1 gm. increase in weight of trout. This figure included about 2 gm. of food for maintenance.

A study of trout populations in Sutherland Lochs (Pentelow, 1944) showed that where the water was soft competitions were absent, with spawning conditions and fry survival good. Pentelow concluded that under these conditions, intraspecific competition for food was great, resulting in small mean size. In hard, alkaline waters competitors were commoner, egg and fry survival being smaller. This resulted in a decrease in population size, less intraspecific competition for food, and hence the surviving fish grew bigger. The great overlap of feeding habits and food in coexisting fresh-water fish has already been discussed, and it is well known that most coarse fish have considerable flexibility of feeding behaviour, (see Hartley, 1940). Maitland (1965) concluded that competition for food was probable under certain conditions in salmon, trout, minnows, stone-loach and three-spined sticklebacks He could not, however, assess the significance of any such competition. Smyly (1955) considered that in the stone-loach there existed a 'strong probability of a direct association between food and growth rate.' Wingfield (1940) states that below a critical temperature of 6^{o}C. no growth takes place, but that seasonal variations in growth appear to be the direct result of fluctuations in available food supply. Under natural conditions both water temperature and available food supply apparently act as limiting factors during the winter. In the summer, above the lethal level, only the available food supply is limiting. Wingfield also suggests the possible importance of light intensity.

Method.

Three large aquaria, containing well aerated ordinary tap water, were set up and 14 minnows introduced into each. The minnows were weighed by immersion into a weighed quantity of water, the fish being added to the pan one at a time so that individual and cumulative weights could be ascertained. The fish chosen were such that the cumulative weight of each group of 14 minnows were approximately the same. The fish were starved for two days prior to weighing, and subsequently, minced liver was added in the following quantities:

Tank A	-	320 mg.
Tank B	-	640 mg.
Tank C	-	1280 mg.

Minced Bullock's liver was chosen as a food supply since it met the need for consistency in nature and ease of availability, and was found to be taken readily by the minnows. All the liver was eaten within a few hours; consequently, two days later, the quantity of food given was doubled in each tank. The fish were thus fed every second day for a period of 56 days. Every 14 days the fishes were weighed as before, time being allowed for emptying of the guts prior to weighing. The liver tended to foul the water badly, so that at least one of the 5 gallons in each tank was changed each alternate day. The continuous aeration seemed to keep conditions fairly suitable. Every 14 days the water in each tank was changed completely and the tank thoroughly cleaned.

The food regime chosen was such that all the food was eaten in tank A, often all eaten in B, and such that it was always in excess in tank C. Before the addition of each food ration, faeces were removed, and uneaten liver partly drier between filter paper and weighed. The latter procedure, though crude, gave a rough idea of the amount of food actually eaten in each tank.

Only 3 fish died during the experiment, two in tank B and one in tank C. Each dead fish was replaced by one of approximately the same size, any difference in weights being allowed for in the calculation of growth.

Results.

The growth of the minnows could not be calculated individually, so that the results are expressed as the percentage increase in net weight, cumulative for each group of 14 minnows. The results so detained are shown in Fig. 5.

In tanks A and C growth was rapid, and quite considerable over the two month period. The fish in tank B, however, decreased in weight until the beginning of the second month. Since, visibly, all conditions, for the amount of food given, were identical in all three tanks, no reason can be put forward for this decrease.

TABLE 6 gives the increase in total weight per tank as a percentage of the total weight of liver eaten. It is noted that, in the last 28 days of the experiment, these values are much greater in tank A than in C. Also, there is a trend towards considerable increase in the latter expression in tank A but is much less so in tank C.

The time and facilities available were such that extended tests with adequate replicates were not possible, and so the results are tentative. However, since the purpose of the experiment was to investigate whether or not growth was related to absolute food availability, it is considered that this was, in part, successful.

The results show that, other things being equal, growth does depend on the amount of food eaten. This is not a simple relation though, since TABLE 6 shows a higher conversion efficiency (production/ingestion) under conditions of decreased food availability. Alternatively, it can be concluded that production/ingestion efficiency decreases with food availability

Many factors probably contributed to the amount of food left uneaten in tank C; an important factor would have been the deterioration in condition of the liver. Tank A fish ate all the liver within 30 minutes, but the amount of food given in tank B and C meant that much food necessarily remained in the water for longer than this. On a few occasions however all the food was eaten in tank B, though it took 24-36 hours for this to occur. The results of this experiment suggest that minnows do not have an insatiable appetite. Evidence of this was also detained in the predation tests with Ephemereptera nymphs (see Fig. 4.)

Growth in length with age.

Using the length frequency data for the Bishop Auckland sample, a growth curve of length with 'suspected age' was drawn (Fig. 6). Only one 4 year old fish was caught so that the curve may not be representative, of the whole 'population' beyond the third year. The growth rate is very similar to that found for River Brathay minnows (Frost, 1943), except that Frost's minnows showed a greater decrease in rate between the second and third year. The mean lengths of the expected ages of the Bishop Auckland fish are, in all cases, greater than those of the River Brathay.

LENGTH-WEIGHT RELATIONSHIP

In fish weight varies with length according to the general formula:

$$\underline{w} = \underline{a}\,\underline{l}^{\underline{b}}$$

$\underline{w}$ = weight.

$\underline{l}$ = length

$\left.\begin{array}{l}\underline{a}\\ \underline{b}\end{array}\right\}$ growth coefficients.

This relationship would best fit an individual fish that was weighed and measured in successive years of its life. It is usual in fisheries biology to determine the coefficients a and b by plotting the logarithm of the weight against logarithm of the length for a large number of fish of various sizes. A value of b = 3 describes 'isometric' growth such as would characterize a fish having unchanging body form and constant specific gravity. Departure from the 'idea' value of 3 may be due to a variety of factors, such as stomach contents, spawning condition and time of year, (Ricker, 1958). Larger minnows, particularly females in breeding condition, might be expected to have b - values significantly different from 3.

Results.

The regression equations shown in TABLE 7 were derived with the aid of a computer. In all the samples tested the regression equations indicate that growth occurs approximately isometrically in both sexes throughout the size range investigated, except for fish greater than 60mm; there is no evidence of allometric growth in minnows less than 60 mm., that is fish less than 2 years old. This may be evidence of the existence of at least two stanzas, according to the definition of Tesch (1968). The small differences between the values of coefficients 'a and b between samples are not significant at the 5% level. There is no clear trend in the form of growth indicated by the equations, though the smallest fish of the Durham Sands June sample do have b values most closely approximating to the theoretical isometric growth value of 3. Significance tests using F-values give $P < 0.01$ for all samples.

REPRODUCTIVE CONDITION

Regan (1911) describes spawning as occuring in May and June. The minnows move to gradually shallows, usually in brooks where the stream runs fairly rapidly. The eggs are laid on the bottom, adhering to each other and to the stones. Frost (1943) describes most minnows under 35 mm. as sexually unmature, though there is a considerable difference between individuals, due to the protracted breeding time, which she gives as between May and July. After spawning the gonads pass through a period of rest, and then, in late summer and autumn, are replenished with spermatogenia and primary oocytes, or with the early stages of secondary oocytes. Low temperature, coupled with a photoperiodic response, prevents any development beyond this stage until spring. The egg diameter increases from the autumn-spring value of 0.5mm. to the fully mature size of 1.4 mm. in summer (Bullough, 1939).

The sexes of even unmature specimens are easily distinguished on internal examination. Prior to spawning the ovaries of sexually mature females contain large yellow eggs, the older females having a greater proportion of ripe eggs.

Methods.

The sex of all the fish was ascertained by internal examination. The condition of the gonads of each female fish was noted.

Results and Conclusions.

The sex ratio of the different samples are shown in TABLE 8.

The June sample at Durham Sands contained females in the following condition:

Condition of ovary	No. of females	Proportion	Length Range (mm).
Full of large yellow eggs or spent	24	35.8%	760
Half eggs yellow	9	13.4%	50-60
Mostly smaller white eggs	11	16.4%	40-50
Small white eggs only	23	34.4%	40
	67	100%	

Assuming a Null Hypothesis of sex ratio of unity, the P values are all low, although only those for Bishop Auckland and Witton-le-Wear fall below the 5% level. It can therefore be concluded that the sex ratio of all minnows examined does not depart very significantly from unity.

Although only the June Durham Sands sample allowed examination of ovarian conditions in a spawning shoal, it is clear that, as Frost describes, minnows over about 40mm. in length are sexually mature. However, the proportion of unripe eggs was high in ovaries of all fish less than 60mm. I therefore appears that although one-year old fish are capable of breeding, they do not reach their full potential until they are at least two years old. They do not therefore contribute greatly to the future population until that time. Mann (1971) records similar observations for minnows in Dorset where 'the majority of fish did not spawn until the end of the second year'.

GENERAL CONCLUSIONS

River Wear minnows do not differ in size range or feeding habits from those examined by other workers in different parts of the country. The problem of sampling a fish population which has an unstudied shoaling pattern was evident throughout the work. This made the formulation of population structure very difficult. It is probable that all the Wear minnows have some degree of association with one another, such that the unit population includes all of these. It is still possible however that shoals of minnows in some stretches of the river do have some degree of discreteness, though the extent of this is unknown. Studies on movement within the river, using methods described by Stott (1968) and Robson & Regier (1968), would be useful here. There is some evidence from length frequency distributions that considerable variation in length with age does exist within the river, though much of the observed distributional pattern is probably a function of the shoaling behaviour. The work carried out indicates very considerable variation in the structure, pattern and size of minnow shoals with time and place.

The feeding behaviour of the minnows does vary with time and place, though in all cases it seems to be dependent primarily on availability. There is no evidence from gut contents analyses, available food in the river, nor from laboratory tests that any selection exists. Evidence suggests that minnows eat anything that moves in a way characteristic of most small invertebrates, any selection occuring after seizure, probably by taste. There may be a certain degree of conditioning involving the establishment of a 'searching image'. Grazing or plant material is also non-selective in terms of types taken, these being predominantly, Cladophora, Ulothrix and and Chaetophora. All the minnows samples, and, in fact, all those observed in the river, seem to live in areas of plentiful food. The catholic diet, with a large variety of food taken, even between members of the same shoal, suggests that food is not a limiting factor, at least in the summer months in the Wear. Minnows move about the river in shoals, probably, as Regan (1911) suggests, in search of new feeding grounds. Theoretically, it is possible that food could become limiting, and intraspecific competition became important if the population increased in size. The labile nature of the shoals suggests that predation pressure in any one area is easily reduced by migration to another feeding area and by a decrease in shoal size. Evidence for the latter possibility is still tentative at present. No correlation exists between gut contents or fullness and body length or weight. Predation and feeding experiments indicate that though feeding rate is not constant, but shows signs of satiability, growth is directly related to food intake. The Breeding season in the River Wear is longer than recorded elsewhere. Fully ripe females were found in early May, and also in late July. The latter were seen at Durham Sands when minnow fry up to 11mm. long were common throughout the river.

SUMMARY

1. Shoals of minnows (Phoxinus phoxinus L.) were sampled from selected sites in the River Wear, County Durham, and their length frequency distributions examined.

2. Shoaling behaviour prevented the examination of population structure, but great variations in shoal structure and size were observed with time and place. Shoals of minnows often consisted of one or two age groups, whilst some contained representatives of up to 4 year classes.

3. The feeding habits of the minnows were studied by examination of gut contents and by means of predation experiments in the laboratory. The diet was seen to consist of a very wide variety of plant and invertebrate material, Chironomidae and Ephameroptera being the major constituents. Evidence suggested that feeding was largely non-selective, the fish tending to seize any small moving object, though rejection after swalling occurs. There was evidence of satiation of the feeding drive. Gut contents generally resembled the faunal composition of the river site in species spectrum and relative abundance.

4. Circumstances and facilities did not enable conclusive growth tests

to be performed, though minnows fed on ox's liver did grow larger when given more food. A higher conversion (production/ingestion) efficiency was observed at lower feeding regimes. Length-weight regressi suggested the presence of at least two 'stanzas', growth being isometric up to the end of the second year.

5. The sex ratio of shoals did not differ widely from unity. Minnows were observed to have a longer breeding season than generally reported. Ripe females were caught in considerable number in mid-July.

ACKNOWLEDGEMENTS.

I am very grateful to Mr. W. B. Woodward for his advice and encouragement at all stages of this work. I also wish to thank Dr. L. Davies for help in identification of some of the gut contents and making available to me some of the results of the River Wear Project. I am also indebted to the Northumbrian River Authority for permission to collect samples in the Wear.

REFERENCES.

ALLEN, K. R. (1941). Studies on the early stages of the salmon (Salmo Salar). 2. Feeding habits.
J. Anim. Ecol. 10, 47-76

ALLEN, K. R. (1942). Comparison of bottom faunas as sources of available fish food.
Trans. Amer. Fish. Soc. 71, 275-83

ANDREWARTHA, J. E. & BIRCH, L. C. (1954). The distribution and abundance of animals.
Chicago: Univ. Press. XV + 782 pp.

