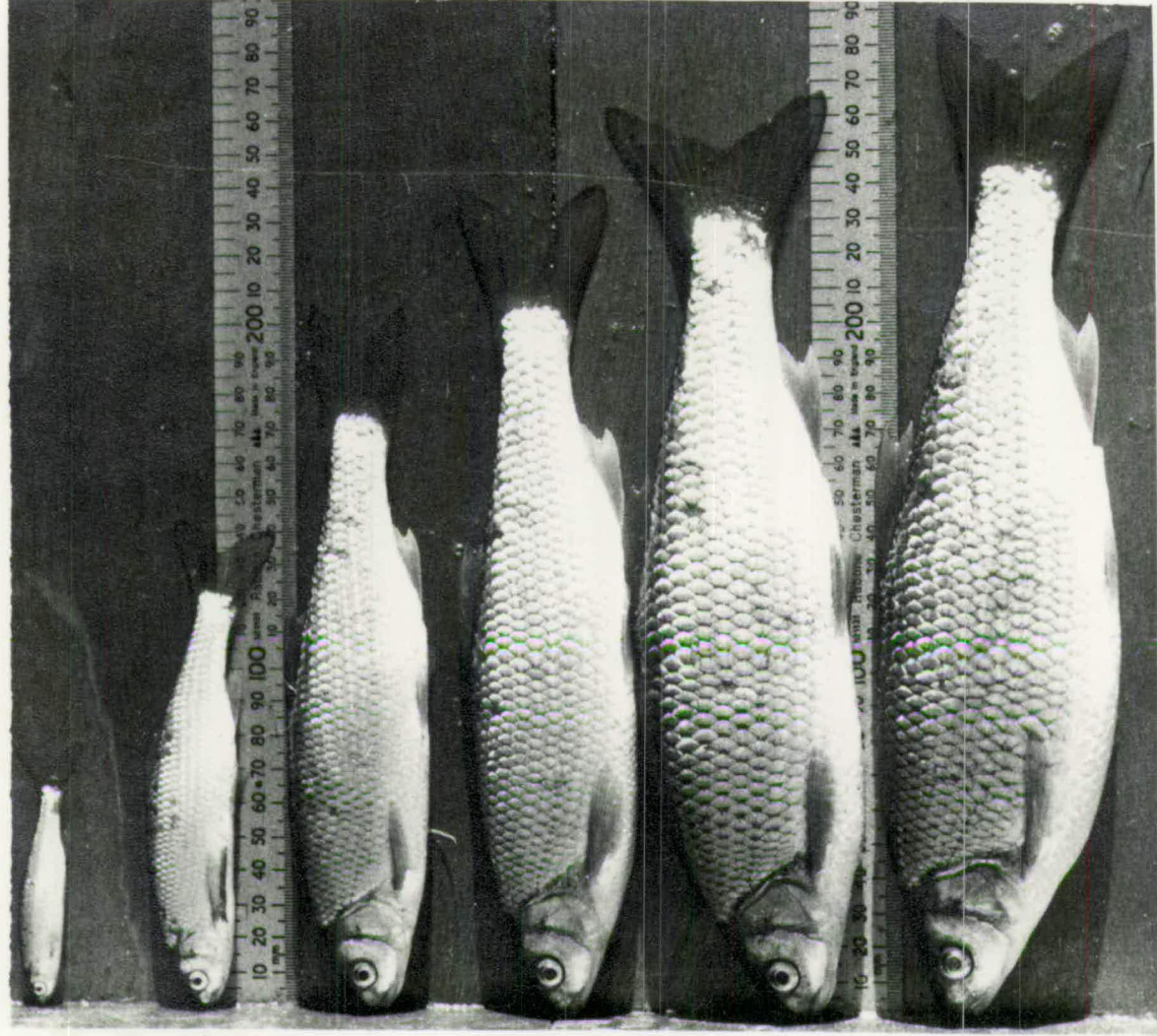


FRONTICEPIECE Tweed dace

Age, from top to bottom 0+  
1+  
2+  
3+  
5+  
7+



Some aspects of the ecology of dace (Leuciscus leuciscus (L.))  
in the River Tweed

Alan Starkie

Thesis submitted in accordance with the requirements of the University  
of Edinburgh for the degree of Doctor of Philosophy.

Department of Forestry  
and Natural Resources.



1975

I hereby declare that this thesis has been composed by myself  
and the research presented in it is my own.



CONTENTS

ACKNOWLEDGMENTS	( v )
SUMMARY	( vii )
INTRODUCTION	1
SECTION 1	3
A. THE TWEED CATCHMENT	3
I Location	3
II Geology and land use	3
III Climate	5
IV The study area	6
B. GENERAL METHODOLOGY	14
I Methods of sampling	14
II Treatment of material	15
SECTION 2 : AGE AND GROWTH	17
I Introduction	17
II Methods	18
III Results and Discussion	19
a) Validity of age determination	19
b) Growth pattern - seasonal variation	25
(i) Length	25
(ii) Weight	25
(iii) Condition factor	28
c) Growth pattern - annual variation	30
(i) Length	30
(ii) Weight	36
(iii) Length-weight relationship	39
SECTION 3 : DISTRIBUTION	43
I Introduction	43
II Methods	43
III Results and Discussion	44
a) Distribution	44
b) Seasonal variation and preferred habitat	46
c) Spread	

SECTION 4 :	MOVEMENT	49
	I Introduction	49
	II Methods	49
	a) Tagging	49
	b) Panjetting	52
	III Results and Discussion	54
	a) Tagged fish	54
	b) Panjetted fish	56
	c) ALL marked fish	56
SECTION 5 :	POPULATION SIZE AND STRUCTURE	65
	I Introduction	65
	II Methods	65
	a) General considerations	65
	b) Possible methods	69
	c) Choice of a suitable method	72
	III Results and Discussion	73
	a) Dace over 10 cm in length	73
	b) Dace less than 10 cm in length	80
	c) Causes of mortality	85
SECTION 6 :	FOOD	87
	I Introduction	87
	II Methods	88
	III Results	95
	a) Seasonal variation in feeding activity	96
	b) Seasonal variation	100
	c) Variation with age (size) of dace	109
	d) Summary	110
	e) Comparison with other fish species	110
SECTION 7 :	GENERAL DISCUSSION	116
	BIBLIOGRAPHY	121
	PERSONAL COMMUNICATIONS	138

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The ecology of the dace (Leuciscus leuciscus (L.)), a species first recorded in the River Tweed as recently as 1967, has been studied. Regular monthly samples were taken at Norham (N.G.R. NT 893464) between October 1971 and October 1972 and the majority of the fieldwork was completed by May 1974. Background information on the climate, geology and land use of the Tweed basin and the characteristics of the river in the study area are given. Seine netting proved to be the most satisfactory method of sampling in the study area, between 5 and 15 km from the mouth, where the river was approximately 100 metres wide and up to 6 metres deep.

Scales and opercular bones were tested for age determination and scales proved to be the most satisfactory. Most dace were less than four years old. Tweed dace were found to have a very good rate of growth when compared with other European populations. Female fish predominated in the 4+ and older age classes. Male fish were found to grow significantly faster than female fish and predominated in the 2+ age class. Study of the seasonal growth pattern over the period October 1971 to October 1972 showed rapid growth was confined to the period May to September with little or no growth occurring between October and April. The time of annual check formation in May coincided with the commencement of rapid growth but may have been preceded by an improvement in condition of the fish.

The distribution of dace in the Tweed was determined in 1972. Dace were most common between Union Bridge (NT 933512) and Coldstream (NT 844397) but were present from the mouth upstream to Kelso.

The possibility of further spread was discussed and considered likely.

The movement of dace was investigated by mark and recapture. 773 fish were marked using tags and 3315 with dyespots. Of the 263 (6.4%) recaptured, 62 (1.5%) had moved an average distance of 6.3 km. The pattern of movement of these fish was displayed using a time-distance plot. It was further suggested that the majority of dace 1+ and older moved distances in excess of 1 km in contrast with other populations described in the literature for which only a small component was considered mobile.

Estimates of population density were made by a number of methods using the recapture data from dace marked with dyespots. Estimates proved very variable from one sampling occasion to the next with the method of Schnabel being the most consistent. However, by the seventh mark and recapture occasion most methods suggested a population of approximately 25,000 to 30,000 dace (over 10 cm in length) in the sample area, i.e. 0.027 dace per  $m^2$  of river surface. Confidence limits calculated separately for the various estimates were found to be unreliable, but a mean and confidence limits calculated for all estimates and the last few sampling occasions suggested a population of 19,500 to 36,500 dace (>10 cm) or 0.020-0.037 dace per  $m^2$  surface in the sample area. An estimate was also produced for the numbers of smaller fish.

The contents of the complete alimentary canal of 655 dace were analysed. An improvement of Swynnerton and Worthington's (1940) points method, later modified by Hynes (1950) was used to allow digested organisms to be compensated for.

Tweed dace were found to feed little between November 1971 and February 1972, a phenomenon correlated with water temperature. 0+ dace fed more during this period than older fish. The main components of the diet of Tweed dace were found to be, in order of importance, Chironomidae (larvae and pupae), Oligochaeta, Trichoptera larvae, aerial Insecta and plants. Seasonal variation, and variation between age groups is discussed. The diet of dace was compared with that of other fish species in the Tweed. Overlap was found to exist with Chironomidae, one of the most common invertebrates, being important to a number of other fish species as well as dace.

The implications of the above findings are discussed in relation to management considerations. It is suggested that the high growth rate and relatively low population density in particular meant that control measures were, at present, unnecessary, but that the position should be reviewed at a later date.

## INTRODUCTION

In recent years progressively more attention has been paid to the management of freshwater fish populations. Interest in this aspect of fisheries has no doubt emphasised the lack of basic scientific information on which meaningful management decisions can be based. This is particularly true in the case of populations of coarse fish species in rivers and much of the recent work that has been undertaken has attempted to fill this gap in our knowledge.

For a number of years Dr. D.H. Mills, of the Department of Forestry and Natural Resources of Edinburgh University, has carried out research work on the River Tweed and its tributaries. Much of this work has naturally been concerned with the economically valuable salmonid species. In 1971, while discussing the interrelationships of salmonids and other fish species in the river system, Dr. Mills drew my attention to the first confirmed record of dace, Leuciscus leuciscus (L.) in the River Tweed. This fish was, in fact, taken on a dry fly by Dr. Mills on 30 May 1967. The presence of a 'new' coarse fish species (Mills, 1973) in a river noted for its salmonid populations, obviously added another dimension to the problems under consideration. Furthermore, this is the most northerly record of dace for the British Isles (Maitland, 1972) and in itself raises interesting questions as to the performance of the species at this latitude. On the Continent however dace are found much further north, though several different forms are distinguished over the geographical range (Muus and Dahlstrom, 1967).

In view of the considerations outlined above it was decided to embark on an ecological study of dace in the River Tweed. Since this was a record of a species in a new situation it was decided to concentrate on the distribution, movement, population size and structure, food and growth of dace. Fieldwork was carried out between September 1971 and May 1974. Regular monthly samples were taken between October 1971 and October 1972.

This thesis has been arranged in sections as outlined in the Contents. Section 1 considers general methods of sampling appropriate to this study, whereas specific methodology is included at the appropriate point. Because the section on age and growth contains information relevant to all subsequent sections it is presented next.

A large amount of raw data has been collected for which a number of alternative forms of analysis are possible. For this reason only the more informative summaries, tables and graphs have been included in the thesis and the raw data are available on request from the author. Unless otherwise stated the 95% confidence limit is used throughout as the measure of variability.

## A. THE TWEED CATCHMENT

I. Location (Fig. 1.1)

The River Tweed rises to the north east of the Lowther Hills, at an altitude of 520 metres, some 9 kilometres north of Moffat, Dumfriesshire. It flows north, then north east for 32 kilometres before turning to flow in a general easterly direction through Peebles, Galashiels, Melrose, Kelso and Coldstream. At Coldstream it turns once more to the north east and flows into the North Sea at Berwick upon Tweed. The river, 160 kilometres in length, together with its tributaries drains a catchment of almost 5,000 square kilometres.

II. Geology and land use

In its upper reaches the River Tweed flows over the drift free Tarannon and Llandovery series of the Silurian. These comprise greywackes, mudstones or shales which have been eroded to give gentle rounded uplands dissected by steep sided valleys. The rounded summits are covered by blanket peat but below this level peaty podsols or peaty-gleyed podsols have developed (Burnett, 1964). The area is one of mostly unimproved acid grassland with typical upland species. The area has a long history of hill sheep farming but recently, as in other parts of the country, large tracts of land are being planted with conifers.

The valley floor of the upper and middle Tweed and its tributaries often contains localised pockets of boulder clay. After improvement these valleys support rotation grasses, hay and fodder crops.

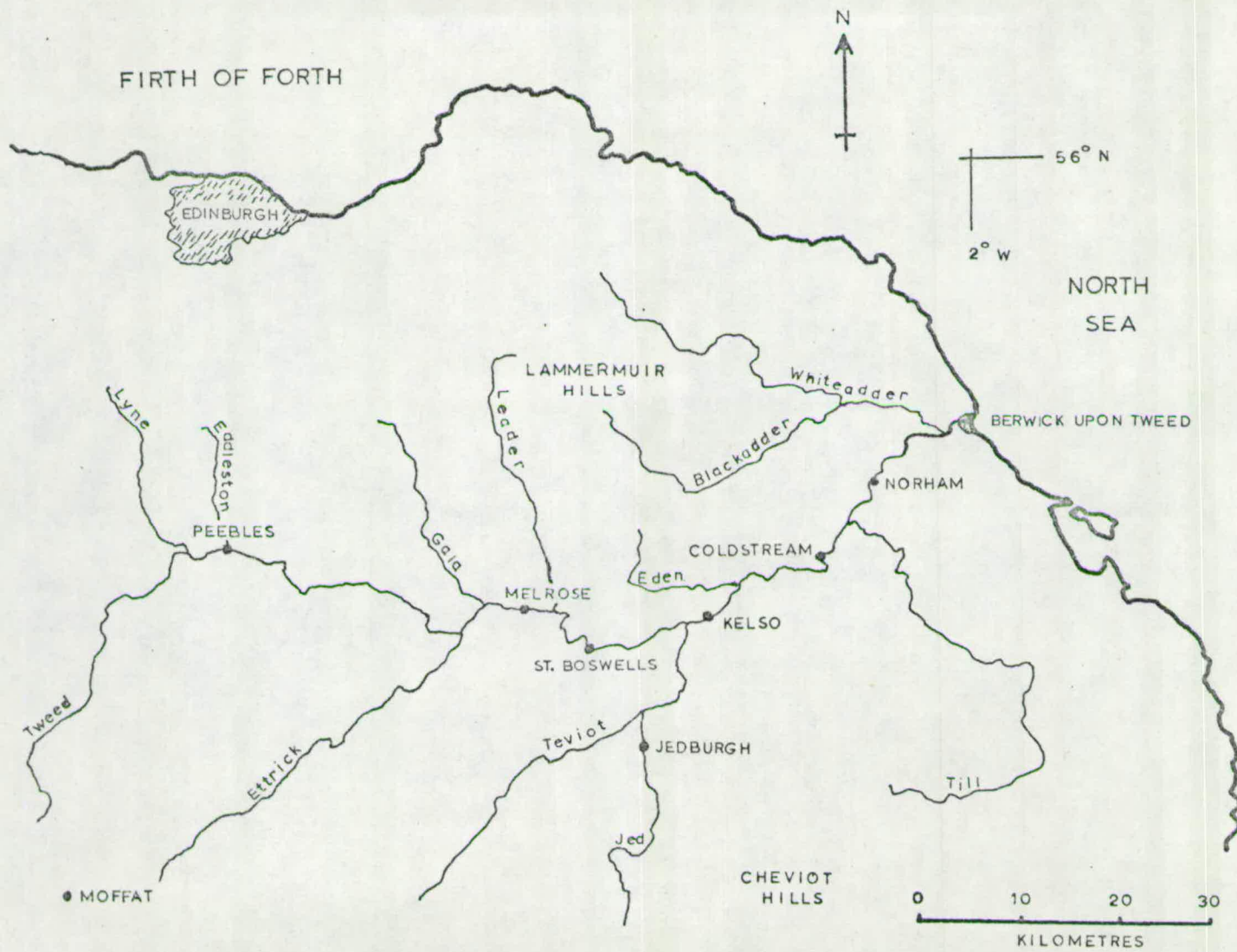


FIG. 1.1 THE TWEED BASIN.

To the east of Galashiels superficial deposits of boulder clay become increasingly common and changes in the solid geology also occur. A band of Old Red Sandstone occurring near St. Boswells weathers to give a reddish brown till or sometimes a clay loam. Downstream from Kelso slightly more recent Calciferous Sandstones of the Tuedian Series underlie the boulder clay and extend almost to the sea. A narrow band of basalt lava of Carboniferous age has been extruded between the Old Red and the Calciferous Sandstones near Roxburgh.

Ragg (1960) has shown that slightly podsolised soils known as Cryptopodsolic Braunerden predominate in the lower basin. The area is important for mixed farming viz. sheep, cattle and crops such as barley and oats. Much of the land is devoted to temporary or permanent grass and used to support stock. Tracts of parkland are also found. In keeping with current farming practice throughout the British Isles moderate amounts of nitrogenous, phosphatic and potash fertilisers, in addition to lime, are applied to the land.

Below its confluence at Kelso with the River Teviot, the River Tweed becomes eutrophic. This is partly due to the influx of nutrient rich Teviot water and partly to the changes in geology and land use described above.

### III. Climate

Climatic conditions vary noticeably over the Tweed catchment ranging from cool and wet in the uplands to warmer and drier in the lowlands. The average temperature and rainfall figures from Meteorological Office Reports for Camps Reservoir (near the source of the River Tweed), Glentress (near Peebles), Kelso and Berwick are

Table 1.1 Climatic data for the Tweed Catchment

	Camp's Reservoir	Glentress	Kelso	Berwick
Daily Mean Temperature, °C	6.7(-)	7.8(-)	8.6(-)	8.8(8.6)
Total Rainfall, mm/annum	1167(1270)	799(773)	579(-)	566(594)

The first figure is a 5 year average (1967-1971) whilst the second figure in parenthesis gives the long term average when available. The 35 year standard period (1916-1950) applies in the case of rainfall and the 30 year period (1931-1960) for temperature.

Most stations record a maximum rainfall in January with a smaller peak between August and October. The length of the growing season (number of days per year when the daily mean temperature exceeds 5.6°C) is 219 days at Kelso compared with 175 days in the more westerly upland areas.

#### IV. The study area

As mentioned in the Introduction, the first confirmed identification of dace in the River Tweed was made in May 1967. The fish in question was caught just downstream from Norham (N.G.R. NT 906477). Subsequently other dace were caught in this general area. While dace may have been caught in the River Tweed before the commencement of this investigation positive identification is not possible due to the confusion of this species with roach (Rutilus rutilus (L.)) by some of the bailiffs, gillies and netsmen.

The study area (Fig. 1.2) was provisionally fixed as the lower reaches of the river; the area around Norham, where the species had been first positively identified, to receive immediate attention.

The stretch of river adjacent to Norham Boathouse (NT 893464) is typical of the lower reaches. The river is moderately fast flowing (actual mean flow, October 1971–September 1972,  $62.265 \text{ m}^3 \text{ s}^{-1}$ ) and well oxygenated (Table 1.2), and the river bed mainly of gravel. The width at Norham is just less than 100 metres and the gradient between Coldstream and Berwick is  $0.47^\circ/\text{oo}$ . Trout (Salmo trutta (L.)) are probably the most common species (Table 1.3). As a result the lower reaches cannot readily be classified by the methods of Carpenter (1928) or Huet (1949, 1954).

Conditions vary considerably with season and location within the section off Norham Boathouse. The deepest point, approximately 6 metres, is at the upstream end whilst at the downstream end large areas are less than 2 metres deep under conditions of normal summer flow (Fig. 1.3). Variation in the monthly mean flow over the sample period is shown in Fig. 1.4.

During the summer months large areas on the shallower south side are covered by plant growth. The dominant species is Ranunculus fluitans (Lam.), (water buttercup), with Enteromorpha and Cladophera spp. being less abundant. During the winter months changes in climate and flow cause the river bed to be exposed and only isolated specimens of R. fluitans can be found (Plate 1.1). Holmes (1974) has carried out a survey of macrophytic plants in the River Tweed and found that R. fluitans and Enteromorpha spp. only occur downstream from the Teviot confluence at Kelso.

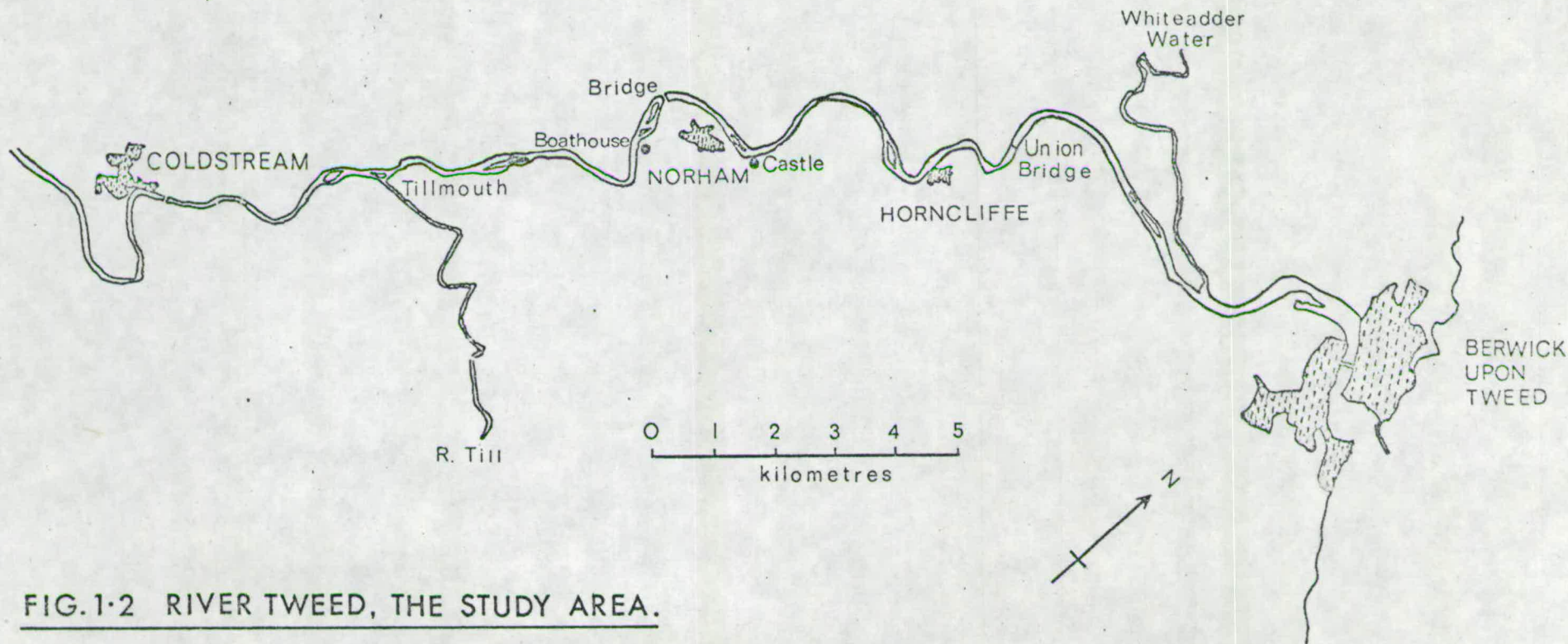


FIG.1-2 RIVER TWEED, THE STUDY AREA.

Table 1.2 Chemical Analyses of the River Tweed at Norham

Date	pH	Suspended Solids	B.O.D.	Temp.	Dissolved Oxygen (At mid-day)	Percentage Saturation	Oxygen Absorbed	Ammonia	Nitrate	Chloride	Total Hardness
16.11.65.	7.8	Nil	2.2	2.5	12.7	95.9	2.2	Nil	1.7	16.0	-
30.4.68.	8.1	Nil	2.6	12.5	11.2	108.5	1.8	0.1	1.4	14.0	104
5.11.69.	7.7	1	1.8	6.0	10.5	87.1	4.2	Nil	0.8	10.5	64
6.7.71.	8.3	Trace	1.6	22.0	10.3	120.8	3.6	0.06	0.8	10.5	80
5.9.72.	9.7	2	3.3	18.0	19.0	206.9	2.5	0.08	0.9	17.5	115.
19.9.73.	9.4	1	1.4	17.5	15.7	169.3	2.6	0.04	0.6	16.5	124.
13.2.74.	7.6	7	1.7	4.0	12.4	97.7	3.5	0.06	2.65	17.5	76.

Data from Currie (personal communication)

Table 1.3 Fish species netted at Norham

<u>Scientific name</u>	<u>Common name</u>	<u>Regularity of capture</u>		
		<u>High</u>	<u>Intermediate</u>	<u>Low</u>
Salmo trutta (L.)	Brown trout	**		
Salmo trutta (L.)	Sea trout	*		
Salmo salar (L.)	Salmon	*		
Leuciscus leuciscus (L.)	Dace	**	***	
Noemacheilus barbatulus (L.)	Stone loach	*	**	
Gobio gobio (L.)	Gudgeon		**	***
Rutilus rutilus (L.)	Roach		**	***
Phoxinus phoxinus (L.)	Minnow		**	
Thymallus thymallus (L.)	Grayling		*	**
Platichthys flesus (L.)	Flounder		*	**
Gasterosteus aculeatus	Stickleback		*	**
Anguilla anguilla (L.)	Eel		*	*
Perca fluviatilis (L.)	Perch			*
Esox lucius (L.)	Pike			*
Lampetra fluviatilis (L.)	Lamprey			*

Asterisks indicate abundance

\* = &lt; 10

\*\* = 10-100

\*\*\* = &gt; 100

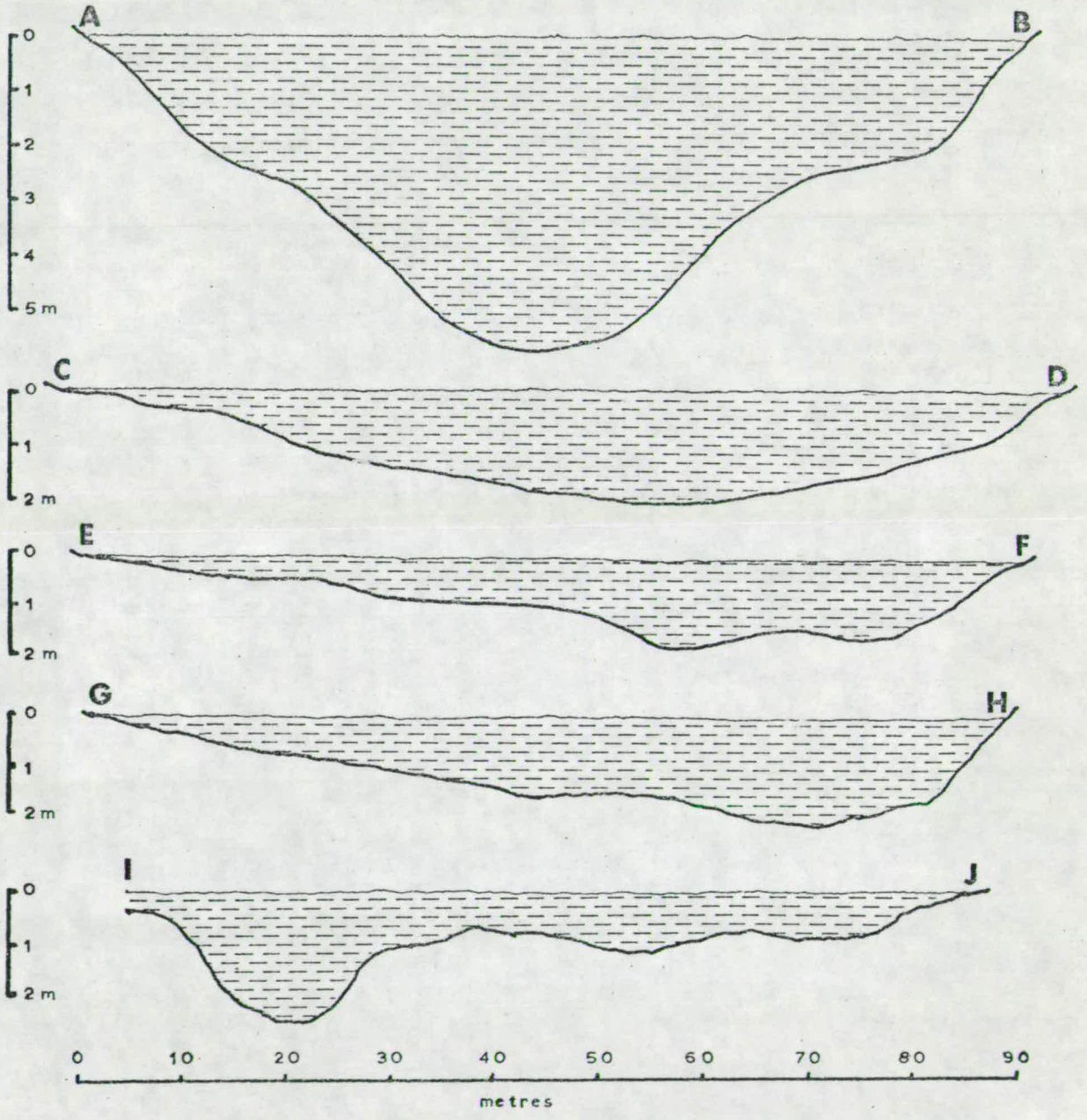
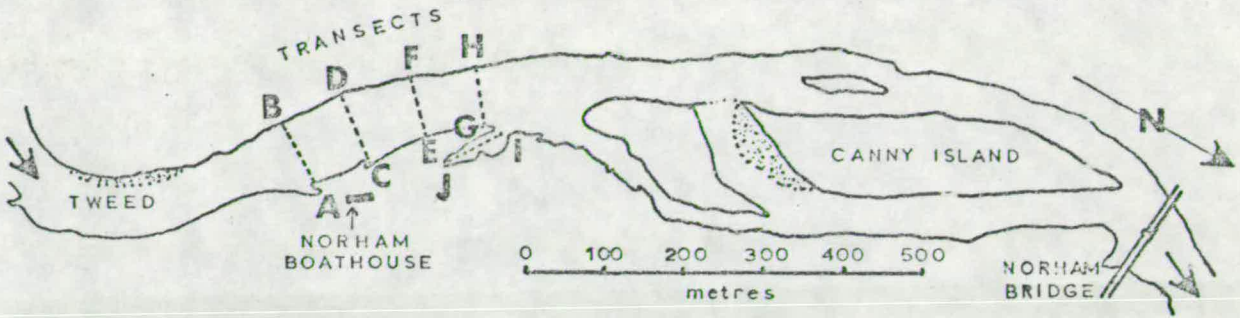


FIG. 1.3 CROSS-SECTIONS OF THE RIVER TWEED OFF NORHAM BOATHOUSE.

