ECOLOGICAL STUDIES ON THE FISH POPULATIONS IN THE INNER ESTUARY OF THE RIVER RIBBLE, NORTH WEST ENGLAND.

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

by

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CONTENTS

ABSTRACT i

INTRODUCTION 1

CHAPTER 1 THE RIBBLE ESTUARY

Physical features 3

Surrounding land use 9

History of the estuary 10

The Port of Preston 11

Hydrology, sedimentology and water quality 12

Migratory fishery 23

CHAPTER 2 COMPOSITION, SEASONAL PATTERNS OF ABUNDANCE AND DIVERSITY, AND AGE STRUCTURE OF THE FISH POPULATIONS IN THE INNER ESTUARY

Introduction 24

Section A: Species composition and seasonal fluctuations in abundance and diversity of the fish populations 26

Methods 26

Field methods 26

Limitations of field methods 29

Laboratory methods 30

Data analysis 31

Results 35

Physico-chemical parameters 35

Species composition of catches 38

Seasonal distribution of catches 44

Distribution of species within the inner estuary 56

Diversity indices 65

Section B: Age structure of the fish populations 69
Methods 69
Results 74
  Marine-estuarine species 74
  Freshwater species and eels 81
  Growth of flounder 85
Discussion 101

CHAPTER 3 INTERTIDAL DISTRIBUTION AND MOVEMENTS

Introduction 114
Methods 115
Results 121
  Species composition 121
  Movements of O-group flounder 121
  Movements of O-group *P. microps* 129
  Movements of O-group *P. minutus* 129
  Movements of O-group *P. lozanoi* 138
  Size distribution with depth 142
Discussion 147

CHAPTER 4 FOOD AND FEEDING HABITS OF FISHES IN THE INNER ESTUARY

Introduction 155
Methods 156
Results 161
  Diet of fish in the channelised section: fish from the channel 161
  Diet of fish in the channelised section: fish on the intertidal banks 182

Feeding periodicity of flounder and
P. microps on the intertidal banks 196
Diet of flounder upstream of Preston Dock 199
Discussion 205

CHAPTER 5 IMPACT OF DREDGING OPERATIONS

Introduction 220
Methods 221
Results 223
Effects of dredging on fish distribution 223
Entrainment 229
Discussion 223
ACKNOWLEDGEMENTS 240
REFERENCES 242
APPENDICES 278

ABSTRACT

Studies on the fish populations in the inner estuary of the River Ribble on the north west coast of England were carried out between March 1978 and September 1980.

Monthly seine and otter trawl samples were taken at five sites along a 11.5 km stretch of the estuary downstream from the upper limit of saltwater intrusion. The samples were collected at high water on spring tides. In the channelised section downstream of Preston Dock the fish community was dominated by the marine-estuarine species Platichthys flesus, Sprattus sprattus, Clupea harengus, Pomatoschistus microps, Pomatoschistus minutus and Pomatoschistus lozanoi. Upstream of Preston Dock the principal species were P. flesus and the freshwater fishes Leuciscus cephalus, Leuciscus leuciscus and Rutilus rutilus. There was a zone of overlap, 2 - 5 km in length, where the marine-estuarine and freshwater species were taken together in catches. A clear seasonal cycle of abundance was observed with maximum numbers of individuals and species in the summer and minimum in the winter. There was, however, little or no seasonal trend in three diversity indices measured. The majority of the fish taken in catches were of the 0-age group.

An investigation was made of the intertidal distribution and movements of P. flesus, P. microps, P. minutus and P. lozanoi in the channelised section over the tidal cycle. P. flesus and P. microps moved onto and off the intertidal banks in shallow water of 0.5m depth, but during the latter stages of the flood tide and at high water they were most abundant in water of 1 - 2m depth. In contrast, P. minutus and P. lozanoi moved onto and off the intertidal banks maintaining their greatest abundance in water of 2m depth. At high water all four species were mainly found on the intertidal banks. There was no definite indication of a size distribution with depth. In addition to the intertidal movements it was evident that there was a movement of marine-estuarine fishes into and out of the inner estuary as a whole with the tide. Trawls showed that normally the only species which were present in any numbers in the channelised section at low water were P. flesus and P. microps.

Diet analyses showed a wide range of food items were eaten by the marine-estuarine fishes in the channelised section. One of the principal food items was the calanoid copepod Eurytemora affinis. There were major differences in the diet composition of fish on the intertidal banks and in the central channel at high water. There was also some evidence that feeding conditions were more favourable on the banks compared to in the channel. A study of feeding periodicity of P. flesus and P. microps demonstrated a rise in stomach contents as they moved intertidally on tides during the day, although at night no feeding occurred. These findings may at least partly provide an explanation for the intertidal movements of the fish species. Dietary overlap was often high, however, it was not possible to suggest whether or not there may have been competition for the food resources. An examination of diet of P. flesus upstream of Preston Dock found that freshwater invertebrates were the main food items.

A study was conducted on the effects of dredging on the fish populations. At low water decreased numbers of P. flesus and P. microps were present for a distance of 50 - 100m behind the cutter suction dredger which operated in the inner estuary. Sampling of the discharge showed that fish were entrained. The possible consequences of the cessation of dredging as a result of the closure of the Port of Preston are discussed.