BUCHANAN-WOLLASTON, H. J. & HODGSON, W. C. (1929). A new method of treating frequency curves in fishery statistics, with some results.
J. Cons. perm. int. Explor. Mer. 4, 207-225.

BULLOUGH, W. S. (1939). A study of the reproductive cycle of the minnow in relation to the environment.
Proc. zool. Soc. Lond. A109, 79-102.

CASSIE, R. M. (1954). Some uses of probability papers in the analysis of size frequency distribution.
Aust. J. mar. freshwat. Res. 5, 513-522.

CHRISTENSEN, J. M. (1964). Burning of otoliths, a technique for age determination of soles and other fish.
J. cons. int. Explor. Mer. 29, 73-81.

DAVIES, RONALD W. & REYNOLDSON, T. B. (1969). The incidence and intensity of predation on lake dwelling triclads in the laboratory.
Ecology 50, 845-853.

DAVIS, P. S. (1971). M.Sc. Ecology Dissertation. University of Durham.

FROST, W.E. (1943). The Natural History of the Minnow, Phoxinus phoxinus
J. Anim. Ecol. 12, 139-162.

HARDING, J. P. (1949). The use of probability paper for the graphical analysis of polymodal frequency distributions.

J. Mar. biol. Assoc. U.K. 28, 141-153.

HARTLEY, P. H. T. (1940) The food of coarse fish: being the interim report of the coarse fish investigation.
Freshw. Biol. Assoc. Sci. Publ. No. 3 1-33.

HARTLEY, P. H. T. (1948) Food and feeding relationships in a community of freshwater fishes.
J. Anim. Ecol. 17, 1-14.

HYNES, H. B. N. (1950) The food of freshwater sticklebacks (Gasterosteus aculeatus and Pygosteus pungitius), with a review of method used in studies of the food of fishes.
J. Anim. Ecol. 19, 36-58

JOHNSTON, M. (1938). Some methods of preparing teleost fish otoliths for examination. J. R. Micr. Soc. 58, 112-119.

JONES, J. W. & HYNES, H. R. B. (1950). The age and growth of Gasterosteus aculaetus, Pygosteus pungitius and Spinachia vulgaris, as shown by their otoliths.
J. Anim. Ecol. 19, 59-73.

LACK, D. (1954). The natural regulation of animal numbers.
Oxford, Clarendon Press, VIII + 343 pp.

LE CREN, E. D. & HOLDGATE, M. W. (ed.) (1962). The exploitation of natural animal populations.
Oxford, Blackwell. XIV + 399 pp.

LE CREN, E. D. (1965). Some factors regulating the size of populations of freshwater fish.
Mitt. Internat. Verein. Limbol. 13, 88-105

MACAN, T. T. (1959). A guide to Freshwater Invertebrate Animals.
London: Longmans 118pp.

MAITLAND, P. S. (1965) The feeding relationships of Salmon, Trout, Minnows, Stone-Loach and Three-Spined Sticklebacks in the River Endrich, Scotland.
J. Anim. Ecol. 34, 109-133.

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

PENTELOW, F. T. K. (1939) The relation between growth and food consumption in the brown trout (Salmo trutta).
J. exp. Biol. 16, 446-473.

PENTELOW, F. T. K. (1944) Nature of acid in soft water in relation to the growth of brown trout.
Nature, London, 153, p.464.

PRESCOTT, G. W. (1964) How to know - the Freshwater Algae.
London: Wm. C. Brown Co. 271 pp.

REGAN, C. TATE, (1911). The Freshwater Fishes of the British Isles.
London: Methuen & Co. Ltd., 287 pp.

RICKER, W. E. (1958) Handbook of computations for biological statistics of fish populations.
Fish. Res. Bd. Canad. Bull. No. 119, 300 pp.

RICKER, W. E. (ed.) (1968) Age and Growth Methods for assessment of Fish Production in Freshwaters. IBP Handbook No. 3.
Oxford. Blackwell Sci. Publ.

ROBSON, D. S. & REGIER, H. A. (1968) Estimation of Population Number and Mortality Rates.
in Ricker 124-158.

SMITH, K. (1968). Some thermal characteristics of two rivers in the Pennine area of Northern England.
J. Hydrol. 6, 405-416.

SMYLY, W. J. P. (1955) On the biology of the Stone-Loach, Nemacheilus barbatula(L.) J. Anim. Ecol. 24, 167-186.

SMYLY, W. J. P. (1957) The Life History of the Bullhead or Miller's Thumb. (Cottus gobio L.)
Proc. Zool. Soc. Lond. 128, 431-53.

STANKOVITCH, S. (1921) Etude sur la morphologie et la nutrition des alevins de poissons cyprinides.
Diss. Grenoble. (Cited by Frost).

STOTT, B. (1968). Marking and Tagging.
in Ricker, 78-92.

SWYNNERTON, G. H. & WORTHINGTON, E. B. (1940). Note on the food of fish in Haweswater (Westmorland).
J. Anim. Ecol. 9, 183-7

TACK, E (1940) Die Ellitze (*phoxinus laevis* Ag.) eine monographische Bearbeitung.
Arch. Hydrobiol. 37, 321-425 (Cited by Frost).

TANAKA, S. (1962) A method of analysing a polymodal frequency distribution and its application to the length distribution of the porgy, *Taius tumifrons*.
J. Fish. Res. Bd. Canad. 19, 6, 1143-1159

TESCH, F. W. (1968) Age and Growth.
in Ricker 93-123.

WHITTON, B. A. & BUCKMASTER, R. C. (1970) Macrophytes of the River Wear.
The Naturalist No. 914, July-September 97-116.

WINGFIELD, C. A. (1940) The effect of certain environmental factors on the growth of brown trout.
J. Exp. Biol. 17, 435-448.

WYNNE-EDWARDS, V. C. (1962) *Animal dispersion in relation to social behaviour.*
Edinburgh and London: Oliver & Boyd, 601 pp.

TABLE I.

Stream flow and major chemical features of the River Wear near the sample stations.

Location	Km. from Wearhead	Stream flow l/sec.	Ca mg./l.	NO_3-4 mg./l.	PO_4-P mg./l.
Wolsingham	24.2	3049.7	36.0	0.28	<0.015
Witton-le-Wear Bridge	35.2	3049.7	34.0	0.51	0.049
Willington Jubillee Bridge	51.0		55.0	1.37	0.101
Page Bank	54.1		53.8	1.66	0.153
Sunderland Bridge	58.3	4615.7	62.6	1.80	0.108
Shincliffe Bridge	65.4		64.4	>2.5	0.106

The following sampling sites were chosen.

Sampling Site	National Grid Reference
Wolsingham	NZ 070370
Witton-le-Wear Bridge	NZ 142307
Bishop Auckland	NZ 205302
Page Bank	NZ 233355
Sunderland Bridge	NZ 266378
Durham Sands	NZ 274430.

TABLE 2.

Modal analysis of River Wear Minnow Length Frequency Distributions.

SAMPLE	RESOLVED COMPONENTS.	
	Mean Length (mm).	Standard Deviation
Durham Sands 10.5.71	33.2 41.9	2.1 2.1
Durham Sands 24.6.71	47.3 71.3	5.5 4.5
Page Bank Upstream Sample	32.8 44.7	4.5 4.25
Bishop Auckland	40.0 62.0 77.5	4.5 8.9 4.0
Witton-le-Wear	50.4	6.1

e Site	Durham Sands 10.5.71			Durham Sands 24.6.71			Sunderland Bridge		Page Bank			Bishop Auckland		
of fish examined in brackets	32-34 (n=10)	38-40 (n=20)	46-48 (n=14)	38-42 (n=22)	52-56 (n=19)	68-72 (n=13)	38 (n=20)	38 (n=14)	34 (n=15)	34-44 (n=27)	46 (n=10)	37-40 (n=22)	50-62 (n=13)	70-80 (n=5)
entous	100	80	70				40	53	60	41		32	77	60
ns	100	80	70				45	57	47	41		32	77	60
omid	20	10	20	50	15.5	53	5		33	48	60	50	54	40
omid				13	27	45	40	29	13	41	70	18	23	40
omid					5					7	10			
Diptera				5	5			7	7			10	31	40
roptera	10	20		23	21	23				33	60	37	77	80
roptera					5		40	28				19		
tera						8		14						
ptera					10.5					11	30	13	8	40
ptera														
tera					11	15	15				20	23	8	20
era													8	20
ida				5	11	15								
oda							5						31	
a													15	
cea												9		

TABLE 4.

Percentage fullness of minnow guts.

Sample site	Minnow length groups (mm.)	% Fullness
Durham Sands 10.5.71	32-34 38-40 46-48	64 49 73
Durham Sands 24.6.71	38-42 52-56 68-72	18 32 * 36 *
Sunderland Bridge	38 38	55 37
Page Bank	34 34-44 46	32 58 77
Bishop Auckland	37-40 50-62 70-80	65 62 100
Witton-le-Wear9	39-48 50-60	68 83

* Spawning fish.

TABLE 5.

Mean number of prey organisms eaten by different sized minnows in 8 hours.

Prey	Lengths of predating minnow		
	38mm.	45mm.	52mm.
Chironomid larvae	several hundred taken.		
Ephemeroptera nymphs (plus stone)	3	0	10
Ephemeroptera nymphs (without stone)	6	4	15
Caddis larvae in cases	0	0	0
Hydropsyche larvae without case.	2	5	4
Gammarus pulex	0	3	7*
Herpobdella	0	0	0*
Ancylus	*	*	*

* See text.

TABLE 6.

Percentage increase in total weight of minnows/total weight of liver eaten.

Duration of experiment (days)	Tank A	Tank B	Tank C
0	-	-	-
14	6.25	8.2	5.1
28	5.8	4.1	6.1
42	11.4	4.1	7.1
56	14.5	6.9	8.8

TABLE 7

Length - Weight Regressions of Durham Sands Minnows.

$Y = \text{Log}_{10}$ weight of minnows (gm).

$X = \log_{10}$ length of minnows (mm).

N = number of minnows per sample.

SAMPLE	SEX	REGRESSION EQUATION	*b significantly different from 3?
Durham Sands 10.5.71 Whole Sample	Males (n=61)	$Y = -4.98 + 2.73x$	No
	Females (n=40)	$Y = -5.77 + 3.24x$	No
Durham Sands 24.6.71			
$>$ 64mm.	Males (n=13)	$Y = -3.92 + 2.47x$	yes
$>$ 64mm.	Females (n=20)	$Y = -4.10 + 2.57x$	yes
50-64 mm.	Males (n=29)	$Y = -5.33 + 3.26x$	No
50-64 mm.	Females (n=16)	$Y = -4.63 + 2.86x$	No
$<$ 50 mm.	Males (n=28)	$Y = -4.93 + 3.03x$	No
$<$ 50 mm.	Females (n=25)	$Y = -4.99 + 3.10x$	No

* Significance test based on whether observed value of 'b' is more than 2xS.E. of 'b' away from 3.

TABLE 8

Sex Ratio of River Wear Minnows.

Sample	Ratio of ♂:♀	P
Durham Sands 10.5.71	59 : 42	14.6%
Durham Sands 14.6.71	105 : 67	20.4%
Sunderland Bridge	19 : 14	13.4%
Page Bank	50 : 31	20.7%
Bishop Auckland	40 : 43	3.1%
Witton-le-Wear	46 : 46	0.0%

Null Hypothesis = sex ratio of unity.