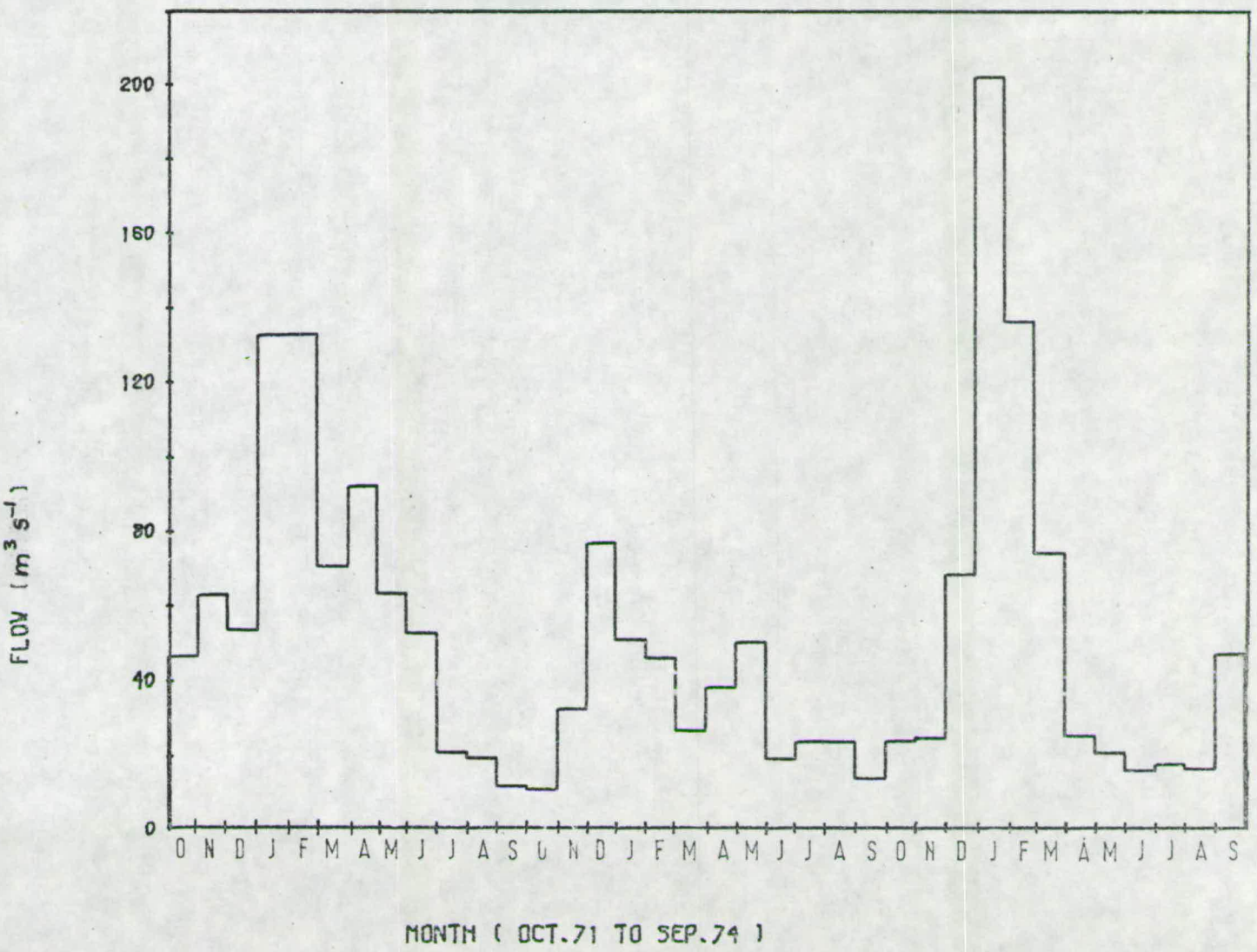


FIG. 1.4 VARIATION IN THE MONTHLY MEAN FLOW AT NORHAM NT893464.  
 (Data from the Annual Reports of the Tweed Purification Board for the years 1971 to 1974).

PLATE 1.1 The River Tweed off Norham Boathouse

(a) Looking downstream from the English bank near  
Norham Boathouse.

(b) Looking upstream from Canny Island (see p. 11 ).  
The entrance to the backwater is to the left of the  
photograph with Norham Boathouse behind it in the  
trees.



A somewhat different habitat, within the sample section at Norham, is the backwater known locally as 'The Dewpond' (Plate 1.2). Except in times of flood, there is no throughflow and the habitat is therefore lentic with a maximum depth of 2 metres in normal summer conditions. The substrate is of silt and dominant plant species in the summer months include Polygonum amphibium (L.) and Potamogeton spp. in open water with other species such as Iris pseudacorus (L.) present near the banks.

PLATE 1.2 The backwater at Norham Boathouse

(a) Seine-netting the deeper end of the backwater.  
Canny Island and the main river are in the background  
to the middle left of the picture.

(b) A view down the length of the backwater in winter.



## B. GENERAL METHODOLOGY

I. Methods of sampling

Summaries of possible methods of capture are given by a number of authors including Lagler (1968) and Kristjonsson (1957, 1963). It is clear from the papers presented at a recent F.A.O. Symposium (1974) that there are no entirely satisfactory methods for sampling lakes and large rivers. Electrofishing, now widely used in smaller streams and rivers, is usually unsatisfactory at depths greater than 1.5 or 2 metres unless expensive equipment and a large team of workers, (Halsband, 1974), are available.

Seine netting therefore promised to be the most suitable method with hook and line fishing or trapping as possible alternatives. Most fish caught in this study were, in fact, taken in a river seine 61 metres in length with a depth of 8 metres at the centre tapering to 1.6 metres in the wings. The stretched mesh size of the nylon was 35 millimetres in the wings and 10 millimetres in the bag. A hand net, with mesh of 1.5 millimetres was also used to sample larval fish.

Preliminary attempts to obtain fish by hook and line were disappointing so the only real use made of this method was in the context of tag returns from sport fishermen. Perch traps, as used by the F.B.A., were set in the backwater at Norham in an attempt to provide recapture data. Again the comparatively small number of fish caught meant that the method was of limited value especially as the trap needed to be visited frequently when in use.

Skin diving was occasionally used for direct observation of the fish. This method was useful for the location of shoals prior to

netting and for the description of distribution. The effectiveness of this technique was sometimes restricted by reduced visibility concurrent, for example, with flooding.

## II. Treatment of material

The fork length of each fish captured was measured to the nearest millimetre. Fork length is defined as the length from the anteriormost extremity, viz the tip of the snout, to the tip of the median rays of the tail. All measurements were made with the fish's mouth closed.

In feeding and growth studies weight was also measured in the field using an appropriate 'Pesola' spring balance (British Trust for Ornithology, Beech Grove, Tring, Herts.). Balances were regularly checked against accurate laboratory balances and a potential accuracy of  $\pm 1\%$  attained. Measurements were recorded at this level of precision to minimise variation, though it was recognised that variation in the degree of wetness, the amount of water engulfed at capture and variation in the amount of food ingested mean that the accuracy of the recorded weights were further reduced.

The anaesthetic MS 222 (tricaine methanesulphonate) (Sandoz) was not used when fish were taken for food analysis, since preliminary investigations had showed that some fish tended to regurgitate their food when placed in a 1:25,000 solution. Fish were killed instantaneously by decapitating them with one stroke of a carving knife, after which the alimentary canal was easily removed complete. Alimentary canals were immediately placed in labelled vials containing 10% formalin, thus avoiding further digestion and subsequent disintegration of the food organisms.

Scale samples were taken from the left side of the fish between the front of the dorsal fin and the lateral line. From a proportion of sample fish the opercular bones were also removed by bending the bone back against its point of articulation with the skull. Scales and opercular bones were placed in labelled envelopes with details of date, place of capture, length, weight, sex (when discernable in the field), sexual condition, presence and position of parasites, wounds or disease. On a limited number of occasions gonads were taken to determine maturity and to estimate fecundity via egg counts.

## SECTION 2

## AGE AND GROWTH

I. Introduction

For more than 250 years the age of fish has been determined in a number of ways (Tesch 1968). The methods have been described many times, e.g. Dahl (1909) or more recently Ricker (1958). It is now well established that in temperate zones age can usually be determined from the number of annual checks laid down in the hard parts of the body such as the scales, opercular bones, otoliths or fin rays.

Dace scales were described initially by Masterman (1923) and they have been used for age determination by a number of authors including Hartley (1947a, b), Healy (1956), Vostradovsky (1961), Klimczyk (1966), Penczak (1967), Williams (1967), Cragg-Hine and Jones (1969), Mann (1974), Hellowell (1974a) and Hofstede (1974).

Opercular bones, however, are not generally used for age determination in dace though they have been used for other species including perch (Le Cren, 1947), pike (Frost and Kipling, 1959), carp Cyprinus carpio (L.) (McConnell, 1952) and roach (Clout, 1972), (Mann 1973).

It was therefore decided to use scales for age determination, but at the same time to look at opercular bones to consider their suitability.

## II. Methods

### a) Terminology

Concentric ridges cover the surface of dace scales and these appear as rings arranged around the nucleus of the scale. In this study these ridges will be referred to as rings. Alternative terms include sclerites (Harley, 1947a), annuli (Hartley, 1947a) and circuli (Tesch, 1968). Wallin (1957) and Yamada (1961) have discussed possible mechanisms for the production of these rings which are normally laid down in a regular sequence.

Any break occurring in this regular pattern of rings will be referred to as a check. If the check persists right around the scale (Plate 2.1) and is characterised, especially in younger fish, in the latero-posterior regions by new rings 'cutting over' previously formed rings (Plate 2.2) it will be referred to as an annual check. If not it will be termed a false check. Cragg-Hine and Jones (1969) also described 'cutting over' as a characteristic of annual checks on dace scales. Annual checks have also been referred to as annual rings (Masterman, 1923), checks (Hartley, 1947a) and annuli (Tesch, 1968).

The convention of referring to fish in their first year of life as the 0+ group, fish in their second year as the 1+ group and so on has been adopted. The plus sign, which is optional (Tesch, 1968), refers to the growth outside the annual check.

### b) Treatment of material

Scales were collected from all sample fish and opercular bones from a sub sample as described on page 16. For each fish a permanent impression was made of a number of scales without

PLATE 2.1 Scale and operculum from 1+ dace

(a) Scale from a 1+ dace (x 30). The first annual check is arrowed. The fish is almost 2 years old but the second annual check is not yet visible.

(b) Operculum from the same 1+ dace (x 10). No annual check corresponding to the end of the first year of life could be distinguished.

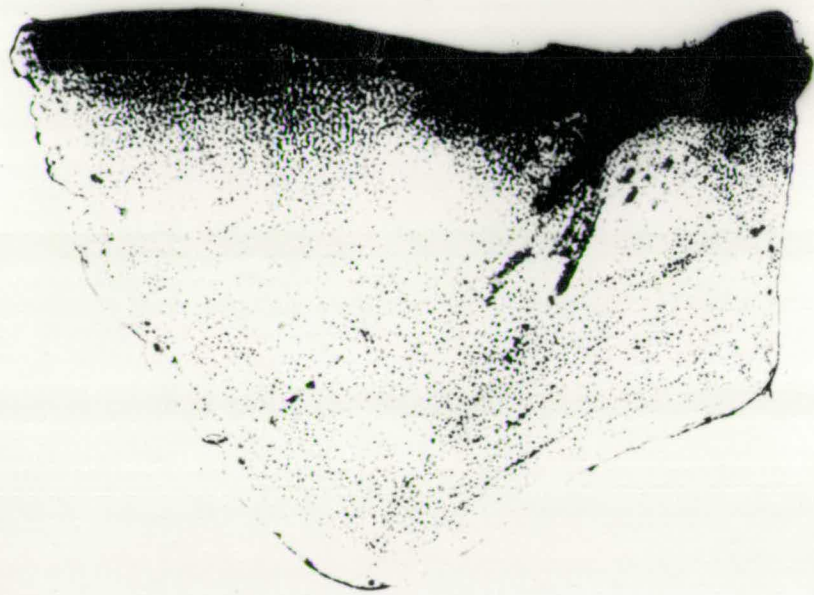
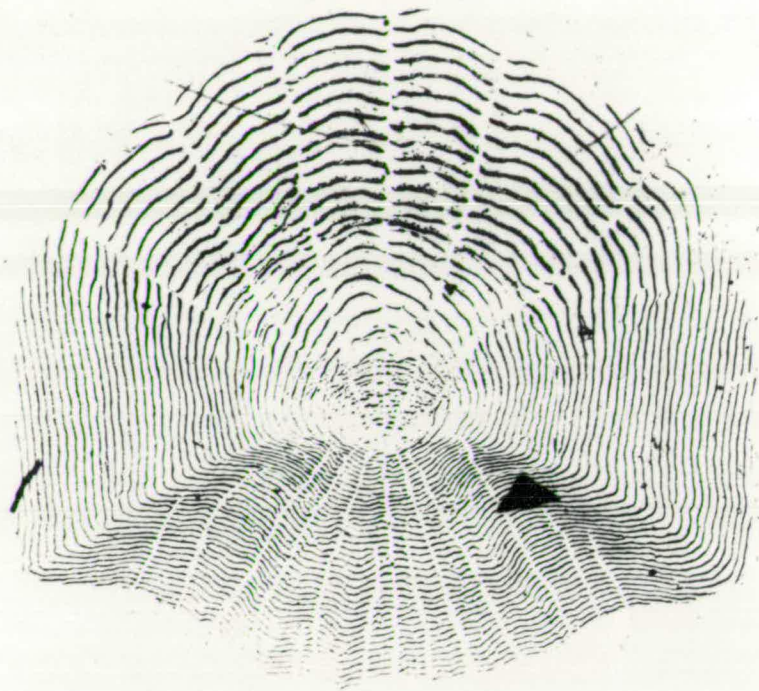


PLATE 2.2 Close up of lateral portion of a scale (x 50)  
showing "cutting-over" in the posterior region  
(arrowed).



regenerated centres. This was done using cellulose acetate slides (Smith (1954)). Though it was not usually necessary, scales were occasionally cleaned by soaking them in 4% Sodium Hydroxide solution prior to rubbing them with tissue paper. The slides were subsequently examined using a 'Projectina' micro/macro projection microscope which produces an image on an 18 centimetre diameter screen. (Projectina Company, Ayrshire, Scotland). The screen was occasionally removed and replaced by a polaroid camera which allowed a photographic record of the image to be made.

Opercular bones were cleaned and projected as described above for scales. They were, however, placed concave side uppermost in xylol as recommended by Frost and Kipling (1959).

Graham (1928) outlines evidence that can be used to substantiate age determination. He emphasises that check formation must be only of annual occurrence and must also be limited to a short period of the year. Consequently both the number of annual checks and the number of rings outside the last annual check were counted, for each scale examined, to verify the time of annual check formation.

### III. Results and Discussion

#### a) Validity of age determination

Opercular bones were found to be unsatisfactory for age determination in Tweed dace. The sub sample examined needed more preparation time than the equivalent scale sample and was more difficult to read. The age estimated from opercular bones was, almost without exception, one year less than the estimate obtained from scales or from the Petersen method (Tesch 1968). This is in

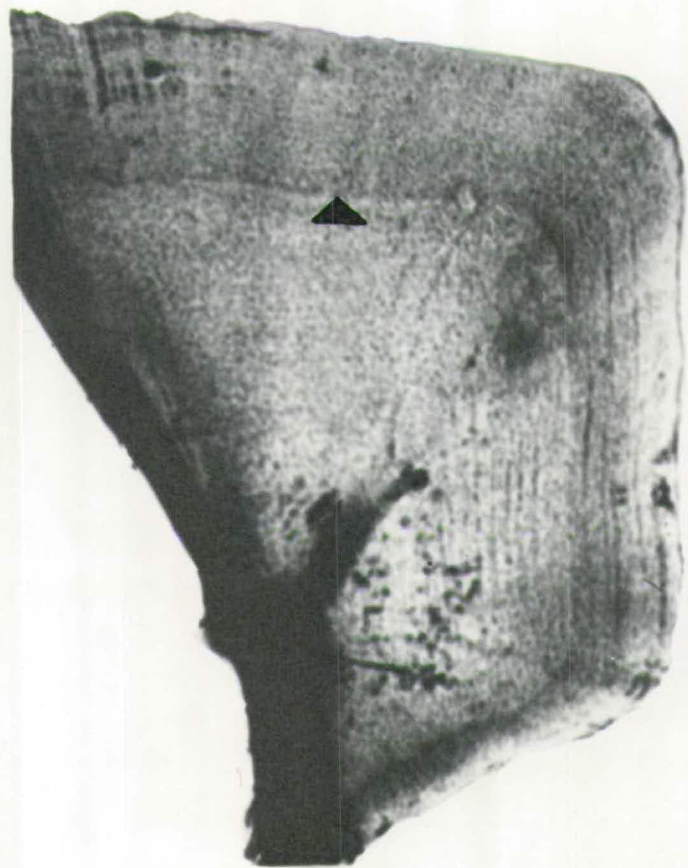
accordance with the findings of other workers (e.g. Clout (1972)). This worker, who investigated roach, found that the first annual check was rarely visible even on fish in his 1+ group. Furthermore, the second annual check was sometimes also missing, due he suggested to the obscuring effect of the buttresses radiating from the fulcrum. (Plate 2.3). McConnell (1952) records that the majority of carp bones could be aged without difficulty despite the fact that he was unable to locate the first annual check in about half of his samples. Le Cren (1947), Frost and Kipling (1959) and Mann (1973) experienced problems of a similar nature for perch, pike and roach respectively. Despite these difficulties, Le Cren (1947), Frost and Kipling (1959), Clout (1972), McConnell (1952) and Mann (1973) all record advantages in using opercular bones for aging fish. Mann (1973), for example, states that scales had clearer inner annual checks but opercular bones had clearer outer annual checks in roach more than 9 years old. As most of the Tweed dace were found to be less than 5 years old (p. 80) the potential advantage of opercular bones being more useful for older fish was not realised.

Age was therefore determined from scales for all fish examined. In general little difficulty was experienced in distinguishing annual checks. False checks were present on some scales but could usually be recognised by their incomplete nature or by their absence on other scales from the same fish. Occasionally what appeared to be an annual check could be found near the nucleus of some scales, particularly those of older fish. These were generally rejected as false checks following comparison of the suspect scale with those from other fish of similar age. These false checks resulted, perhaps, from unfavourable weather or a change in preferred food at an early age.

PLATE 2.3 Scale and operculum from 2+ dace

(a) Scale from a 2+ dace (x 20). The two annual checks are arrowed.

(b) Operculum from the same 2+ dace (x 10). Only one check (arrowed) could be readily distinguished.

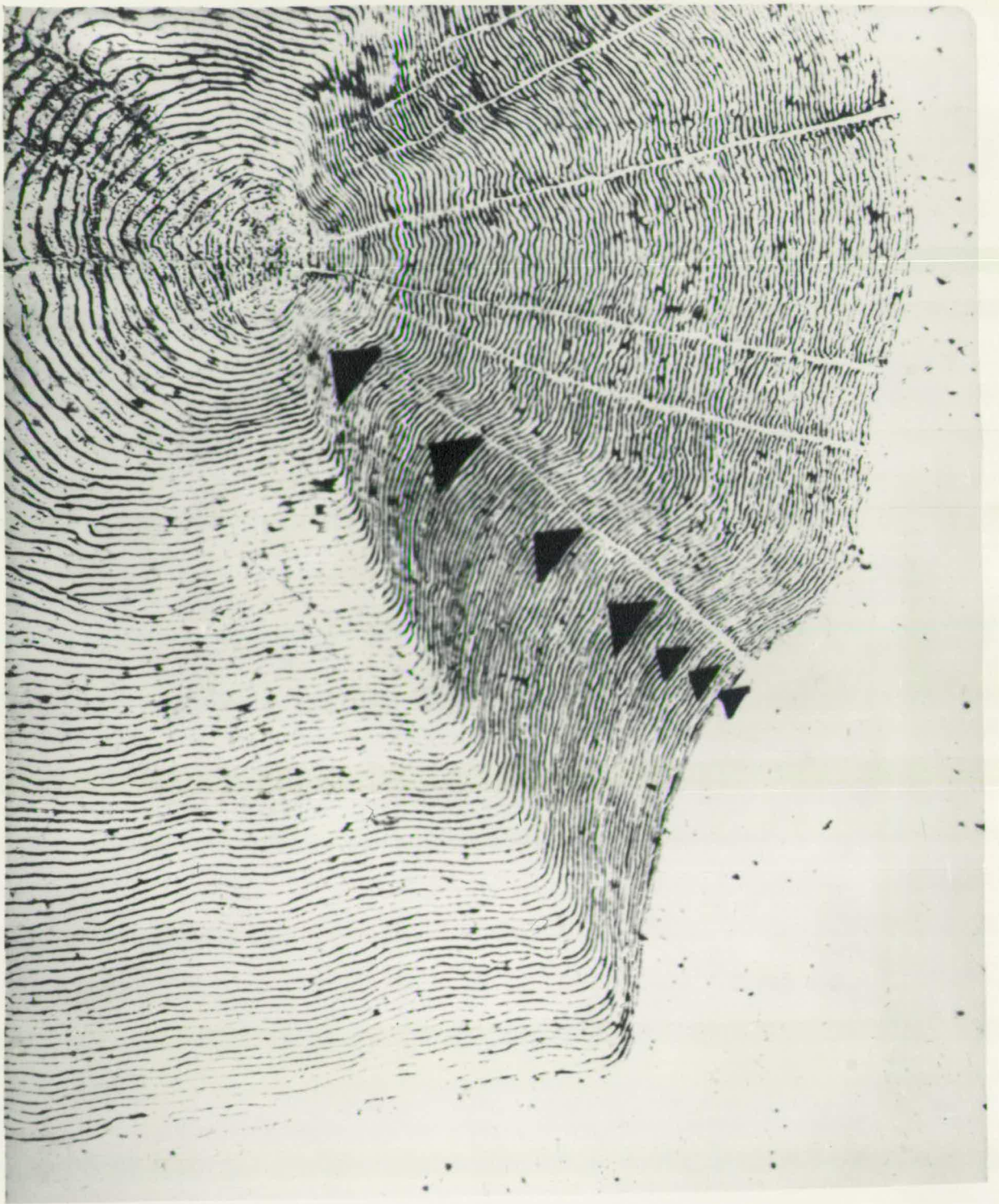


It is, however, possible that these individuals may have been particularly slow growing in their first year. This problem deserves further attention in future studies. In older fish there was also a slight possibility that age was incorrectly determined due to the close proximity of annual checks at the outer edge of the scale (Plate 2.4). Careful examination of a number of scales from each fish and re-examination at a later date (without prior reference to the original estimate) were used to reduce this source of observer error. As mentioned above most of the Tweed dace were less than 5 years old. Consequently the problems associated with such older fish were of little overall importance in this study.

It was found that the time of annual check formation for Tweed dace in 1972 was, almost without exception, restricted to the month of May (Fig. 2.1). In this respect Tweed dace differ from those of the River Lugg and Afon Llynfi which Hellowell (1974b) showed to have a protracted period of check formation. There is, however, a possibility of variation from year to year as shown by Cragg-Hine and Jones (1969).

Further proof of the annual nature of check formation is afforded by comparison of the age of fish as determined from scales with their age as determined by the Petersen method. This latter is suitable for fish with a short spawning season and rapid uniform growth. In Tweed dace, growth is sufficiently rapid to allow the separation of age groups 0, 1 and 2 with certainty and group 3 in the majority of cases. These groups correspond with the age as determined from the scales. Fig. 2.2 is presented as a typical example. It can be seen that after the fourth year growth is too slow for the Petersen method to be reliable, as one age class overlaps the next.

PLATE 2.4 Anterior lateral portion of the scale of  
a 7+ dace (x 30). The positions of the  
annual checks are shown by arrows.



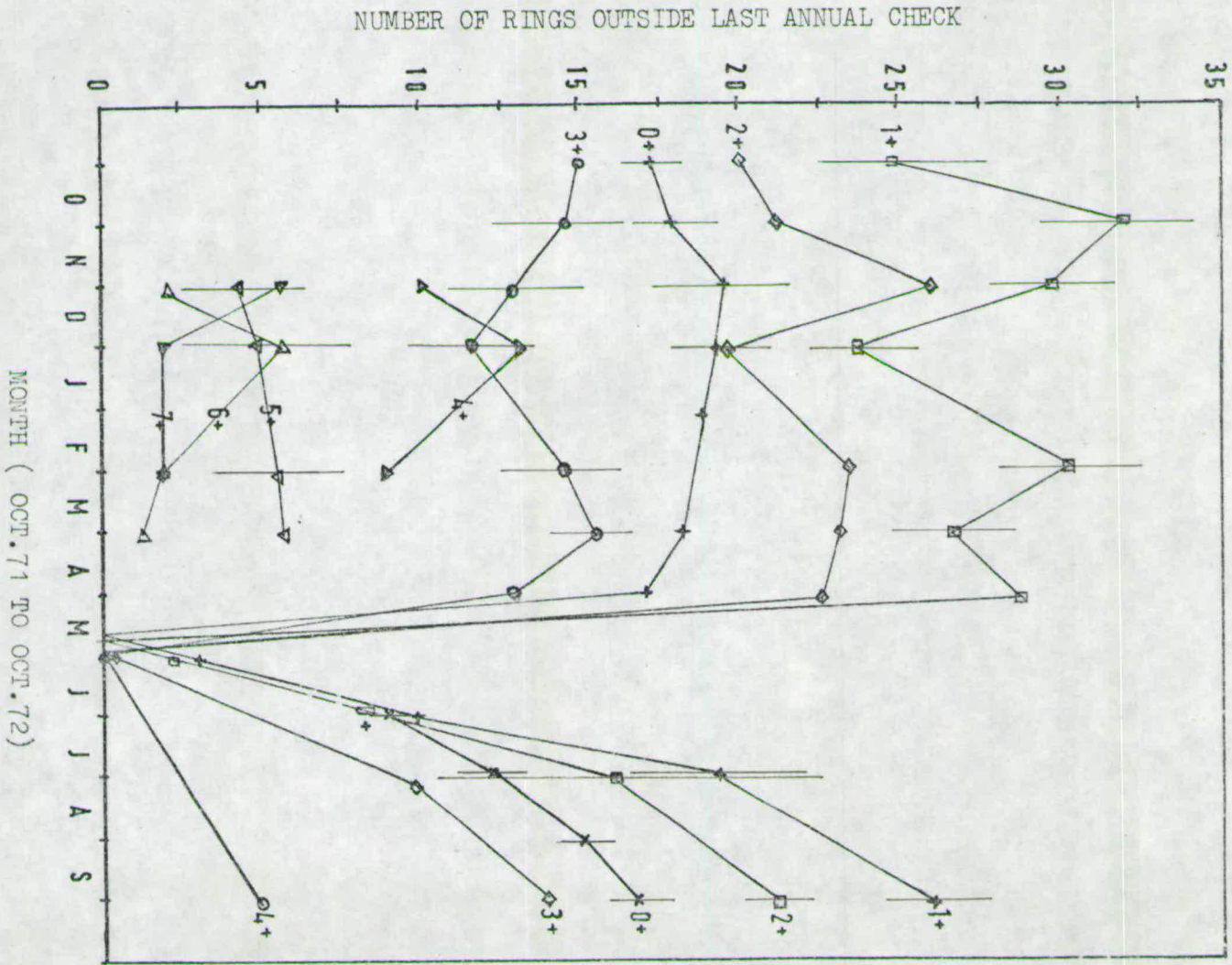
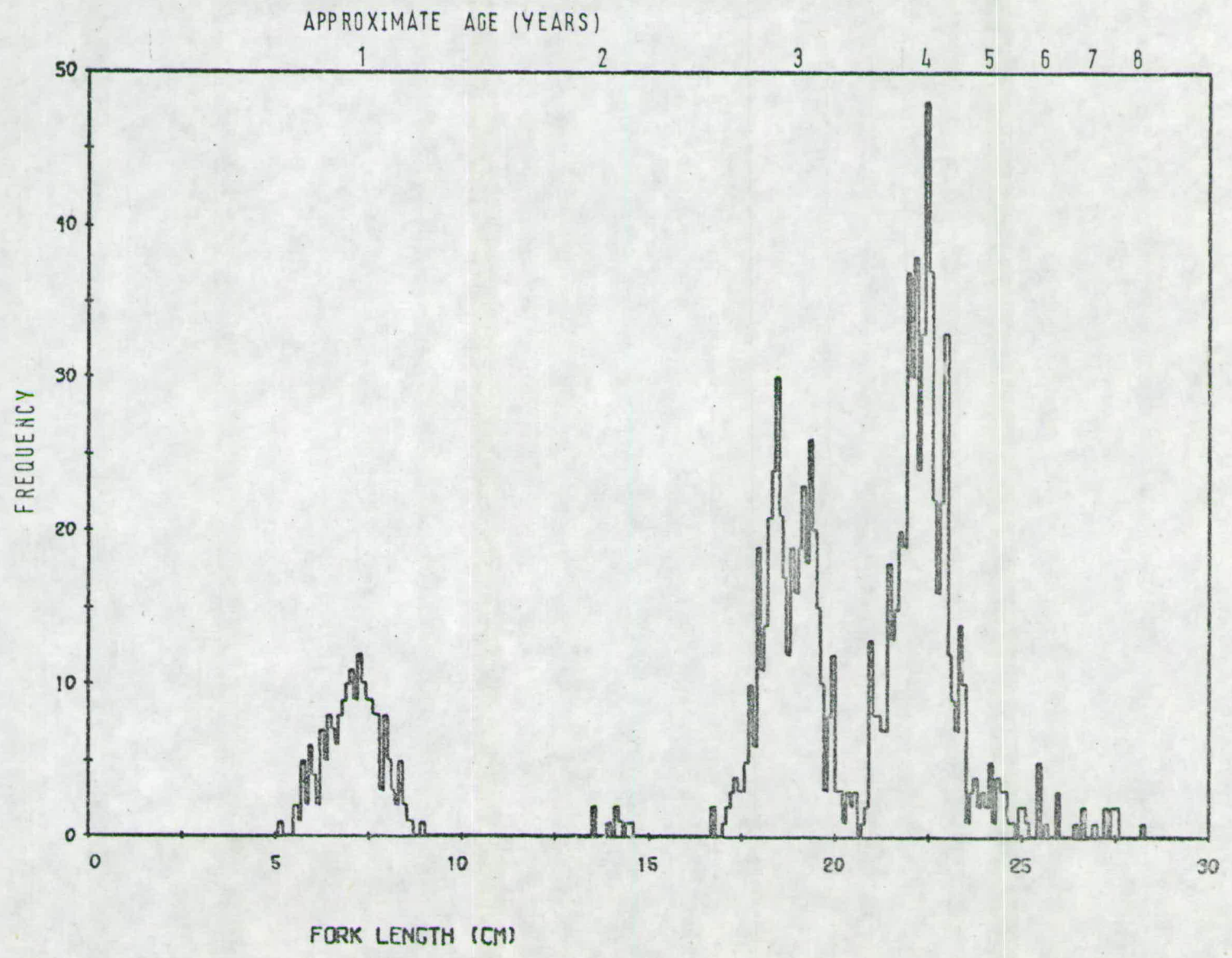


FIG. 2.1 MONTHLY VARIATION IN THE NUMBER OF RINGS OUTSIDE THE LAST ANNUAL CHECK ON THE SCALE FOR AGE GROUPS 0+ TO 7+. In 1972 most Tweed dace formed their annual check in May.

FIG. 2.2 LENGTH FREQUENCY HISTOGRAM FOR TWEED DACE SAMPLE (8-2-73, FROM NORHAM BOATHOUSE NT 893464).



Additional methods of verifying age are given for example by Le Cren (1947) from Graham (1928) and Van Oosten (1929, 1941). They include the marking of fish and subsequent re-examination after a known time period, the observation of dominant year classes and the observation of fish confined in tanks or ponds. Tweed dace were marked as described on page 49 ff, but as most fish were recaptured within a few months verification by this method was limited. Three batches of dace were brought into aquaria in the laboratory. The first batch were obtained as larvae in April 1972. The second batch, from the same year class, were brought in 4 months later and, as expected, showed no sign of check formation. The third batch were brought in as 1+ fish in September 1973. All surviving fish were re-examined in May 1975. The 12 fish in the first batch had no obvious check on their scales despite the fact that they were then 3 years old (Plate 2.5). The 12 fish in the second batch, again 3 years old, all had only one clear check on the scales. The position of the check approximated to the size of the scale at the time of transfer (Plate 2.6). The third batch had 2 obvious checks (Plate 2.7), the inner one being the first annual check formed in the wild whilst the outer one was again at a position approximating to the time of transfer.

The growth rate of these fish, especially those retained for 3 years in the laboratory, was significantly reduced ( $p < 0.001$ ) in comparison with wild fish of the same age. The mean length of the first batch was  $7.5 \pm 0.4$  centimetres, and the second batch was  $10.7 \pm 0.4$  centimetres compared with  $19.8 \pm 0.7$  centimetres for wild fish. The more or less constant conditions in the laboratory coupled perhaps with this reduced growth rate, were presumably responsible for the absence of annual checks.

PLATE 2.5 Scale from a 3-year old dace (x 50)  
which was brought into a tank in the  
laboratory very soon after hatching.  
No annual checks could be distinguished.



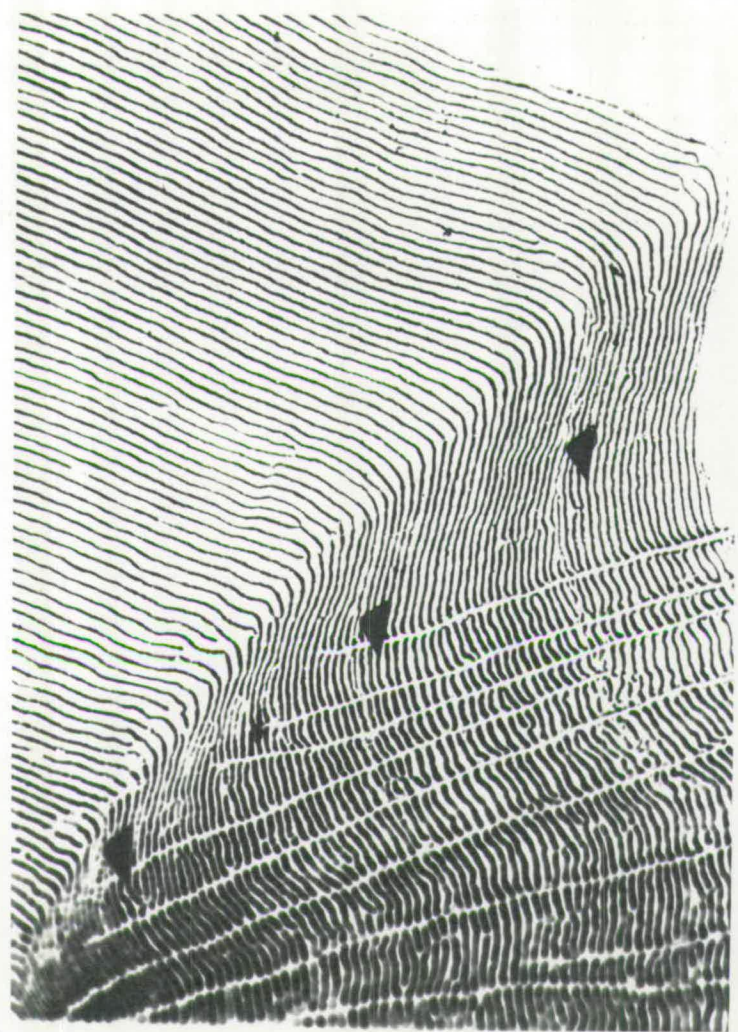
PLATE 2.6 Scales from 3-year old dace (x 20) brought into tanks in the laboratory after spending approximately 5 months in the wild. One clear (and possibly a second) check is apparent at a position corresponding to the time of transfer to the laboratory. Slight erosion of the lower scale (arrowed in the photograph) has occurred.