INTRODUCTION

In Britain relatively few ecological studies have been undertaken on estuarine fish populations. Comparison can be made with American estuaries where investigation of the ichthyofauna has received considerable attention. This is a serious omission given the generally recognised importance of estuaries as nursery areas for fishes, including economically important species, and the concern which is often expressed over the potential impact of man induced changes on these areas.

Moreover, studies on fish populations in British estuaries have usually only been carried out where the presence of power station intakes has provided an easy sampling method, fish being collected from the various screening mechanisms used to filter the intake water. This is especially so in those examining the fish community as a whole and not a single component species. Power station sampling is effectively point sampling of an estuary and while this method is sufficient for a study of numbers and species, further more detailed investigations of spatial utilisation of estuaries are precluded. Such data, when combined with diet analyses, are a prerequisite before applied aspects, particularly pollutant contamination, can be approached in a more realistic manner.

The research documented in this thesis considers the ecology of the fish populations occurring in the inner reaches of the estuary of the River Ribble. Using netting techniques collections were made at a series of locations in order to examine both the seasonal and tidal distribution of fishes. The study was intended to provide the baseline information which is essential before any meaningful interpretation of energy flow and the position of fish in the estuarine food web can be attempted.

Of interest in the initial planning of this research was the possible closure of the Port of Preston, situated at the landward end of the estuary. Engineering reports suggested that large changes in the hydraulic behaviour of the estuary would take place as a result of the cessation of the dredging operations required to maintain a navigable channel for shipping. During the study the Port's closure was confirmed, and it was further intended that the information obtained could in future be used to assess any changes which occur in the ichthyofauna of the inner reaches.

CHAPTER 1

THE RIBBLE ESTUARY

Physical features

The Ribble Estuary is located on the north west coast of England (Figure 1.1). It is one of three large estuaries opening into Liverpool Bay, the others are the estuaries of the Mersey and Dee to the south. To the north is Morecambe Bay.

The River Ribble which gives rise to the estuary has its source on the slopes of Wold Fell in the Pennines from where it flows south and south west through Lancashire to the coast (Figure 1.1). The geology along its course is detailed by Gresswell (1953) and Simpson and Broadhurst (1962). The total drainage basin of the Ribble and its tributaries has an extent of 186×10^3 ha. Tributaries include the Hodder and Calder, entering a kilometre apart near Clitheroe. At Preston the river is also joined by the River Darwen, and downstream of Preston the River Douglas (or Asland) enters from the south.

The Ribble has a tidal length of 29.5 km (Figure 1.2). The upper limit of salt water intrusion on spring tides is 0.5 km upstream of the confluence with the Darwen, although tidal freshwater continues for a further 2 - 3 km upstream. The tidal length can be divided into two sections: from the coast to the entrance of Preston Dock situated 24 km inland, and thence to the tidal limit.

Below Preston Dock the estuary is predominantly straight and funnel shaped. At the coast between Southport and Lytham St. Anne's it is more than 15 km wide, but narrows rapidly landward. From the Naze to Preston Dock the waters of the estuary at high tide are confined between reclamation embankments and saltings 200 - 250 m apart (Plates 1 and 2), the saltings immersed only on the highest tides. Through the centre of the estuary flows the low water

FIGURE 1.1

The River Ribble and its principal tributaries.