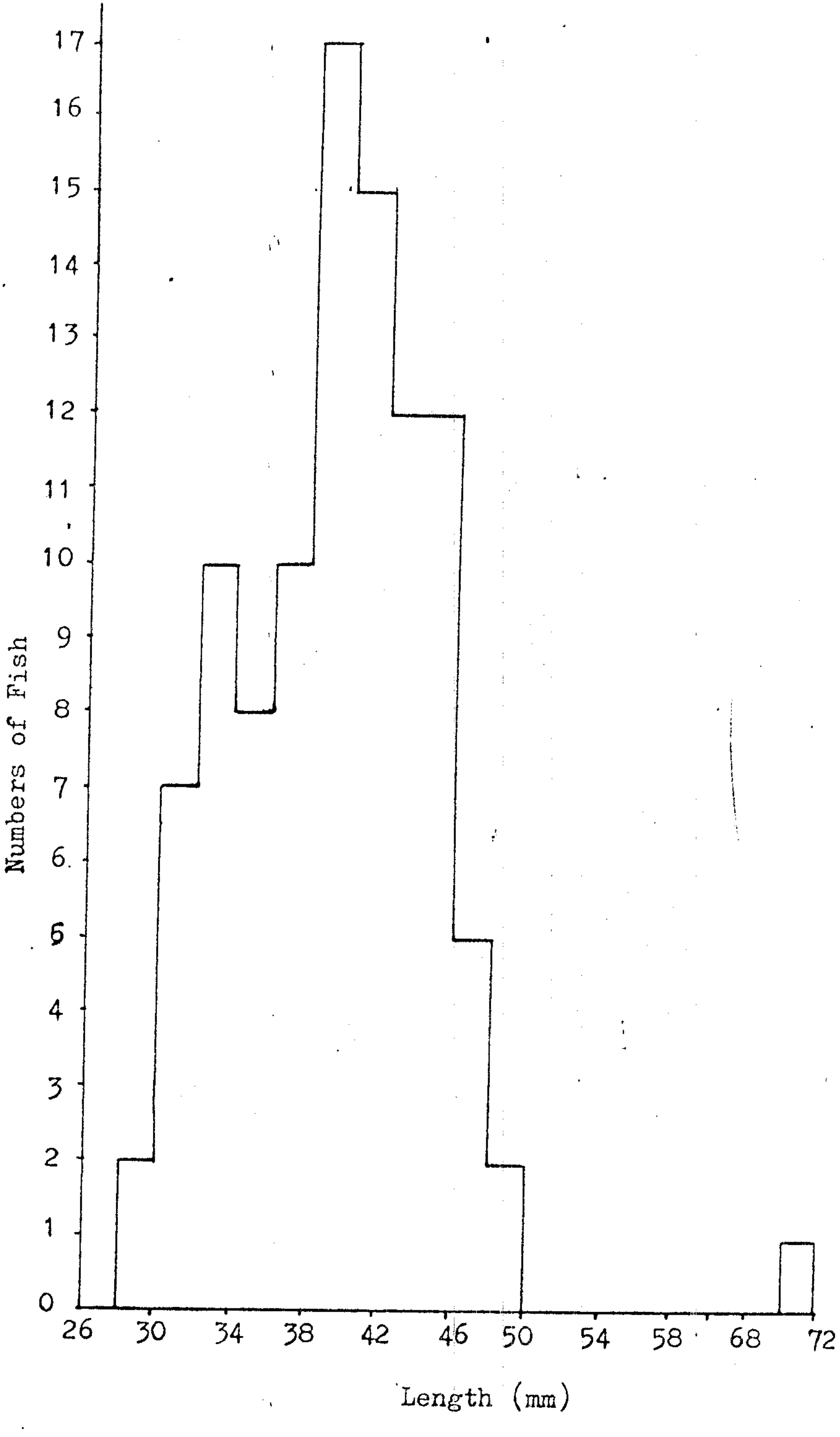


FIG 1a. Length Frequency distribution of Durham Sands minnows 10.5.71.