PLATE 2.7

(a) Scale from a 3-year old dace (x 20) transferred from the Tweed to a tank in the laboratory at age 1+. The first annual check is present, as is an additional check formed at a position corresponding to the time of transfer. Pronounced erosion has occurred at the former edge of the scale (arrowed).

(b) Latero-anterior portion of a 3+ dace (x 50) captured in the wild. The positions of the annual checks are arrowed. No erosion is apparent.



On balance the evidence suggests that the majority of fish in this study have been aged correctly. Hellowell (1974b), after reviewing the available evidence, suggested that the use of scales for age determination in dace was valid. He did, however, add that it was imperative to establish the validity of the method for each new population studied.

b) Growth pattern - seasonal variation

(i) Length

The seasonal pattern of growth in length was found to correspond closely to the pattern of growth in scales described in the previous subsection. Fig. 2.3 shows the mean monthly lengths of the different year classes for the period October 1971 to October 1972. There was little change in length over the period November to May, differences being insignificant at  $p = 0.05$ . Growth occurred mainly between June and September and reached a maximum in July. No seasonal growth pattern was discernible for fish over 4 years old as sample sizes were too small.

This pattern is very similar to that described by other workers. For example Mann (1974), when studying 0+ and 1+ dace, recorded May to July as the period of rapid growth with slower growth in August and September and very little increase in length from October to April.

(ii) Weight

Changes in weight (Fig. 2.4) were again of a similar pattern to those of length. There appeared to be a tendency in some age groups for a loss in weight to occur over the period November to January, but a 't' test showed that the differences were not significant ( $p > 0.5$ ). The weight recorded was the whole wet weight. This could have been

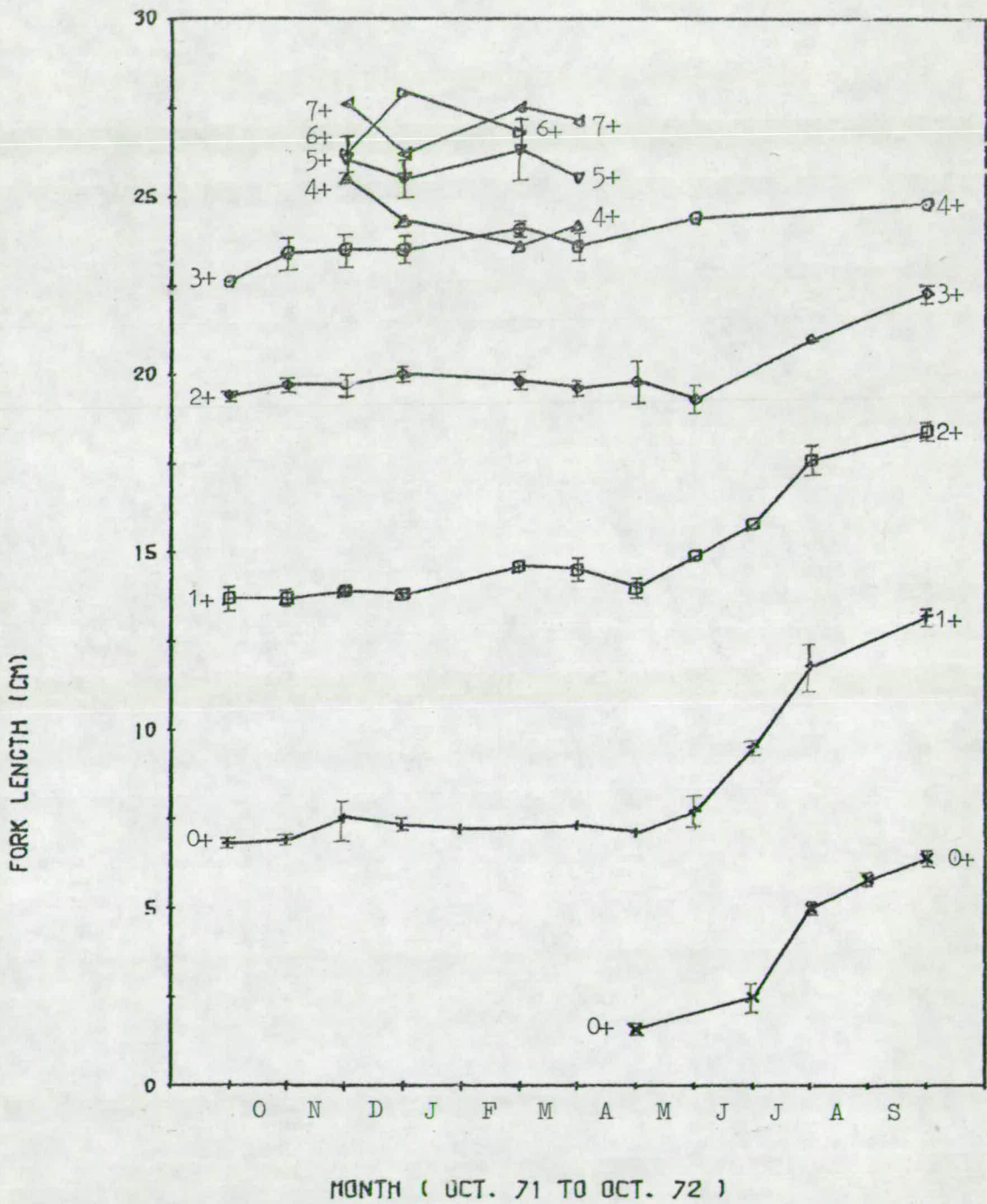


FIG. 2-3 SEASONAL CHANGES IN LENGTH FOR AGE GROUPS 0+ TO 7+.

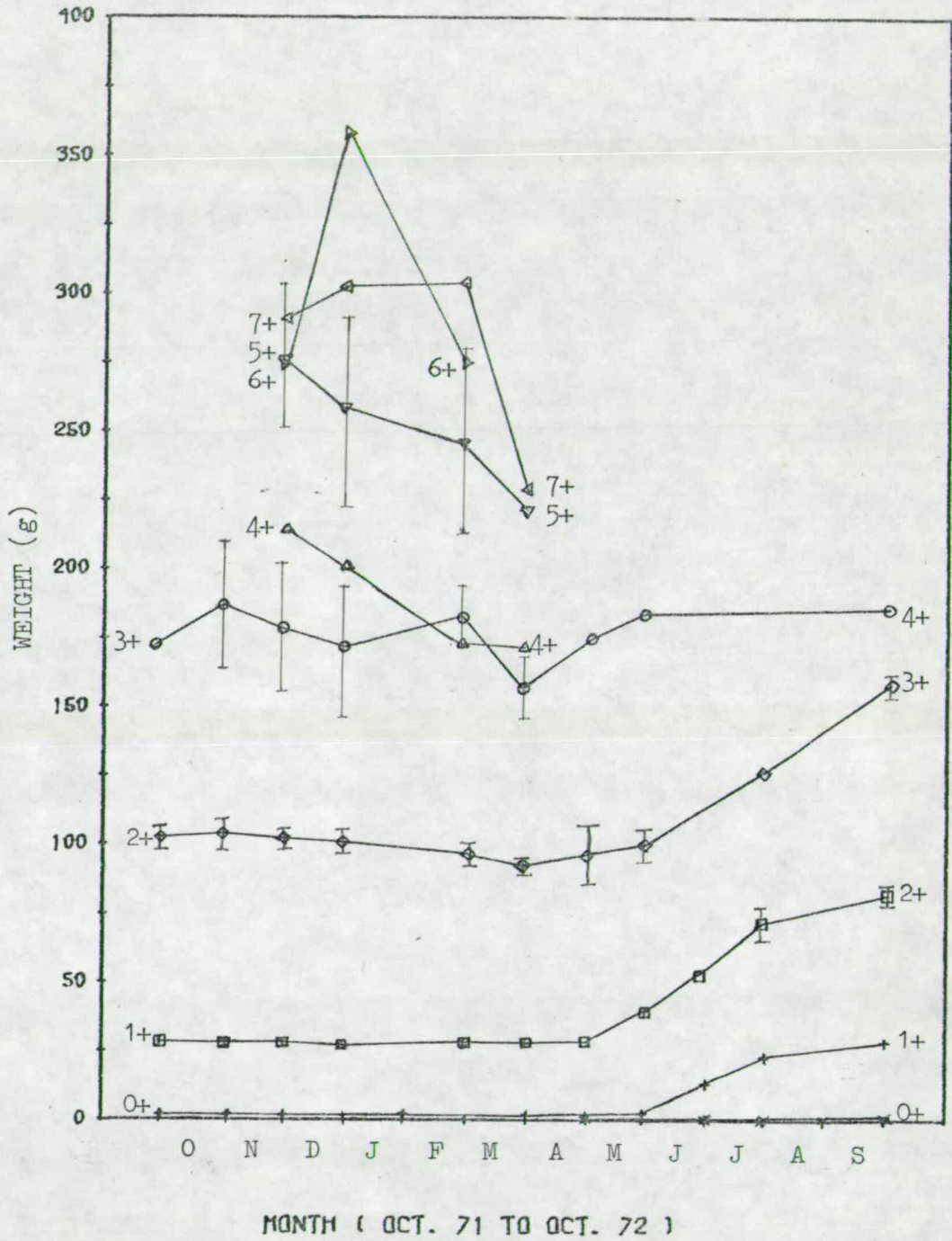


FIG. 2.4 SEASONAL CHANGES IN WEIGHT FOR AGE GROUPS 0+ TO 7+

influenced by changes in the quantity of food in the gut, which was lower in winter, and by changes in gonad weight which occurred in mature fish, viz those over 2+, as a result of the reproductive cycle. There was a gradual increase in gonad weight over the season until, just before spawning in March it comprised, for example,  $12.86\% \pm 0.95\%$  of the total weight of 3+ females or  $1.42\% \pm 0.12\%$  of the total weight of 3+ males. After spawning a loss in weight was recorded in mature fish which presumably corresponded to the release of eggs and sperm. Further details of gut fullness and gonad weights are given later. (p. 97 and p. 83 ).

### (iii) Condition factor

To investigate seasonal differences in the condition of fish the condition factor CF was calculated as follows:-

$$CF = \frac{100 \times W}{L^3}$$

where W = weight in grams  
and L = length in centimetres

Tesch (1968) stated that condition factor confounds two sources of variation, variation between individuals of a given size and changes in relative weight that are a normal consequence of the growth, when growth is allometric. A measure of the former type of variation was obtained by calculating a mean condition factor with a 95% confidence limit. This was done for each age class separately to exclude changes resulting from allometry from one year to the next. It is then possible to consider seasonal changes in condition of dace in the various age classes with season (Fig. 2.5). In all age classes there was a loss of condition over the winter months with a subsequent improvement in April before the time of annual check formation in May. Further marked

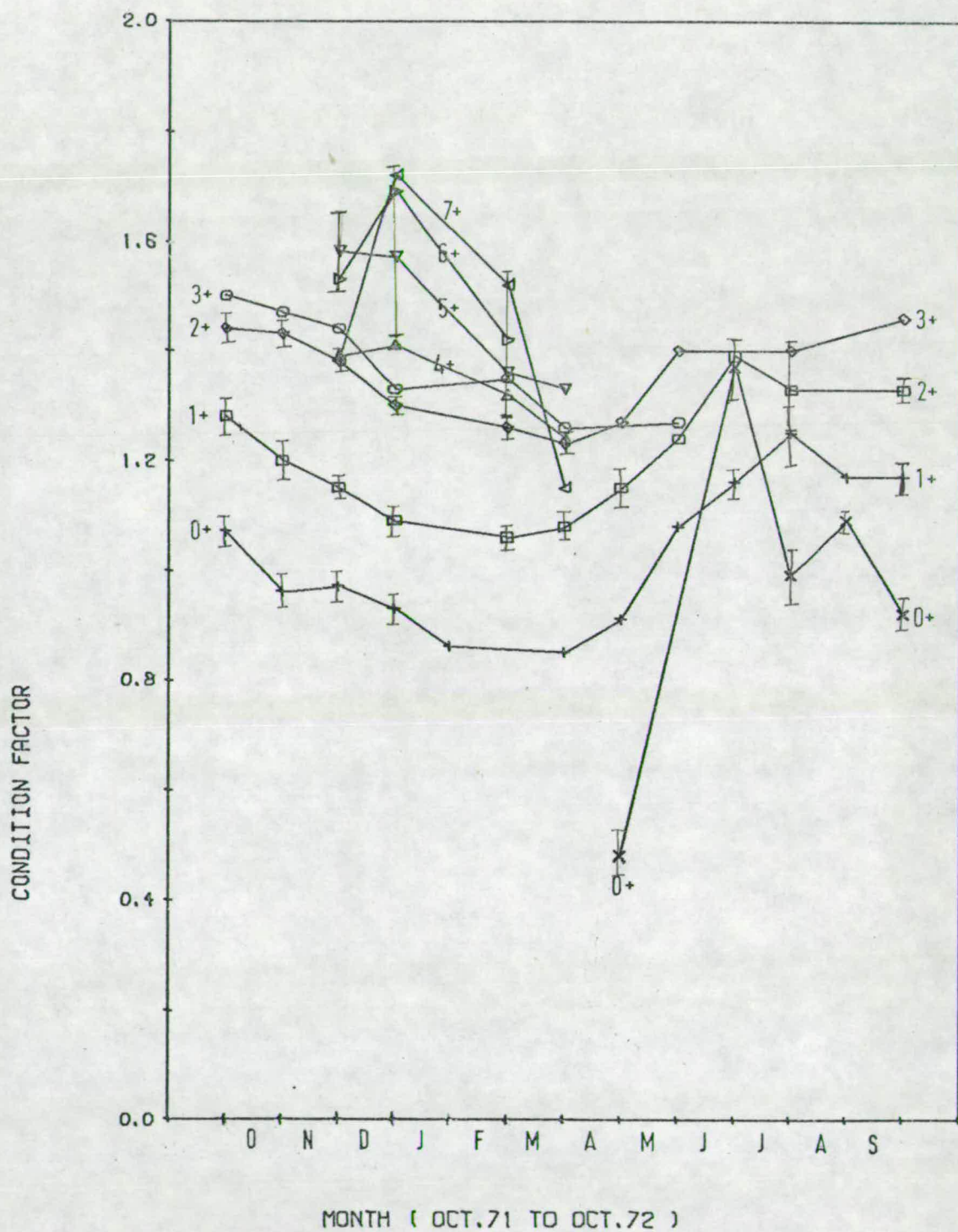


FIG. 2.5 SEASONAL CHANGES IN MEAN CONDITION FACTOR FOR AGE GROUPS 0+ TO 7+.

improvement occurred between May and July.

It is therefore suggested that Wallin's (1957) hypothesis is applicable to dace. He was of the opinion that an annual check was formed on the scales of roach as a result of the change from slow winter growth to rapid summer growth. Furthermore, it would appear that an improvement in condition precedes annual check formation and growth in length. Thus it seems likely that annual check formation is not directly connected with spawning, as was suggested by Hartley (1947a), as immature fish form annual checks and the time of spawning in March was 2 months earlier than the time of annual check formation in May.

#### c) Growth pattern - annual variation

Due to lack of time it was not possible to follow the growth of one year class through successive years. Though there are significant variations in growth from year to year ( $p < 0.05$ ) the actual differences were found to be less than  $\pm 5\%$  for those year classes represented in the samples in 1971 and 1972. The changes in length and weight observed between year classes of dace were therefore considered representative of changes in length and weight between years.

#### (i) Length

Fig. 2.6 shows the growth in length of Tweed dace. The hypothetical birthday was taken as the 1st May, the approximate time of annual check formation in 1972. As Tweed dace hatched in April 1972 the 0+ group were probably about 13 calendar months old when the first annual check was formed on the scales. The use of back calculation, as outlined for example by Le Cren (1947), was not necessary as a good selection of age classes was obtained on most sampling occasions.

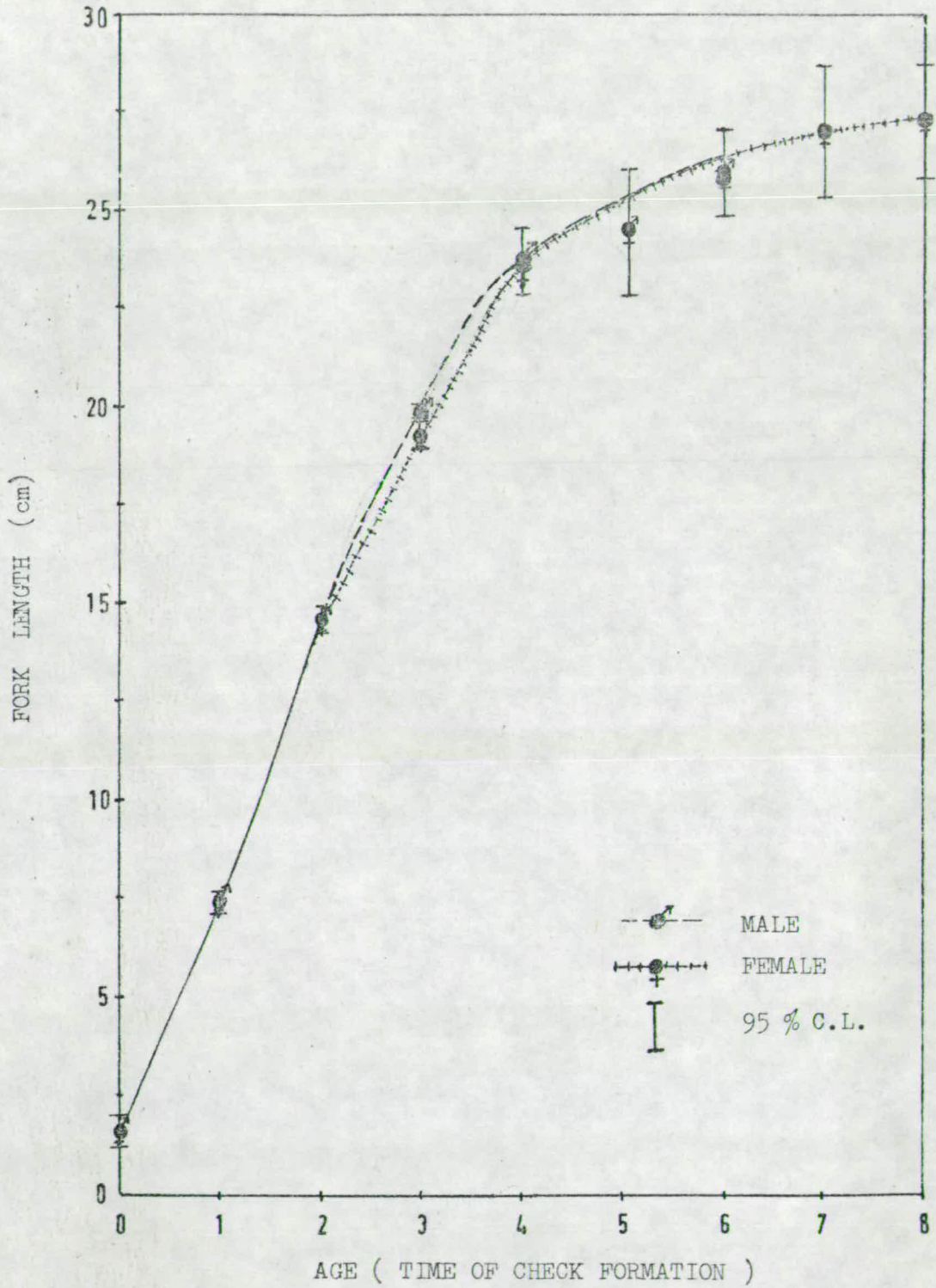


FIG. 2.6 GROWTH IN LENGTH OF TWEED DACE.  
Trend lines were fitted by eye.

The growth rate is high in young fish and declines with age. This can be illustrated by the calculation of G, the specific growth rate (Frost and Brown, 1970) where:

$$G = \frac{\log_e l_t - \log_e l_{t_0} \times 100}{t - t_0}$$

$l_{t_0}$  is the initial length at time  $t_0$   
and  $l_t$  is the length at time  $t$

The mean lengths of the different year classes for the hypothetical birthday of May 1st, together with the specific growth rates, are given below:

Table 2.1 Specific growth rates of Tweed dace

Age (yr)	0	1	2	3	4	5	6	7	8
Length(cm)	1.6	7.1	14.0	19.8	23.3	24.4	25.8	27.0	27.1
G	149.0	67.9	30.5	20.1	4.9	6.6	4.6	0.4	

After the fourth year growth in length is very much reduced in Tweed dace.

Male dace in the 2+ age group were found to grow significantly ( $p < 0.05$ ) faster than female dace. In the 3+ age group there was no significant difference ( $p > 0.05$ ). A Chi-square test on the ratio of male to female fish in the 4+ and older age groups showed significantly more females were caught than would be expected by chance ( $p < 0.05$ ). A similar heterogeneity has been noted by other workers, for example Healy (1956), Hellawell (1974a) and Mann (1974).

Fig. 2.7 illustrates growth curves for dace in various European waters. The growth of the Tweed dace is one of the best recorded. It should perhaps be noted that discrepancies were found between Healy's (1956) data for the Funshion and her data as presented by Mathews and Williams (1972), where 1 dace of length 8.7 centimetres is recorded as age group 0 in May. As the majority of fish taken at the end of May had already formed an annual check, it was therefore assumed that this fish was age 1. Similarly the fish recorded at length 18.2 centimetres and age group 2 in May were taken as age 3 etc. Though Mathews and Williams also record the fish of 8.7 centimetres as age 1 they have not altered the other age classes of Healy. This, in itself, would cause the problem of a missing age class which they mention and not the lack of formation of the first annual check as they suggest.

Growth can also be described by means of a Ford/Walford plot (Ford, 1933; Walford, 1946), Fig. 2.8. This allows the validity of the Bertalanffy equation for organic growth (Bertalanffy, 1957) to be determined as discussed by Mann (1973) among others. Bertalanffy suggested the relationship:

$$l_t = L_\infty (1 - e^{-K(t-t_0)})$$

where  $l_t$  = length at age  $t_0$

$L_\infty$  = length as age approaches infinity

$K$  = constant determining the rate of change of the length increment.

In the case of Tweed dace the Ford/Walford plot is satisfactory over most of the range though there is a tendency for points to occur below the curve at the extreme lower end. The points at the upper end of the curve are based on smaller sample sizes and would therefore be

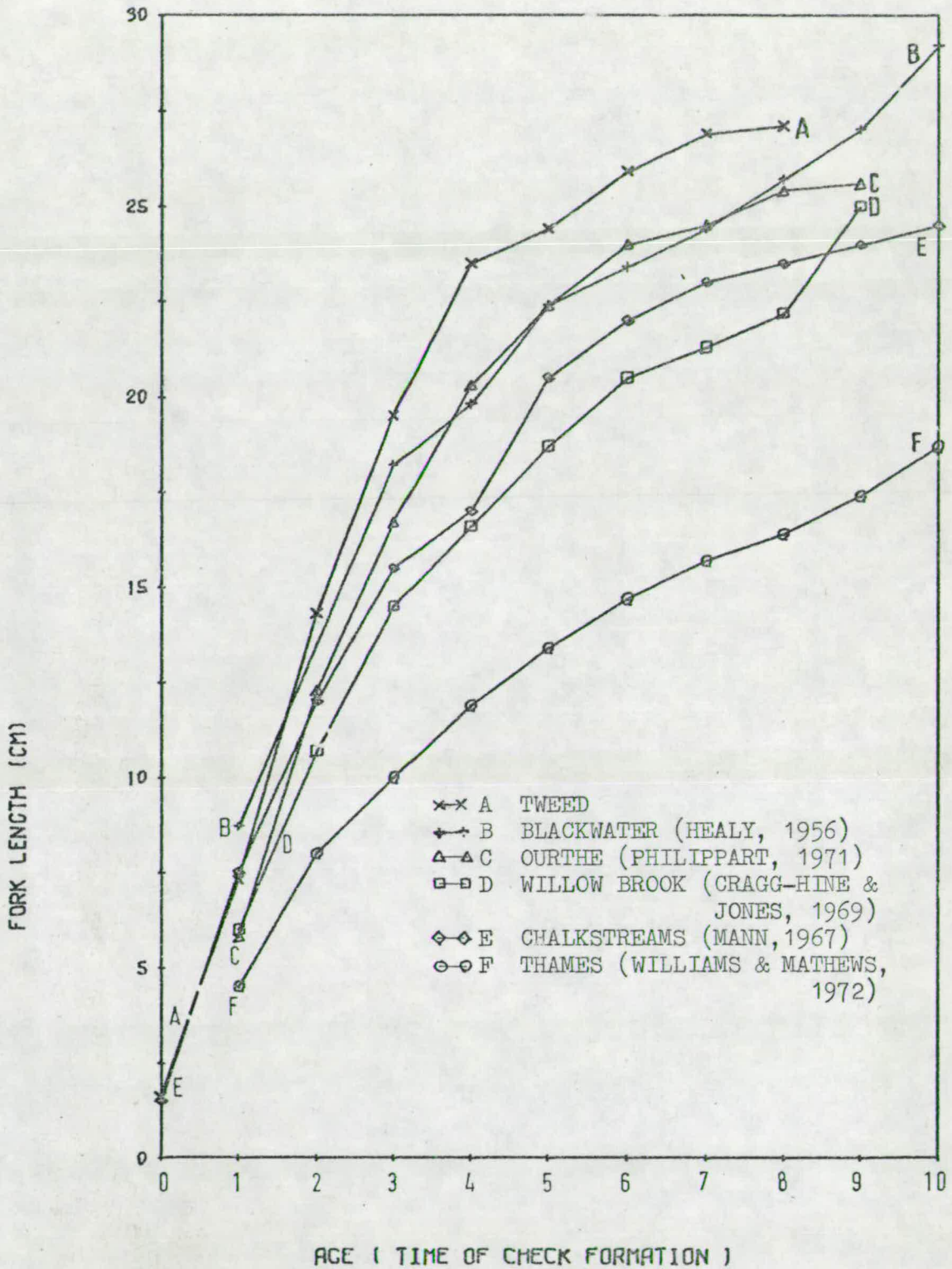


FIG. 2.7 THE GROWTH OF DACE IN VARIOUS EUROPEAN WATERS. Data converted to fork length & time of check formation when necessary. The data for several waters, falling in the mid-range of values given above, have been excluded for clarity.

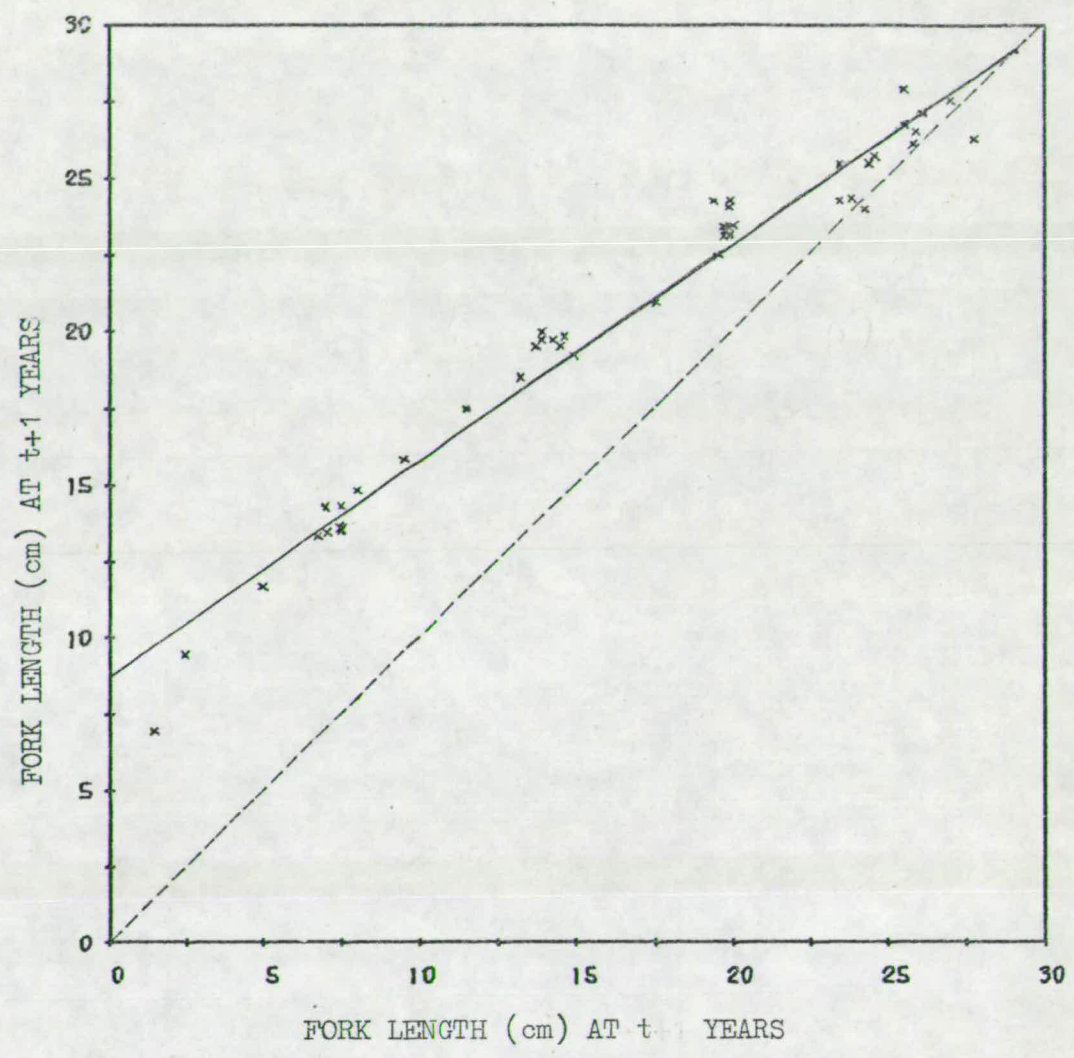


FIG.2.8 FORD-WALFORD PLOT FOR TWEED DACE.  
 (Plotted as mean monthly lengths of each age class).

The solid line is the regression line calculated by the method of least squares; the pecked line is the line of zero growth and their intercept at 29.2cm is the estimated maximum length ( $L_{\infty}$ ).

expected to be more variable than the others. Variation in the rate of growth between year classes, as mentioned in the first paragraph of this subsection on annual variation, will also have caused variation.

From the Ford/Walford plot the estimated maximum size,  $L_{\infty}$ , of Tweed dace was found to be 29.2 centimetres. The Bertalanffy coefficients for anabolism (E) and catabolism (K) were calculated as  $E = 10.5$  and  $K = 0.36$ . K was calculated as  $-\log_e k$ , where k is the slope of the Ford/Walford plot and E was estimated as  $K.L_{\infty}$ ,  $L_{\infty}$  being in centimetres. Equivalent data for other waters, given in Table 2.2 again demonstrates the good growth of Tweed dace.

#### (ii) Weight

Fig. 2.9 shows change in weight corresponding to changes in length plotted in Fig. 2.6. Dace seem to continue to increase in weight throughout their life. There was little evidence from Fig. 2.9 of the marked decrease in rate of growth in terms of weight as there was for length. The instantaneous growth rate (I) was calculated for each age group from the formula:

$$I = \log_e (W_t / W_{t_0}),$$

where  $W_{t_0}$  is the weight in grams at time to

and  $W_t$  is the weight in grams at time t.

The mean weight of the different year classes for the hypothetical birthday of May 1st, together with instantaneous growth rate are given overpage.