FIG. 1.1

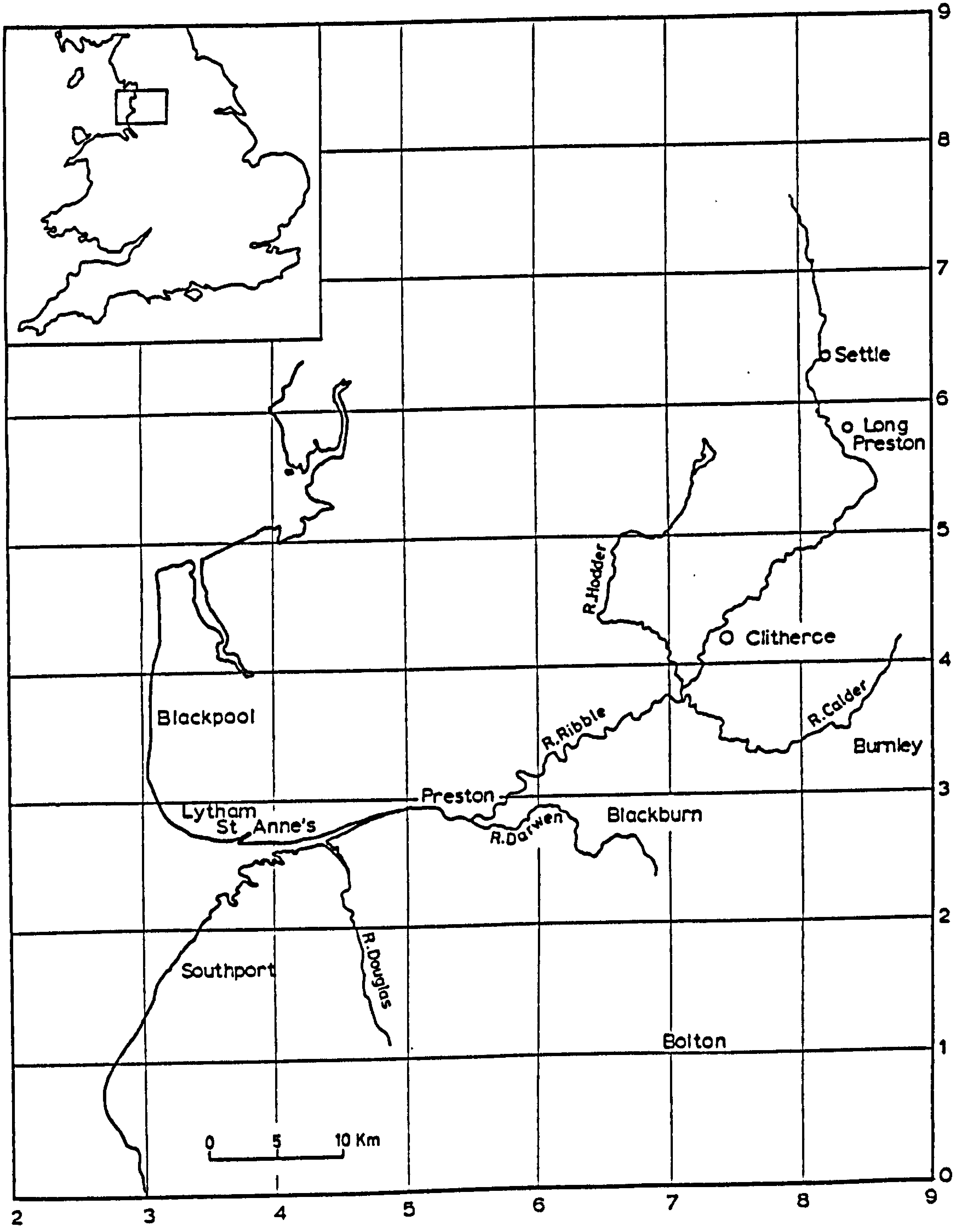

Settle
Long Preston
R.Hodder
Clitheroe
R.Calder
Burnley
R.Ribble
Blackpool
Preston
Lytham St Anne's
R.Darwen
Blackburn
R.Douglas
Southport
Bolton
0 5 10 Km
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9

FIGURE 1.2

The Ribble Estuary.