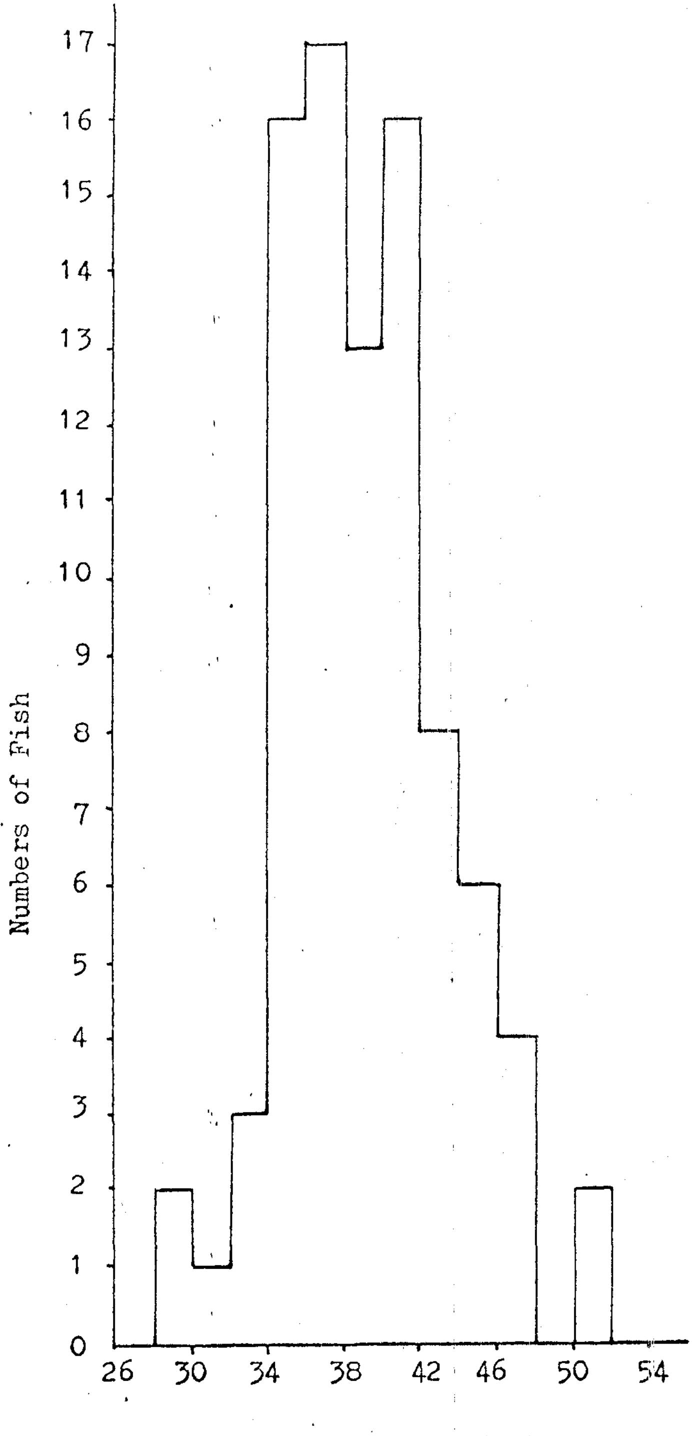


FIG 1b Length Frequency distribution of Durham Sands minnows 1.6.71

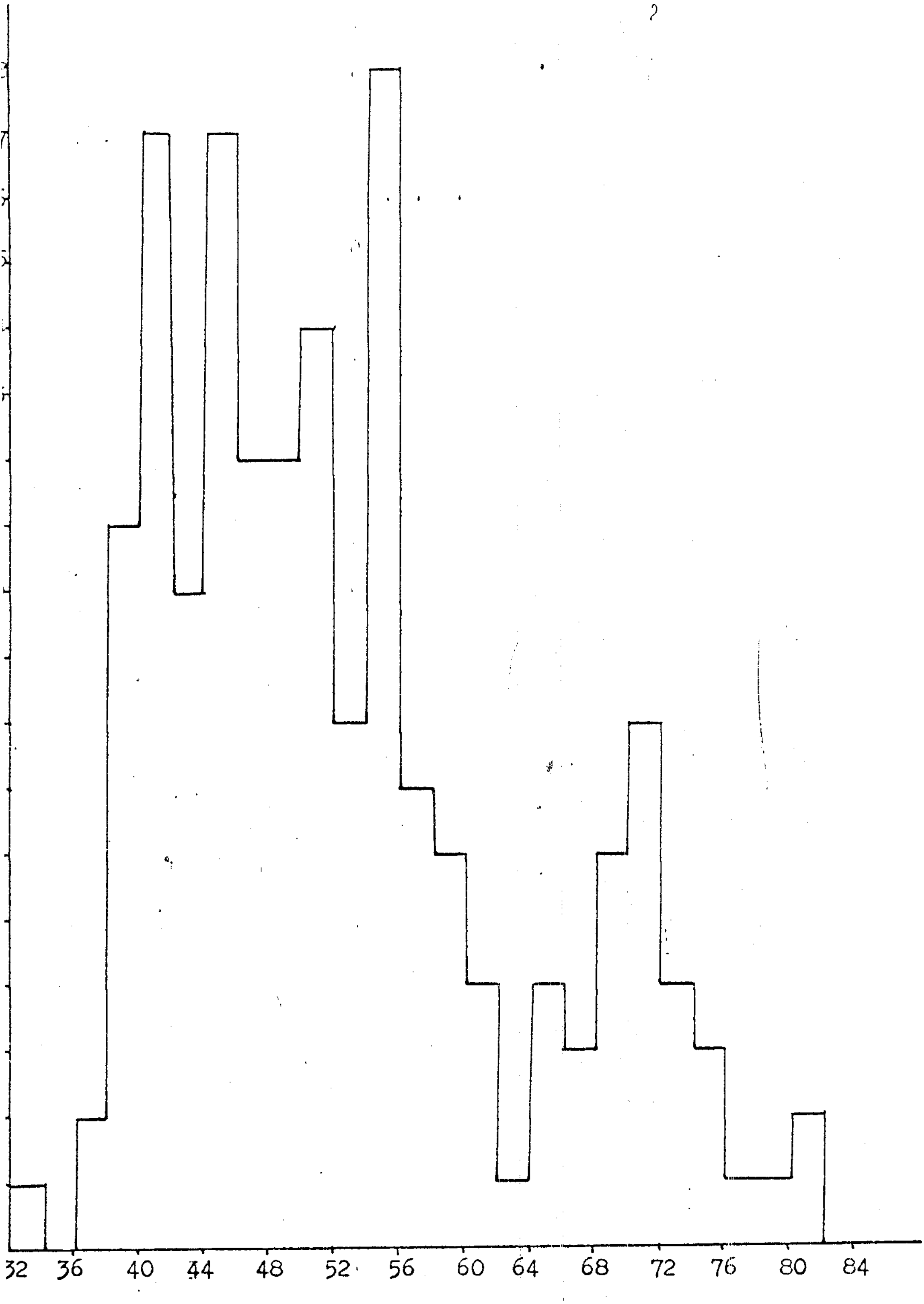


FIG 1c. Length Frequency distribution of Durham Sands minnows 24.6.71

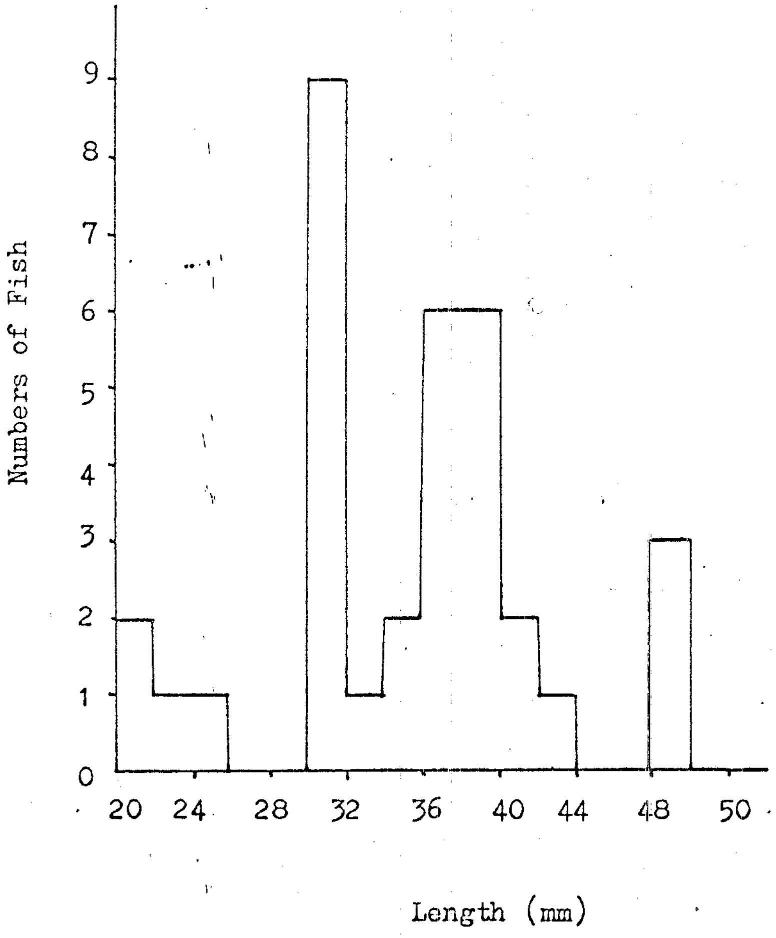


Fig. 1d. Length frequency distribution of Sunderland Bridge minnows 18.5.71

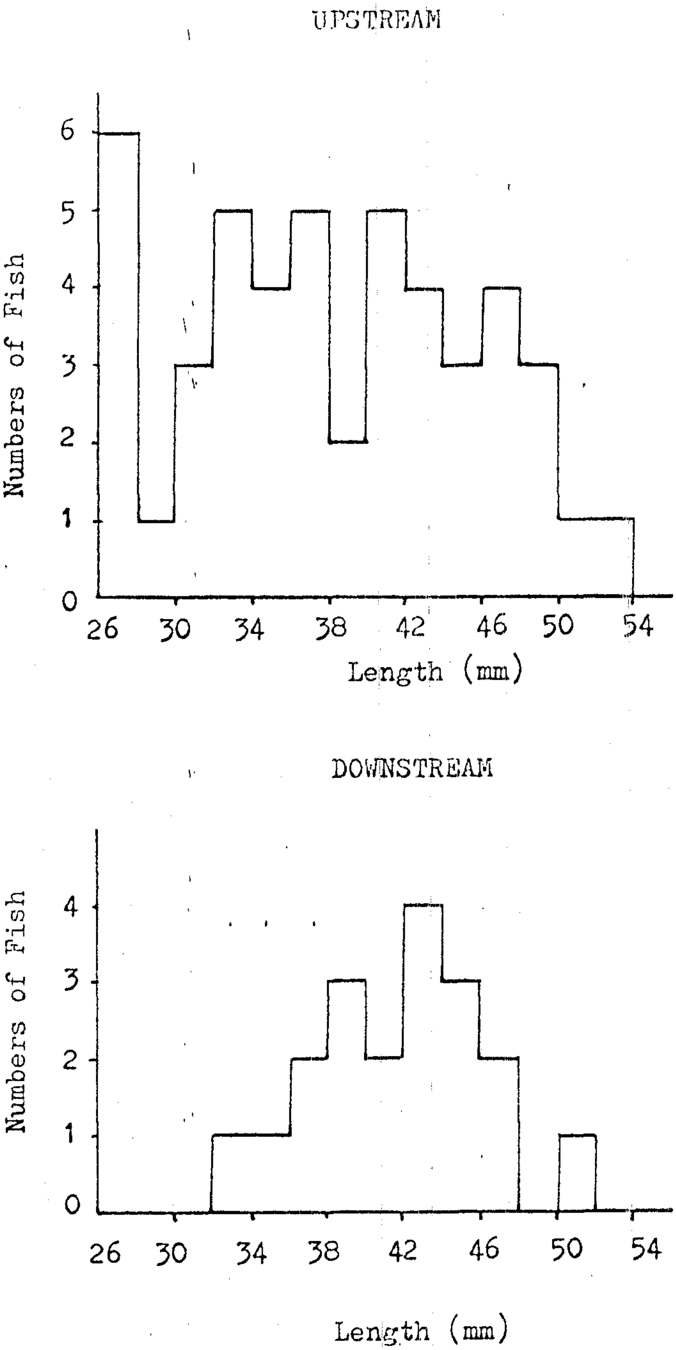


FIG. 1e. Length Frequency distributions of Page Bank minnows 14.5.71

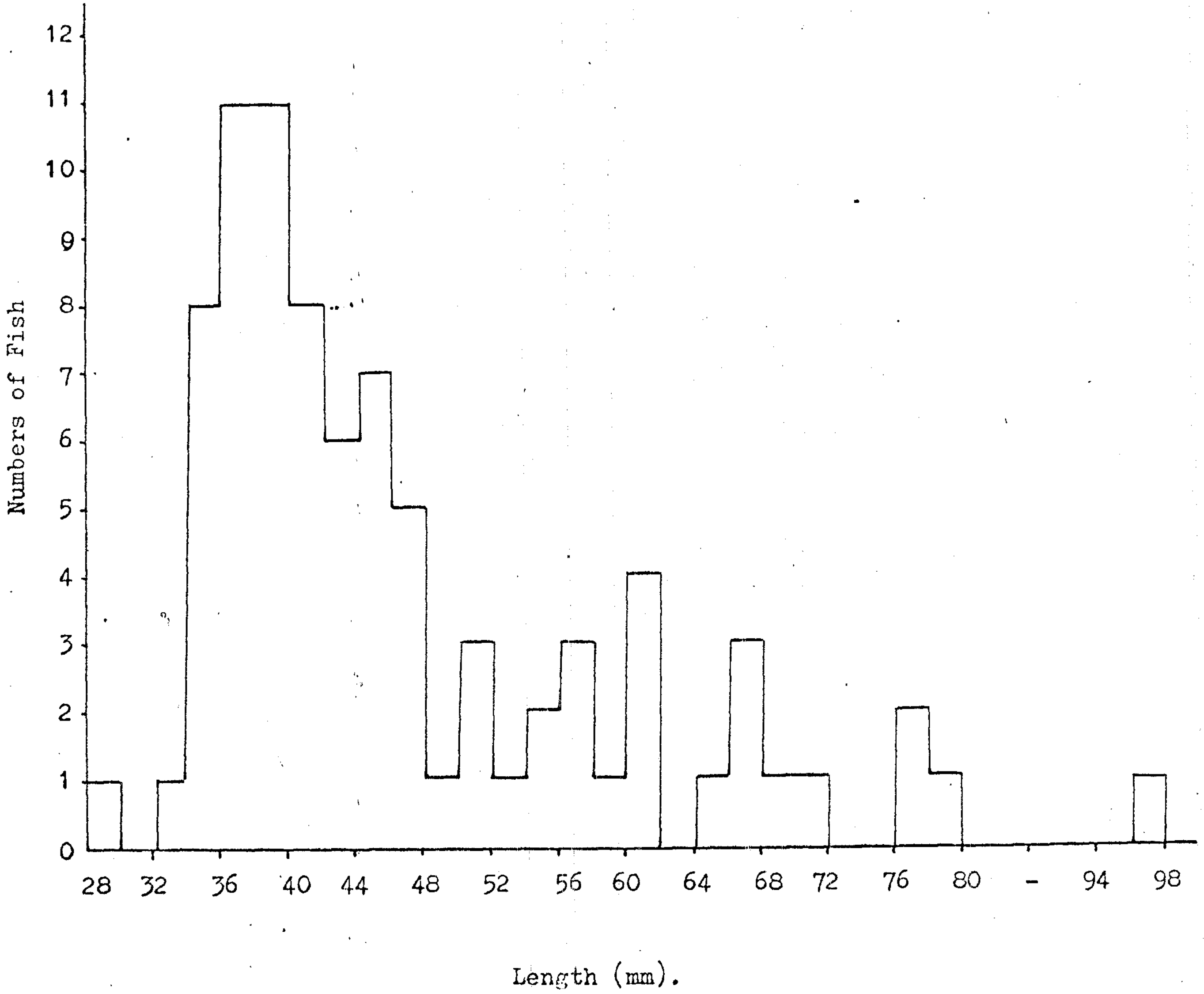


FIG. 1f. Length Frequency distribution of Bishop Auckland minnows 6.7.71

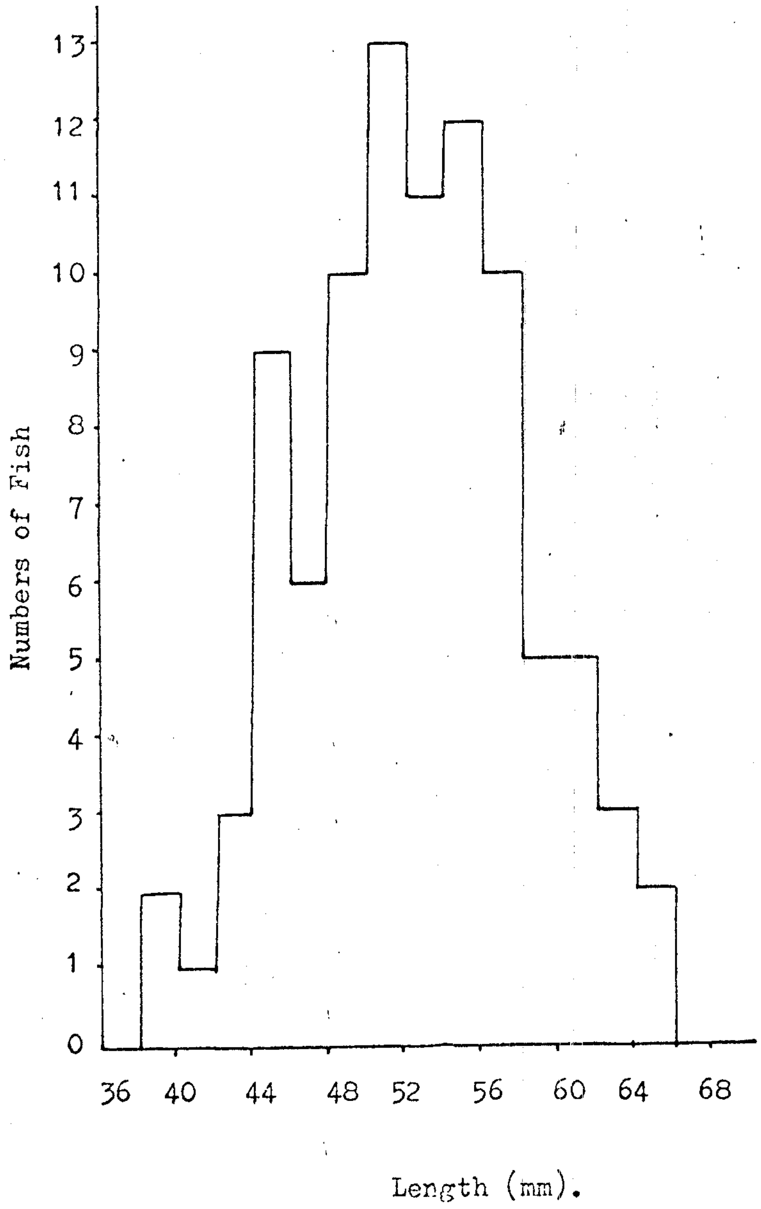
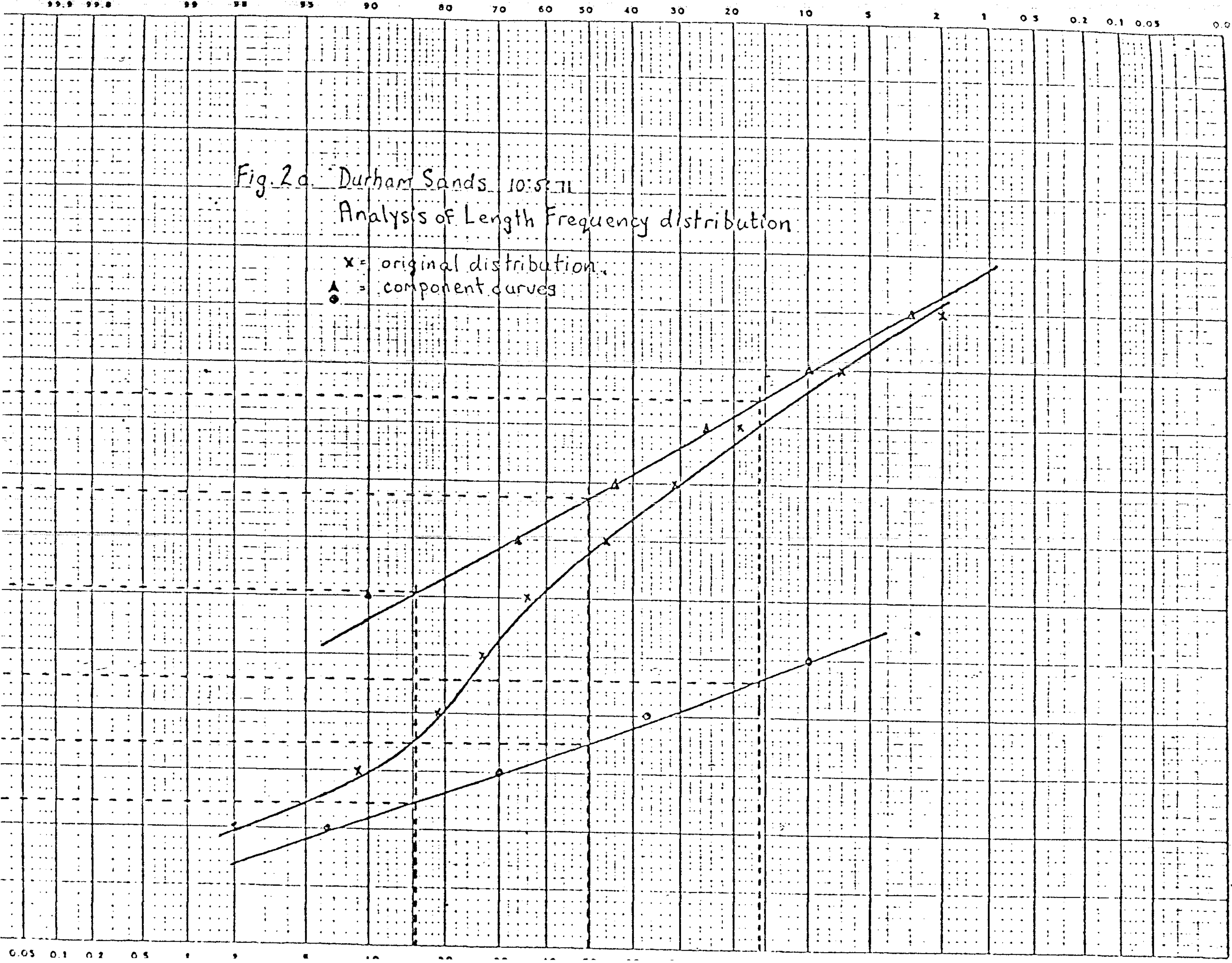