Table 2.2 Ultimate length (cm) and Bertalanffy coefficients E, K for anabolism and catabolism in European waters

Site	Author	$L_{\infty}$ (cm)	K	E
Tweed		29.2	0.36	10.5
Stour-- male	Mann (1974)	26.5	0.19	5.1
female	" "	25.8	0.17	4.3
Frome - male	" "	26.5	0.28	7.4
female	" "	27.5	0.22	6.0
Blackwater	Healy (1956)	27.0	0.35	9.5
Thames	Williams (1967) *	21.0	0.18	3.8
Lodz plateau	Penczak (1967) *	30.0	0.14	4.2
Willow Brook	Cragg-Hine & Jones (1969)*	24.0	0.32	7.7
Ourthe	Philippart (1971) *	28.7	0.37	10.6
Berwine	" " *	24.7	0.32	7.9

\* Data from Mann (1974)

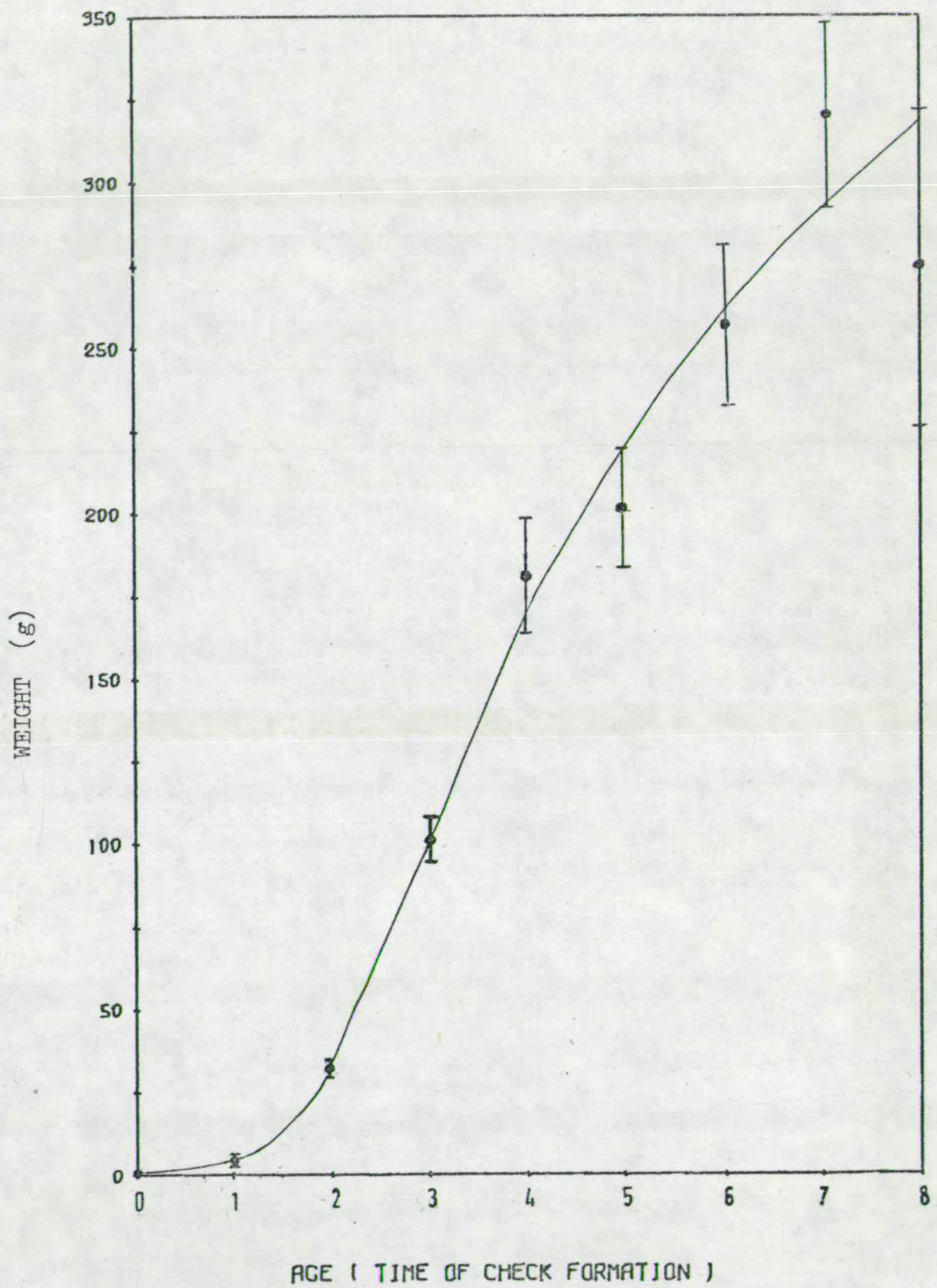


FIG. 2.9 GROWTH IN WEIGHT OF TWEED DACE ( $\sigma$  &  $\phi$  COMBINED).

The trend line was fitted by eye.

Table 2.3 Instantaneous growth rates for Tweed dace.

Age (yr)	0	1	2	3	4	5	6	7	8
Mean Weight(g)	0.02	3.4	31.9	98.8	177.3	192.6	252.3	273.0	285.0
I	5.14	2.24	1.13	0.58	0.09	0.27	0.08	0.04	

These rates are very similar to figures produced by Mann (1974).

(iii) Length-weight relationship.

To investigate the relationship of length and weight mentioned above in greater detail the length-weight relationship of the form

$$\log_{10} \text{ weight} = b \log_{10} \text{ length} + \log_{10} a$$

was calculated by the method of least squares, weight was in grams and length in centimetres. In most cases the value of  $b$  was found to be significantly different from 3 (Table 2.4). Growth is therefore said to be allometric or asymmetrical. Values less than 3 indicate that the fish is lighter for its length, whereas values greater than 3 indicate that it is heavier for its length. When the length-weight relationship was calculated separately for the various age classes it was found that the 0+ and 1+ age groups tended to have values for  $b$  less than, or significantly different from 3, whilst older age groups had values equal to or over 3. A typical example is given at the foot of Table 2.4. It would therefore appear that initial growth of dace is more in terms of increase in length whilst later in life the fish increase proportionately more in weight. This relationship is displayed graphically in Fig. 2.10.

Vaznetsov (1953) is quoted by Tesch (1968) as stating that during their development fish typically pass through several stages, each of which may have its own length-weight relationship. Tesch (1968) points

Table 2.4 Length-weight relationships for Tweed dace  
 Regression coefficients from equation  

$$\log_{10} \text{weight} = b \log_{10} \text{length} + \log_{10} a$$

Date	Coefficients			Sample size	Age groups in sample	2 x SE of b	sig. diff from 3
	a	b	r				
4.10.71.	-2.209	3.284	0.999	97	0+ to 3+	0.027	YES
4.11.71.	-2.321	3.358	0.998	87	0+ to 3+	0.042	YES
3.12.71.	-2.373	3.388	0.999	80	0+ to 7+	0.039	YES
7.1.72.	-2.344	3.351	0.997	112	0+ to 7+	0.047	YES
16/25.2.72.				3	0+ & 2+		
3.3.72.	-2.499	3.456	0.997	86	1+ to 7+	0.055	YES
21.4.72.	-2.317	3.306	0.994	74	0+ to 5+7+	0.086	YES
10.5.72.	-2.292	3.306	0.998	39	0+ to 3+	0.064	YES
7.6.72.	-2.195	3.253	0.997	62	1+ to 4+	0.060	YES
6.7.72.	-1.825	2.892	0.999	39	0+ to 2+	0.036	YES
9.8.72.	-2.174	3.240	0.997	45	0+ to 3+	0.076	YES
5.9.72.	-2.036	3.095	0.994	31	0+ (2+)	0.125	NO
12.10.72.	-2.333	3.363	0.999	135	0+ to 4+	0.026	YES

Breakdown, by age, of a typical monthly sample

7.1.72	-1.753	2.675	0.876	35	0+	0.512	NO
7.1.72.	-0.936	2.099	0.698	29	1+	0.828	YES
7.1.72.	-2.103	3.166	0.886	22	2+	0.741	NO
7.1.72.	-1.823	3.012	0.657	8	5+	2.615	NO

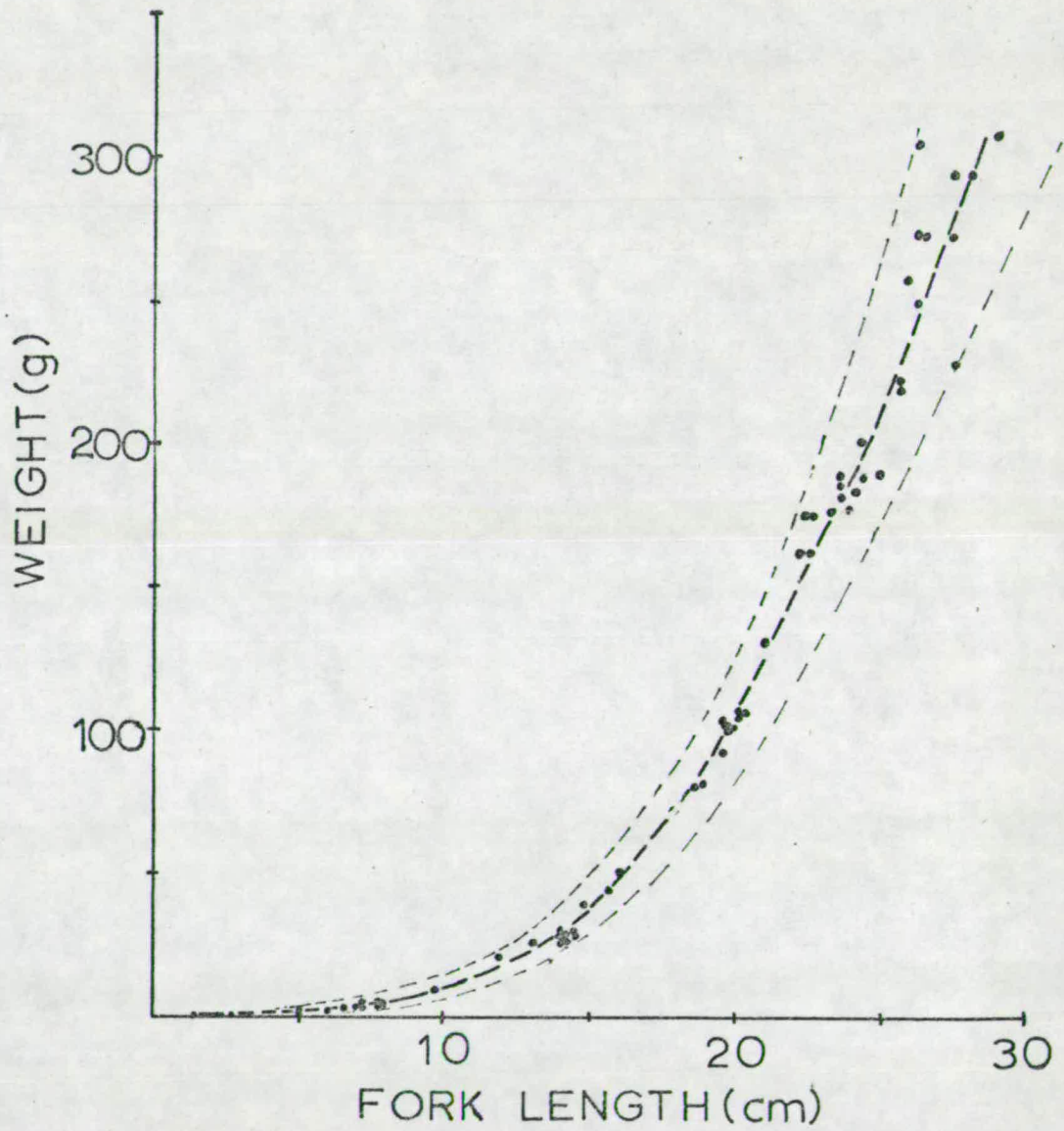


FIG. 2·10 LENGTH-WEIGHT RELATIONSHIP FOR TWEED DACE.

(TREND LINES FITTED BY EYE.)

out that several stages are completed during embryonic and larval life so that, for many species, growth from age 1 onward comprises a single stage. The relative constancy of the relationship in Tweed dace is apparent after the first year (Table 2.4), though there are variations due, in part, to changes in sexual condition and gut fullness (p.97 ff).

## SECTION 3

## DISTRIBUTION

I. Introduction

To enable the spread of the dace in the River Tweed to be monitored in future it was decided at the start of this study to map the present (1972) distribution of this species. As an estimate of population size was also planned a description of the distribution was necessary to determine whether the total population was restricted to a small area, making an estimate of the whole population feasible, or whether it occupied a larger area, making extrapolation of the estimate of numbers in a smaller sample area necessary.

II. Methods

As the investigation of distribution is dependent on methods of sampling the reader is referred to Section 1 (p.14 ).

Dace are generally considered to be a shoaling species, (Day, 1880-84; Regan, 1911; Wheeler, 1969 and Muus and Dahlstrom, 1971). This characteristic, combined with their mobility and the problems of sampling precluded a quantitative assessment of distribution, (e.g. based on the number of fish per sweep of a known surface area). A qualitative assessment on a presence or absence basis was therefore used. As positive proof of identification was considered necessary for an investigation of this nature, unconfirmed reports of the presence of dace in other parts of the river were not included until the site had been checked, usually by netting, and the presence of dace verified. Captures made in the presence of one of the water bailiffs

or the author were also used when the fish was available for identification.

The presence of dace in certain areas was occasionally impossible to verify. There were two main reasons for this:

- a) because of the unwillingness of the owners or tenants of some salmon beats to allow access to the river between February and October, since in their view netting for dace might adversely affect the fishing
- and b) because conditions unsuitable for netting occurred in a number of areas of the river. These included excessive depth, high water velocity, large boulders or other obstacles and steep banks. When netting was unsuccessful or difficult in an area thought to be inhabited by dace, skin diving was used to check whether in fact dace were present. If dace were observed, then netting or one of the other methods of sampling was attempted in that location.

### III. Results and Discussion

#### a) Distribution

Dace were captured within the area marked on the map (Fig. 3.1). At the extreme ends of the zone captures were few in number. For example, only one specimen was taken from the Junction Pool in Kelso and only one specimen from the mouth of the river at Berwick upon Tweed. This may be due, at least in part, to reduced sampling intensity, coupled, at the mouth of the river, with reduced netting efficiency. Other authors including Day (1880-84), Muus and Dahlstrom (1971) and O'Hara (personal communication) also record the presence of dace in brackish water. Furthermore, Tweedmouth is only 10 km. by river from Union Bridge, a site at which dace are present in large numbers. At Union Bridge a reversal in the direction of flow often occurs at high

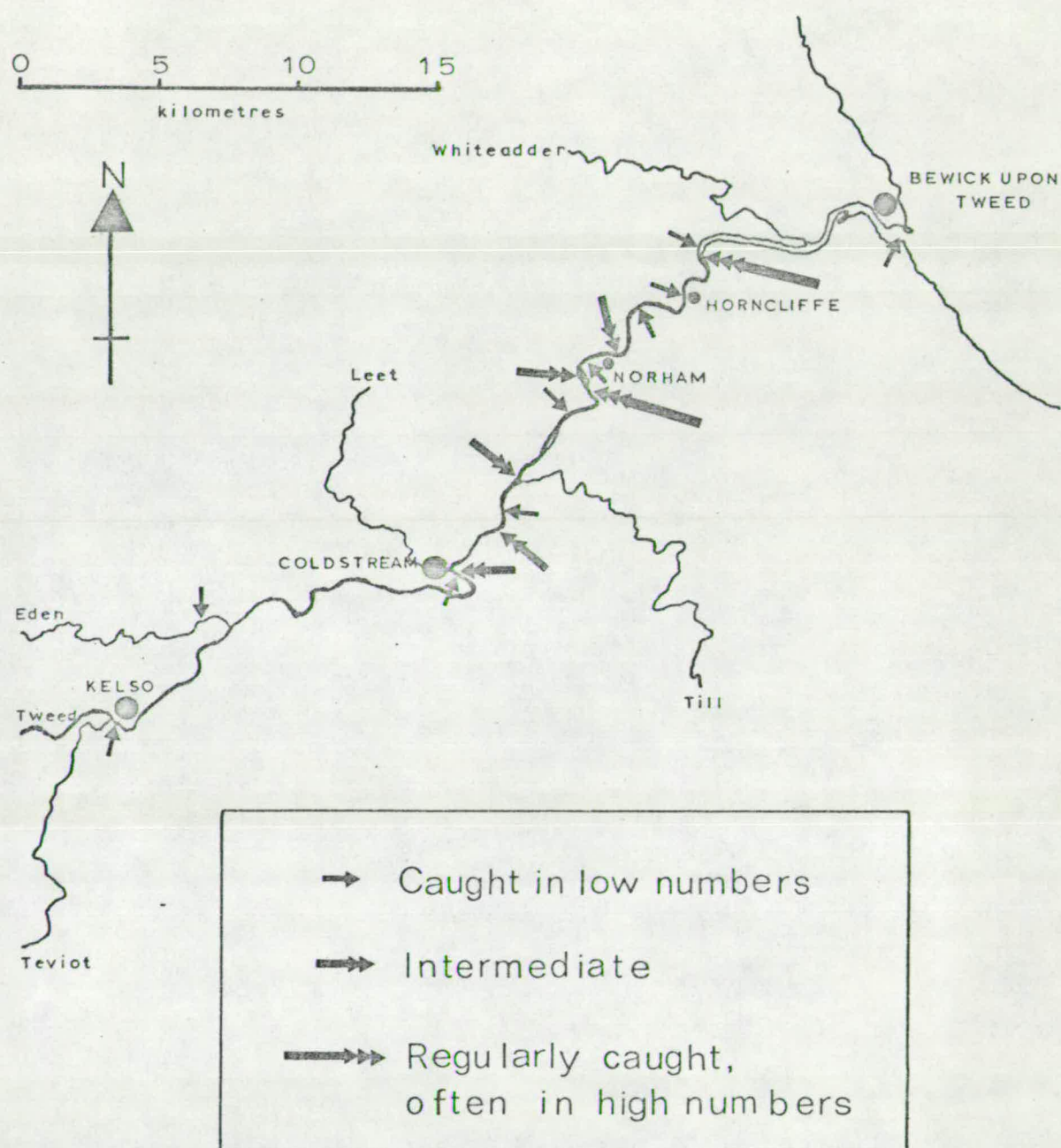


FIG. 3.1 DISTRIBUTION OF DACE IN THE RIVER TWEED, 1972.

tide and specimens of marine algae, such as Fucus vesiculosus (L), have occasionally been noted. Despite this, the analysis of water samples usually shows little increase in salinity at Union Bridge when compared with a freshwater site upstream. Such a comparison is shown in Table 3.1.

Table 3.1 Variation in chloride (p.p.m) at Norham and Union Bridge

	Norham (NT 900470)	Union Bridge (NT 895463)
5-11-69	10.5	11.0
6-7-71	10.5	12.0
5-9-72	17.5	17.0
19-9-73	10.0	16.5
13-2-74	17.5	17.5

(Data from Currie (personal communication)).

A 't' test on the figures in Table 3.1 shows no significant difference at  $p = 0.05$ .

b) Seasonal variation and preferred habitat.

The choice of Norham as the regular monthly sampling site was, in retrospect, a good one in that for most months between October 1971 and October 1972 a range of age classes of dace were readily obtained.

During the winter months of November, December 1971 and January 1972 both large and small dace were captured in the backwater and were feeding little (p.96ff). In February 1972, however, all 4 attempts to obtain a sample were unsuccessful. The most likely explanation seemed to be a lack of dace in or near the sample section. Movement may have been caused by the freezing over of the backwater in mid January, followed, later in the month, by very high water levels. In

March and April dace were again captured in the backwater but their gut contents included Ephemeroptera nymphs and Simulium larvae which had, almost certainly, been eaten in the main river. During the summer months only small dace were caught in the backwater but both large and small dace were netted, albeit in smaller numbers, in the river. The smaller fish were generally taken in or near weed beds whilst the larger dace were present in more open water, suggesting a behavioural difference at least during the summer months.

A difference in behaviour is also indicated by the fact that the vast majority of dace captured at Coldstream and upstream thereof were in the O+ age group. From the observations made at Norham it may have been that the larger fish were present in the same general area of the river as the small fish but evaded capture or could not be netted when they occupied salmon "lies". Alternatively it may have been that one or other of these age groups had moved relative to the other at some time after spawning. It would seem that the greater mobility of the larger dace combined with the seasonal differences in behaviour are responsible for this apparent difference in distribution of young and old dace.

As dace were often observed and captured in backwaters (e.g. Norham Boathouse (N.G.R. NT 893464), Norham Castle (NT 906477), Tweedmill (NT 870434), Tillmouth Park Estate (NT 863422) or in areas where the current speed was reduced and the river eddied (e.g. Union Bridge (NT 933512) and Norham (NT 895463)) it may well be that sites such as these on the Tweed are regularly occupied by both large and small dace. From these sites large dace in particular move out and disperse into faster water especially when feeding during summer months. Several of the earlier general works, e.g. Day (1880-84) and Regan (1911)

make reference to dace retiring to deeper water in the winter months and more recently Hellowell (1969) has described a pattern of distribution which varied with season.

The use of sonic tags to determine preferred habitat was considered, but their use was prevented by lack of finance.

### c) Spread

The origin of dace in the River Tweed is not known but their present distribution, coupled with their relatively short history in the river, suggests an introduction in the lower reaches. The introduction of dace in about 1889 to the River Blackwater in Ireland was described by Went (1950). Healy (1956) recorded that dace had thriven in the river since their introduction, had ascended many of the tributaries and were regarded as a menace by trout anglers. Dace have also spread in rivers in Northern England, namely the Border Esk and the Lune, where they are again regarded as a problem.

The conditions upstream from Kelso, both in the Tweed and the Teviot appear quite suitable for dace and it would seem to be only a matter of time before the species spreads over a larger area. Following this initial survey in 1972, 2 O+ dace were caught in May 1973 at N.G.R. NT 758378, some 3 km. up the Eden Water (Mills, personal communication), a tributary which enters the Tweed below Kelso. A weir, across the Tweed at Kelso may temporarily restrict the dispersal of dace in that direction.

Recent unconfirmed reports suggest that dace are now present in the River Beamish, a tributary of the River Till (Proudlock, personal communication) and in the River Jed (Ryan, personal communication).

## SECTION 4

## MOVEMENT

I. Introduction

Although large numbers of dace could be captured on some occasions in certain areas, on subsequent occasions they proved to be absent. This suggested that this species moved actively from place to place and an investigation of movement was undertaken. Furthermore, this facility for active movement required to be investigated before attempts were made to estimate the size of the dace population within a given area so as to produce an estimate of density. Following the work on distribution, Norham was chosen as the most suitable site at which to determine the density estimate. The movement of dace in this area (N.G.R. NT 893464) was therefore investigated.

II. Methods

## a) Tagging

Prior to this study, brown trout, sea trout, salmon and a small number of grayling had been marked by tagging on the Tweed. The procedure to be adopted by anglers or commercial netsmen capturing tagged fish had been publicised by Col. R.M. Ryan (late Superintendent to the Tweed Commissioners) and his staff, as shown in Fig. 4.1. As tags were immediately available it was decided to use them initially as a method of marking since it was anticipated that anglers and netsmen would recognise and return tagged fish. As tag returns were required from as many sites as possible the advantage of involving other fishermen was considered to outweigh the disadvantages of using tags. These disadvantages, which have already been discussed,

## RIVER TWEED COMMISSIONERS

**REWARD**

A number of fish of different species have been tagged in the Tweed and its tributaries.

A reward of **50p** is given for the return of each tag. Tags should be sent to **Col. R. M. Ryan, Stockstruther, Rutherford, Kelso**, or handed to any Water Bailiff, with the following information:—

**Your name and address**  
**EXACT position of capture**  
**Date of capture**

It would be an advantage if the fish could be examined. All Tweed Bailiffs' telephone numbers are in the book under Tweed Commissioners. Reverse charge calls will be accepted and any Bailiff will collect the fish.

***Please help us to help your sport***

FIG. 4.1 PUBLICITY HANDOUT ISSUED BY COL. R. M. RYAN,  
LATE SUPERINTENDENT TO THE TWEED COMMISSIONERS,  
AND USED FOR DACE IN THIS STUDY.

(e.g. Stott 1968), include the length of time taken to attach tags, tag loss, change in the behaviour of tagged fish and change in the liability of tagged fish to attack or capture by predators. These problems are, however, not as important when movement is being studied as they would be in the investigation of such population parameters as density, mortality - and recruitment rates. In the case of movement the most likely disadvantage in the use of tags is a possible loss of information.

Over the period March 1972 to April 1973 a total of 776 dace were tagged by attaching a numbered plastic disc in a position at the anterior of the dorsal fin (Plate 4.1). Tagged fish were retained in holding boxes, for at least half an hour, to ensure that they were fully recovered. Often only a proportion of the fish captured could be tagged in the time available. When this occurred both tagged and untagged fish were released together at the end of the day. Captured fish were liberated as close as possible to the point of capture to minimise the movement induced by the tagging process. Up to 151 (exceptionally 300) captured fish were marked on any one occasion.

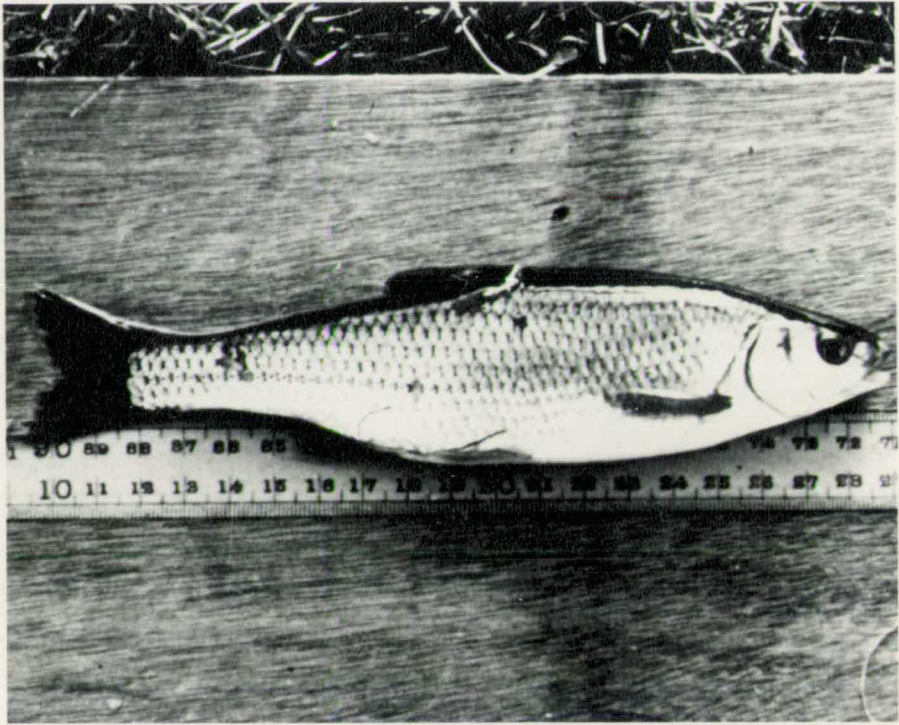
Tags were initially attached using silver wire (0.0148" diameter). After a number of tagged fish had been recaptured and examined it did, however, become apparent that the wound had not healed in a satisfactory manner. The problem of scales being dislodged when the hypodermic needle was inserted through the dorsal musculature during tagging appeared to be aggravated by the rigidity of the silver wire, moving in response to movements of the tag. A change was therefore made and tags were subsequently attached using polypropylene monofilament. Though insufficient fish were tagged by this latter method to compare the performance of the two types of tag on a statistical basis, the



PLATE 4.1

a) 2+ dace with tag attached by silver wire at the anterior end of the dorsal fin.

b) Close-up of dorsal fin showing attachment of tag.



polypropylene attachment appeared to be much more satisfactory.

#### b) Panjetting

After tags had been used for several months it became apparent that most tagged fish were being recaptured by the author (Fig. 4.2). Furthermore, few fish recaptured by third parties were coming from new recapture sites. As insufficient fish were being marked to provide a good indication of the scale of movement or to allow the use of marked fish for estimating population size, a Fish Tattooing Panjet was obtained (Wright Dental Manufacturing Co. Ltd., Kingsway West, Dundee, DD2 3QD). The use of this instrument was described initially by Kelly (1967) and was subsequently tested in Great Britain by Hart and Pitcher (1969). Their investigations reinforced the view that it provided a long lasting batch in the form of a sub-dermal dye spot which was quickly and easily applied.

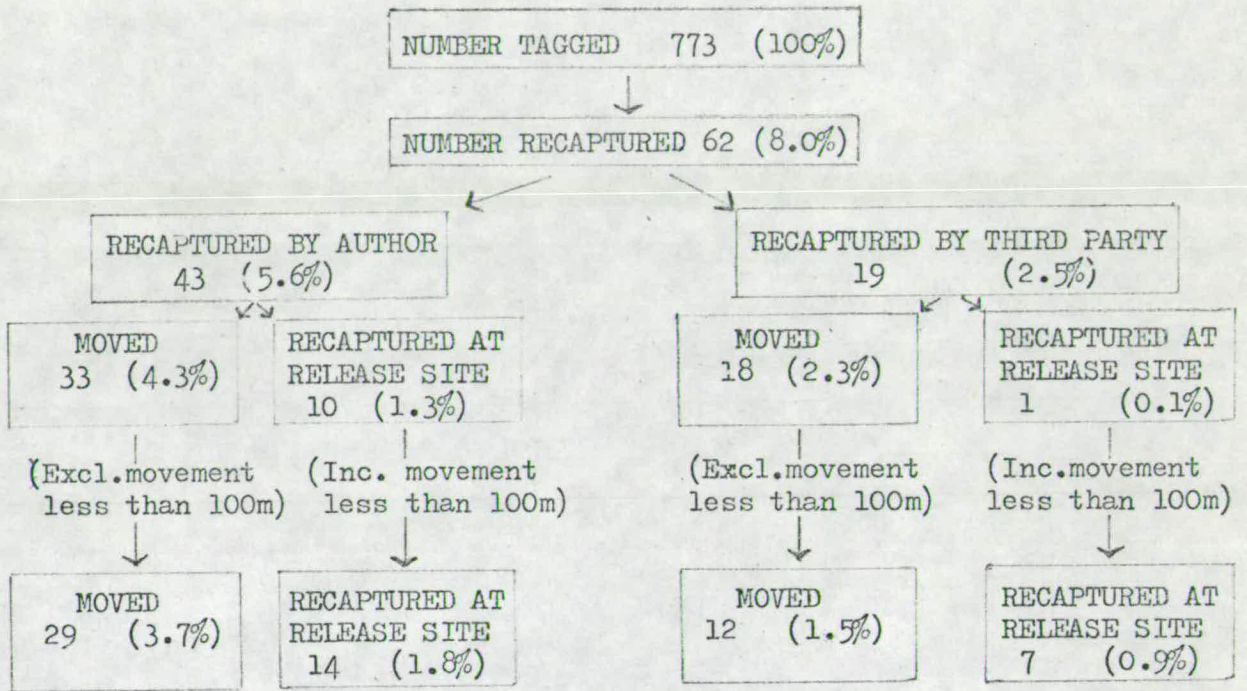
A small number of dace (18) were marked both with Alcian Blue (Gurrs, 8GX; 1 g. per 100 g. water + 1 thymol crystal) and Indian ink (Reeves waterproof); two dyes recommended by Hart and Pitcher (1969), and kept in tanks in the laboratory to test the lasting qualities of the dye. Contrary to the suggestion of Hart and Pitcher the Indian ink marks only lasted for 2 to 3 months. The Alcian Blue marks were, however, unchanged at that time, and remained clear for 18 months. Accordingly all fish marked in the field were marked with Alcian Blue. At the time of writing dace have been recaptured after 15 months in the wild still clearly marked. \*

Hart and Pitcher (1969) used MS 222 to anaesthetise their fish during marking, but this was found to be generally unnecessary in the present study. Consequently the marking process was speeded up and

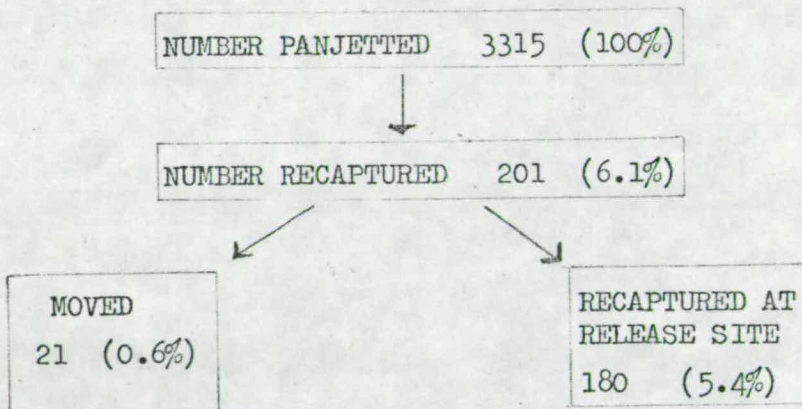
\* A note to this effect was published in May 1975 (Appendix I).