FIG. 1.2

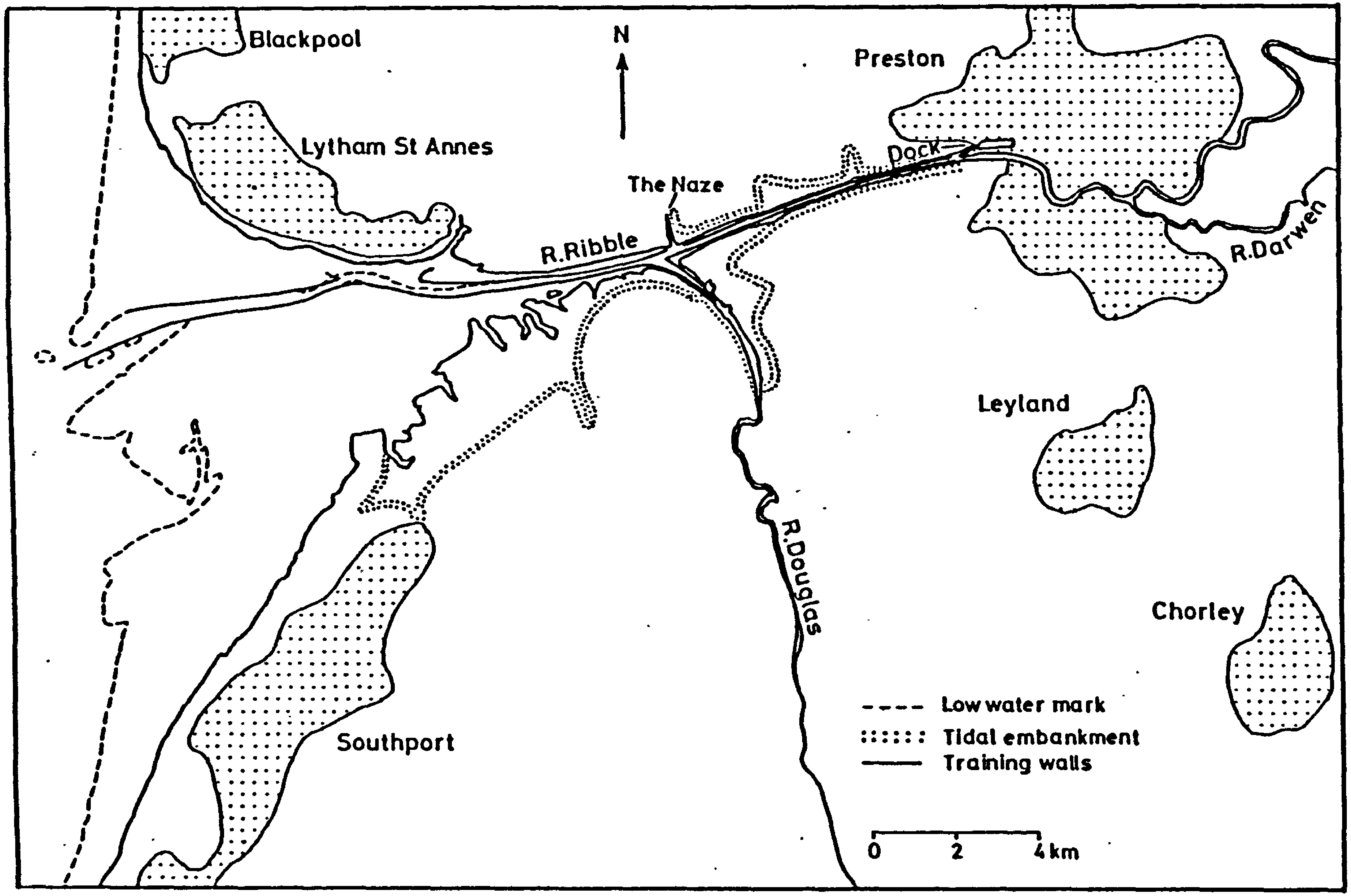

Blackpool
N
Preston
Lytham St Annes
The Naze
Dock
R.Ribble
R.Darwen
Leyland
R.Douglas
Chorley
Southport
Low water mark
Tidal embankment
Training walls
0
2
4 km

PLATE 1

The estuary 1 km downstream of Preston Dock.

1.5 hours before high water.

PLATE 2

The estuary 5 km downstream of Preston Dock.

High water.

PLATE 3 and PLATE 4

The estuary 5 km downstream of Preston Dock

at low water.

PLATE 5

The tidal reaches upstream of Preston Dock.

Low water.

PLATE 6

The tidal reaches upstream of Preston Dock.

High water.

channel which has been trained in stages from 1840 onwards, so that low rubble walls now extend almost continuously from the Dock to the sea. The training walls are completely covered at high water but are exposed at low water (Plates 3 and 4). The distance across the channel from wall to wall increases slowly seaward from 60 m at Preston Dock to 425 m at the coast. In the narrow stretch of the estuary between the Dock and the Naze the low water channel is bounded by mud banks which rise steeply up to the reclamation embankments and saltings, but beyond the Naze in the wide outer stretch an extensive area (6.5×10^3 ha) of sand and mud flats is uncovered at low tide.

Upstream of Preston Dock to the tidal limit there is marked change in the character of the estuary. Bed levels rise sharply and underlying red sandstone outcrops onto the bed to form a series of rocky bars with intervening deeper stretches of sand and silt. At low water this section has an essentially pool and riffle structure (Plates 5 and 6). This section can also be compared to the freshwater reaches above the tidal limit where the Lower Ribble has the features of a typical lowland river, flowing slowly in broad meanders through the Ribble valley.

Surrounding land use

The landscape surrounding the estuary is mainly flat and featureless. Below Preston large areas of land have been reclaimed (see later) and on the south side this land is used for intensive arable farming. Remaining salt marshes are used for grazing and wildfowling. On the north side while much of the land is agricultural, situated 5 km downstream of Preston is the Clifton Marsh Effluent Treatment Works and refuse disposal site, and beyond the Naze is a British

Aerospace airfield and works.

At the coast there are the urban areas of Southport and Lytham St. Anne's, and at the head of the estuary is Preston. The former are holiday resorts with little industrial development. Preston, the administrative headquarters of Lancashire, is a large town with industries centred on engineering and textiles. For much of its course through Preston the estuary is bordered by parkland and other open areas used for recreation.

The extensive areas of sand and mud flats in the outer estuary together with the adjoining salt marshes and farmland, are of major importance as feeding and roosting areas for birds. The Ribble ranks among the five principal estuaries in Britain for wader populations (Smith and Greenhaigh, 1977). Most of the estuary is now designated an SSSI.

History of the estuary

Over the last 150 years work by the various navigation companies for the purpose of improving the Ribble for shipping has substantially altered the estuary.

The early history of the estuary and the development of navigation on the Ribble have been thoroughly described by Barron (1938). Maps of the estuary reproduced in Barron's book show that before the low water channel was trained the estuary was much wider than at present. A number of channels entered from seaward and the flow of the Ribble joined up with one or more of them to discharge into the sea. The maps show that throughout the estuary the low water channel was continually changing position, meandering over a wide area.

To provide a channel more suitable for navigation the first sections of the training walls were constructed in the 1840's. In 1910 the north wall was completed followed by the south wall in 1937.

Originally the walls extended to 22.5 km and 25.5 km respectively from Preston Dock. However, since these dates some reduction in length has occurred through erosion and sedimentation, especially at the seaward limits.

After the introduction of the training walls the other channels in the outer estuary silted up, although the remnants of a southerly channel can still be seen (Fig. 1.2). Also, with the low water channel held stable and high water velocities in the channel, the sand and mud flats on either side began to rise in height due to continual accretion of material (Berry, 1967). As the saltings advanced large areas were reclaimed. The training of the channel has therefore been accompanied by a loss of estuarine area.

The estuary through Preston has also been subject to alteration. Before excavation of the Dock basin between 1884 and 1892 the Ribble flowed in a large bend to the north of the Dock. During the construction of the basin and quays the estuary was diverted by a 2.6 km excavation cutting across the bend some 350m south of the original course, the latter then being filled in. This diversion forms the present course of the estuary.

The Port of Preston

The Port, controlled by Preston Borough Council since 1883, used to be one of the country's more important small ports. After World War 2 the world's first roll-on - roll-off service was pioneered between Preston and Larne, the development of this trade leading to a particularly successful and profitable period for the Port. In the mid-1960's over 2 million tonnes of cargo were handled annually with an average of 10 ships entering or leaving the Port each day.