FIG. 1g. Length Frequency distribution of Witton-le-Wear minnows 13.7.71

Fig. 2a Durham Sands 10:5:71

Analysis of Length Frequency distribution



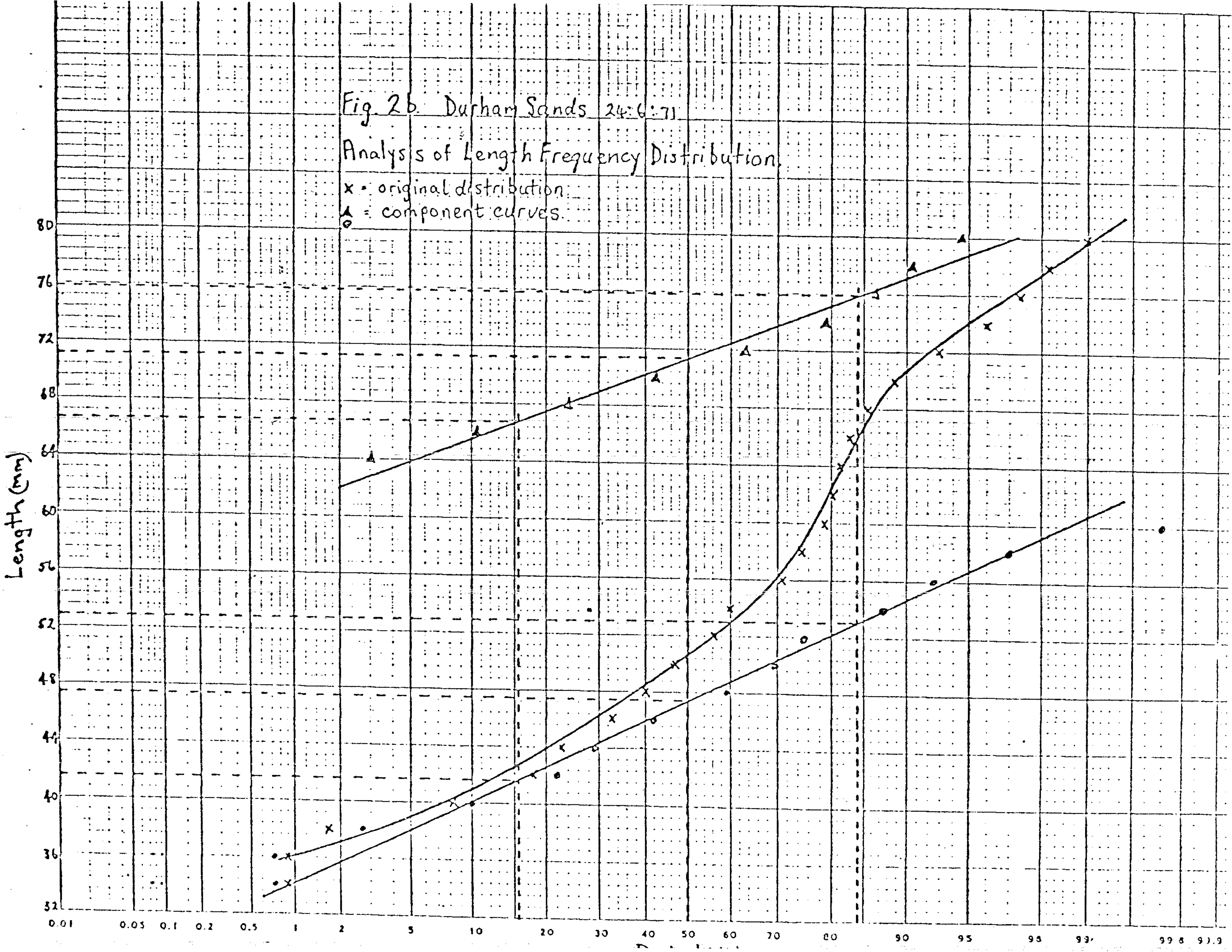


Fig. 2b Durham Sands 24.6.71

Analysis of Length Frequency Distribution

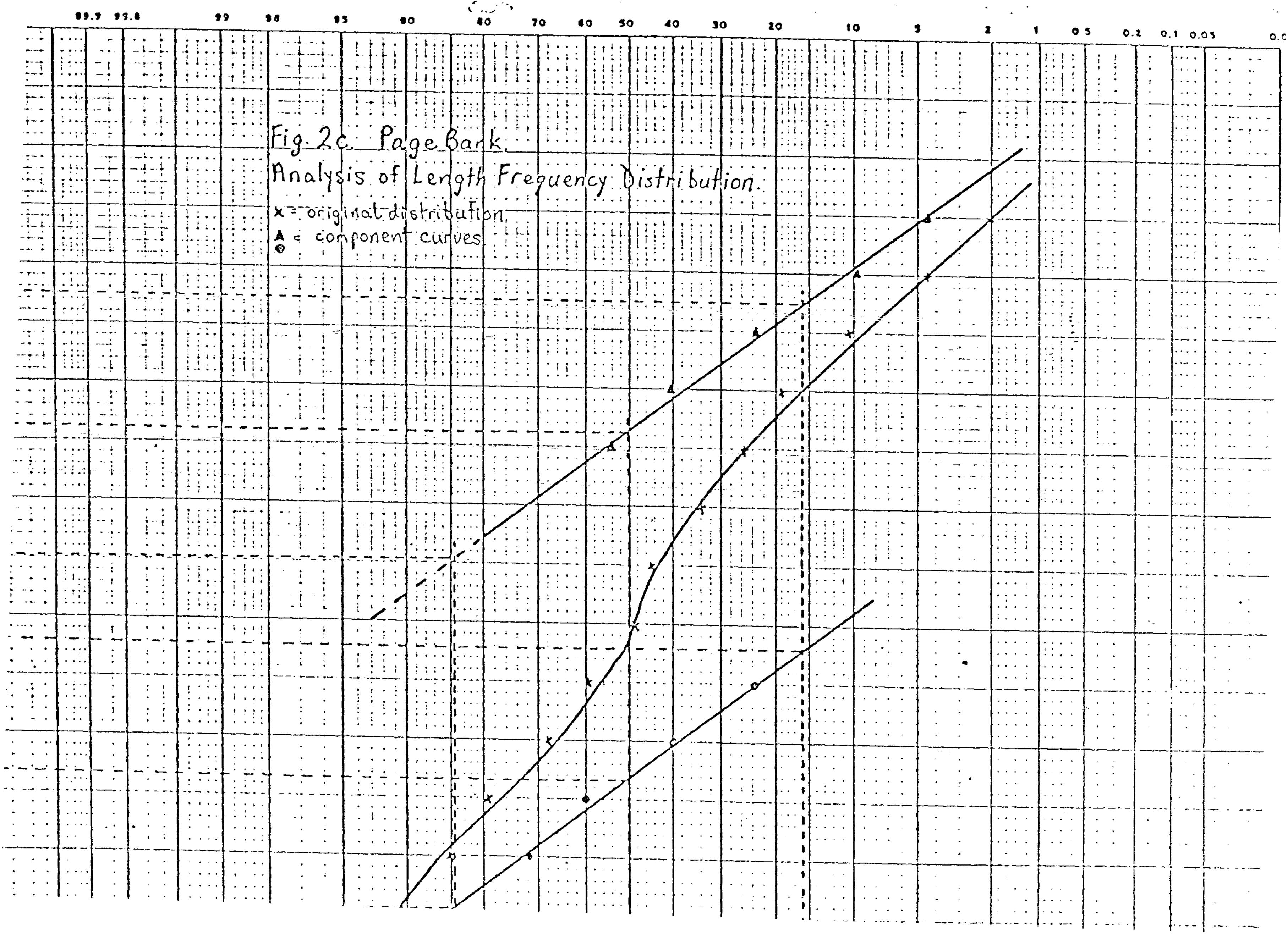


Fig. 2c. Page Bark.

Analysis of Length Frequency Distribution.

x = original distribution

▲ ⊗ = component curves

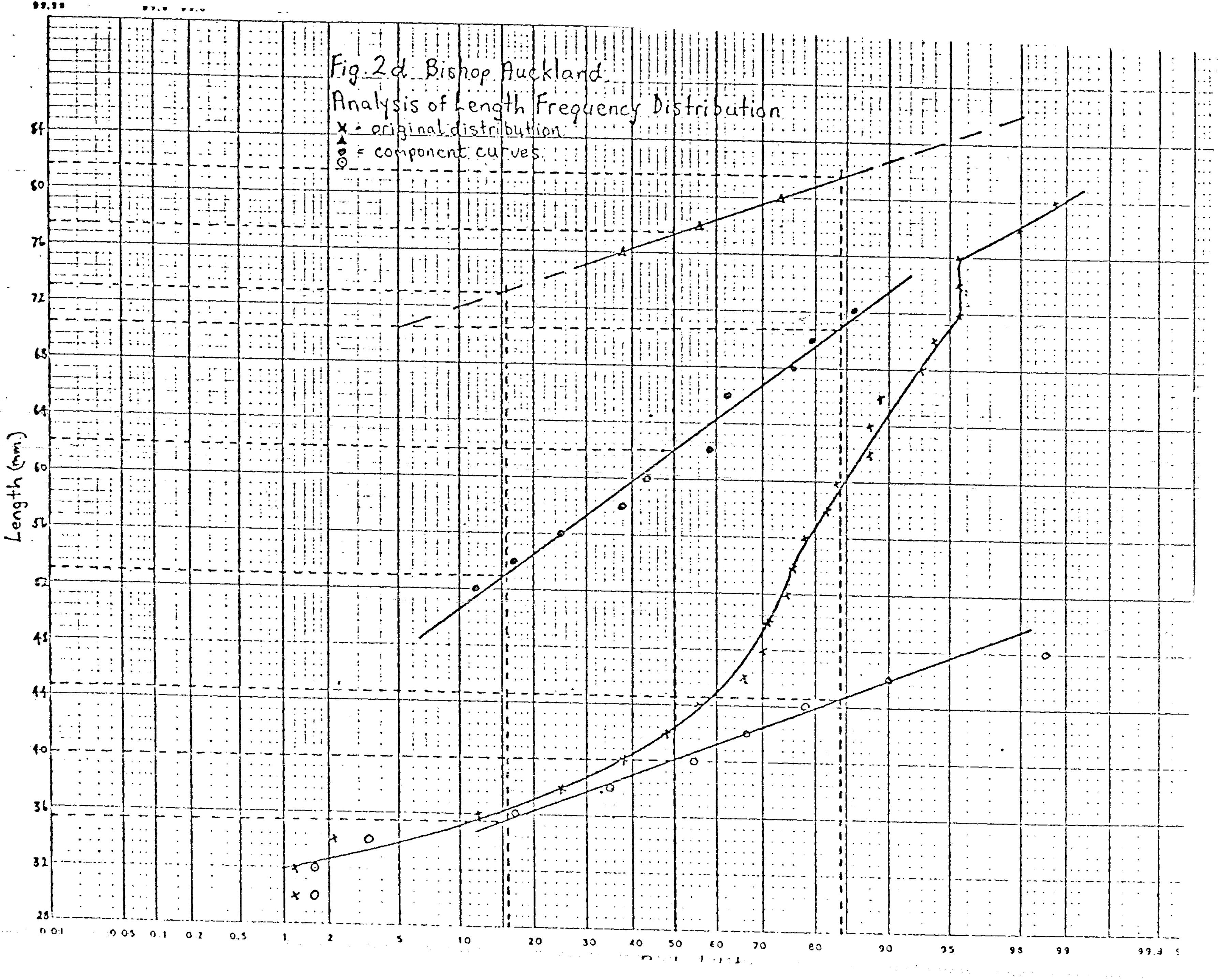


Fig. 2d Bishop Auckland
Analysis of Length Frequency Distribution
x - original distribution
▲ ● ⊙ = component curves