FIG. 4.2 Recaptures of marked dace

## a) TAGGED DACE



## b) PANJETTED DACE



there was rapid recovery of marked fish. All fish aged 1+ and over, i.e. fish over 10 cm. in length, were marked. A different position on the underside of the body or fins was used on each occasion. The positions (Fig. 4.3) were similar to those suggested by Hart (1969) and Hart and Pitcher (1969) but no double marks were used.

Between October 1973 and April 1974 3,316 dace were marked in this way on 7 separate occasions.

### III. Results and Discussion

No fish less than 10 cm. in length were marked and all results and comments therefore apply only to dace over 10 cm. in length.

#### a) Tagged fish

A breakdown of recaptures of tagged fish is given in Fig. 4.2(a). A significantly higher proportion ( $p < 0.05$ ) of the fish recaptured by anglers and netsmen showed movement in excess of 100m. This is perhaps to be expected as most of the effort expended in capture by anglers and netsmen was at sites other than the sites of marking. There were, however, only 2 recaptures at sites not netted by the author.

The mean distance moved by fish which had travelled distances greater than 100 m. was  $6.1 \pm 1.7$  km. The average time interval between marking and recapture of these fish was  $13.7 \pm 4.9$  weeks compared with an interval of  $11.7 \pm 2.7$  weeks for dace recaptured at their site of release. This difference is not significant ( $p > 0.05$ ) and suggests that in this case, apparent lack of movement was not caused by fish being recaptured before movement could take place.

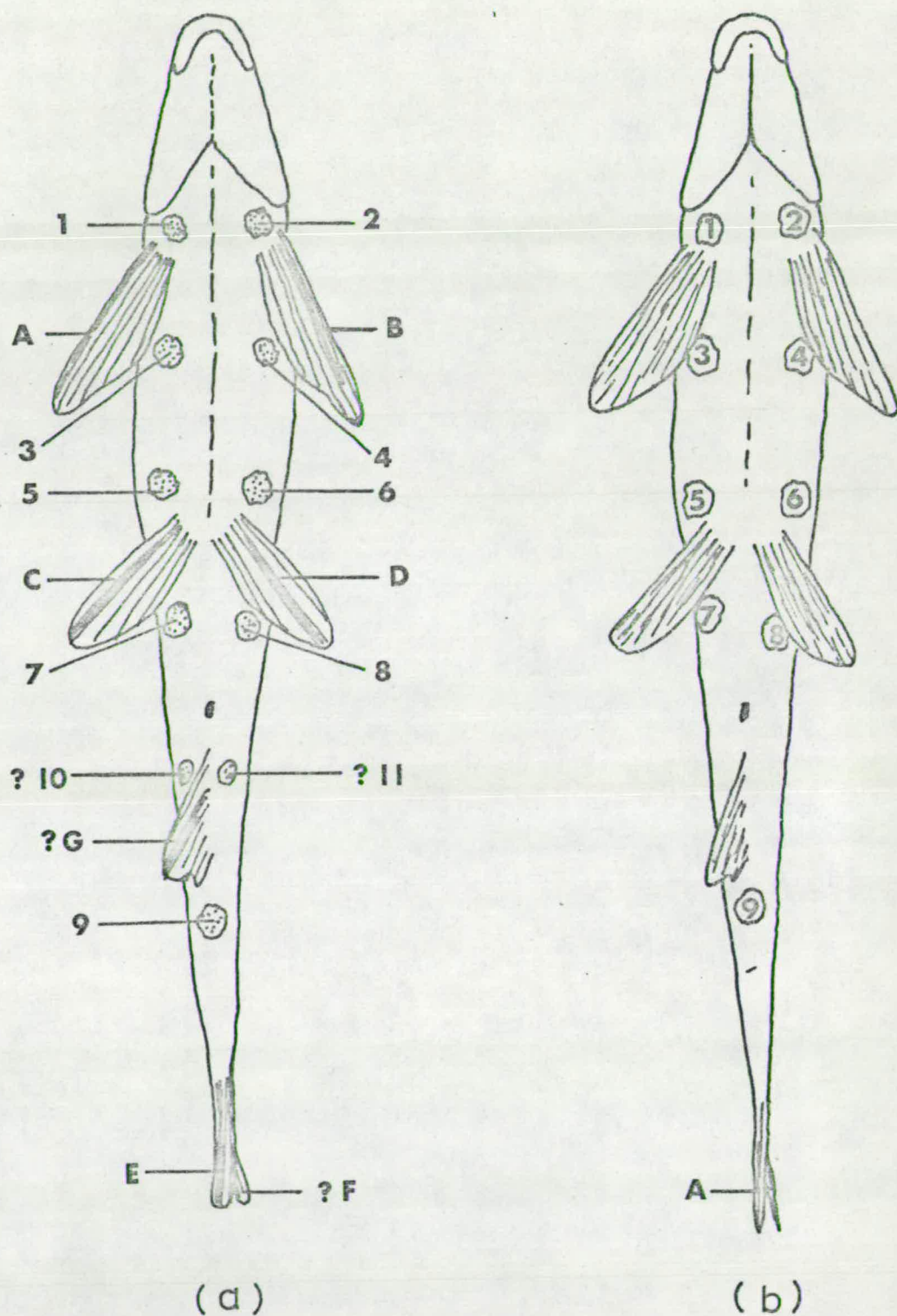


FIG. 4.3 MARKING POSITIONS

(a) Proposed combinations

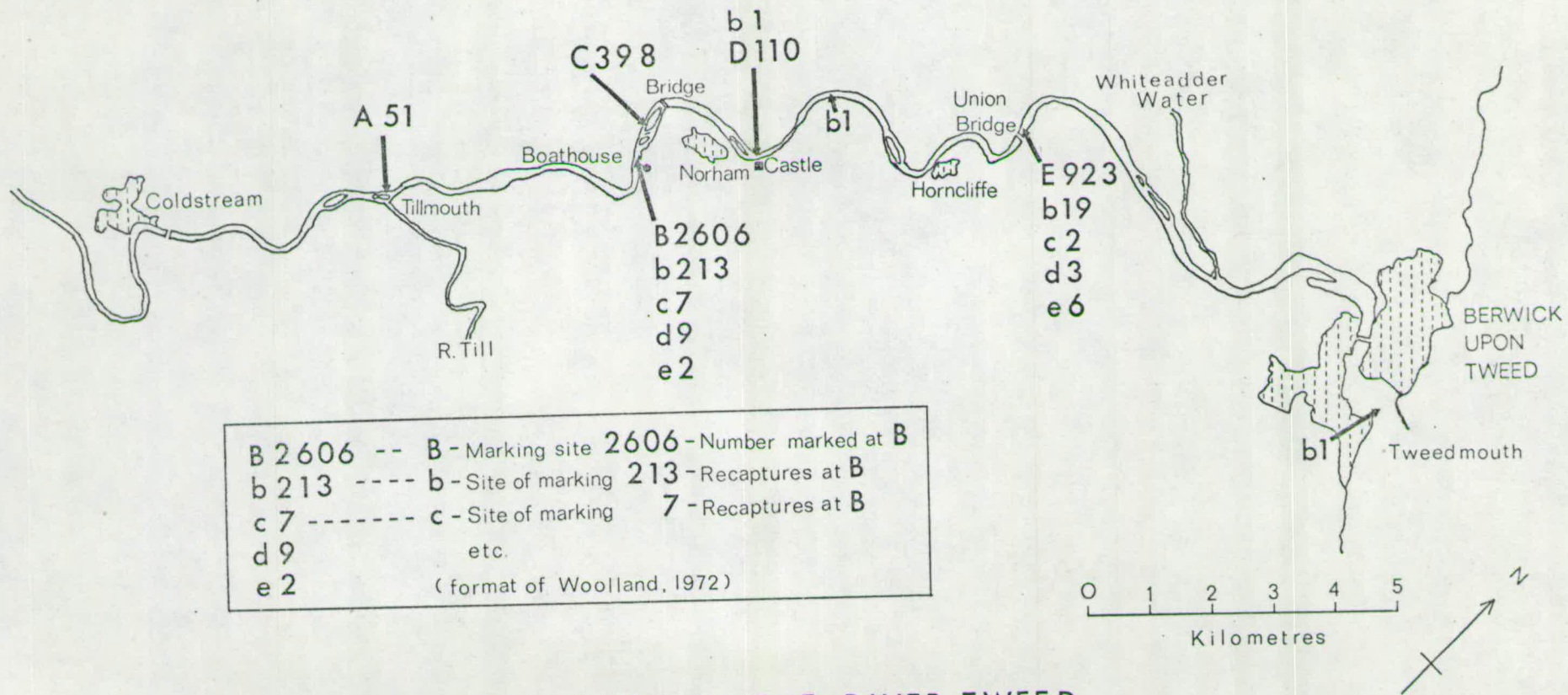
(b) Positions used

Fig. 4.2(b) gives the breakdown of panjet recaptures. Fish recaptured away from the site of marking had travelled an average minimum distance of  $6.7 \pm 1.7$  km. in the average time interval of  $13.5 \pm 2.5$  weeks. The equivalent time interval for fish recaptured at their site of release was only 4.0 weeks. The 95% confidence limits could not be calculated for this latter figure as the data were not normally distributed. The median and its 95% confidence limits were therefore calculated after Campbell (1967) and were found to be median 3.6, 95% confidence limits 1 to 4 weeks. The shorter time interval between mark and recapture for dace which were captured at the site of release is presumably affected by the fact that the site was renetted before dispersal of marked fish had occurred.

## c) All marked fish

The recapture data for all 4092 marked fish is displayed in Fig. 4.4, using the format of Woolland (1972). This has the advantage of including all recaptures, whether or not movement has occurred. It does not, however, give any indication of the time factor. To rectify this deficiency a time/distance plot (Fig. 4.5) has been devised. This display relates only to those marked fish which showed movement. Movement in space is plotted on the x axis (abscissae) and movement in time on the y axis (abscissa).

The record of movement obtained from marked fish is of the minimum distance moved as there was no way of knowing where the fish had been between release and recapture. The time taken for movement is, however, likely to be above the minimum as marked fish probably arrived at the recapture site some time before recapture. For example,



**FIG. 4.4 DACE RECAPTURES IN THE RIVER TWEED**

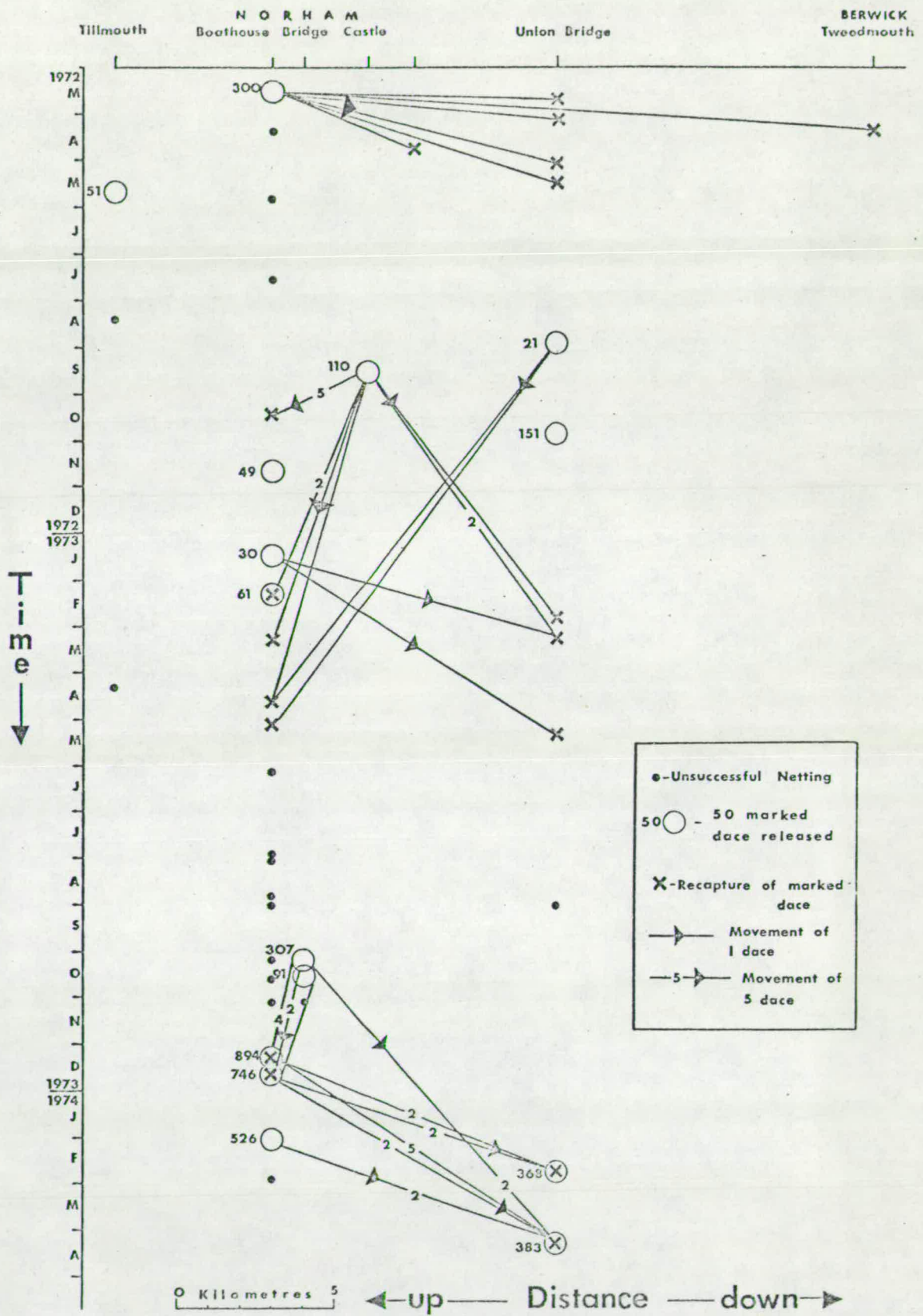


FIG. 4.5 MOVEMENT OF MARKED DACE

one of the dace released at Norham on 16th March 1972 moved a distance of 9 km. in only 6 days whereas another fish, released at Union Bridge on 1st September 1972 took up to 8 months to move this distance. This latter fish may have moved greater distances in the intervening 8 months or may have completed the journey in a much shorter time. The fact that the recapture site at Norham was netted a number of times prior to this individual being caught would tend to suggest that it had only arrived at the site shortly before recapture. With a low rate of recapture of marked fish this suggestion must, however, be viewed with caution as the fish may have been present at the site but avoided recapture on a number of occasions.

Interpretation of the results of this study is further complicated, not only by the different numbers of dace initially marked at each site, but also by the variation in suitability of sites for netting. The multiplicity of factors involved made it unrealistic to correct for these differences.

Despite these limitations it is clear that at least a small element of the population is very mobile. Movement in the lower reaches of the Tweed was well established especially between Norham and Union Bridge. These two localities have been previously described (p. 47 ) as preferred habitats of dace and this appears to be confirmed by the recapture of marked fish.

The possibility that only a section of the population is mobile has been suggested for some coarse fish species by a number of workers including Williams (1965) for dace and roach; Stott (1967) for gudgeon and Hunt and Jones (1974b) for barbel. In contrast it would appear that the majority of Tweed dace exhibit some degree of mobility. This was

suggested by the probable movement of all dace out of the sample section at Norham, described in Section 3 (p. 46 ) supported by the following additional observations:- For example, 300 fish from a larger catch were tagged and released at Norham (NT 893464) on 16th March 1972. Netting for a whole day on 11th April 1972 at their site of release and for about 1 km. upstream and downstream produced no dace over 10 cm. 10 days later, however, on the 21st April 1972 the first netting at the release site produced a sizeable catch and included tagged fish number 163. Thus, although this fish is included in Fig. 4.2(a) as showing no apparent movement it would appear, along with the rest of the shoal, to have moved at least 2 km. In fact, other recaptures from this batch (Fig. 4.5) suggest that the shoal had probably dispersed as far as Union Bridge, some 9 km. downstream. A similar downstream movement was observed in other years especially 1974. Information of this kind is rather unsatisfactory from a scientific point of view since it is only possible to prove the presence of dace with certainty but not their absence. It would seem, however, from information of this kind that movement of virtually all dace (over 10 cm. in length) from a specific area did occur. One method of checking would have been to poison the section of the river, but this is impracticable owing to the presence of salmon and trout in the Tweed.

Another factor which deserves comment is the apparent seasonality of the data; little or no movement being recorded in the summer months. The last recapture from fish marked on 16th March 1972 was made on 10th May 1972. A further sample of 51 fish was released on 19th May 1972, but none were recaptured. In the following 3 months, June, July and August 1972 only small numbers of unmarked dace were

caught at Norham and these were used in destructive sampling for food and growth studies. Insufficient numbers of large dace could be caught at the other netting sites to make tagging worthwhile. It was not until 15th September 1972 that another batch of larger dace were caught and tagged, on this occasion at Norham Castle (NT 906477). The lack of recaptures during the summer months was therefore a result of insufficient tagged fish being present, probably due to the behaviour of the species as outlined on page 46ff.

A similar situation occurred in the following year (June, July and August 1973). An attempt was made on 6th June 1973 to elucidate the problem by rod and line fishing a number of sites which were unsuitable for netting. The only two dace caught that day by a party of 10 anglers were taken on a dry fly at a point (NT 892472) near Norham Bridge. No evidence of a large shoal of dace could be seen again supporting the suggestion that in the summer months Tweed dace tend to disperse over a large area of the river. On the 5th October 1973 a total of 307 dace were captured again in the main river at Norham (NT 891468). These fish were all marked and released. 5 days later the site was renetted and although 91 dace were captured, none had been previously marked. Renetting this site, and others in the area, on 2nd November 1973 resulted in no dace, other than 0+, being captured. It was not until the 7th December 1973 that recaptures from the above 398 fish, marked in October, were made.

There is relatively little published information on the movement of dace. Some of the older texts e.g. Day (1880-84) and Regan (1911) note a seasonal difference and suggest that dace move into deeper water in winter. More recently Hart (1969) demonstrated movement of dace which varied with season on four adjacent 200 yard (183 m)

sections of his experimental area on the River Nene. Dace captured in any one section were, however, released after marking at the centre of that section and some displacement of fish must have occurred. This may have helped to induce small scale movement. Williams (1965) gained some information on the movement of dace in 4.2 km. of the River Thames at Reading. He records that there was no direct evidence of the total area occupied by the marked dace, though a certain (unspecified) proportion left the home site. Champion and Swain (1974) produced information on the movement of dace through a fish trap on the River Axe over the period 1960-69. 216 dace were found to move up whilst 877 moved down. The main downstream movement was generally between March and May whilst the main upstream movement occurred during the period September to December. January and February and June to August were periods in which little movement was observed. The disadvantage with these data is that the distance moved is not known and the position of the trap (about 3 km. from the river mouth), is probably of importance. The movement of the Tweed dace seems in reasonable agreement with these above observations with the exception that movement does occur in January and February on the Tweed (Fig. 4.2).

The use of sonic tags was suggested as a future research tool on page 48 and these could also be used to provide information on the direction, speed and time of movement as well as the dispersal of dace in the summer months. A relatively unsophisticated system could be used as tagged fish would only need to be located along the length of the river. The technique could perhaps also be used to obtain information on the behaviour of dace, especially in relation to shoaling. Information on the permanence of dace shoals, the structure

of dace shoals in relation to age and sex and the "territorial" behaviour of shoals would be most useful for work on populations. Halliday (1972) expresses the opinion (p. 104) that the shoaling behaviour of roach in Humble Reservoir had adversely affected his attempts to estimate population size, although he was unable to obtain further information on this behaviour.

Some tentative observations on the behaviour of dace shoals can, however, be made from the recaptures of marked dace. Since dace marked at different times and in different places were recaptured together it would seem that dace shoals are not discreet in nature and that shoals in a given stretch of river have "home ranges" that do overlap with at least some intermixing of shoals occurring. This may be due a) to the reason suggested by Stott (1967), that when two shoals meet some fish (not always the same individuals) may transfer, by accident, from one shoal to the other when they redivide. There is published information on the behaviour of fish in a shoal. Shaw (1962) shows, for example, how fish at the front of a shoal change position in the shoal when it turns. The same individuals would, therefore, not always be on the periphery. b) Intermixing of shoals could also be due to other reasons including, perhaps, disruption caused by sampling. It is most unlikely that all dace in a shoal were caught when netting took place. The captured fish were retained in holding boxes, sometimes for several hours, while marking was effected and it is not known whether these marked fish would regroup with the rest of the shoal when released, or whether they formed one or more additional shoals. Though this problem could not be avoided, on occasions when dace were observed to be feeding at the surface before, during and after marking was carried out, it appeared that the original

shoal had probably regrouped. If this was the case, it would seem unlikely that marking would, in itself, be the cause of subsequent movement.

## SECTION 5

## POPULATION SIZE AND STRUCTURE

I. Introduction

To place the information obtained on dace in context and to allow any changes in population size to be followed in future years, an attempt was made to investigate the size and structure of the population within the sample area. Once the size of the population within a given area was known, the density of the species could be readily determined.

II. Methods

## a) General considerations

When a population under study is not commercially exploited, several possible methods are available for estimating population size. Some of these techniques have previously been used in studies on dace, including mark and recapture (Williams, 1965; Hart and Pitcher, 1973), successive removal (Mann, 1967; Mathews, 1971; Wilkinson, 1974) and a method involving a calculation using the area swept by a net, the efficiency of the net and the average number of dace in a successful haul (Williams, 1965).

This latter method would yield a gross overestimate if applied to Tweed dace which show a clumped or overdispersed distribution. If the average number of fish in all hauls (successful or not) were used in the calculations a closer estimate of the true density would be obtained, provided that a sufficiently large area was netted to allow the capture of a number of separate shoals. This is not practical for Tweed dace, however, partly because of the sampling difficulties

previously mentioned (p. 14 and p. 44 ) and partly because the time required for this sampling operation would allow movement of shoals within the area to be netted (with consequent over or underestimates as a result of renetting or failing to net a given shoal). The method of successive removal (e.g. Seber and Le Cren, 1967) is suitable for sections of streams and rivers which can be isolated during sampling and could not therefore be applied to this part of the Tweed. Consideration of the available methods indicated that a mark and recapture technique was most suitable in relation to the prevailing conditions on the Tweed and so this was used to estimate the population size of Tweed dace.

The first recorded use of a method equivalent to a simple mark and recapture was quoted by Cormack (1968) as being that of Laplace (1786). A variety of mark and recapture methods are now available and these have been described by a number of authors including Bailey (1951), Mills (1964), Southwood (1966), Regier and Robson (1967) and Cormack (1968). The following basic assumptions apply to most methods of analysis.

- 1) Marked fish are not affected by being marked as regards, for example, survival rate or probability of capture.
- 2) Marked fish mix completely with the rest of the population.
- 3) Marks are retained for the duration of the experiment.
- 4) The population is sampled randomly with respect to marked and unmarked fish.
- 5) Sampling is at discrete time intervals and the actual time involved in taking samples is small in relation to total time.
- 6) Fish are correctly classified as marked or not on recapture.

Cormack (1968) stated that the behaviour of the species under study must be understood before any attempts are made to provide statistically valid estimates of population parameters. Unfortunately, as Hunt and Jones (1974) point out, knowledge of the behaviour of the Cyprinidae in Britain is sparse. Some observations (p.59 and p.63) on the shoaling of Tweed dace were made in the Section on movement and this was expected to cause problems with respect to conditions 1, 2 and 4 above. For the reasons described in Section 4 (p.52) all dace used in population estimation were marked by Panjet.

The population structure of the netted shoals is presented later (p.80). Although the proportions of the age classes vary (Fig. 5.1), with the frequent exception of the 0+ group, a mixture of age classes was usually present. These small fish were difficult to mark successfully and were more likely to be damaged during marking, (e.g. by loss of scales on handling) negating assumption 1) above. It was therefore decided to restrict the direct estimation of population size to fish 1+ and above.

When estimating population size and density it is important to define correctly the area to which the estimate is being applied. The movement of dace in the Norham area was investigated in 1972 and 1973 by tagging, as previously described (p.49) and the population estimate was made in that area between October 1973 and April 1974. The movement of these marked dace was also described (p.56ff) and they were found to disperse over the river between Norham Boathouse (NT 893464) and Union Bridge (NT 933512).

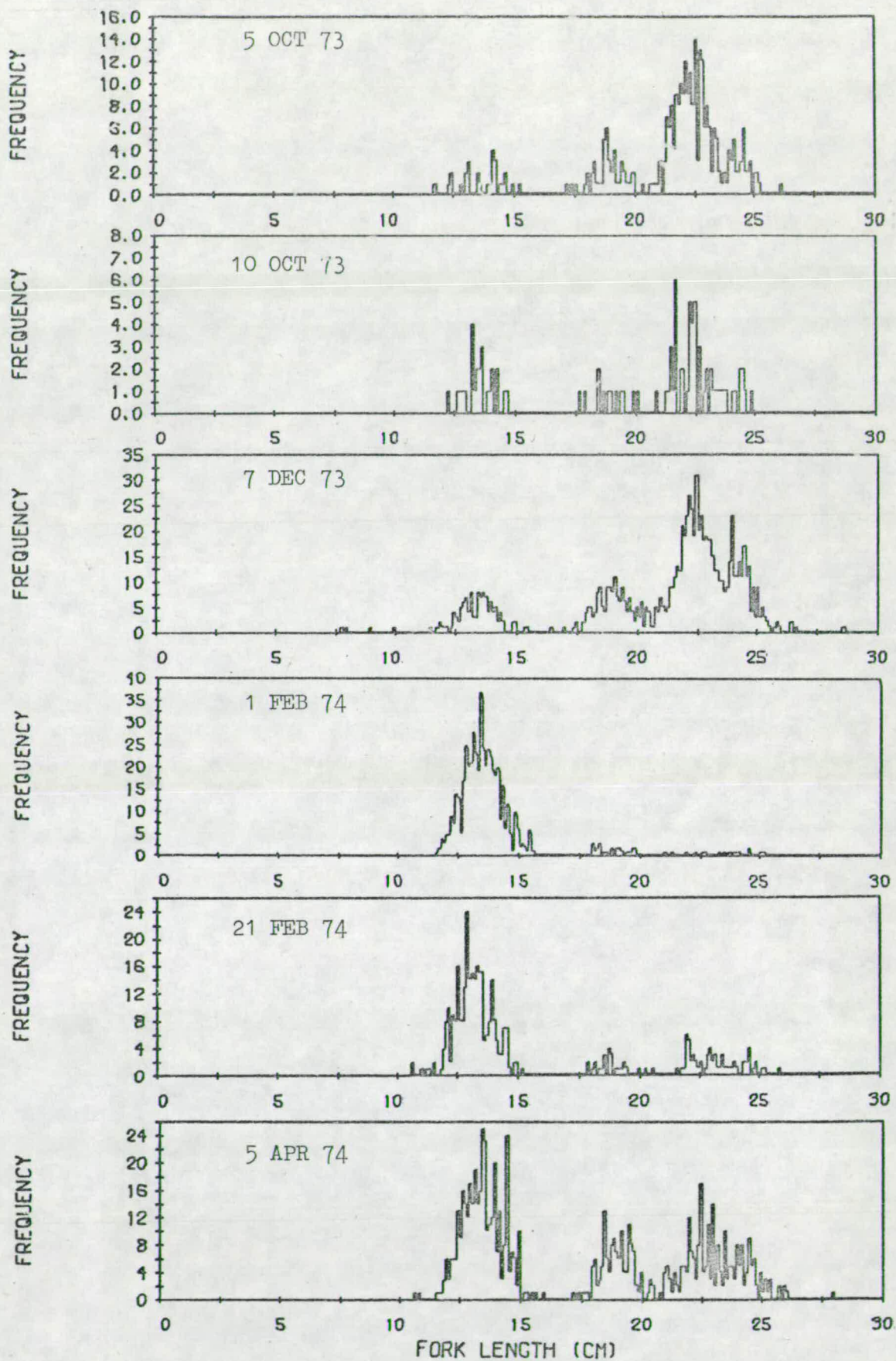


FIG. 5.1. LENGTH FREQUENCY HISTOGRAMS FOR PANJET SAMPLES

## b) Possible methods

The same notation (after Cormack, 1968) is used throughout this section.

(i) Petersen Method (quoted by Le Cren, 1965 as Petersen, 1889). This is also known as the Lincoln Index (Lincoln, 1930) but the recommendation of Le Cren (1965), that it should be known as the Petersen Method, is adopted here. The basic Petersen estimate is

$$\hat{N}_i = \frac{M_i n_i}{m_i}$$

where  $\hat{N}_i$  is the estimate of population size at time  $t_i$

$M_i$  is the number of marked fish at large at time  $t_i$

$n_i$  is the size of the sample taken at time  $t_i$

$m_i$  is the number of marked fish in the sample at time  $t_i$

Due to the problem of bias which has been shown to exist (e.g. Bailey, 1952) even if samples with no recaptures are rejected, similar modifications to this basic formula were suggested by Chapman (1952) and Bailey (1951, 1952). Bailey's modification results in the formula

$$\hat{N} = \frac{M_i (n_i + 1)}{m_i + 1}$$

with the variance of  $\hat{N}$  being estimated by

$$M_i^2 \frac{(n_i + 1)(n_i - m_i)}{(m_i + 1)^2(m_i + 2)}$$

(ii) Schnabel modification. A simple extension of the above estimate is the method of Schnabel (1938). This is the equivalent of a series of combined Petersen estimates calculated as:

$$\hat{N} = \frac{\sum n_i M_i}{\sum m_i}$$

This was modified by Chapman (1952) to reduce bias:-

$$\hat{N} = \frac{\sum n_i M_i}{\sum (m_i + 1)} \quad \text{--- (2)}$$

Chapman also gave the following expression to produce an approximate estimate of the variance of  $\hat{N}$ :-

$$\frac{\hat{N}^2}{\sum n_i M_i} \left\{ 1 + \frac{2\hat{N}}{n_i M_i} \right\}$$

(iii) Schumacher and Eschmeyer (1943) proposed an alternative method of calculating population size from a multiple marking experiment viz.

$$\hat{N} = \frac{\sum n_i M_i}{\sum m_i M_i}^2 \quad \text{--- (3)}$$

with the variance of  $1/\hat{N}$  being given by

$$\frac{\sum (m_i^2/n_i) - (\sum m_i M_i)^2 / \sum (n_i M_i^2)}{d - 1}$$

where d is the number of days on which samples were taken.

(iv) Of a more sophisticated nature than the methods described above are the deterministic models which usually assume a deterministic death and birth rate and possibly also a deterministic immigration and emigration rate. Models of this type include those put forward by Jackson (1937, 1939, 1940, 1948); Dowdeswell, Fisher and Ford (1940), Fisher and Ford (1947) and Bailey (1951).

Using deterministic birth and death rates Bailey, for example, gives the following solution for a triple catch sample i.e. samples being taken at times 0,  $t_1$  and  $t_2$ :

$$\hat{N}_1 = \frac{(s_1 - m_1)n_1 (m_{02} + m_{012})}{m_{01} m_{12}}$$

where  $s_1$  is the total number of fish released on day 1

and  $m_{012}$ , for example, refers to marked fish seen on occasions 0, 1 and 2.

The above formula was again modified for small samples to give

$$\hat{N}_1 = \frac{(s_1 - m_1)(n_1 + 1)(m_{02} + m_{012})}{(m_{01} + 1)(m_{12} + 1)} \quad \text{--- (4)}$$

An estimate of the variance of  $\hat{N}$ , is given by

$$\hat{N}_1^2 - \frac{(s_1 - m_1)^2 (n_1 + 1)(n_1 + 2)m_{12} (m_{12} - 1)}{(m_{01} + 1)(m_{01} + 2)(m_{12} + 1)(m_{12} + 2)}$$

The deterministic model of Fisher and Ford (1947) was recommended by Hunt and Jones (1974a). Fisher and Ford estimated the average survival rate  $\phi$  from the average time interval separating release and recapture. From this the population on day  $j$ , i.e. prior to sample at  $i$ , was estimated by

$$\hat{N}_j = \frac{\hat{M}_j n_j}{m_j} \quad \text{--- (5)}$$

where  $\hat{M}_j$  is an estimate of the number of marked animals alive at time  $j$ , calculated by

$$\hat{M}_j = \sum_{i=1}^{j-1} s_i \phi^{j-i}$$

This counts each individual at any recapture as often as it has previous marks but Cormack (1968) states that the use of the last previous recapture is more valid.

(v) Cormack (1968) suggests that the above deterministic models should be totally superseded by the more recent stochastic models (based on probability theory), such as those of

Jolly (1965) and Seber (1965). The reasons for this are not only that the stochastic models are less complicated to analyse than their deterministic counterparts but also because they are thought to provide more valid results. Jolly estimates the population size at time  $i$  ( $\hat{N}_i$ ) as follows:-

$$\hat{N}_i = \frac{n_i}{m_i} M_i \quad (i = 1, 2, \dots, k-1) \quad \text{--- (6)}$$

where  $k+1$  is the total number of samples, capture and recapture and

$$\hat{M}_i = z_i \frac{s_i}{r_i} + m_i, \quad (i = 1, 2, \dots, k-1)$$

where  $z_i$  is the number not seen at  $i$ , seen after  $i$

$s_i$  is the number released after sample at  $i$

$r_i$  is the number released at  $i$  which are recaptured later

Manly (1970) tested the methods of Fisher and Ford (1947), Jolly (1965) and Manly and Parr (1968). He found Jolly's (1965) method to be less affected by age-dependent mortality than the method of Fisher and Ford (1947), whilst the method of Manly and Parr (1968) was more sensitive to poor data resulting from small samples being taken.