However, in the 1970's there was a rapid deterioration in the Port's trading position, major disadvantages being the long navigation up the Ribble with access restricted by tides. The shallow depth of the navigation also meant that access to Preston Dock was limited to vessels of less than 5000 tonnes. While the overall tonnage handled by North West ports was declining by 5 - 7%, tonnage at Preston was declining by 11.45%.

The loss of trade coupled with expensive dredging costs led to increasing financial deficits. After an unsuccessful experiment with new management and working systems in the late 1970's, in 1979 it was announced that the Port was to cease trading in March 1982.

Hydrology, sedimentology and water quality

The data presented in this section are taken from studies conducted in the estuary by other authorities; these are detailed below as appropriate. Emphasis is given to the data on the inner reaches of the estuary from the Naze to the tidal limit, where the research on the fish community documented in this thesis was carried out.

a) Tides

Generally, high water levels in the estuary at Preston are determined by the tides and low water levels by the freshwater flow from the river (Sir William Halcrow and Partners, 1980). In the outer estuary freshwater discharge has little effect on water levels.

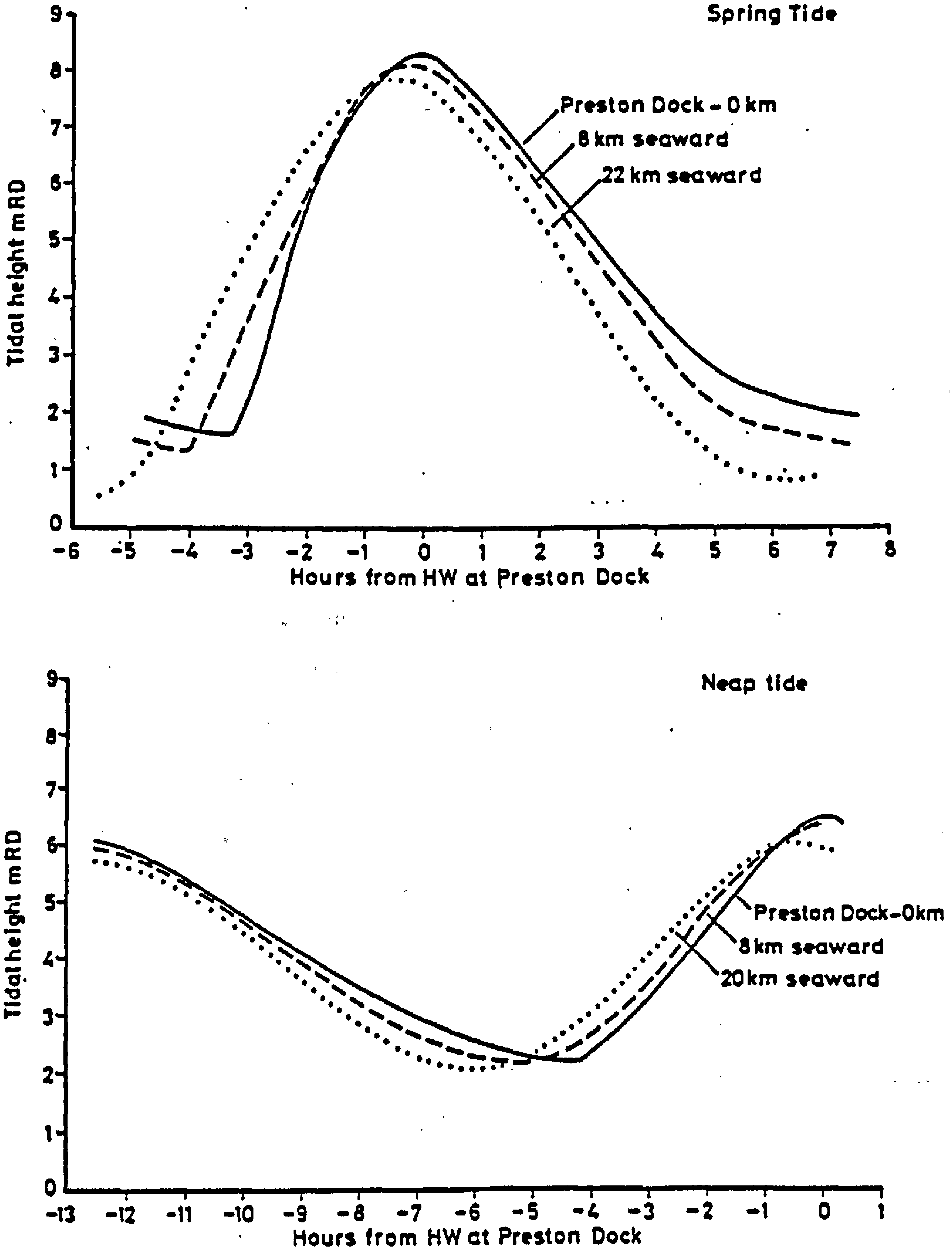
During the period of this study low water depths in the central channel from Preston Dock to the confluence with the River Douglas were usually of 1 - 2.5m, depth varying according to the river discharge, areas of sedimentation and erosion, and dredging operations.

Simultaneous observations of changes in water levels over the tidal cycle at different locations along the estuary are shown in Figure 1.3 (data from Rendel, Palmer and Tritton, 1967). On the

FIGURE 1.3

Tidal variations of water levels in the estuary on a spring (30 September 1966) and neap (22 November 1966) tide. Data from Rendel, Palmer and Tritton (1967).