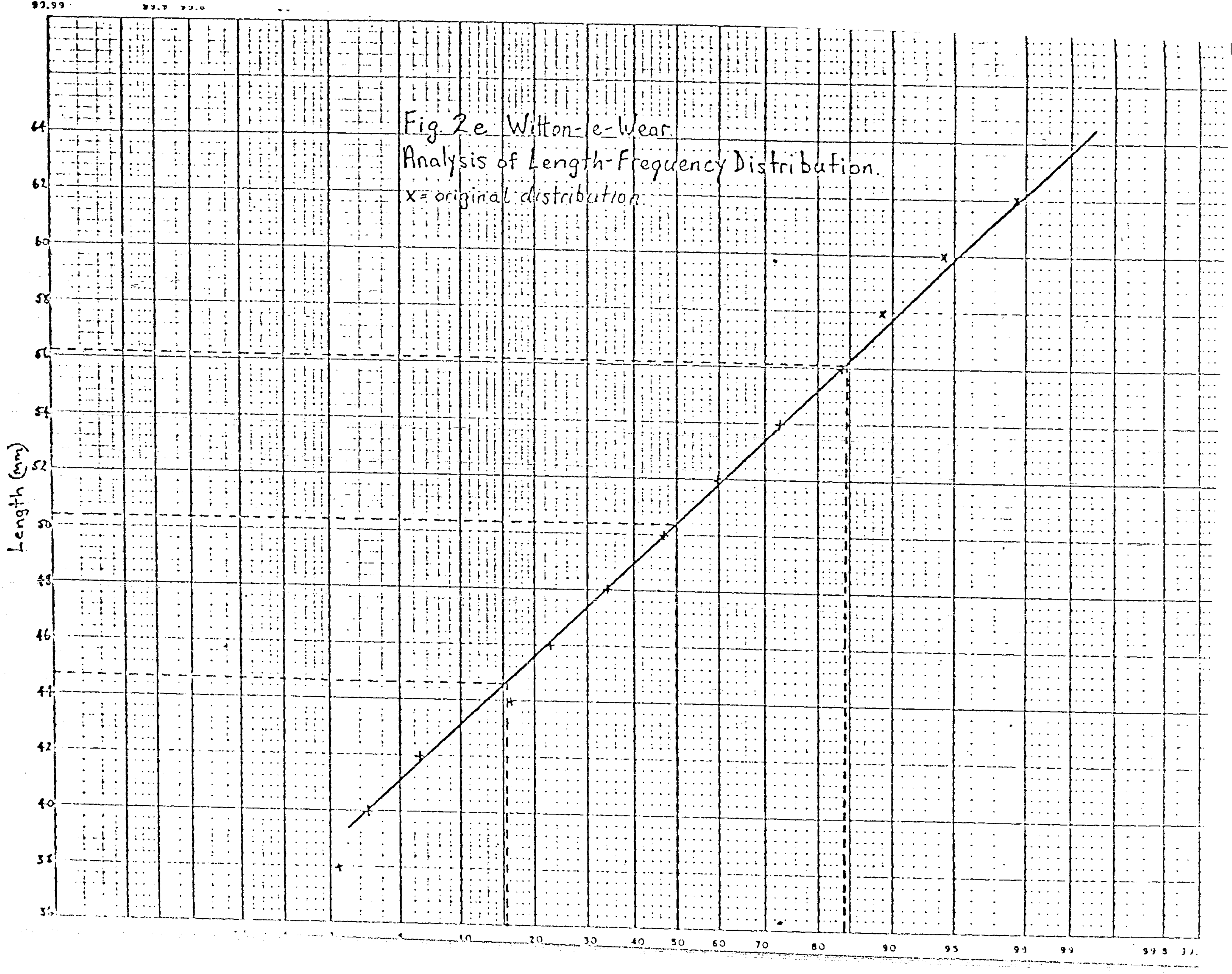


Fig. 2e Wilton-le-Wear
Analysis of Length-Frequency Distribution.
x = original distribution

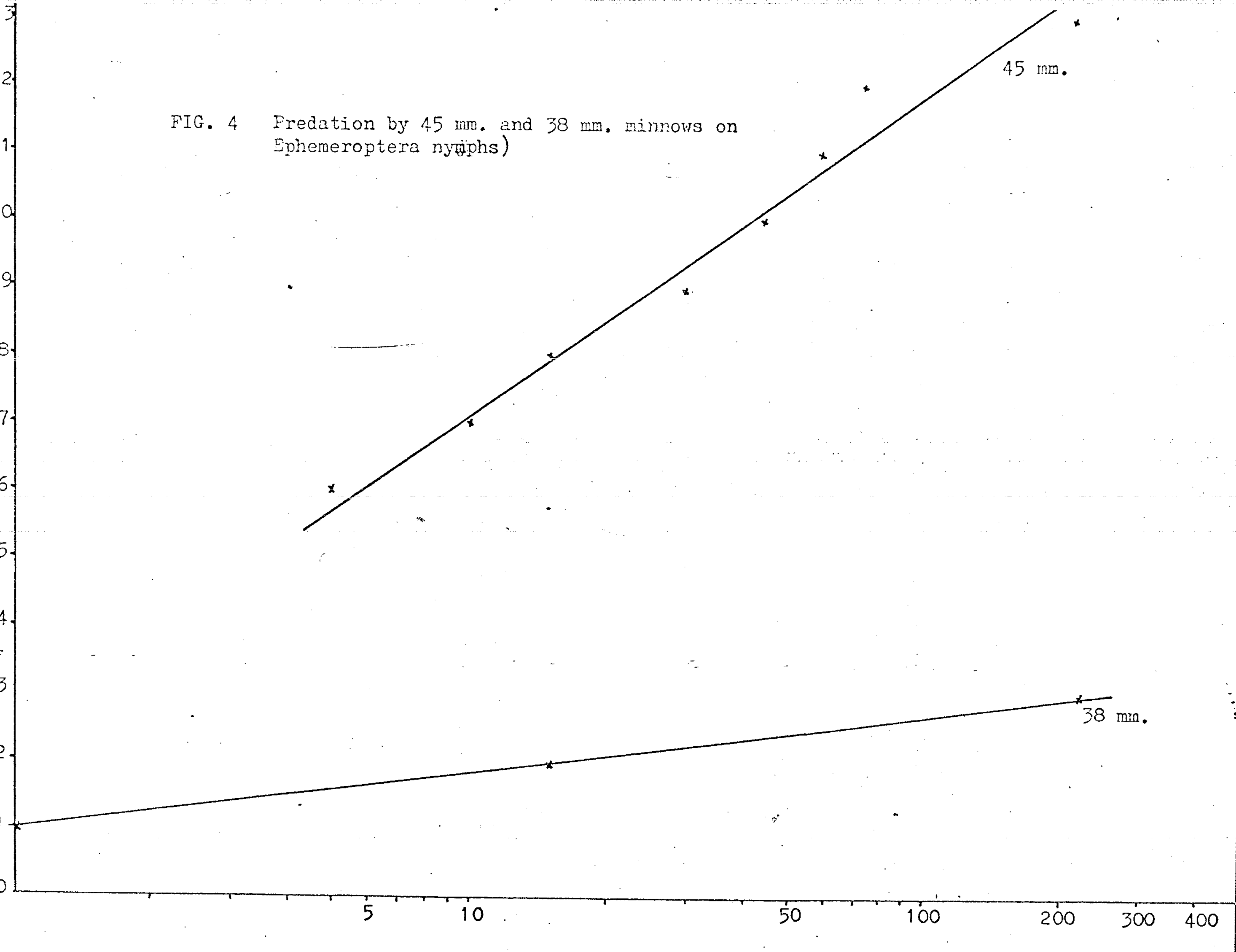


FIG. 4 Predation by 45 mm. and 38 mm. minnows on Ephemeroptera nymphs)

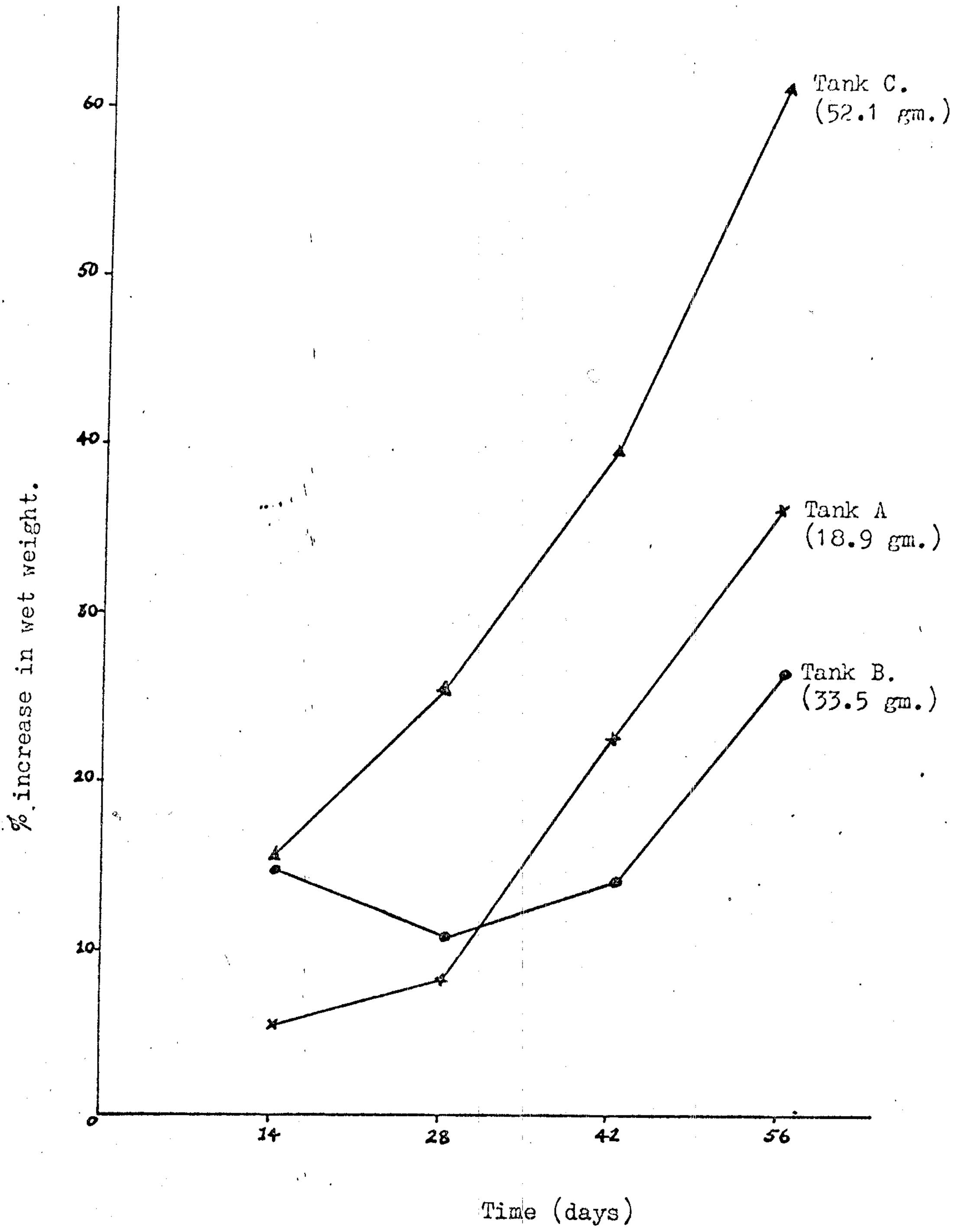


FIG. 5 Growth of 3 groups of 14 minnows fed on different quantities of minced ox's liver (total eaten in parenthesis).