### c) Choice of a suitable method

From the information presented above it seemed that the stochastic model of Jolly (1965) would be the most suitable method to use, and the mark-recapture programme was undertaken with a view to using this technique.

During a study of barbel, Barbus barbus (L.) in the River Severn Hunt and Jones (1974a) found that, probably as a result of shoaling behaviour, the assumptions for all four methods of population estimation they used (Schnabel; Schumacher and Eschmeyer; Fisher and Ford;

Jolly) were invalid and that all population estimates were therefore inaccurate. Halliday (1972) experienced a similar problem when working on roach in Humble Reservoir and noted a remarkable lack of consistency in the population estimates using different population models (Petersen; Bailey's Triple Catch; Jolly). He emphasised that even the most complicated mathematical function for computing population parameters was often still subject to the inherent defects of the simpler models.

It was therefore decided:

- 1) to test all of the methods outlined above, when the recapture data was suitable, in an attempt to detect discrepancies that might not be obvious if only one method was used, and
- 2) to examine the structure of shoals on mark and recapture to supplement information obtained on the degree of mixing from the combinations of marks taken on recapture. Methods outlined by Cormack (1968) are available to test some of the assumptions of the methods listed on p. 66 but as Hunt and Jones (1974a) point out the cost of catching and marking fish in a population study often makes it impracticable to undertake the large scale preliminary investigations necessary for a check of this kind. Even if one or more of the assumptions was shown to be invalid Le Cren (1969) has emphasised that approximate data on population density is distinctly better than no data at all.

### III. Results and Discussion

#### a) Dace over 10 cm in length.

The recapture data for marked dace i.e. fish over 10 cm in length is given overpage in Table 5.1

Table 5.1 Recapture data for marked dace (Format after Jolly, 1965)

Occasion	Date	Site	Interval (days)	Number Caught	No. Marked & Released	Max.No. Marked & at Large	Recaptures
A	5-10-73	NT891468		307	307	0	A
B	10-10-73	NT891468	5	91	91	307	0 B
C	7-12-73	NT893464	58	896	894	398	4 0 C
D	14-12-73	NT893464	7	746	746	1292	3 1 82 D
E	1- 2-73	NT893464	49	526	526	2038	0 0 15 10 E
F	21- 2-74	NT933512	20	368	368	2564	0 0 2 2 0 F
G	5 - 4-74	NT933512	43	741	383	2932	2 0 29 18 35 0 G
						3315	<u>9 1 105 14 2 0</u>

The number of recaptures was generally too small to enable the numbers of each age class to be estimated separately, though most age classes were represented in the samples (Fig. 5.1).

Using formulae (1) to (6) above, population estimates for the dace population (over 10 cm in length or age 1+ and over) were produced (Table 5.2). Blank spaces in the table result from insufficient recaptures being obtained for a population estimate to be made using that method. The results are very variable. As the confidence limits calculated for individual estimates were found to be giving a completely false impression of accuracy when compared with the variation observed between successive estimates they have not been included in the table. For example the estimate made by the Petersen method for the 4th sampling occasion produced an estimate of population size of 8,050 with 95% confidence limits  $\pm 1,600$  i.e. suggesting a population of between 6,450 and 9,650 individuals. The estimate for the 5th occasion was, however,  $35,700 \pm 20,000$  i.e. suggesting a population of between 15,700 and 55,700 fish. The minimum figure in this latter estimate is, however, well above the previous maximum estimate. Manly (1970) also noted that confidence limits, calculated during a simulation study, were more closely related to the estimate than to the actual variation. The estimates produced by all methods for the 4th sampling occasion are low due to the higher number of recaptures obtained (Table 5.1). This in turn suggests that inadequate dispersal and mixing of marked fish had occurred between occasions 3 and 4. In contrast the recaptures on sampling occasion 3 are probably biased in the other direction. This emphasises the point that, in this type of situation the limiting factor is not the crudeness of the model being used for estimation, but rather the inherent unpredictability of

biological material and the difficulties of sampling a species such as the dace in a large water body.

Table 5.2 includes 2 sets of figures for the Jolly (1965) method. The first is calculated from the general model which allows for birth, death, immigration and emigration. This method was, however, found to be estimating more marked fish present in the population than had actually been marked (Table 5.3).

Table 5.3 Calculations for Jolly (1965) analysis a) allowing for death  
b) assuming no death over sample period

Occasion i	Proportion Marked in Sample	Estimated No. Marked & at large $M_i$		Estimate Population Size $\hat{N}_i$	
	$\frac{m_i}{n_i}$	(a)	(b)	(a)	(b)
B	0	819	307	$\infty$	$\infty$
C	0.0045	55	398	12222	88444
D	0.1153	1418	1292	12298	11206
E	0.0475	3707	2038	78042	42905
F	0.0109	$\infty$	2564	$\infty$	$\infty$
G	0.1134	-	2932	-	25855

This problem was also encountered by Hunt and Jones (1974a) who ascribed the difficulty to the movement and shoaling behaviour of the barbel. The second method of Jolly (1965) which assumes immigration but no death was therefore used to overcome this difficulty. For this latter method all fish that have been marked are assumed to be present in the population and available for recapture.

A similar problem was encountered when determining survival rate in the Fisher and Ford method (Table 5.4). Again the calculations

Table 5.2. Population estimates (for dace &gt; 10 cm fork length)

Sampling Occasion	Petersen	Baileys Triple	Schnabel	Schumacher & Eschmeyer	Fisher & Ford	Jolly	Jolly No. Death	Row Mean
B	NR	NR	NR	NR	NR	NR	NR	NR
C	NR	NR	64,000	94,000	(290,000)	12,200	88,000	(110,000)
D	8,050	9,150	14,500	12,900	17,000	12,300	11,200	12,300
E	35,700	50,400	20,400	21,900	53,900	78,000	42,900	43,300
F	NR	NR	27,200	34,500	NR	NR	NR	30,800
G	NR	NR	25,000	29,400	25,900	-	25,900	26,550
								± 3,100
Column Mean	21,900	29,800	30,200	34,200	32,500	34,000	42,000	28,000
								± 8,500 (C excluded)

N.R. indicates no recaptures applicable to that method of calculation, viz: a failure to recapture dace released on the previous sampling occasion.

On other occasions, e.g. occasion C, the number of recaptures is too low for a satisfactory estimate to be made (see Table 5.1 p 74).

Table 5.4. Calculations for the Fisher and Ford (1947) method of estimating population size ( $\hat{N}$ )

Date	Interval (Weeks) (r)	Number Marked (m)	Survival Rate ( $\phi^r$ )	( $m \cdot \phi^r$ )	Cum. Number Marked	Sum of Cum. Number Marked	Total Recaptures (mj)	Total Weeks Survived	Expected Weeks Survived	Excess Over Expctn.	Number Last Released (nj)	Population Estimate ( $\hat{N}$ )
5.4.74.	0		1									
	1		1		2932	42693	84	5344	1223	+4121	741	25,900
	2		1		2932	39761						
	3		1		2932	36829						
	4		1		2932	33897						
	5		1		2932	30965						
21.2.74.	6	368	1	368	2932	28033	4	290	38	+ 252	368	270,000
	7		1		2564	25101						
	8		1		2564	22537						
1.2.74.	9	526	1	526	2564	19973	25	1330	195	+1135	526	53,900
	10		1		2038	17409						
	11		1		2038	15371						
	12		1		2038	13333						
	13		1		2038	11295						
	14		1		2038	9257						
	15		1		2038	7219						
14.12.73.	16	746	1	746	2038	5181	86	849	219	+ 630	746	17,700
7.12.73.	17	894	1	894	1292	3889	4	252	12	+ 240	896	290,000
	18		1		398	3491						
	19		1		398	3093						
	20		1		398	2695						
	21		1		398	2297						
	22		1		398	1899						
	23		1		398	1501						
	24		1		398	1103						
10.10.73.	25	91	1	91	398	705	0	0	0	0	91	8
5.10.73.	26	307	1	307	307	307	0	0	0	0	307	-

suggested that the survival rate was higher than 1, the maximum possible 100% survival rate. Clearly, at least some of the assumptions given on p. 66 are not being met.

The later estimates in Table 5.2 should be more reliable than the earlier ones as there was a higher proportion of marked fish in the population towards the end of the exercise. For this particular set of data neither the method of Jolly (1965), recommended by Cormack (1968) nor the method of Fisher and Ford (1947) appears substantially better than either of the two earlier methods (Schnabel, 1938; Schumacher and Eschneyer, 1943). In fact, the method of Fisher and Ford gives the most variable estimates and is probably therefore the least satisfactory, though the final estimate for occasion 7 is very close to the others. Therefore, averaging the 4 estimates for the 7th (final) occasion gives an estimate of 26,550 dace (over 10 cm in length) in the sample area. The 95% confidence limit can be calculated directly from these four samples giving  $26,550 \pm 3,200$  ( $\pm 12\%$ ). The sample area has not yet been defined. The movement of these marked fish was described in Section 4 (p.56ff) and Fig. 4.5 (p.58) suggests that marked dace dispersed over the stretch of river between Norham Boathouse (NT893464) and Union Bridge (NT 933512). Recaptures on 21.2.74. and 5.4.74. which were used in these calculations were taken at Union Bridge in comparison with the earlier catches taken at Norham. Dace were netted at Union Bridge following an inability to locate the shoal at Norham and the presence of marked fish at Union Bridge indicates that the shoal had moved downstream. The surface area of the river between Norham and Union Bridge was calculated to be approx.  $1,000,000 \text{ m}^2$ . The population density of dace (over 10 cm in length) is therefore  $0.027$  dace per  $\text{m}^2$

of river surface, or 1 dace every  $37 \text{ m}^2$  of river surface. This figure is similar to figures given by Hart and Pitcher (1973) for the River Nene, which ranged from 0.0028 to 0.0220 dace (aged 3-9) per  $\text{m}^2$  of surface, but much lower than the figure of 0.1 dace (over 10 cm in length) per  $\text{m}^2$  of the surface of the River Thames (Williams, 1967).

b) Dace less than 10 cm in length

Although a direct estimate of population size for Tweed dace was made only for fish over 10 cm in length, an approximate indirect estimate can be produced of the numbers of younger fish hatching and surviving using a) estimates of the fecundity of female dace b) estimates of the sex ratio of the population and c) estimates of the proportion of mature fish from the population structure of the catches. The population structure of the catches is given in Fig. 5.1 (p.68) as numbers against length and the age structure is summarized in Table 5.5

Table 5.5 Age structure of 'Panjet' samples

Occasion	Date	Age 1+		Age 2+		Age 3+		Age 4+ & older	
		Number	Row%	Number	Row%	Number	Row%	Number	Row%
A	5.10.73	28	9.12	49	15.96	189	61.56	41	13.36
B	10.10.73	25	27.47	12	13.19	46	50.55	8	8.79
C	7.12.73.	119	13.31	160	17.90	435	48.66	180	20.13
D	14.12.73.	(Not fully analyzed, but similar to occasion C)							
E	1.2.74.	485	92.21	23	4.37	9	1.71	2	1.17
F	21.2.74.	279	75.82	26	7.07	49	13.32	14	3.80
G	5.4.74.	370	49.93	145	19.57	140	18.89	86	11.61
Overall		1306	44.62	415	14.18	868	29.65	338	11.55

There was a marked difference in the proportions of dace in the different age groups in the catches taken in autumn and winter 1973 as compared with those taken early in 1974, but all the figures have been averaged to determine the overall population structure. For example, the fact that there are more 3+ dace than 2+ probably reflects spawning success and subsequent survival in 1970 and 1971.

Examination of the gonads of dace in different age groups showed that both female and male dace from the Tweed were generally mature at 3+, although maturity was also attained by a smaller number of 2+ male dace. These observations were supported by information on changes in gonad weight as a proportion of the total weight. (Fig. 5.2). Cragg-Hine (1964) found dace spawned at 2+ in Willow Brook and Hartley (1947a, b) also records dace of 2+ in spawning condition. In contrast Hellowell (1969) and Wilkinson (1974) both record the first spawning of dace during the 4th year of life i.e. at 3+. Because of their faster growth rate Tweed dace might have been expected to spawn at a younger age than other populations (Nikolskii, 1969). Wilkinson (1974) notes however that this did not apply in the case of Hellowell's (1969) population and it appears that these interrelationships require further investigation.

Information was obtained on the sex ratio of maturing and mature dace in the Tweed population a) from the monthly food and growth samples taken between October 1971 and October 1972 and b) by examining a larger number of dace for the presence or absence of tubercles (Plate 5.1 a, b) in March 1973 and February 1974. Results are presented in Table 5.6. Though a large sample of fish can be sexed and returned live to the water, the secondary sexual character, i.e. tubercles, can only be used over the spawning period. At this time the sex ratio of

PLATE 5.1

(a) The surface of a male dace photographed at the end of February showing the tubercles which are present only during the breeding season.

(b) The surface of a female dace without tubercles.



Table 5.6 Sex ratios of dace samples

Date	Total No. Males	Total No. Females	No. 2+ Males	No. 2+ Females	No. 3+ & older Males	No. 3+ & older Females
a) Sexed by examination of gonads						
4.10.71.	34	8	33	7	1	1
4.11.71.	16	8	13	3	3	5
3.12.71.	26	18	20	4	6	14
7.1.72.	27	21	17	5	10	16
3.3.72.	41	15	26	8	15	7
21.4.72.	25	22	23	11	2	11
10.5.72.	13	3	10	3	3	0
7.6.72.	9	14			9	14
9.8.72.	1	4	1	2	0	2
12.10.72.	<u>36</u>	<u>15</u>	<u>    </u>	<u>    </u>	<u>36</u>	<u>15</u>
TOTAL	228	128	143	43	85	85

## b) Sexed by presence or absence of tubercles (Plate 5.1)

9.4.73.	693	387
13.4.73.	493	301
26.2.74.	53	150

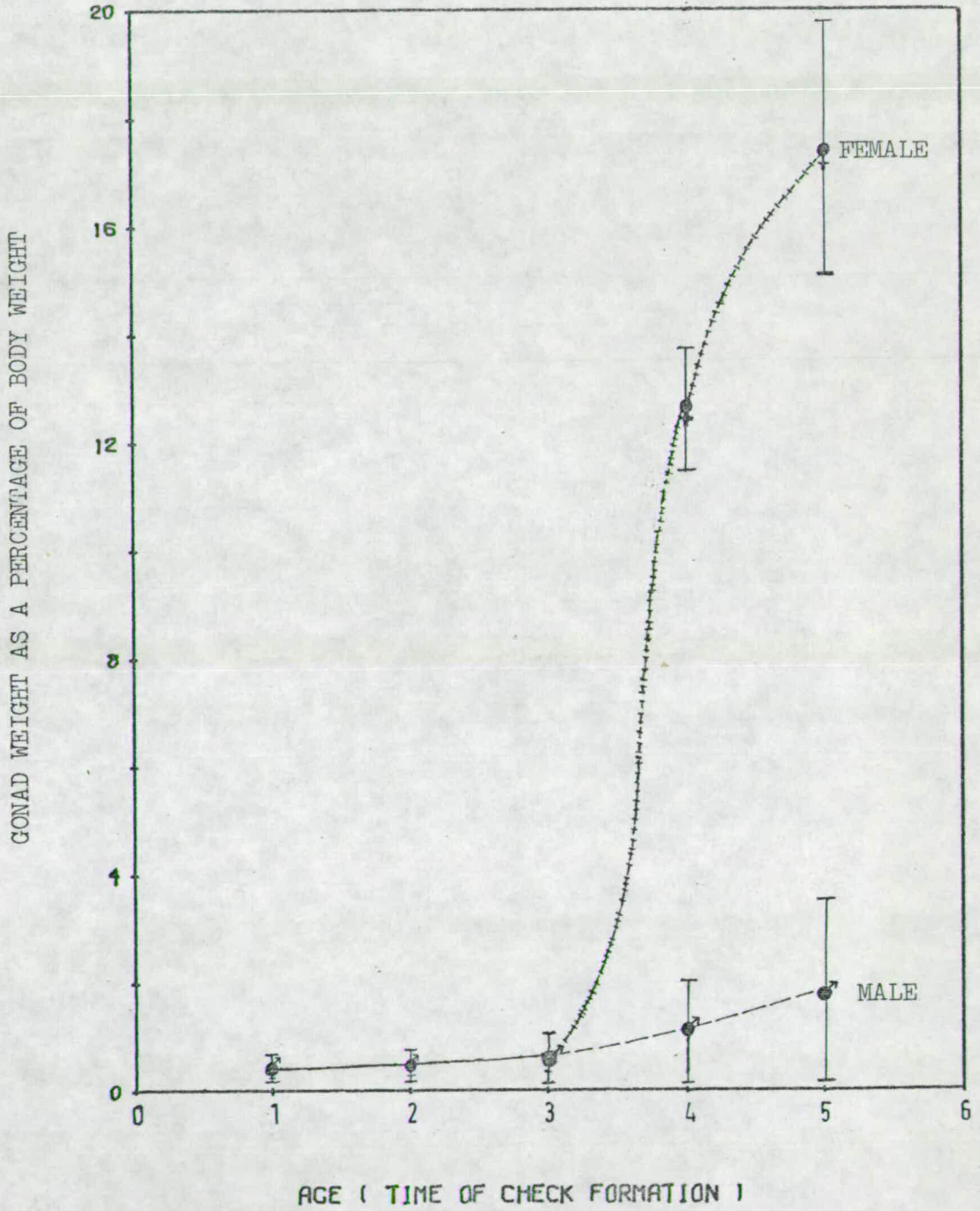


FIG. 5.2 CHANGE IN GONAD WEIGHT WITH AGE

the sample taken is liable to be disturbed by differences in the behaviour of male and female fish. This may explain the change from male to female dominance in 1973 and 1974 samples respectively as there appeared to be no marked difference in the age structure of the samples. (A predominance of female fish in older age classes was demonstrated in Section 2, p.32).

An overall sex ratio of 1:1 was therefore assumed to exist. Hellowell (1969) found differences in sex ratio varying with age from 1:1 in young fish to a male predominance in the fourth year, returning to 1:1 and a final female predominance in later years.

Applying the above information on time of maturity and sex ratio to the data in Table 5.5 it would appear that 40% of the dace sampled were 3+ and older (i.e. sexually mature) and that half of these were female. Extrapolating to the estimated population of 26,550, it follows that there were approximately 5,300 mature female dace in the sample section of which the majority were apparently 3+ (Fig. 5.1, p.68).

The fecundity of the 3+ age group was determined by counting dried eggs (Simpson, 1959, described by Bagenal and Braum, 1968). No attempt was made to relate fecundity to age due to the predominance of the 3+ age group. It was found that 3+ female Tweed dace each contain  $12,000 \pm 1,600$  eggs and thus it would appear that approximately 60,000,000 eggs would be laid by the dace in the sample section.

Some of the eggs laid will not be fertilised, other fertilised eggs will die or be killed before hatching, the proportion depending to a certain extent on the prevailing conditions from one year to the next. Backiel and Zawisza (1968) record fertilization rates of 75% - 100% for bream Abramis brama (L.) with overall losses varying between 6.8% to 65% in difficult habitats as a result of non-fertilisation,

oxygen deficiency, dessication, fungal infection and predation. In the absence of specific information for dace in the River Tweed it has been assumed for the purposes of calculation that 66% of eggs laid would hatch as larvae. Consequently some 40,000,000 larval dace could be expected to have hatched in the sample section, i.e. approximately 40 per m<sup>2</sup> surface. Between the time of hatching, which for the Tweed is usually in early April, and the hypothetical birth date of 1st May these numbers will be reduced. Chapman (1968) indicates that an exponential model of mortality is frequently appropriate in older year classes or is used in the absence of exact information. Assuming that an exponential mortality rate applies to these Tweed dace it can be estimated that the 40,000,000 dace hatching will be reduced to about 660,000 at age 1 i.e. 0.66 per m<sup>2</sup> of surface. This figure is lower than the density of 0.8 to 1.7 dace age 0+ for the Thames at Reading (Matthews, 1971), but this is in keeping with the lower estimate for older fish given earlier in this Section (p.80).

#### c) Causes of mortality

Information on the causes of mortality among Tweed dace is scanty. As might be expected in a clean river like the Tweed no large scale mortality was observed over the period of study. The level of infestation by gut and other internal parasites appeared to be low, though at certain times of the year the fish leech Piscicola geometra(L.) was found to be present on up to 5% of dace examined (4.3.75). Attack by this parasite was however considered unlikely to result in mortality; the number of parasites per fish generally being low.

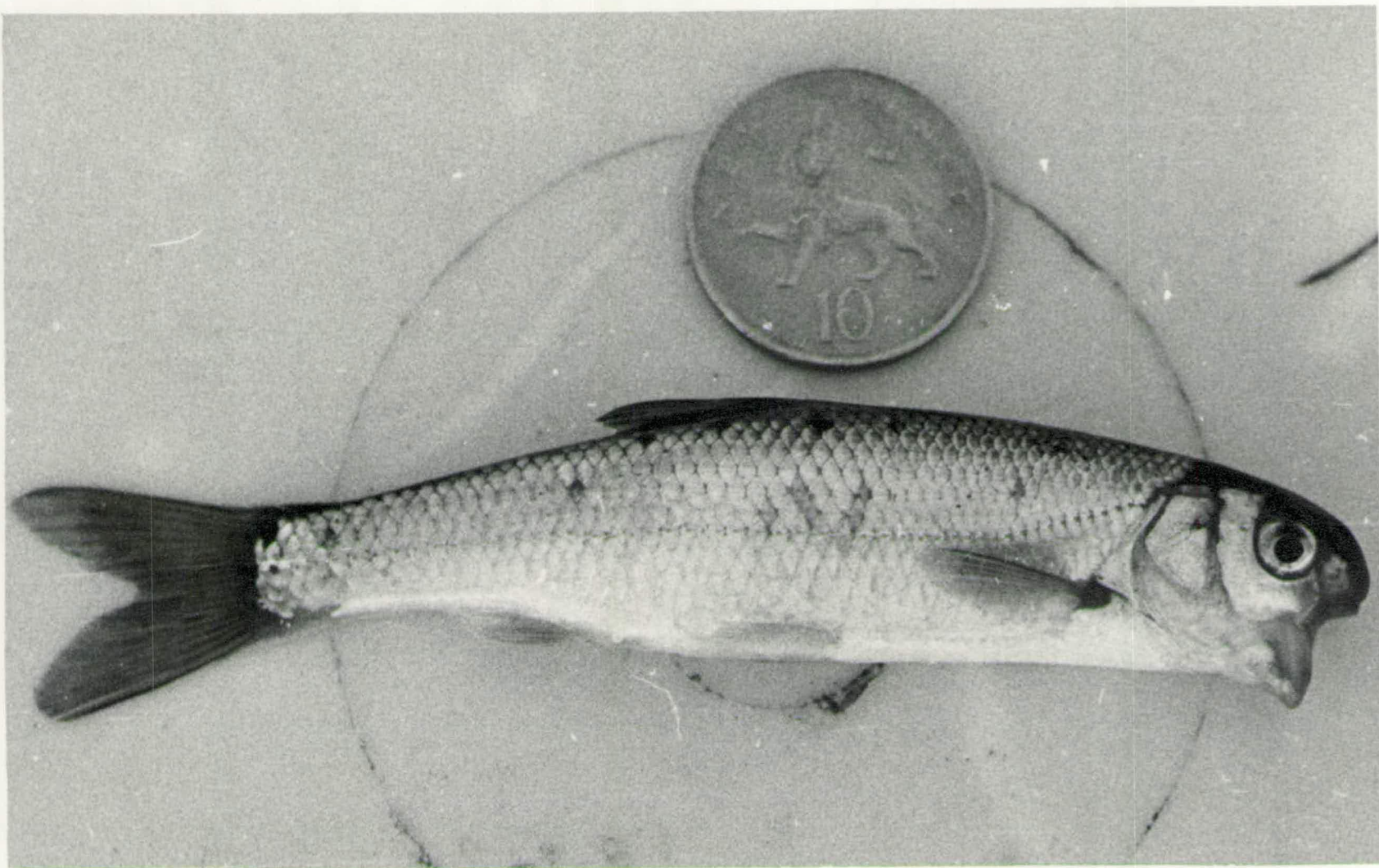
Limited evidence of predation of dace both by other fish and by birds was obtained. A 23cm trout from a sample of 21 taken at Union Bridge on 4.3.75. contained two 0+ dace. A 46 cm pike, caught at Norham Boathouse on 3.3.72. contained two 0+ dace as well as roach and

gudgeon. The number of pike in the Tweed is probably very low (only 3 were caught during the whole period of study) and predation of dace by pike was therefore considered of limited importance. The presence of dace in 1 trout of a sample of 21 could, however, be of much greater importance and has interesting implications from the point of view of competition.

McIntosh (1973) examined the food of the cormorant (Phalacrocorax carbo (L.)). He found that one bird from a sample of 24 had eaten 2 dace, of 7 cm length, i.e. again in the 0+ age group. He records that the most common food species were roach, salmon parr and flounders. Heron (Ardea cinerea (L.)) have also been observed in the sample area and it is likely that their prey includes dace.

Some angling for dace is carried out on the Tweed and although coarse fish anglers usually return the fish to the river a proportion of fish are damaged (Plate 5.2) and sometimes killed as a result of capture, handling and/or retention in keep nets. Probably of more importance from the point of view of dace mortality are the game anglers. For example in 1973 Norham A.A. insisted on either a "kill-off" of all catches of roach and dace or transfer of the fish to other waters (Taylor, 1973).

PLATE 5.2 An 11 cm (1+) dace captured with obvious signs of damage to the mouth. The fish was presumed to have been hooked by an angler at an earlier date.



## SECTION 6

## FOOD

I. Introduction

The ecological concept of niche and competition, discussed in more detail later (p.116 ff) are closely related to nutritional considerations. The food of Tweed dace was therefore investigated to provide some information on the relationships between dace and other species. Since Gause's (1932) laboratory investigation of competition between two yeast species much work has been done on competition but transferring the results of laboratory work to field populations has proven difficult (Krebs, 1972). Fish are probably more difficult to investigate than are other groups of animals since fish have a flexible growth rate. For this reason Weatherley (1963), dismissed, in general, the idea of deleterious effects arising from competition for food among fish. He accepted that the growth rate would often be reduced but did not seem to consider it deleterious.

Although a detailed study of competition (including, for example, an investigation of the numbers and productivity of food organisms, the demand for and consumption of these organisms by dace and other fish species) was beyond the scope of this study, it was decided that an investigation of the organisms consumed by dace would be useful in determining the niche occupied by dace in the Tweed and thus to pinpoint possible areas of competition with other species.

## II. Methods

Hynes (1950) reviewed the methods used in studies of the food of fish. The general methods given for the enumeration of stomach/gut contents are a) frequency of occurrence

- b) numerical
- c) volumetric
- d) gravimetric
- e) points
- f) dominance

These methods are also detailed by Windell (1968) who pointed out that combinations of 2 or more of the above methods might also prove useful. Since 1950 improvements to these techniques have been proposed including the rapid volumetric method of Hellowell and Abel (1971) and the centrifugal method, again used to determine volume, of Aldorri (1972).

A number of authors have argued the relative merits of the above methods and it would seem that the more quantitative and/or less subjective methods, such as the numerical, volumetric and/or gravimetric methods should provide more reliable information than the other techniques. This may apply in the case of fish species which ingest their food more or less intact, but does not apply to those fish species (including dace) which macerate and mix their food, making the determination of numbers, volume or weight of the various components difficult. The presence in the diet of soft bodied organisms which can be rapidly digested, such as oligochaetes, whose presence must usually be ascertained from their undigested chaetae (Kennedy, 1969), again makes these methods unreliable.

The numerical method was therefore considered unsuitable for Tweed dace due to the difficulty of and time involved in counting macerated and/or digested organisms and also to the fact that a count cannot readily be made of macroscopic plant fragments or strands of filamentous algae which vary in size. Volumetric and gravimetric methods were also dismissed as they underestimate species susceptible to maceration and digestion and overestimate the more resistant hard bodied species unless time consuming correction methods are employed. McIntyre (1969), for example, estimated the biomass of chironomids ingested by trout and grayling from the size of undigested head capsules in the stomach.

Consideration of other possible methods resulted in the points method being chosen since it avoided the problems mentioned above but was relatively quick and easy to use. The possible disadvantage of this subjective method seemed to be more than compensated for by the fact that a) digested organisms could be given a value and b) the size of organisms could be balanced against numbers. Results from this method can also be presented on a frequency of occurrence or a dominance basis if required.

The points method was originally proposed by Swynnerton and Worthington (1940) who listed food items in each fish stomach as very rare, rare, frequent, common or very common. This 5 point classification was then condensed, with 1 point being allocated to very rare and rare food items, 2 points to frequent items and 3 points to common or very common species. These integers were then summed and scaled down to percentages to give the percentage composition of the food of each size class of fish species examined. Hynes (1950) used this method in a slightly modified form allocating 1, 2, 4, 8 or 16 points to the 5

categories respectively. No intermediate values were given but he suggests that the use of 5 categories rather than 3 allows for greater flexibility. By this argument more categories could be used if desired. Although Hynes does not give reasons for the choice of the specific values 1, 2, 4, 8 and 16, they are more likely to be representative when added than the values 1, 2, and 3 of Swynnerton and Worthington (1940). Suppose, for example, that 3 fish each eat 1 individual specimen of a given food organism. Each would be allocated 1 point, giving a total of 3 points from 3 individual food organisms. In contrast 1 fish may consume 100 specimens of the same food organism again giving a total of 3 points, but in this case the 3 points are derived from 100 food organisms rather than 3. The geometric progression used by Hynes (1950) helps avoid this problem. However, by suggesting that food organisms are allocated points on the basis of the volume occupied by the organisms in the stomach Hynes loses the advantage of being able to compensate for digested food organisms, even though this is on a subjective basis. It was therefore decided to base the points awarded on a combination of estimates of the numbers and original (undigested) size of the food organism. Due to the subjectiveness of this method and the possible difficulty of defining accurately the division between one category of abundance and the next only five categories were used. These categories can be described as 1) very rare 2) rare 3) frequent 4) common 5) abundant, based on the estimated numbers and/or volume of that given food type which could be contained in a full alimentary canal of that particular size class of fish. These five categories were subsequently awarded points as given below

Table 6.1 Points awarded for gut analysis

Category	1	2	3	4	5
Points awarded	1	6	20	50	85
Estimated % of potential food intake	0-2	3-9	10-30	31-69	70-100

These particular point scores were chosen as they appeared to be the most realistic figures from an additive point of view for most of the food organisms. The range from 1 to 85 (i.e. 0-100) was determined by the fact that some organisms in the gut were estimated to have occupied initially no more than 1% of the volume of the gut before being macerated and digested. (Examples include the presence of 1 copepod crustacean in a 1+ dace or one or two chironomid larvae in a 3+ dace). The point score was related to the size of the fish so that the importance of the various food types to the different age classes of fish could be readily compared. It is appreciated that the total amount of food that can be consumed by a small fish is less than that consumed by a large fish, but the greater numbers of small fish present in the population (p. 80) will serve to balance out this effect.

The highest category any given food organism could be placed in was category 5 and as a result 85 points was the maximum score for one particular food type. It is, however, quite possible for the total number of points awarded to all the food types present in the gut to exceed 100, implying that the gut was more than 100% full. Hynes (1950) avoided this situation by allocating a total of about 20 points to a full stomach (irrespective of the size of the fish). The fact that the total score for a dace gut in this study could, in certain cases, be

well in excess of 100 was not considered unreasonable as it merely implied that an additional quantity of food had been digested. For example, if an alimentary canal appeared, on initial examination under a low power binocular microscope to be full of undigested molluscs in their shells, they would be designated abundant (5) and later awarded 85 points. It is, however, possible that subsequent examination of the contents under higher magnification on a transmission microscope could show that very large numbers of oligochaete chaetae were also present, the oligochaetes themselves having been digested. In this situation oligochaetes would also be designated abundant (5) and awarded 85 points bringing the total, for that gut, to 170 points.

A decision had to be made as to how much of the alimentary canal was examined for food analysis. When the fish species under study possesses a discrete stomach as, for example, does the trout, most workers base their investigations solely on the stomach contents as these are less digested and more easily identified and quantified. In fish species (including dace) with no well defined stomach, some authors have chosen to examine the contents of the whole alimentary canal whilst others have only used a certain part. For example, Radforth (1940) states that she examined the contents of the stomach and intestine of roach and gudgeon. In contrast Aldoori (1972) working on roach used what he termed the 'Standard Portion' viz. the first loop of the tract and the first quarter of the second loop; whilst Mann (1974) used the anterior one third of the tract of dace. Some authors do not specify exactly how much of the tract was examined; Hartley (1947a) used the terms stomach and gut on what appear to be an interchangeable basis.