FIG. 1.3


Spring Tide
Preston Dock - 0 km
8 km seaward
22 km seaward
Tidal height mRD
0
1
2
3
4
5
6
7
8
9
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
Hours from HW at Preston Dock
Neap tide
Preston Dock-0km
8km seaward
20km seaward
Tidal height mRD
0
1
2
3
4
5
6
7
8
9
-13
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
Hours from HW at Preston Dock

coast mean spring and neap tides rise to 8.23m and 4.65m respectively above Ribble Datum which is measured as mean low water of spring tides at sea. However, there is a gradient in water surface levels along the estuary with tide heights at Preston Dock slightly greater than at the coast.

The tidal curves produced in Figure 1.3 show that at Preston the periods of flood and ebb are asymmetrical. The flood arrives at the Dock 3h 10min before high water on spring tides, on neaps it arrives 4h 20min before. In the summer months on spring tides with low river discharge the appearance of the flood tide in the upper estuary may be marked by a small bore.

In addition to affecting low water levels in the upper estuary, increased freshwater discharge may have a pronounced influence on high water levels. The Hydraulics Research Station (1980) estimated a tidal volume of 2.4×10^8 m^3 for the outer estuary seaward of 12.5 km from Preston Dock, landward of this point the tidal volume was estimated as 1.5×10^7 m^3. They calculated that a high freshwater flood flow of 200 m^3/s supplies during a rising tide 4.3×10^6 m^3 of water, which is 2% of the volume of the outer estuary but 30% of the volume of the upper estuary. High freshwater flows will therefore have a considerable influence on tide levels in the latter section.

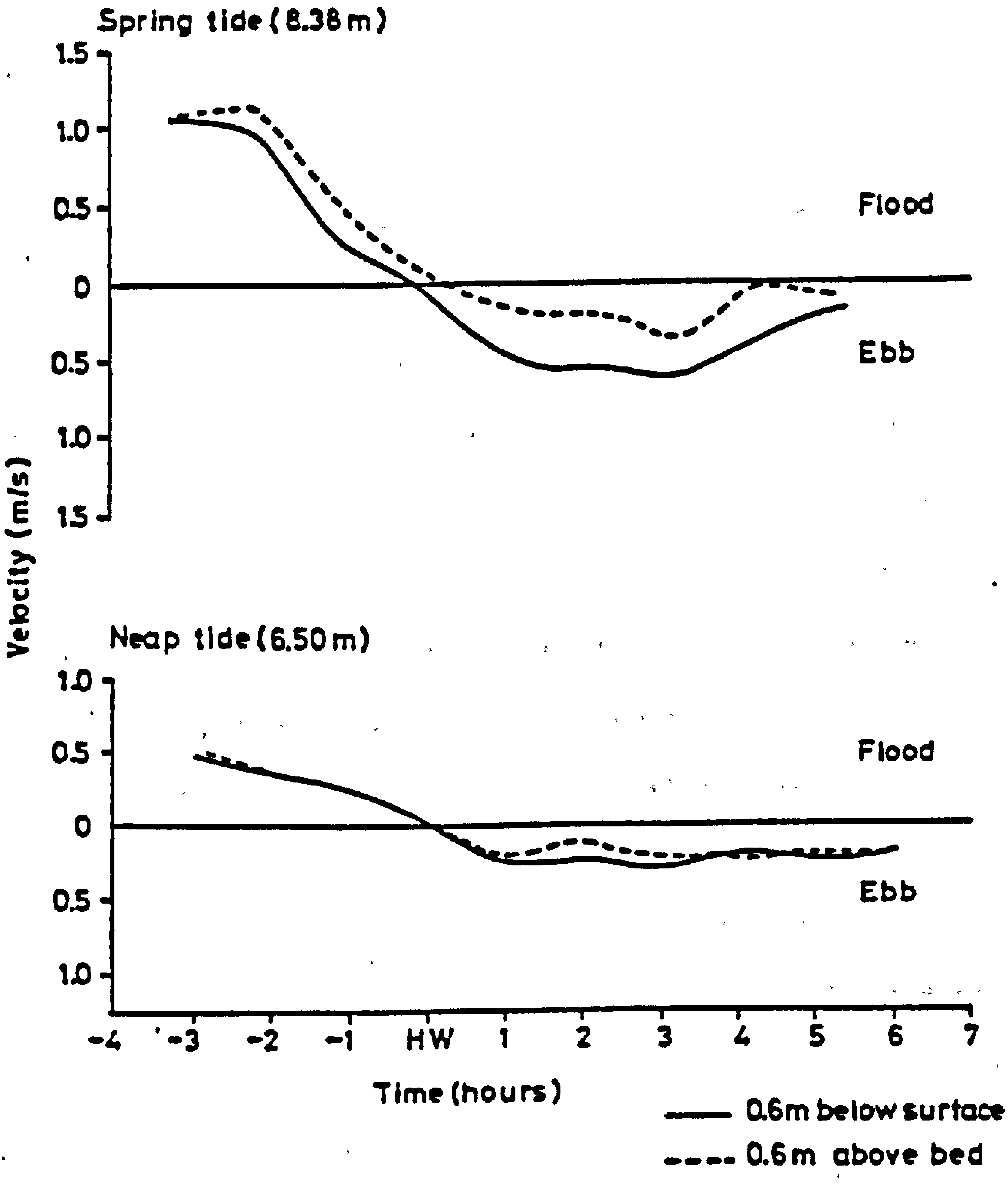
b) Current velocities

Water velocities in the trained channel over the tidal cycle have been measured by Rendel, Palmer and Tritton (1967). Recordings taken at a station 1.6 km below the Dock are shown in Figure 1.4. The measurements were taken at a time of low freshwater flow. Greatest velocities occurred during the flood with maximum readings of 1.15 m/s and 0.48 m/s on the spring and neap tides respectively. On the spring tide observations at stations in the outer reaches of the estuary

FIGURE 1.4

Current velocities over the tidal cycle on a spring (30 September 1966) and neap (22 November 1966) tide. Data from Rendel, Palmer and Tritton (1967).