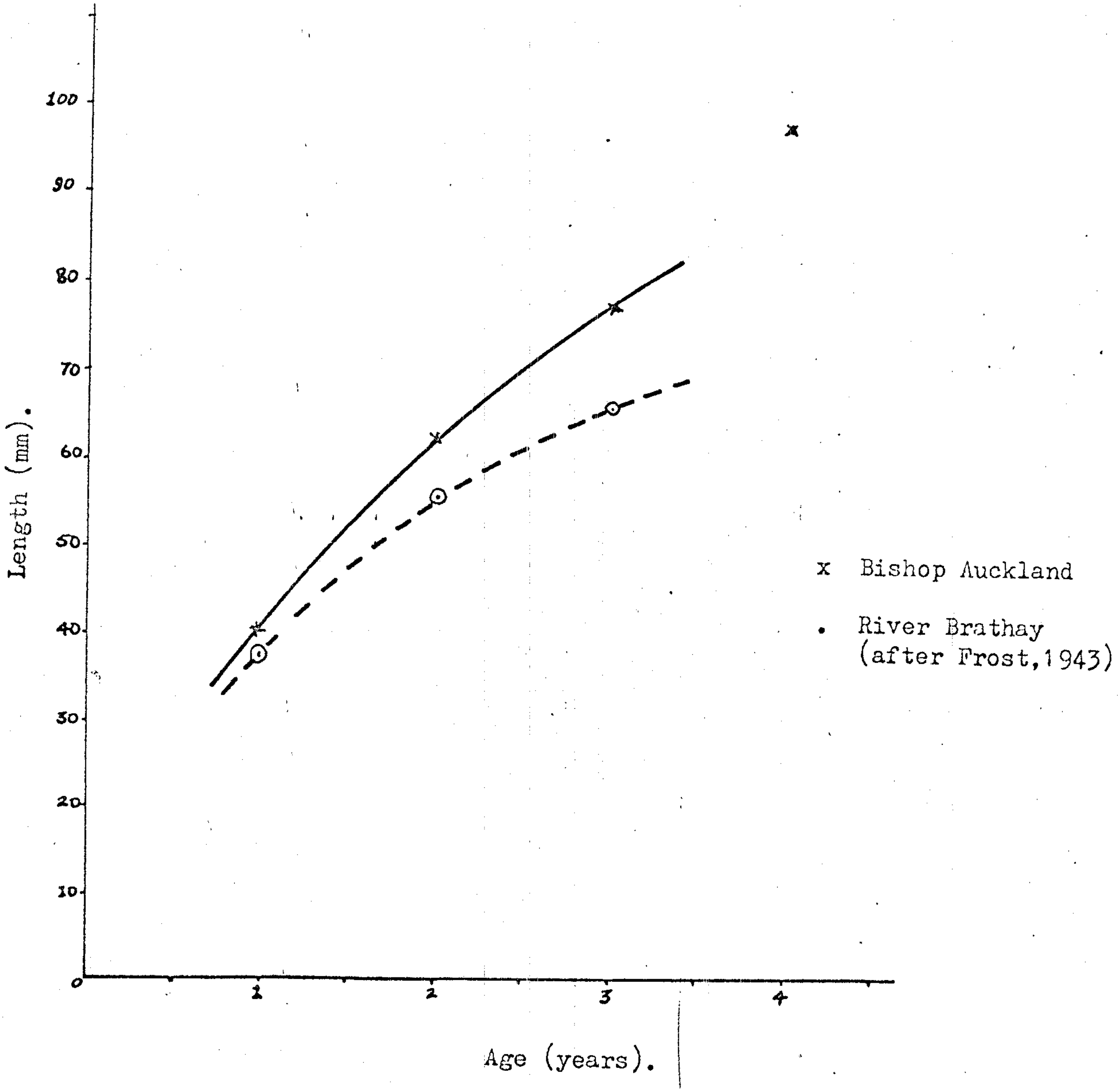
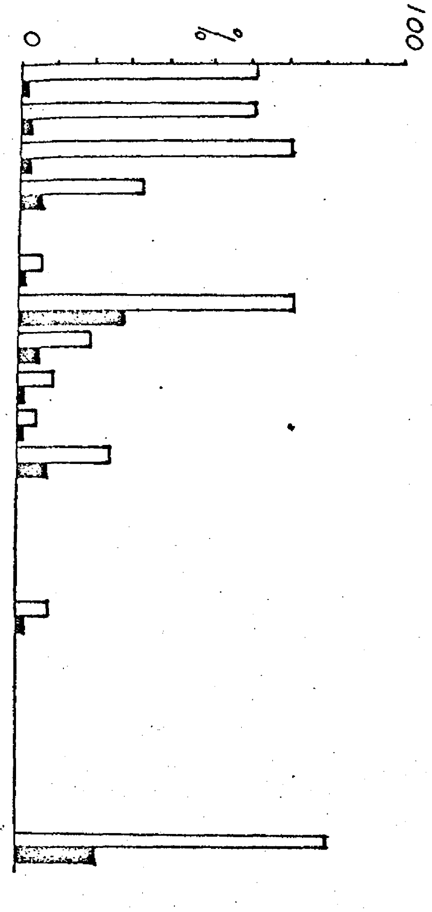


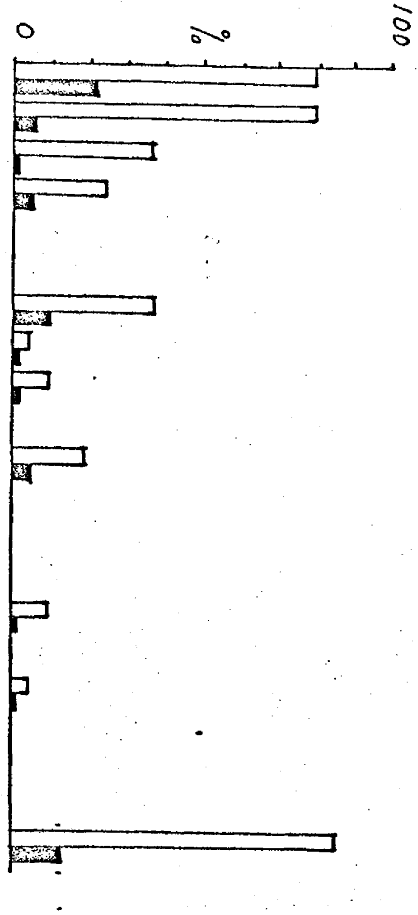
FIG. 6 Length for suspected age of Bishop Auckland minnows



Witton-le-Wear

50-60 mm.

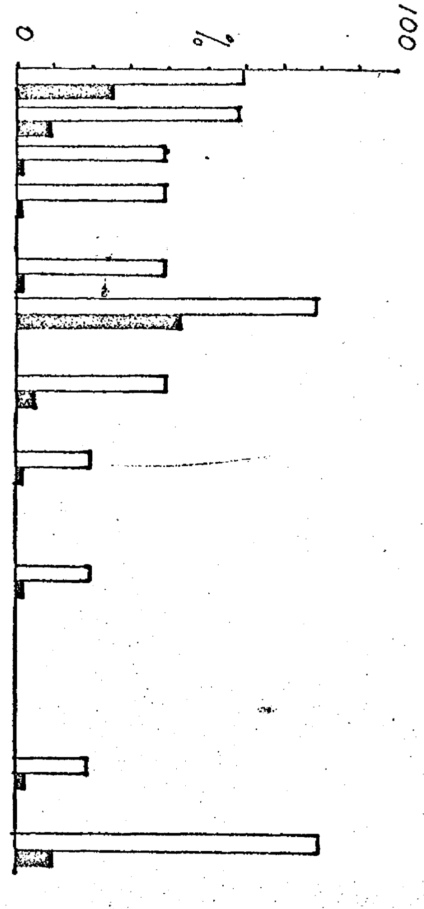
n = 21



Witton-le-Wear

39-48 mm.

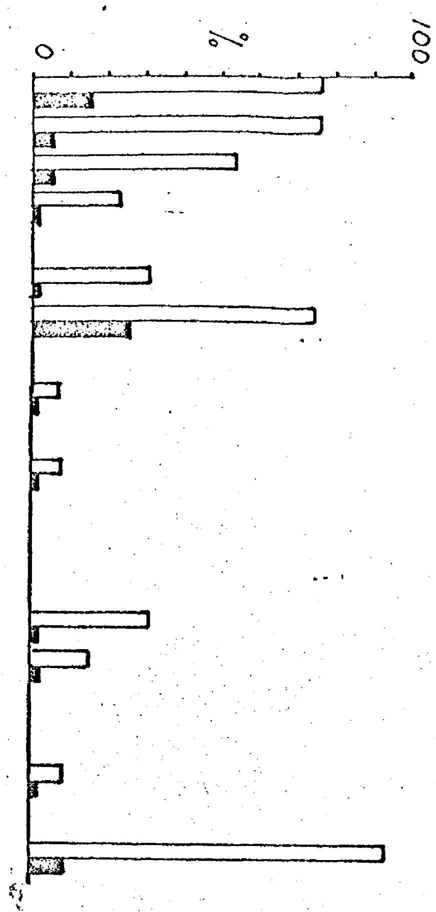
n = 21



Bishop Auckland.

70-80 mm.

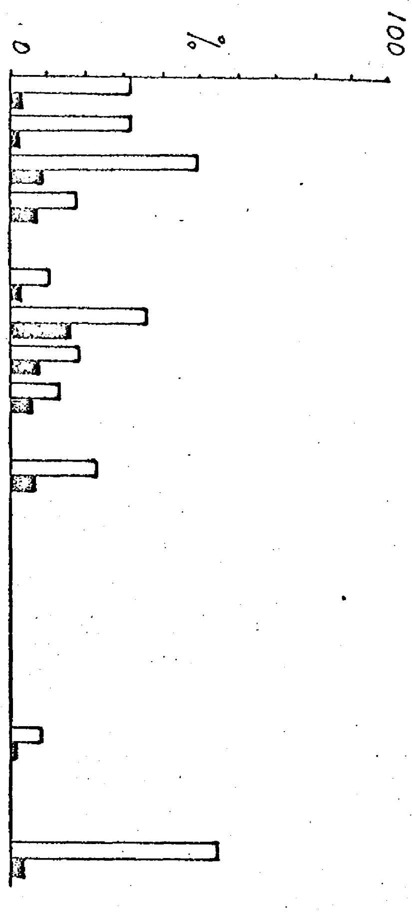
n = 5



Bishop Auckland

50-62 mm.

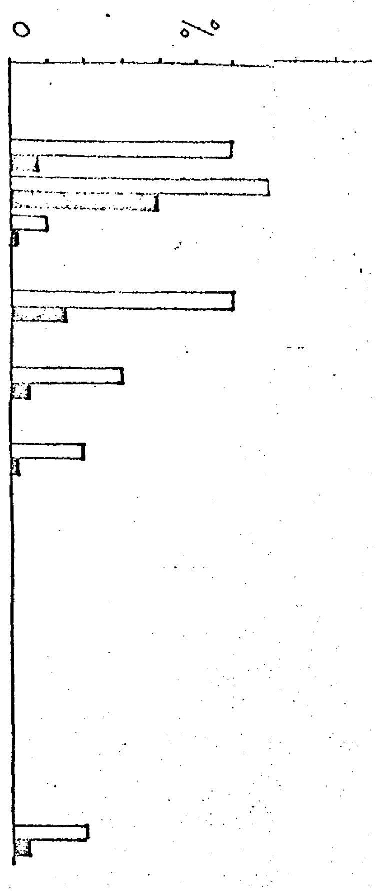
n = 13



Bishop Auckland

37-40 mm.

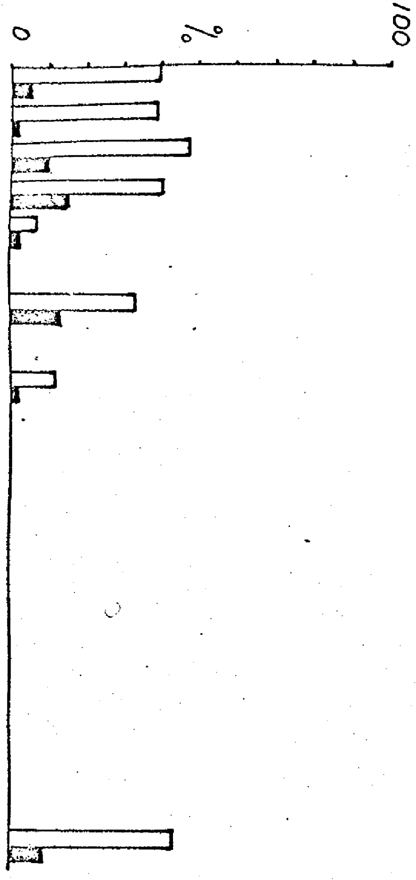
n = 22



Page Bank

>46 mm.

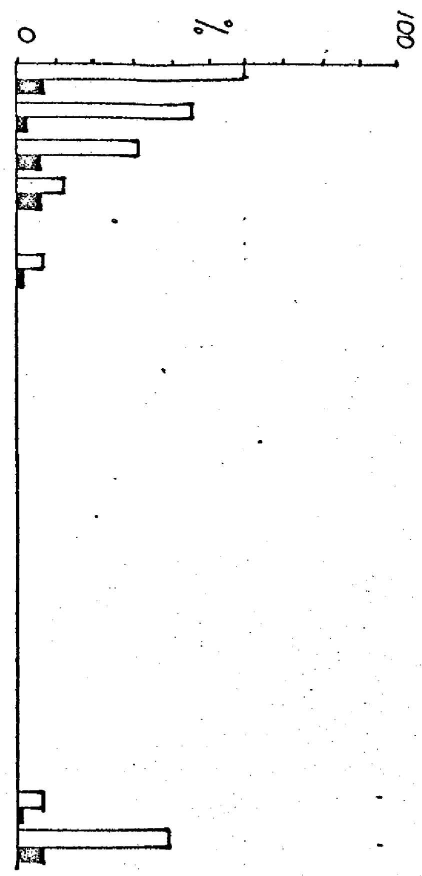
n = 10



Page Bank

34-44 mm.