It was decided that there were good reasons for examining the whole of the alimentary canal. Fish are known to feed more intensively at

certain times of the day than others. Elliott (1970), for example, investigated invertebrate drift and the food of trout and was able to show diurnal variation with major peak in feeding activity in the evening. Vostradovsky (1961) related feeding activity in dace to circadian rhythms amongst their prey. Apart from changes in feeding activity changes in the type of food being eaten make it advisable to examine the whole gut. Layering of gut contents i.e. the abrupt change from one food type to another has been noted by several authors and applied in the case of Tweed dace. Hartley (1947a) refers specifically to a 21 cm male dace which had 4 distinct layers in the gut. If only part of such a gut were examined, a wrong assessment of the importance of the various food types to the fish would be obtained.

In addition to examining the whole of the alimentary canal of dace sampled throughout the year at a given time of day (samples were actually taken as near as possible to midday) some round-the-clock sampling in spring, summer, autumn and winter was also considered to supplement the routine samples. Unfortunately the problems of obtaining more than one sample from a given area, without unduly disturbing the mobile dace population or the habitat made this impracticable. Consequently there was even more reason to examine the contents of the whole of the gut.

A sample of dace was taken at the beginning of each month over the period October 1971 to October 1972 inclusive at Norham Boathouse, NT 893464, as described in Section 2 (p.18). Every effort was made to take samples on a pre-arranged day, usually the first Friday in the month, so that the decision as to whether or not to sample was not biased by the prevailing conditions. In this way it was hoped that the samples taken were more likely to have been representative of that particular

month. Later in the laboratory preserved alimentary canals were opened longitudinally and an estimate made of their fullness to investigate seasonal variation in feeding activity (Hynes, 1950). A ten point scale was used with, for example, 0.9 corresponding to a gut which appeared 90% full. Very small quantities were initially recorded as a 'trace', but for additive purposes were valued at 0.1 rather than 0. This was done to distinguish between fish which had completely empty guts and fish which, though they might appear almost empty, could, in fact, have digested most of the organisms taken into the gut.

After the fullness of the gut had been assessed the contents were removed using forceps and placed in a petri dish marked on the base with a grid. Placing the contents in order helped, in some cases, to relate the various pieces of a macerated organism together and thus facilitate easier identification and allocation of points. Gut contents were examined in 40% isopropyl alcohol as recommended by Needham and Needham (1962) as this was found to be a more pleasant material to work with than the 10% formalin solution used for the initial fixation and preservation. Initial examination and identification was carried out on a 'Nikon' binocular microscope (Projectina, Skelmorlie, Ayrshire) using reflected light at a magnification ranging from x8 to x40. Points were awarded as described above. The petri dish was then transferred to the moveable stage of a 'Gibert and Sibert' transmission light microscope (G & S, Battersea Park Road, London), and the contents re-examined at a magnification of x70 or x150 mainly to ascertain the presence of oligochaete chaetae and other microscopic organisms. It was found almost without exception, to be impossible to distinguish the presence of oligochaetes except by use of the chaetae, especially bifid crotchets, as described by Kennedy (1969). These small forked bristles

are of cuticular material and, unlike the rest of the animal, are resistant to digestion. The number of bifid crotchets is variable, depending on the species (Brinkhurst, 1971), but, with experience, it was possible to use the number of chaetae as an approximate index of the number of oligochaetes.

Quantitative information on the food of trout (Mills, unpublished); grayling (Radforth, 1940); gudgeon (Downie, 1973); and flounder (Radforth, 1940 and Edwardson, 1974) from the lower course of the River Tweed was already available in addition to other information on the food of fish in tributary streams. Permission was however obtained to take a small sample of trout concurrently with a dace sample to permit a more reliable comparison of the diet of the two species. Larger samples of roach and dace were also taken concurrently on a number of sampling occasions, when they were caught together in large numbers.

### III. Results

For the purposes of comparison the results in this section are based on 4 groupings which correspond to the age classes 0+, 1+, 2+ and 3+-and-older to prevent dace of one year class being separated into different length classes. With very few exceptions, mostly in the June 1972 sample, these groups correspond to the length classes of

0+	less than 10 cm fork length
1+	10 to 15 cm fork length
2+	15 to 20 cm fork length
3+ and older	over 20 cm fork length

Further details of the fork length of the sample dace are to be found in Section 2 (p. 26 ).

The word 'food' is used for convenience to cover the material which was found to be present in the alimentary canals of sample dace. It is recognised, however, that some of the contents such as stones or an occasional feather were of no nutritional value and were therefore not food in the strict sense of the word.

#### a) Seasonal variation in feeding activity

In each of the monthly samples the proportion of dace found to have food (in any quantity) in the alimentary canal gives an indication of seasonal variation in feeding activity. This variation is displayed separately for the 4 age groups (Fig. 6.1). Trend lines were fitted by eye to aid interpretation. None of the 115 0+ dace sampled during the year October 1971 to October 1972 was found to have a completely empty alimentary canal. In contrast, in the older groups the proportion of the sample with food in the gut fell to below 50% during the winter months.

The estimated fullness of the guts of sample dace is probably a more reliable indication of changes in feeding activity. As these data were usually found to show a skewed distribution, it was not possible to calculate the 95% confidence limits on the mean fullness for each month. The median and its 95% confidence limits were therefore obtained (after Cambell, 1967) and these data are presented in Fig. 6.2. The trend lines were again fitted by eye. Though the overall pattern is similar to that shown in Fig. 6.1 a reduction in feeding activity during the winter months, especially December 1971, is now also apparent in the 0+ age group.

Similar trends are shown by the average (total) number of points awarded per gut examined (Fig. 6.3) indicating consistency between the

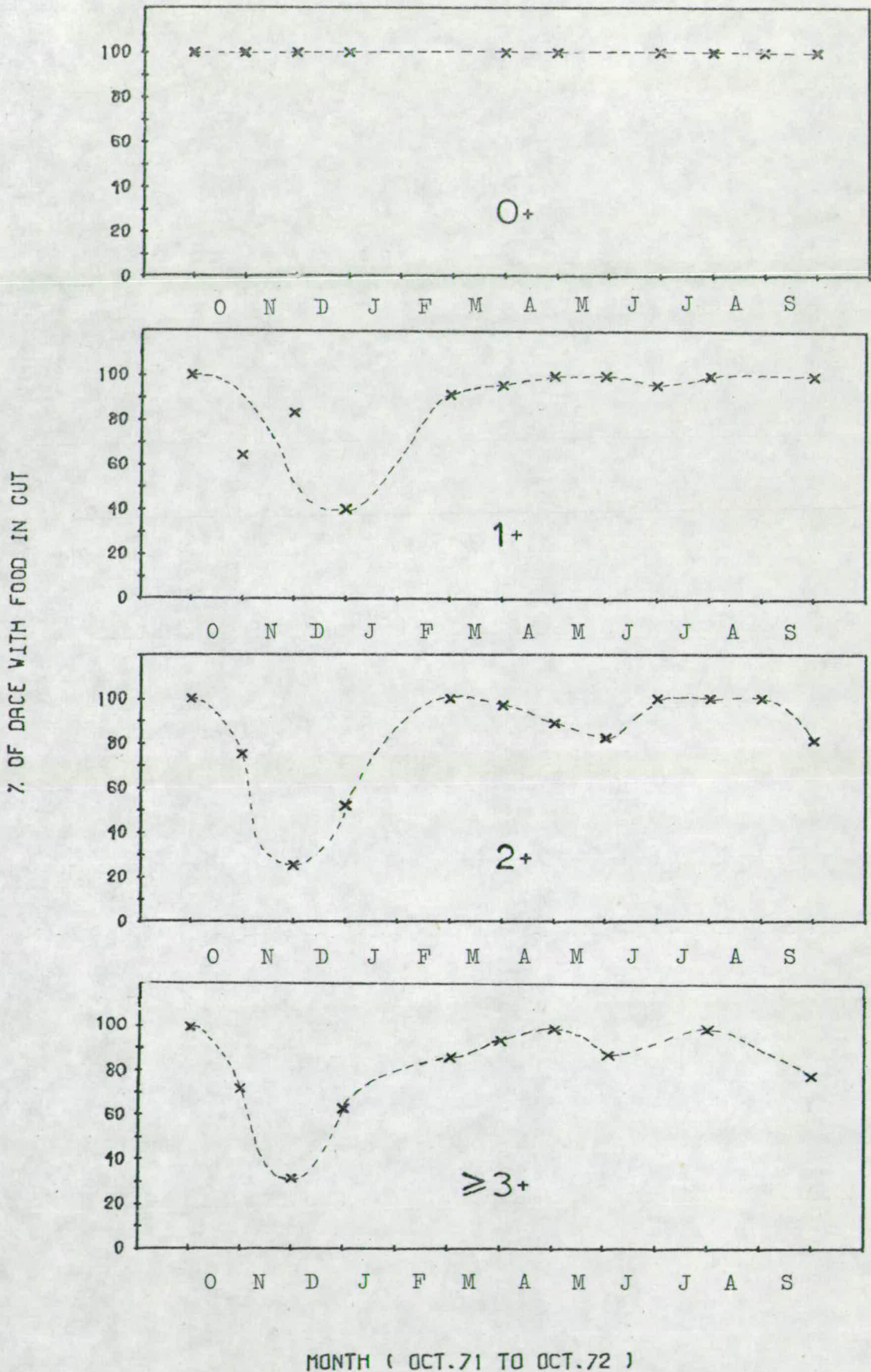


FIG. 6.1 SEASONAL VARIATION IN FEEDING ACTIVITY.  
From the % of dace with food in the gut

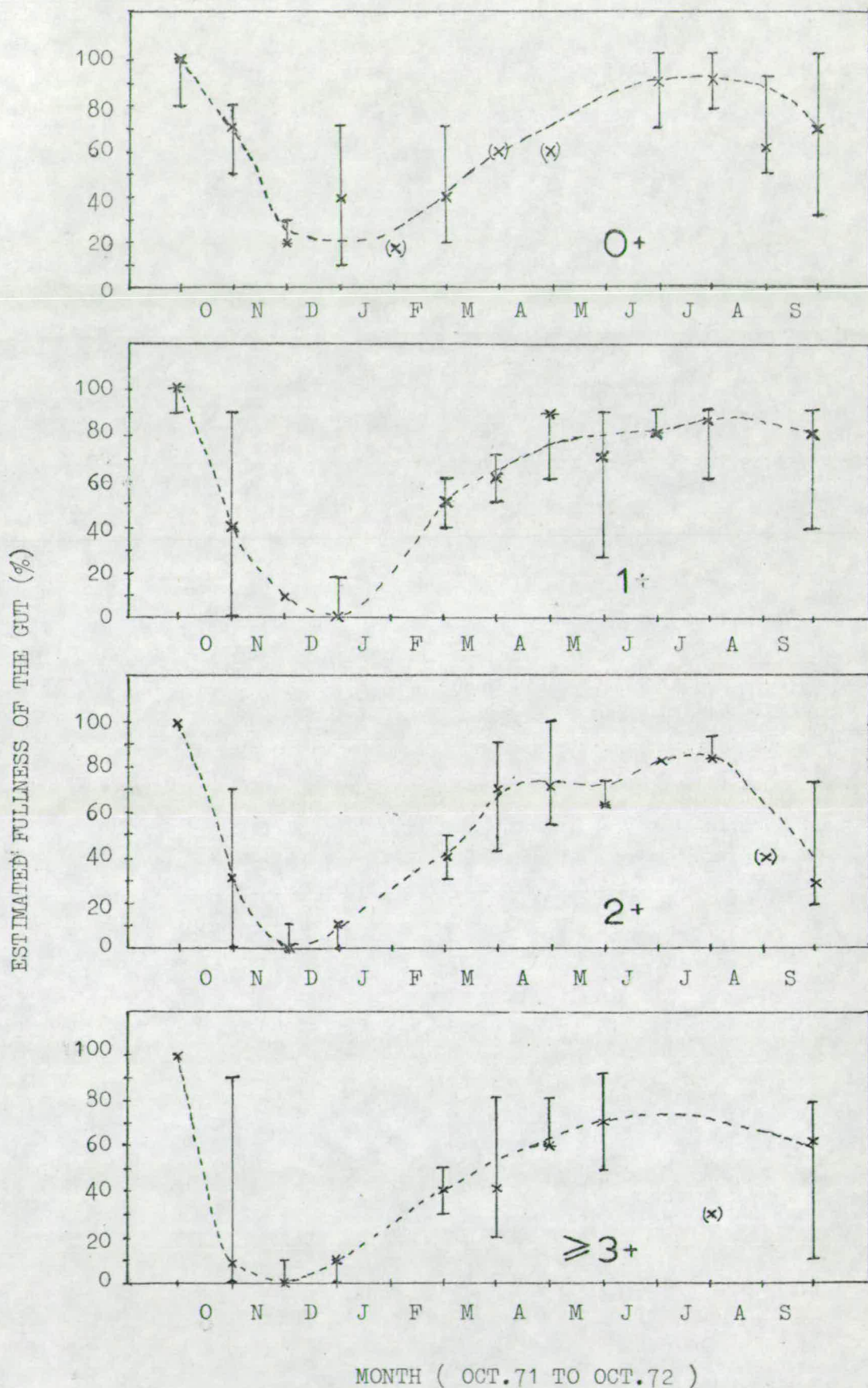


FIG. 6.2 SEASONAL VARIATION IN FEEDING ACTIVITY.  
From the estimated fullness of dace guts,  
plotted as median with 95% C.L.

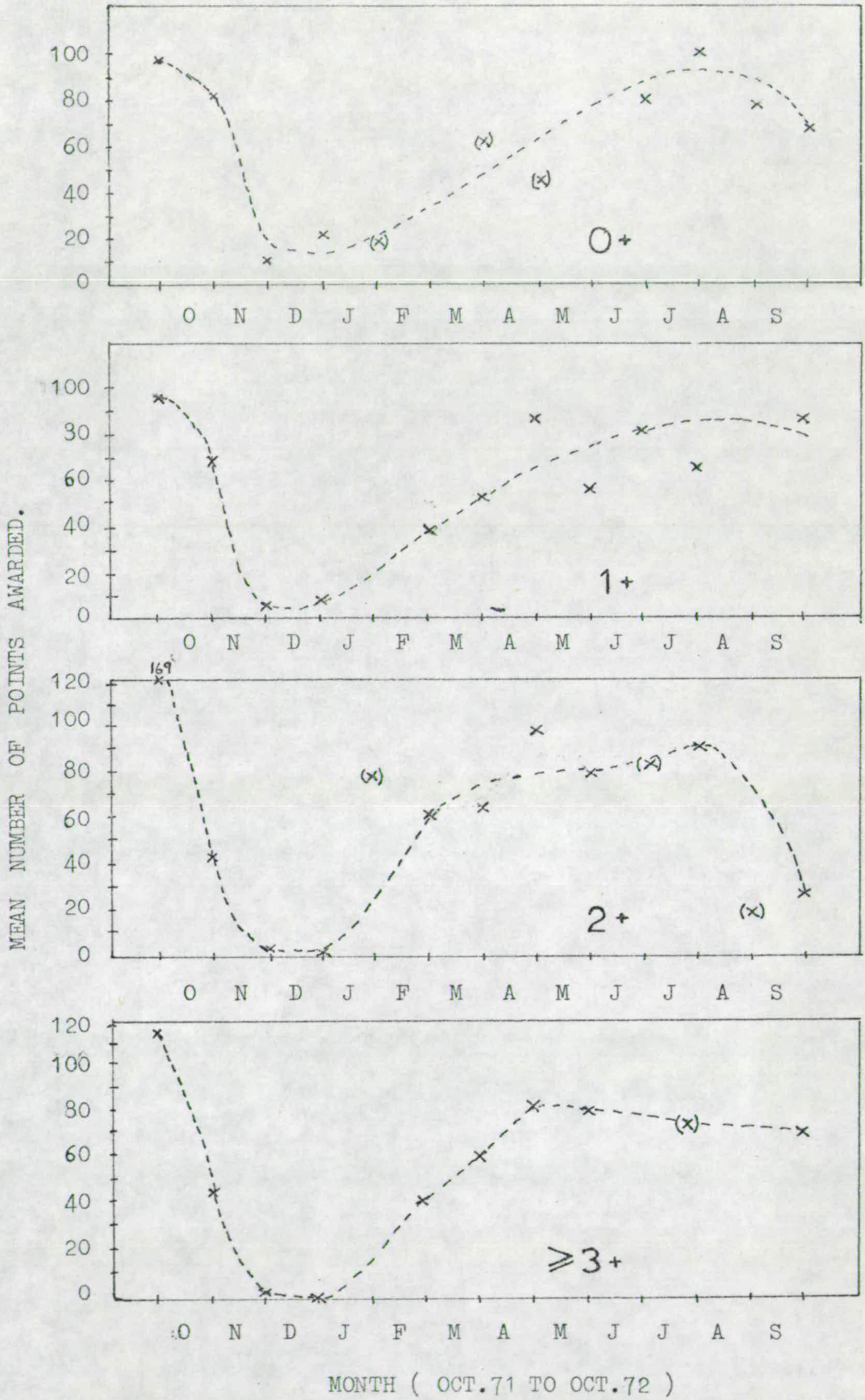


FIG. 6.3 SEASONAL VARIATION IN FEEDING ACTIVITY.

From the mean number of points awarded.  
 confidence limits not calculated—data skewed.

subjective allocation of points and the estimation of gut fullness. Differences will be due, in part, to the presence of digested material.

A difference in feeding activity exists between the dace sampled in October 1971 and those taken in October 1972. This was not entirely unexpected and serves to emphasize that there will be variation in the general pattern from year to year, confounded, perhaps, by short term variation. Despite the precaution mentioned on p.93 this short term variation may have resulted in a sample being unrepresentative of the particular month in which it was taken and this must be borne in mind when the results of this section are examined.

A relationship was noted between feeding activity and water temperature at the time of sampling (Fig. 6.4). The correlation coefficient was calculated at 0.8113 i.e. significant at  $p < 0.001$ . It may, however, be incorrect to conclude that feeding activity depends mainly on water temperature as other factors (e.g. daylength, food availability etc.) will also vary on a seasonal basis.

#### b) Seasonal variation

The average number of points awarded to each food type is shown separately for each monthly sample of each age class in Figs. 6.5, 6.6, 6.7, 6.8, plotted on a log scale. For all age groups seasonal variation tends to be more quantitative than qualitative though some seasonal differences occur in the type of food ingested.

In the 0+ (< 10 cm) age group larval and pupal Chironomidae and Oligochaeta are important throughout the year but Oligochaeta become comparatively more important than the Chironomidae in the winter months. In some months Ephemeroptera nymphs, Trichoptera larvae and plant material (especially filamentous algae) were of importance, but no

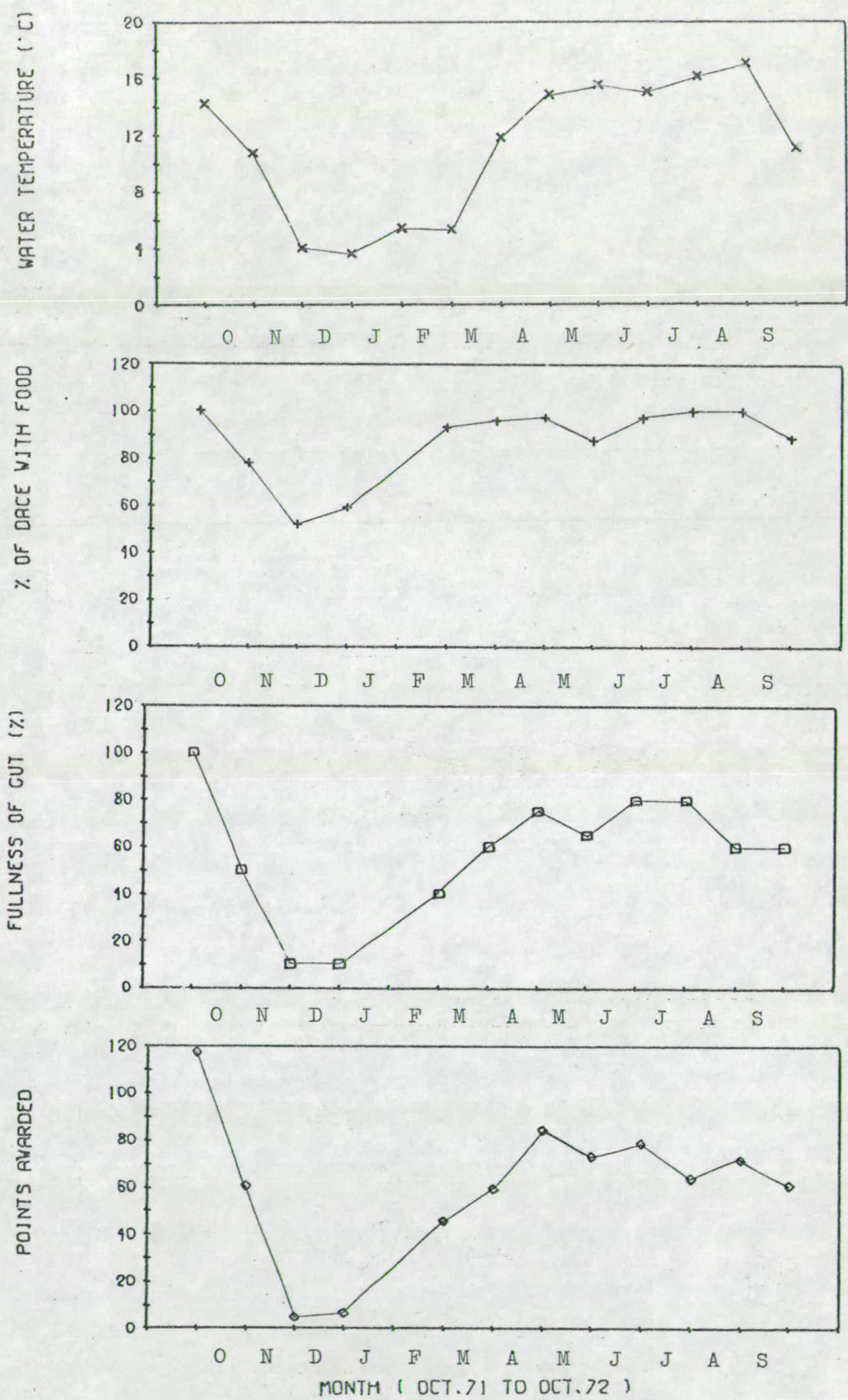


FIG. 6.4 WATER TEMPERATURE (upper curve) & FEEDING ACTIVITY.

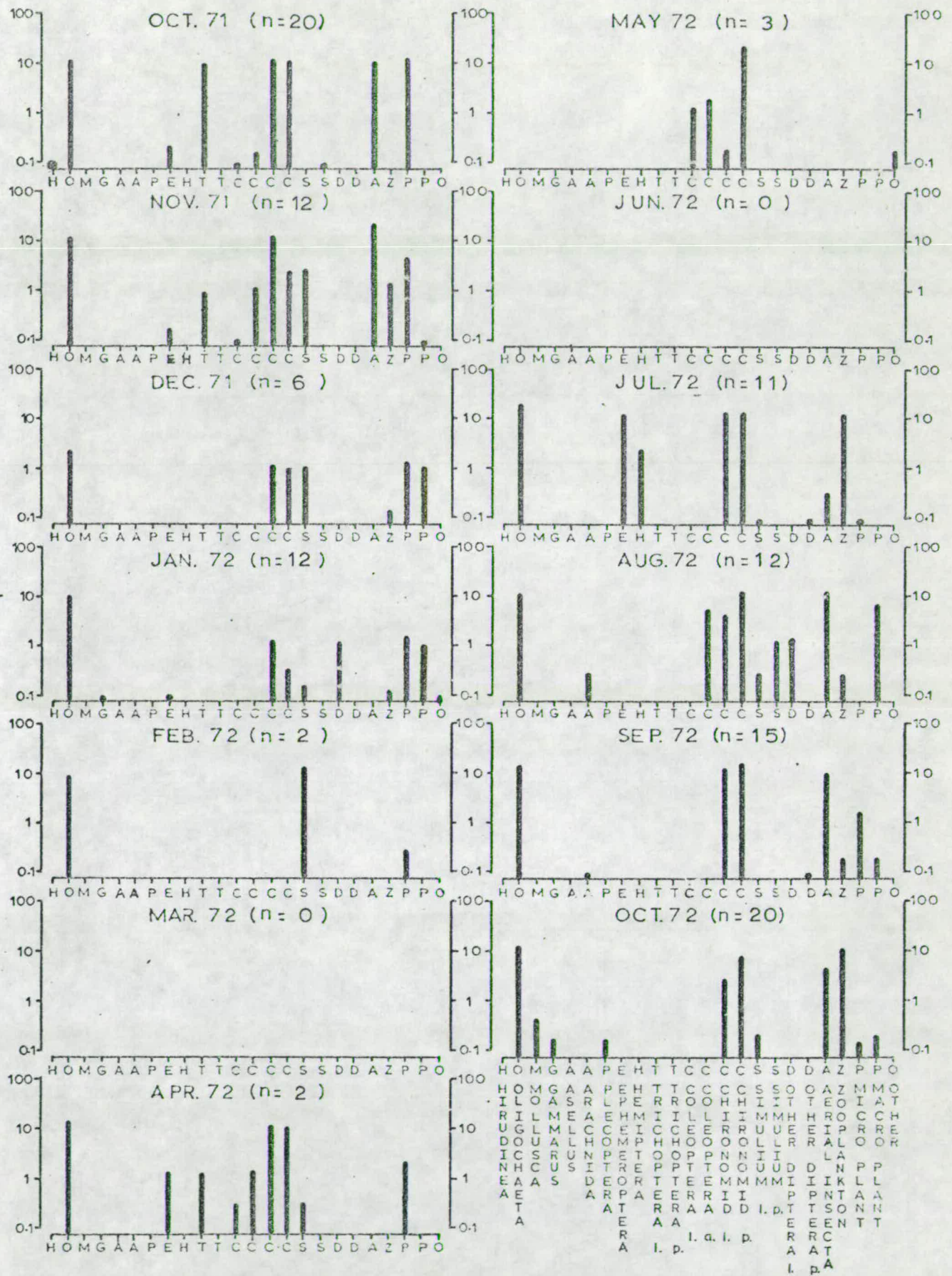


FIG. 6.5 FOOD OF 0+ DACE. (Composition of the diet by mean number of points awarded).

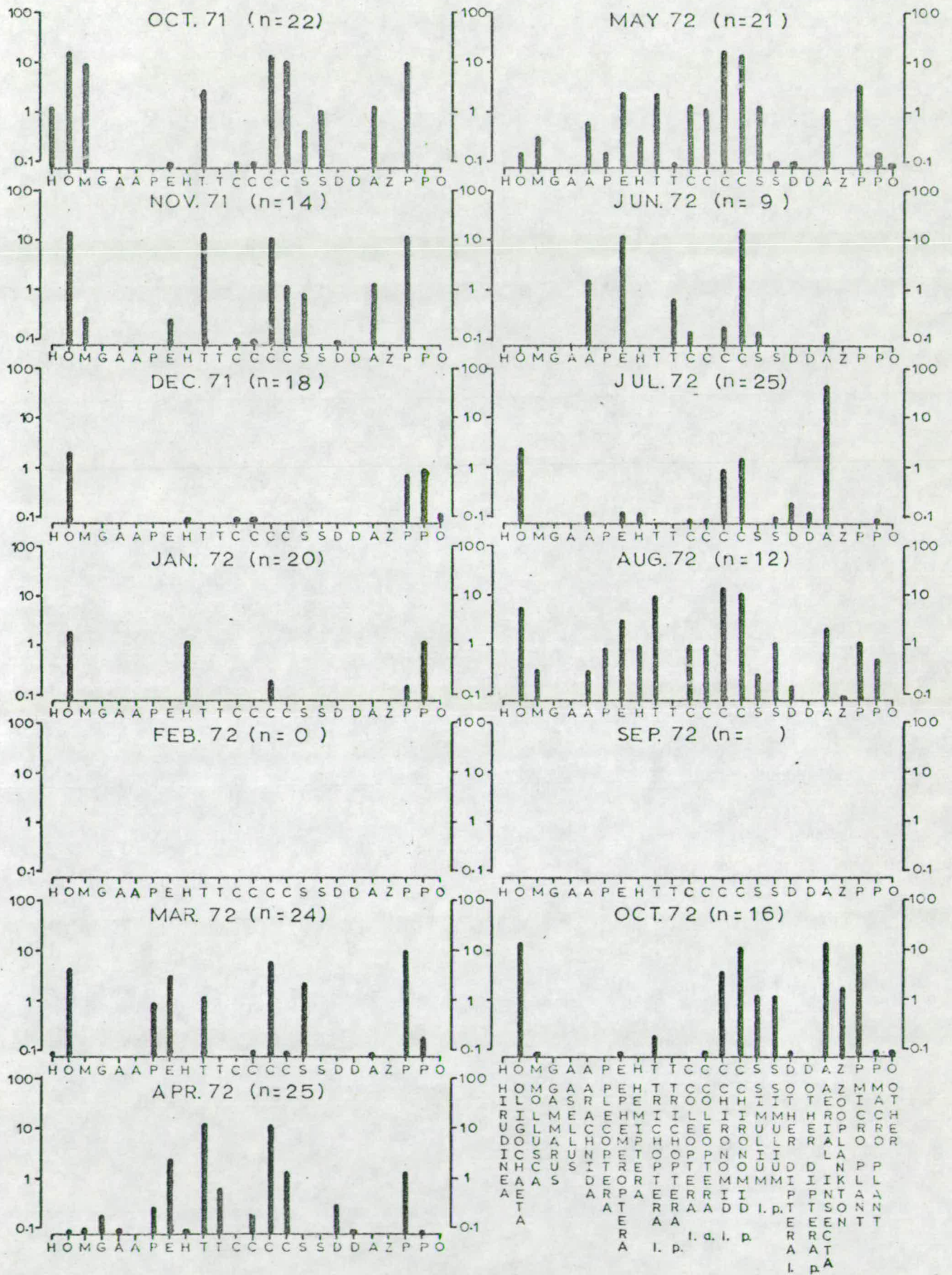


FIG. 6.6 FOOD OF 1+ DACE. (Composition of the diet by mean number of points awarded).

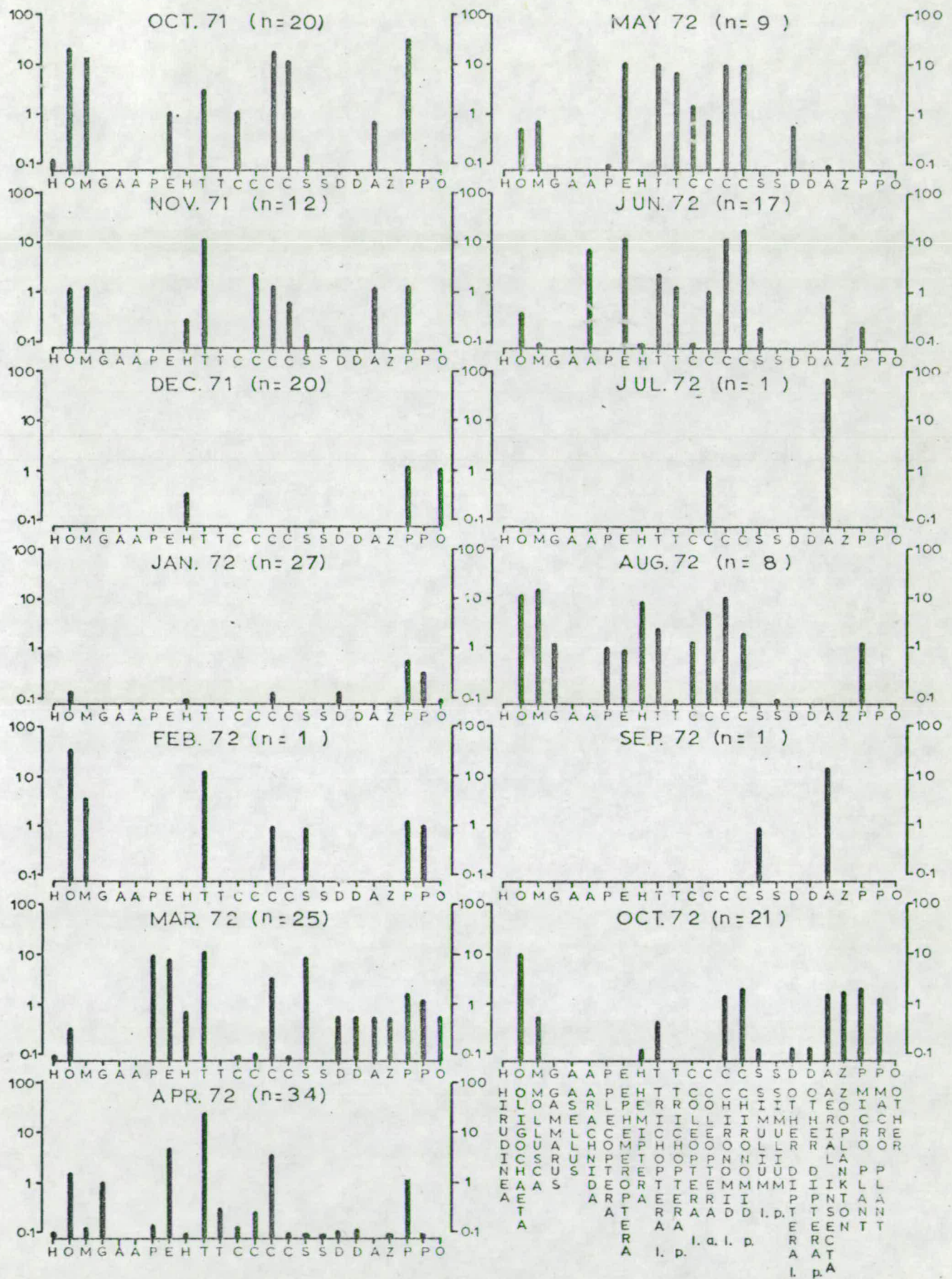


FIG. 6.7 FOOD OF 2+ DACE. (Composition of the diet by mean number of points awarded).



marked seasonal trend was readily discernable.