FIG. 1.4


Spring tide (8.38 m)
1.5
1.0
0.5
0
0.5
1.0
1.5
Flood
Ebb
Velocity (m/s)
Neap tide (6.50 m)
1.0
0.5
0
0.5
1.0
Flood
Ebb
-4
-3
-2
-1
HW
1
2
3
4
5
6
7
Time (hours)
0.6m below surface
0.6m above bed

velocities over 2.0 m/s were recorded during the flood (Rendel, Palmer and Tritton, 1967).

c) Bed material

Variations in bed material along the estuary below Preston have been detailed by the Hydraulics Research Station (1965a, b, 1980) and Rendel, Palmer and Tritton (1967). In the low water channel medium sand at the coast grades to fine sand ($d_{50} = 0.15$ mm) in the upper estuary, with a stretch of coarse sand, shell, gravel and mud at 14.5 km to 20.5 km downstream of Preston. In the upper estuary silt ($d_{50} = 0.045$ mm) is the predominant material on the intertidal banks of the channel.

From personal observations during this study it was apparent that immediately below the Dock entrance the floor of the channel consists almost entirely of mud, with varying amounts of allochthonous material (leaves etc.) also present. The distance along the channel which this substrate extends was found to vary seasonally. In winter when river discharge was normally high mud and allochthonous material continued to 3 km from the Dock entrance, whereas during the summer when freshwater flow was low sand was observed in the centre of the channel less than 0.5 km downstream of the entrance.

Also, for the first 2 km below the Dock and a short distance above, the silt on the intertidal banks is more fluid and present in deeper layers than further down the estuary. The greater deposits of silt and the substrate of mud-allochthonous material on the channel floor, are presumably the result of lower current velocities and the interaction of the tidal and freshwater flows in this region. The layers of mud and silt form the edges of the low water channel in this stretch of the estuary, the stone revetment of the training walls having virtually disappeared.

d) Sediment movements

Siltation and the need for dredging to maintain a navigable channel for shipping has always been a problem in the estuary. The first dredging operations to improve depths were carried out in 1839 (Barron, 1938). In the years leading up to the closure of the Port dredging was mainly confined to the first 3.2 km below Preston Dock, of 5.7×10^5 m^3 of sediment dredged in 1979 94% of the output was from this stretch.

The behaviour of sediment in the trained channel has been the subject of a number of studies (Rendel, Palmer and Tritton, 1967; Hydraulics Research Station, 1963, 1965a, b, 1968, 1980). The following account is taken from these sources.

It was found that during periods of high freshwater flow sediment is scoured from the bed of the trained channel between Preston Dock and 4.5 km seaward, the material being carried down the estuary and accreting in the section 6.5 km to 11.5 km from the Dock. During low freshwater flows the reverse process occurs, erosion in the seaward section and accretion near the Dock. Monitoring of bed levels through periods of sustained high discharge have shown depth changes of the order of 0.2m to take place, with on occasion much larger changes of 0.6m recorded (Hydraulics Research Station, 1980).

In addition, the studies have shown there are periods in which erosion and accretion occur in the channel throughout the upper compartment of the estuary (Dock to 11.5 km) independent of river discharge. Although there are periods of erosion, overall this second system of sediment movements leads to an accumulation of material in the upper compartment and a consequent rise in bed levels. The most likely source of this material is the extensive area of sand flats bordering the channel in the outer estuary (Hydraulics Research Station, 1965a, b).

The system of sediment movement linked with freshwater flow causes local changes in depth but no new material is brought into the channel from seaward, there is simply a redistribution of material already present (Hydraulics Research Station, 1965b). It will be evident, however, that river discharge carries some material from upstream with greater quantities at times of high discharge, a fact illustrated by seasonal variation in amounts of mud and allochthonous material observed below the Dock in the present study (see earlier).

Finally, brief mention should be made of a further process of sedimentation taking place in the outer estuary at the coast. Here, an alternative flood channel is developing outside the trained channel in which considerable sand deposition is occurring. It has been suggested that with the closure of the Port and the ending of channel maintenance, the low water channel may eventually begin to freely meander through the outer estuary, as it did before the construction of the training walls and commencement of dredging (Hydraulics Research Station, 1980; Sir William Halcrow and Partners, 1980).