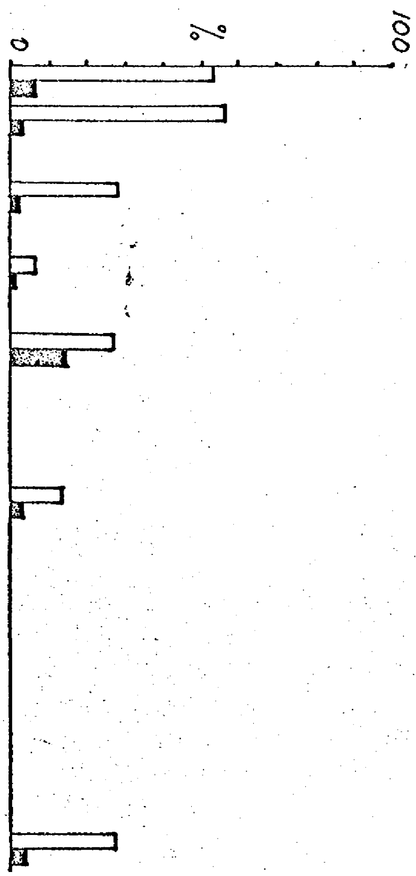
n=27



Page Bank

<34 mm.

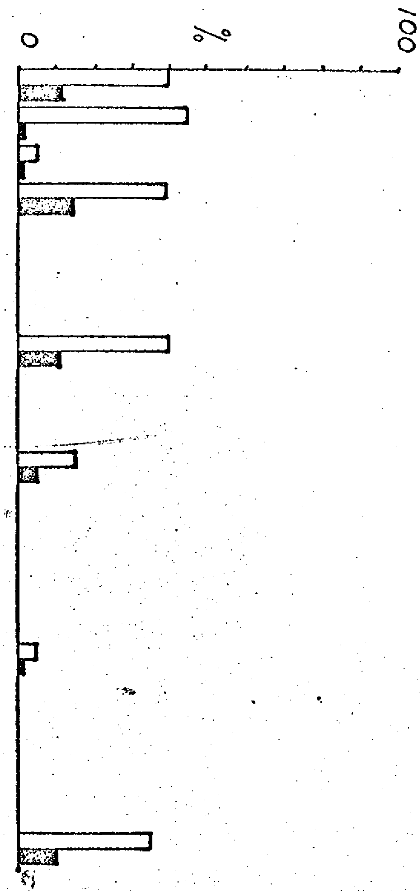
n=15



Sunderland Bridge

>38 mm.

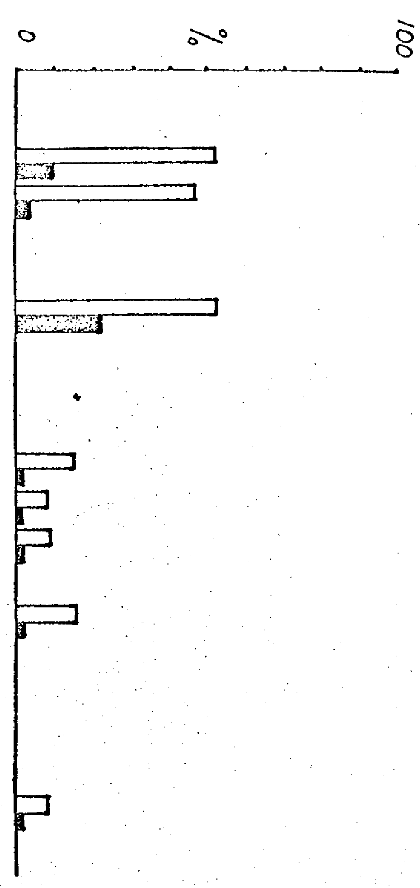
n=14



Sunderland Bridge

<38 mm.

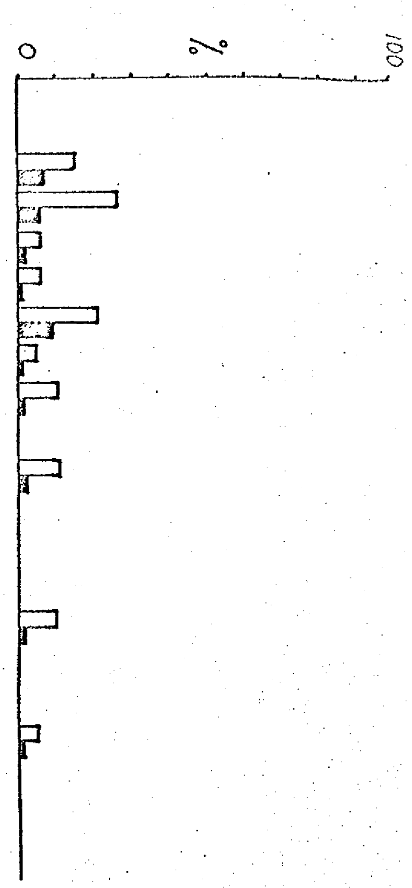
n=20



Durham Sands 24:6:71

68-72 mm.

n=13



Durham Sands 24:6:71

52-56 mm.

n=19

Fig. 3

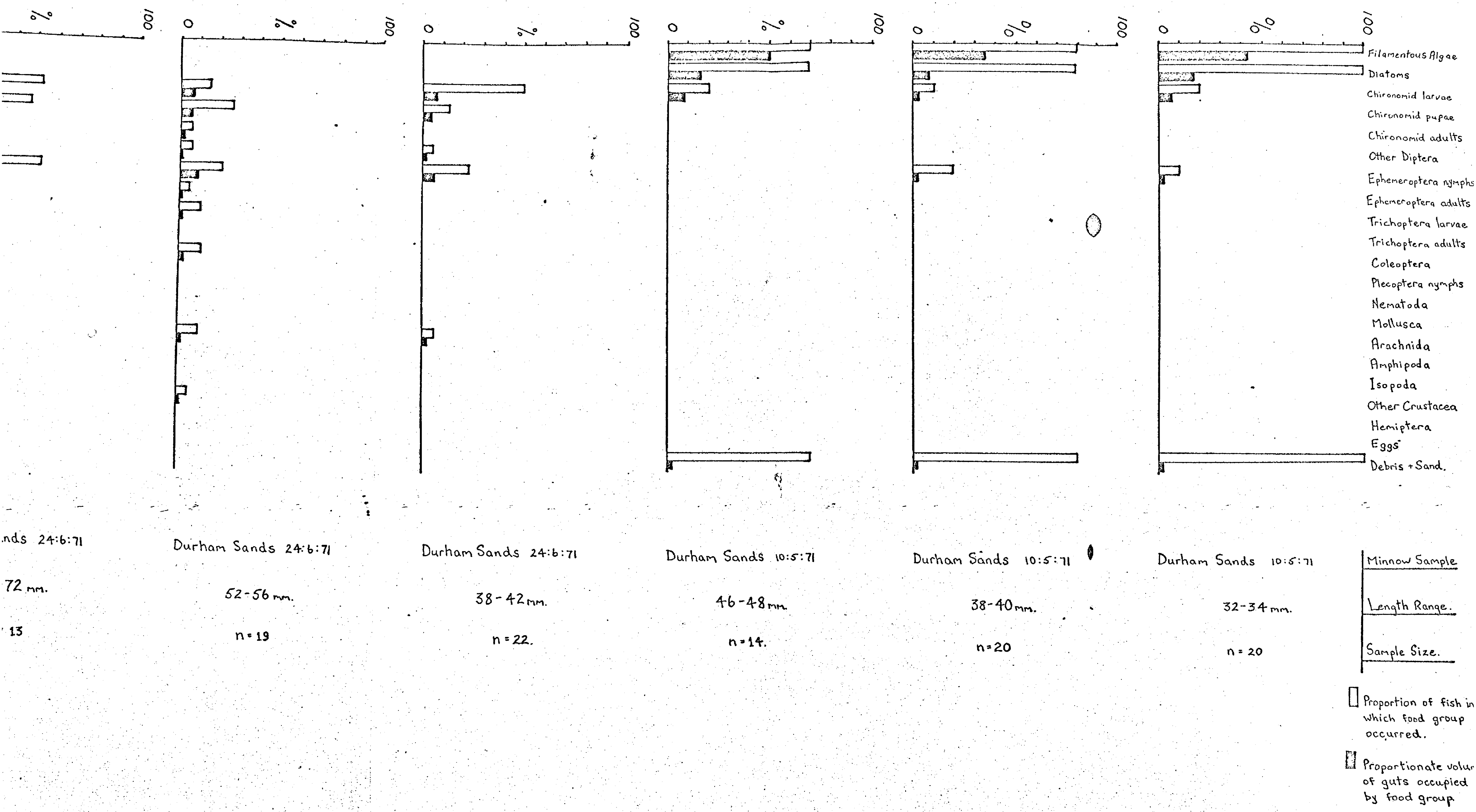

100
%
0
Filamentous Algae
Diatoms
Chironomid larvae
Chironomid pupae
Chironomid adults
Other Diptera
Ephemeroptera nymphs
Ephemeroptera adults
Trichoptera larvae
Trichoptera adults
Coleoptera
Plecoptera nymphs
Nematoda
Mollusca
Arachnida
Amphipoda
Isopoda
Other Crustacea
Hemiptera
Eggs
Debris + Sand.
Minnow Sample
Length Range.
Sample Size.
Durham Sands 10:5:71
32-34 mm.
n = 20
Durham Sands 10:5:71
38-40 mm.
n = 20
Durham Sands 10:5:71
46-48 mm.
n = 14.
Durham Sands 24:6:71
38-42 mm.
n = 22.
Durham Sands 24:6:71
52-56 mm.
n = 19
nds 24:6:71
72 mm.
13
Proportion of fish in which food group occurred.
Proportionate volu of guts occupied by food group

TABLE 3(b)

Sample Site	Length Groups (mm.) No. of fish examined in brackets	Filamentous algae	Diatoms	Chironomid larvae	Chironomid pupae	Chironomid adults	Other Diptera	Ephemeroptera nymphs	Adult Ephemeroptera	Plecoptera nymphs	Trichoptera larvae	Trichoptera adults	Coleoptera	Hempitera	Arachnida	Amphipoda	Isopoda	Other Crustacea	Nematoda	Mollusca	Eggs	Debris and Sand
Durham Sands 10.5.71	32-34 (n=20)	43	17	5				2.5														+
	38-40 (n=20)	35	7	3				2.5														+
	46-48 (n=14)	50	15	7																		1
Durham Sands 24.6.71	38-42 (n=22)			7	4		1	5								+						
	52-56 (n=19)			5	5	3	1	9	1		1		3			+						
	68-72 (n=13)			9	3			22		1			1			+						
Sunderland Bridge	38 (n=20)	11	+	+	17				11				5				1					10
	38 (n=14)	7	3		3			1	15	3												5
Page Bank	34 (n=15)	7	3	6	7			1													1	7
	34-44 (n=27)	5	1	10	15	4		13			1											9
	46 (n=10)			8	40	1		15			5		3									5
Bishop Auckland	37-40 (n=22)	3	3	9	7		3	16	8		6		6					4				3
	50-62 (n=13)	16	7	6	2		2	25			2		1	1	+	1						8
	70-80 (n=5)	25	10	1	1		1	43			5		3	3						3		10
Witton-le-Wear	39-48 (n=21)	23	6	1	5			10	1		1		5		1		1					16
	50-60 (n=21)	1	3	3	6		1	28	6		1	1	7		1							25

Proportionate volume of guts occupied by food group (%)

TABLE 3(a)

Sample Site	Durham Sands 10.5.71			Durham Sands 24.6.71			Sunderland Bridge		Page Bank			Bishop Auckland			Witton-le-Wear	
Length Groups (mm.) No. of fish examined in brackets	32-34 (n=10)	38-40 (n=20)	46-48 (n=14)	38-42 (n=22)	52-56 (n=19)	68-72 (n=13)	38 (n=20)	38 (n=14)	34 (n=15)	34-44 (n=27)	46 (n=10)	37-40 (n=22)	50-62 (n=13)	70-80 (n=5)	39-43 (n=21)	50-60 (n=21)
Filamentous algae	100	80	70				40	53	60	41		32	77	60	81	60
Diatoms	100	80	70				45	57	47	41		32	77	60	81	60
Chironomid larvae	20	10	20	50	15.5	53	5		33	48	60	50	54	40	38	71
Chironomid pupae				13	27	45	40	29	13	41	70	18	23	40	25	33
Chironomid adults					5					7	10					
Other Diptera				5	5			7	7			10	31	40		5
Ephemeroptera nymphs	10	20		23	21	23				33	60	37	77	80	38	71
Adult Ephemeroptera					5		40	28				19			5	19
Plecoptera nymphs						8		14								
Trichoptera larvae					10.5					11	30	13	8	40	10	9
Trichoptera adults																5
Coleoptera					11	15	15				20	23	8	20	20	15
Hemiptera													8	20	20	1
Arachnida				5	11	15										
Amphipoda							5						31		9	9
Isopoda													15		5	
Other Crustacea												9				
Nematoda																
Mollusca						8								20		
Eggs						8			7							
Debris and Sand	100	80	70				35	29	40	45	20	55	93	80	85	81

Proportion of fish in which food group occurred (%)