In the 1+ (10-15 cm) group larval and pupal Chironomidae were again important throughout the year with Oligochaeta comparatively more so in autumn and winter and less so in summer. Aerial insects, mostly small dipteran flies, and Ephemeroptera nymphs were important during the summer months as were Trichoptera larvae, though the trend was not so obvious in the latter case, with notable quantities also being eaten in autumn.

The 2+ (15-20 cm) group show a more obvious change with Oligochaetes becoming less important overall in spring and summer months when they are supplemented by Trichoptera larvae and Ephemeroptera nymphs. In some of the samples plant material, especially filamentous algae, appears very important.

Trichoptera larvae, and to a lesser extent Mollusca, appear regularly in samples of the 3+ (>20 cm) group. This diet is supplemented by Plecoptera and/or Ephemeroptera nymphs particularly in late spring and summer. Plant material, predominantly filamentous algae, is ingested in quantity in some months.

It is possible to combine the results of all the fish sampled in each month to obtain an overall picture (Fig. 6.9), but it must be remembered that this will be biased in some months by a complete or partial lack of one or more age classes in the sample. The distribution of age classes in the samples is given below in Table 6.2

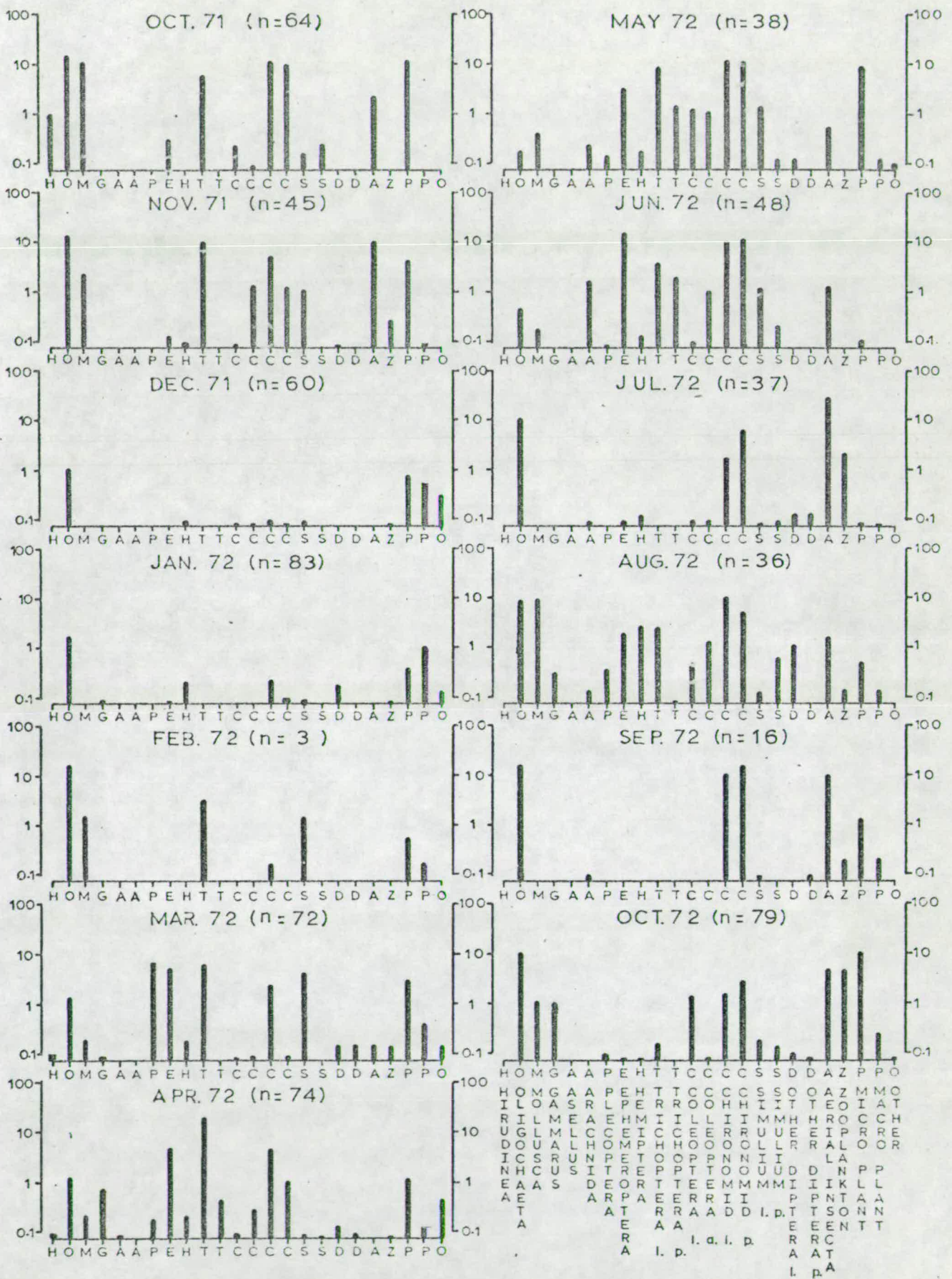


FIG. 6.9 FOOD OF ALL DACE. (Composition of the diet by mean number of points awarded)

Table 6.2 Age composition of monthly samples for food

Approx. length	Age	SAMPLE SIZE (Numbers of dace in each age/length class)														Total
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct		
10 cm	0+	20	12	6	12	2	0	2	3	0	11	12	15	20	115	
10-15 cm	1+	22	14	18	20	0	24	25	21	9	25	12	0	16	206	
15-20 cm	2+	20	12	20	27	1	25	34	9	17	1	8	1	21	196	
20 cm	≥3	2	7	16	24	0	23	13	5	22	0	4	0	22	138	
3-30 cm	ALL	64	45	60	83	3	72	74	38	48	37	36	16	79	655	

The lack of molluscs in the July and September samples could, for example, be due to the absence of older dace age classes from these samples. The differences between age classes are dealt with in more detail below.

As may be expected the seasonal variation of all dace sampled reflects many of the observations made above for the individual age groups. Oligochaetes appear most important in the autumn and winter months being replaced in the spring and summer months by Plecopteran and Ephemeropheran nymphs and Trichoptera larvae. The latter are also taken in the autumn. In some months, particularly in late summer and autumn, large quantities of aerial insects, usually small dipteran flies, and/or plant material are consumed.

The possibility of correlating the food eaten with availability on a quantitative basis was investigated, but it was found that this topic alone would have provided more work than could be accomplished in the time available for the study. Since dace were found to be feeding not only on the river bed (e.g. Oligochaeta, Mollusca), but also in mid-water (e.g. Hemiptera, Crustacea) and at the surface (e.g. aerial

insects) it would be necessary, in a study of food availability, to sample organisms at all of these levels. As dace are mobile there is the problem of knowing at which site the dace were feeding and therefore which particular part of the river to sample. In addition, one must be able to distinguish between the food organisms which are available for example to a kick sampling technique and those organisms which are actually available to the dace.

From information which is available on the invertebrate fauna of this part of the River Tweed (Mills and Smith, 1974; Smith, unpublished data) it would appear that dace are generally opportunists in the selection of food organisms. Individual fish did, however, on occasion show marked selectivity and as a result a sample of 20 dace in each age group was taken whenever possible. The optimal sample size did vary in fact from age group to age group and from month to month, but a sample size of 20 fish was apparently always large enough to include all the major food items for that group. In some months fewer fish could have been examined without significantly altering the results for that group, but it was found that only slightly more time was taken to analyse the full sample of 20 fish than to calculate a running mean for the number of points awarded to each food type and thus calculate the optimal number of dace required for that sample.

#### c) Variation with age (size) of dace

By averaging the results presented above over the number of months in which samples of that age class were taken an assessment, which is not complicated by seasonal variation can be made of the importance of the various food types to that age group of dace. A mean of the monthly means was taken in preference to an overall mean of individual values to compensate for the different numbers of dace in the monthly samples

This assumes that smaller samples were representative and although in extreme cases this will not hold true, seasonal variation is probably more pronounced than the variation caused by small sample sizes. This procedure was therefore considered the more satisfactory. The data are presented in Fig. 6.10. The main trends with age appeared as follows: oligochaetes and chironomid pupae decreased in importance with age, being a main part of the diet of 0+, 1+ and 2+ fish, but of less importance in older fish. Aerial insects and chironomid larvae also become less important as a food source with increasing age of fish, although the trend was much less pronounced. In contrast Mollusca increased in importance with age, as did plant material and Ephemeroptera nymphs.

#### d) Summary

The percentage composition of the diet was calculated from the data for all age classes (Fig. 6.9) and these data are presented in Fig. 6.11.

Chironomidae (larvae and pupae) were the most important constituent in the diet of Tweed dace (27.8%) with Oligochaeta (18.2%) Trichoptera larvae (11.8%), aerial insects (11.4%) and plant material, mainly filamentous algae (11%), also of major importance. Ephemeroptera nymphs (5.6%), Mollusca (3.8%), Simuliidae (2.5%) and Crustacea (2.0%) were of lesser overall importance whilst other organisms were of minor importance.

#### e) Comparison with other fish species

The percentage composition of the food of a number of species is given in Table 6.3 with a note of the sample sizes, date of capture, size range of fish sampled and source of information. Roach samples were taken concurrently with those of dace over a number of months and are therefore the most satisfactory for comparison. As they were taken

MEAN NUMBER OF POINTS AWARDED

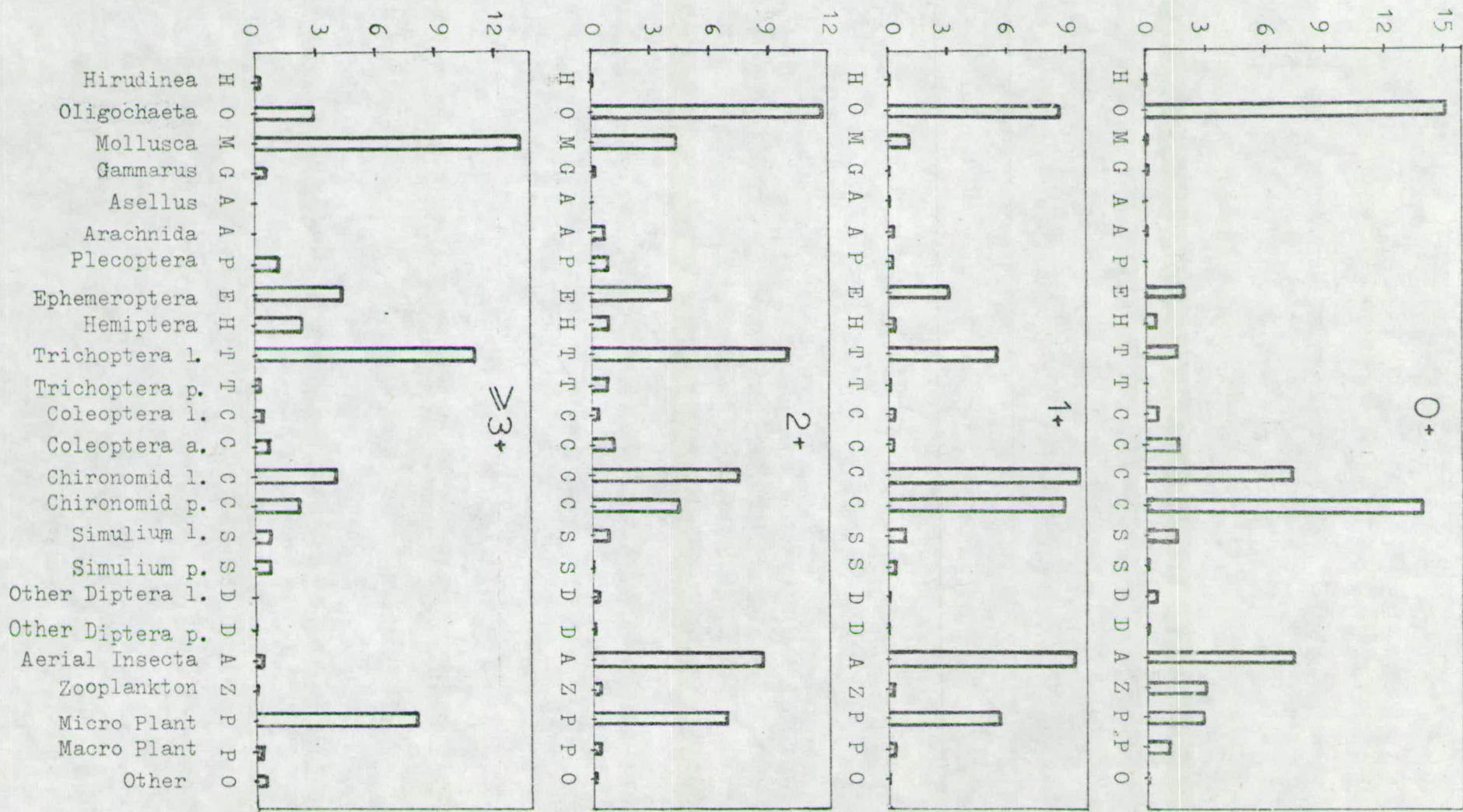


FIG. 6.10 DIETARY DIFFERENCES BETWEEN AGE GROUPS.

MEAN NUMBER OF POINTS AWARDED

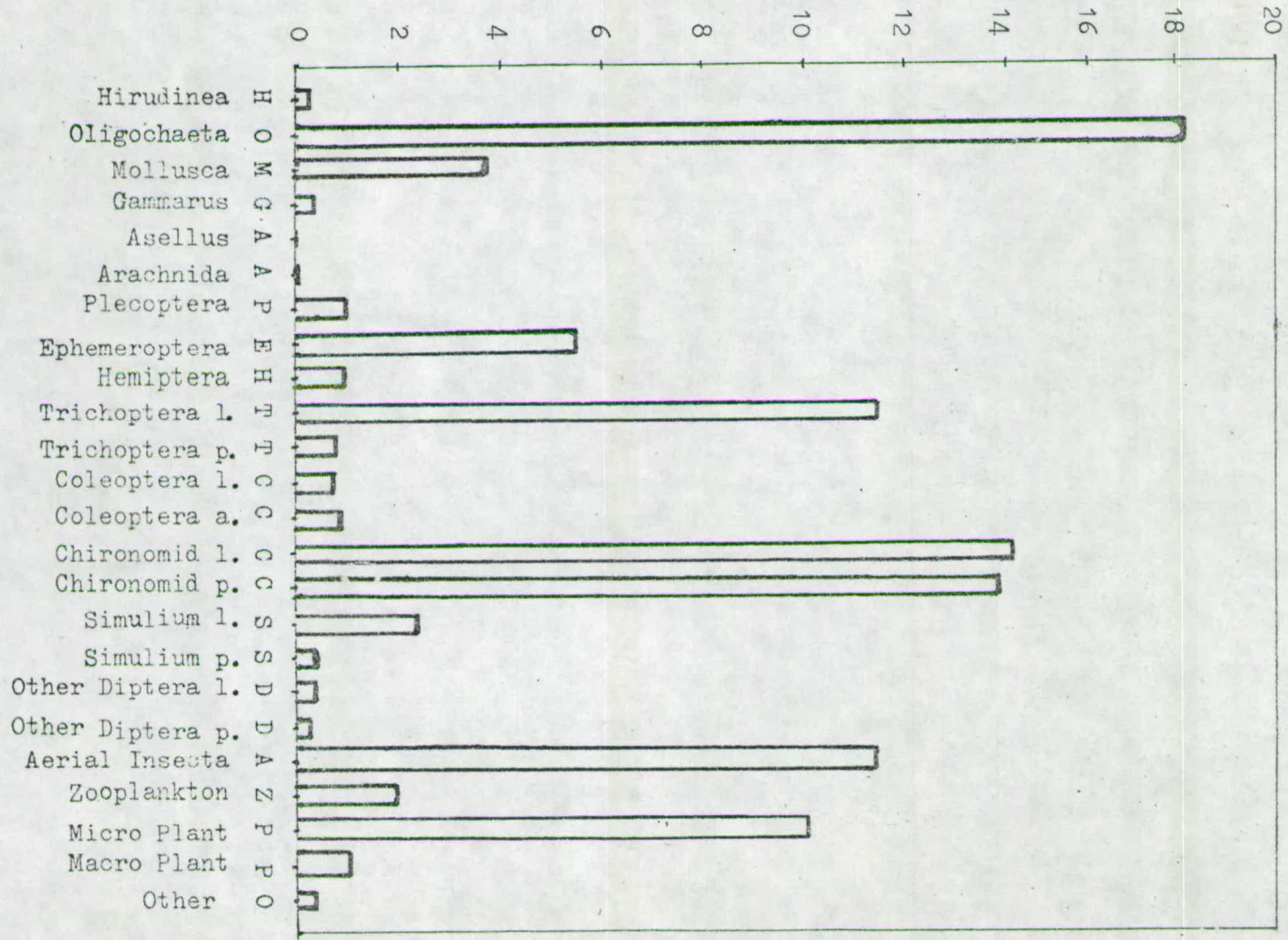


FIG. 6.11 COMPOSITION OF THE DIET OF TWEED DACE.

Table 6.3 Percentage composition of the diet of various fish species in the River Tweed  
(Data recalculated from that of other authors where necessary)

Food type	DACE	ROACH	GUDGEON	FLOUNDER	FLOUNDER	GRAYLING	GRAYLING	TROUT	DACE	TROUT
HIRUDINEA	0.2	0.1	0.4	1.4	+	3.6		1.0		1.7
OLIGOCHAETA	18.2	15.4		1.8	0.7	5.5				
MOLLUSCA	3.8	9.3	9.0	12.1		12.7	0.2	8.0	1.6	
GAMMARUS	0.3		2.9	5.1	+	5.5	0.1	0.4	8.7	0.5
APELLUS	+		0.7	6.1		1.8		2.7	7.9	4.4
ARACHNIDA	0.5	+		0.6	+	1.8	0.2		0.1	
PLECOPTERA Nymphs	1.2	+			+	9.1	0.3	0.7	8.7	1.1
EPHEMEROPTERA "	5.6	1.1	8.3	14.4	0.5	10.9	15.8	9.1	28.1	4.0
HEMIPTERA	0.9	1.1		2.1	+	3.6	0.1	15.6	3.8	13.9
TRICHOPTERA larvae	11.8	1.6	3.3	3.6	0.2	7.3	1.1	2.0	3.5	0.1
TRICHOPTERA pupae	0.7									
COLEOPTERA larvae	0.7	0.1	4.7	} 1.2	0.4	5.5	15.1		0.2	
COLEOPTERA adults	1.0	0.7				1.8	0.3	0.1	0.9	
CHIRONOMIDAE larvae	14.0	7.2	19.5	48.0	88.9	16.4	49.9	0.4	3.6	0.6
CHIRONOMIDAE pupae	13.8	2.2		3.5	8.5		9.0	0.4	1.3	0.1
SIMULIIDAE larvae	2.2	0.2	6.5	0.8	+	16.4	0.1	16.1	16.0	4.3
SIMULIIDAE pupae	0.3				+		2.3			
OTHER DIPTERA larvae	0.3	0.1	7.3	0.6			0.1	38.1*	9.1*	61.6*
OTHER DIPTERA pupae	0.2	0.1								
AERIAL INSECTA	11.4	0.8				5.1	0.4	0.1	0.1	0.1
PLANKTONIC CRUSTACEA	1.7	12.6	15.5			0.1				
MICRO PLANT	10.1	44.4	8.3					0.1	6.3	0.6
MACRO PLANT	0.9	1.8	13.7					0.7		
OTHER	0.3	1.4						4.4**		7.2**
AUTHOR			DOWNIE (1973)	EDWARDSON (1974)	RADFORTH (1940)		RADFORTH (1940)			
SAMPLE PERIOD	Oct71- Oct72	Oct71- Oct72	Oct72- Apr73	Feb.74- Apr.74	Sep.38	1.3.74.	Sep.38	1.3.74- 4.3.75.	4.3.75.	4.3.75
SAMPLE SIZE	655	303	95	80	50	9	50	36	51	21
SIZE RANGE OF FISH (cm)	3-29	3-35	2-16	4-18	Mean 17.6	14-29	Mean 25	10-25	12-25	13-25
SITE	Norham	Norham	Norham	Norham & Union Bridge	Norham Area	Norham	Norham Area	Norham & Union Bridge	Union Bridge	Union Bridge

+ = Present, but less than 0.05%

\* MAGGOTS

\*\* DACE

in the same location as dace they are useful to demonstrate the degree of overlap. They suffer, however, from the disadvantage that they may not be typical of the roach population as a whole in that catches of roach were sparse in the summer months and the majority of the population may have been utilising a different food source from those captured.

Additional limitations must be borne in mind when the food of the various species is compared. In particular the fact that samples were not all taken at the same time and in exactly the same location is unfortunate. Furthermore, there is variation in the size range of fish sampled. As the trout sample is based on a total of only 36 fish sampled on 1.3.74. and 4.3.75. it does not provide a good basis for comparison with the dace analysis which applies to a whole year. Consequently comparable data for dace and trout samples taken on the 4.3.75. are repeated at the end of the table.

Due to these limitations no more than a general comparison has been attempted. Considerable overlap existed between the food of all species under consideration. Chironomidae (larvae and pupae) were eaten in quantity by all species with the possible exception of trout. This is, perhaps, not unexpected in that Mills and Smith (1974) record that Chironomidae were found to be the most abundant of all aquatic insects in samples from the Tweed. Dace and roach appear to eat much larger quantities of oligochaetes than the other species, but in the case of gudgeon and flounder, this may be the result of other authors failing to recognise their presence in the digested form. Other differences do exist between the species. Trout and grayling consume greater quantities of Ephemeroptera nymphs, Plecoptera nymphs and Hemiptera (viz. water boatman). Roach ingest considerably more plant material than any of

the other species, an observation confirmed for the Tweed by Radforth (1940).

The data for the trout and dace sample of 4.3.75. from Union Bridge (NT 933512) differs from other samples in that anglers' maggots featured prominently as a food organism. It was interesting to note that only 6 dace from 51 had eaten a total of 24 maggots whilst 10 trout from a sample of 21 had eaten a total of 206 maggots. If this observation is to be taken at its face value, it has a number of implications from the management point of view. It suggests, for example, that the action of groundbaiting attracts trout which may then tend to feed less at the surface and consequently be more difficult to catch on a fly. In contrast they may, perhaps, be more susceptible to capture by coarse fish anglers. An extended investigation of these implications is necessary before any firm conclusions can be drawn as the above observations may only apply at certain times of year.

## GENERAL DISCUSSION

Though the first dace identified from the Tweed seems to have been caught by Mills in 1967, it would appear from their 1972 distribution and their 1973/4 estimated population that they had been present for a number of years before this. Although no information could be obtained it would seem most likely that dace were accidentally or deliberately introduced by man, a situation comparable perhaps with that of the Cork Blackwater discussed earlier (p.48 )

No matter what their origin, dace now appear to be firmly established in the lower reaches of the River Tweed and it will probably only be a matter of time before they disperse over a larger area. As the 1972 distribution has been described it will be possible for a check to be made on the dispersal of the species at some future date.

The Tweed is the most northerly point at which dace presently occur in the British Isles, but they do not appear to be limited by environmental factors. This is not unexpected in view of their presence at more northerly latitudes in Europe (Muus and Dahlstrom, 1971). Additional support for this contention is lent by the fact that the growth of Tweed dace is superior to that of most other dace populations which have been investigated (p.34 ). At first glance this may seem to be explained by their relatively recent establishment in the Tweed and the fact that intra-specific competition is not yet limiting. The density of dace in the Tweed, though not high, was shown to be comparable with that of other waters which exhibit a lower rate

of growth (p. 80) suggesting that factors other than density are also of importance. Weatherley (1963, 1972) discussed the plastic nature of the growth of fish as related to the availability of food. This has been demonstrated by a number of workers including Aldoori (1971), Kennedy and Fitzmaurice (1969) and Le Cren (1958), and it is generally suggested that poor feeding results in a reduced rate of growth. The high growth rate of Tweed dace therefore implies that the availability of suitable food must be high in relation to the population density. The Tweed is, of course, well known for the quality of its salmonid species, but work on coarse fish species other than dace has also shown high rates of growth. For example high growth rates have been demonstrated for roach (Mills, 1969; Clout, 1972), flounder (Edwardson, 1974) grayling (Greendale, personal communication) and gudgeon (Downie, 1973). This is interesting in view of the overlap in the variety of food organisms eaten (P. 113). Thus, although a potential for competition clearly exists, it would seem that, at present, the demand for food has not yet exceeded supply. In this context the population densities of the various species are obviously important as well as the absolute quantity of food available. In the case of the dace population it could be that it is still expanding and has not reached its maximum density. If this is so, then the further increases in numbers will result in heavier demands on the available food, increased intra and interspecific competition with corresponding reductions in growth rate. The population structure of the dace (p. 80), biased towards the younger age groups with comparatively few fish older than 5 years supports this idea of a young, unstable population. However, death at a younger age often results from faster growth and earlier maturation (Nikolskii, 1969) and this may be a contributory factor. Furthermore, the other coarse fish species

which also show high growth rates have been present in the Tweed for some considerable time and high growth rate in this instance cannot therefore be explained by the population being 'young'.

It would therefore seem reasonable to assume that a situation exists in which the quantity of available food is sufficient to support adequate growth of dace and other species at their present densities and, conversely, that an ecological balance exists which maintains fish population numbers low enough to ensure an adequate supply of food and a high growth rate (no marked change in growth rate having been noted in recent years).

Several causes of mortality in dace have been noted (p. 85), but the relative importance of these and other factors needs to be investigated. The fact that small dace are eaten, at least to some extent, by trout may mean that while competition appears of little importance the presence of dace in the Tweed is as much to the benefit of the trout as to its disadvantage.

The attitude of the Ladykirk and Norham Angling Association was mentioned in Section 5 (p. 86) and they did, in fact, come out in favour of a restriction on the numbers of coarse fish anglers on their waters (Taylor, 1973) as well as a proposed reduction in the numbers of coarse fish. The fact that dace do rise to an artificial fly does make them unpopular with game fish anglers. Tillmouth Park have also restricted the numbers of anglers mainly, it appears, to prevent litter bugs despoiling the banks. During the period of study it was noted that most coarse fish anglers seemed to favour the site at Union Bridge (NT 933512) or a site above Coldstream Bridge (NT 848402). Neither of these sites, or other sites that were used by coarse fish

anglers, such as the backwater at Norham (NT 893464), were sites that would have been chosen by game fishermen. Only one trout was in fact caught over the whole sampling period in the backwater at Norham. It should therefore be possible to permit both game and coarse fishing in the lower reaches of the Tweed with the possible proviso that there is some restriction on the sites used by coarse fish anglers. As trout can be caught along with coarse fish at some sites e.g. Union Bridge, there is, however, the possibility of their being damaged during unhooking and handling as they are returned to the water. The presence of large numbers of maggots (i.e. bait used by coarse fish anglers) in the stomachs of the trout sample taken at Union Bridge (p. 115) could have interesting implications if the sample was typical. Not only are the trout in this area likely to benefit from this additional source of food but they are also more likely to be caught by coarse fish anglers using maggot as bait.

Although the purchase of a permit is necessary for coarse fishing on the north bank of the River Tweed at Coldstream (£0.25 per day or (£0.87 per week) fishing at the other sites mentioned is free. No close season is laid down for coarse fish on the Tweed and Drysdale (1974) found that this situation tends, not unnaturally, to attract coarse fish anglers. 51% of the anglers sampled came from England and Drysdale was of the opinion that English anglers were attracted particularly during the English coarse fish close season (14th March-16th June). Furthermore, game fish anglers tended, to a certain extent, to turn to coarse fish angling during the close season for trout (September-April). 25% of the anglers interviewed by Drysdale (1974) came into this category. His survey showed that the Border rivers, particularly the Tweed, are frequently fished by coarse fish anglers

from the North of England in addition to Scots living within 20 miles of the site they were fishing.

Thus, apart from the objections outlined above such as the annoyance caused to game fishermen by dace rising to a fly or the problem of trout being caught and handled especially during their close season, there seems no real reason why dace and other coarse fish should be killed off and why coarse fish angling should not be allowed at least in certain areas and/or at certain times. The introduction of a permit system would make revenue available for a part-time bailiff(s) to be employed to prevent any abuse of the fishing being offered.

It is possible, in view of a) the relatively recent establishment of dace in the Tweed and b) possible changes in prevailing conditions in particular in water quality over the years that the population density of the dace may increase with the need to take positive measures to reduce their numbers. This should present no real problem as large numbers of dace were captured during the period of this study by Seine netting at certain sites mentioned earlier (p. 47 ). Netting these sites at an appropriate time of year, for example between November and February, before the fish are able to spawn should allow the population to be reduced to a level which would minimise interspecific competition and improve the growth rate as a result of reduced intraspecific competition.

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APPENDIX I

## A Note on the Use of a Jet Inoculator for Marking Fish

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Kelly (1967) was the first to suggest the use of a jet inoculator for marking fish. The method was subsequently tested in Great Britain by Hart and Pitcher (1969) who published details of technique and the results of field trials on 13 different coarse fish species.

The Panjet inoculator is a slightly modified dental tool which injects a spot of dye under the skin. The dye is injected under pressure and without the use of a needle. Hart and Pitcher (1969) discussed the use of several dyes. Alcian Blue 8GX (Code number 700, price £1.10 per 25 g) had a known duration of 11 months in the field and 14 months in the laboratory. For Durazol Blue (Code number 10350, price 80p per 25 g) they record a known duration of 4 months in the field whilst Alcian Yellow as found to last for less than a week in the laboratory. Though they give no figures for the duration of Indian ink they state "Some (*Alcian Blue*) marks tend to disperse and fade slightly over these long periods (11–14 months), but this does not seem to apply to black Indian ink marks". Indian ink does, of course, have the advantage of being readily available and inexpensive.

The author tested Indian ink (Reeves waterproof) and Alcian Blue on dace (*Leuciscus leuciscus* (L.)) held in tanks in the laboratory. Contrary to the suggestion of Hart and Pitcher (1969) the black Indian ink marks all faded completely after 2 months and before 3 months. The Alcian Blue marks however are still distinct, though somewhat faded, after 18 months. As a result only Alcian Blue marks were used in the field and, to date, dace have been captured up to 15 months after release with the marks still clear. The marks were applied in various positions on the underside of the body and also to the fins as suggested by Hart and Pitcher (1969) and Hart (1969). It was, however, found necessary to hold the nozzle of the instrument very much further from the fish during application of the dye than Hart and Pitcher (1969) indicate in their paper. For larger fish (approx. 15–30 cm) distances of 2–3 centimetres were used rather than 2–3 millimetres suggested by Hart and Pitcher (1969). These distances were increased for smaller fish.

The panjet has also been tested on brown trout (*Salmo trutta* (L.)). In the case of the trout, all of which were being used for restocking, marks were applied only to the fins, to reduce the possibility of complaint by anglers. The marks were found to be as easy to apply and as satisfactory as those applied to coarse fish.

Though Hart and Pitcher (1969) state that they were able to mark fish at rates up to 30/min the number of additional helpers they used is not stated. Hart (1969) does, however, record that the most fish he marked in one day was 123, though it must be emphasized that during the day he also had to catch, weigh and measure the fish that were being marked. With one helper and only length being taken a realistic marking rate for captured fish probably lies at about 3 or 4/min. With additional helpers to take the length, etc. and supply fish to the marker there is, however, no doubt that rates of up to 30/min are quite possible. The use of anaesthetic was found by the author to be generally unnecessary, consequently the marking process is speeded up and there is a rapid recovery of marked fish.

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