e) Salinity regime

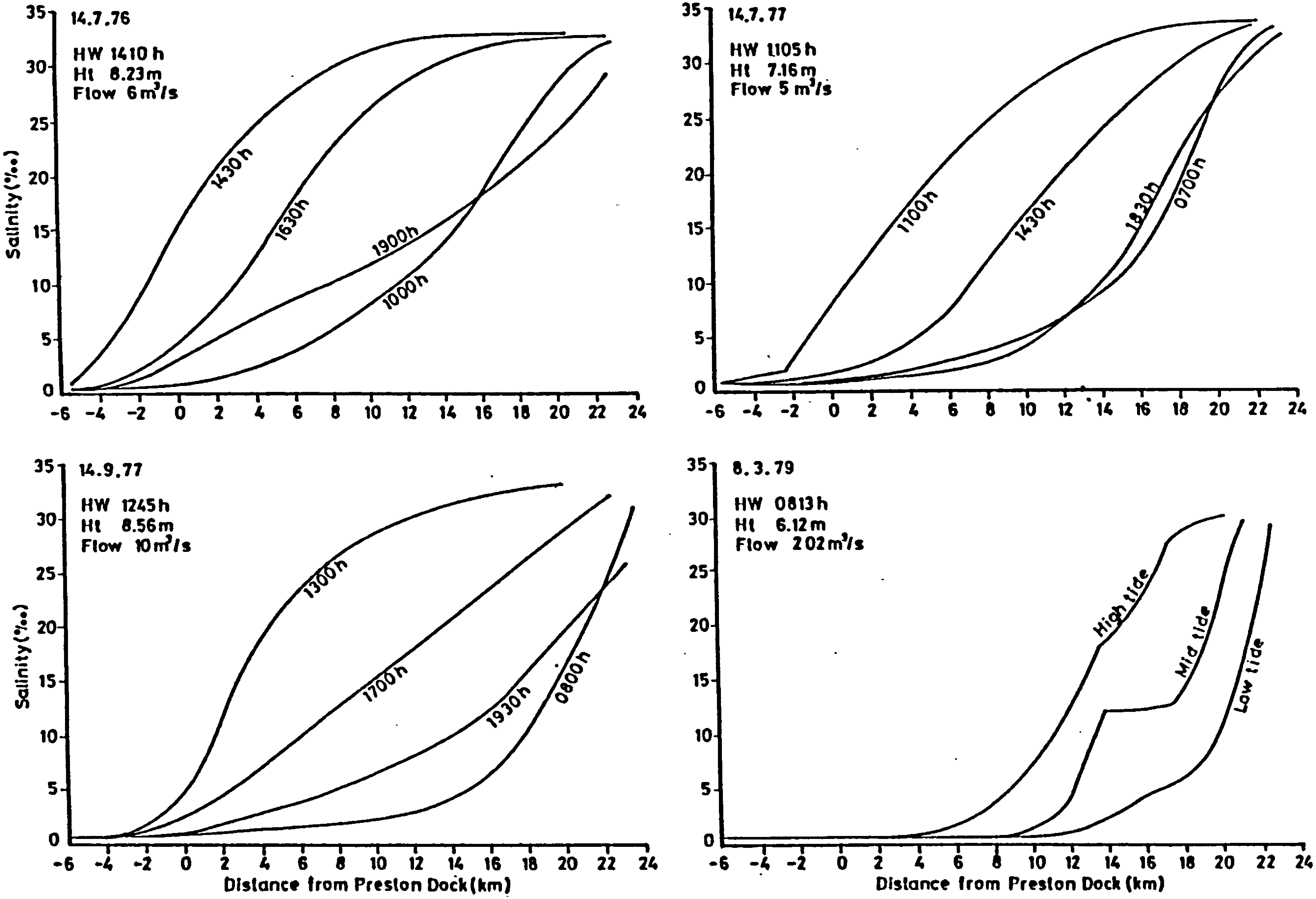
Measurements of salinity distribution in the estuary at different states of the tide are shown in Figure 1.5 (data from North West Water Authority, 1977, 1979a). The graphs show the effects of different tidal heights and freshwater flow conditions on salinity distribution. The graph for 8 March 1979 is included to illustrate the results of exceptional river flows with salinities of 5 ‰ not recorded until 9 km downstream of Preston Dock.

It can be seen that in the inner estuary there is a large change in salinity over the tidal cycle; for example on 14 July 1976

FIGURE 1.5

Distribution of salinity in the estuary at different states of the tide. Data from North West Water Authority (1977, 1979a).

FIG. 1.5


14.7.76
HW 1410 h
Ht 8.23m
Flow 6m³/s
1430h
1630h
1900h
1000h
14.7.77
HW 1105 h
Ht 7.16m
Flow 5 m³/s
1100h
1430h
1830h
0700h
14.9.77
HW 1245h
Ht 8.56m
Flow 10m³/s
1300h
1700h
1930h
0800h
8.3.79
HW 0813h
Ht 6.12m
Flow 202m³/s
High tide
Mid tide
Low tide
Salinity(‰)
0
5
10
15
20
25
30
35
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24
Distance from Preston Dock (km)

values at 2 km downstream of the Dock ranged from 1.5 ‰ at low water to 20.5 ‰ at high water.

It should be noted that the measurements shown in Fig. 1.5 refer to surface salinities. In the central channel just below the Dock differences of 5 ‰ have been recorded between bottom and surface salinities at high water on a spring tide, with even greater differences of 12.5 ‰ measured on the ebb (Rendel, Palmer and Tritton, 1967). Further down the estuary stronger currents induce greater mixing and there is little stratification (Rendel, Palmer and Tritton, 1967).

f) Water quality

The River Ribble lies at the interface between the industrialised and heavily urbanised areas of Merseyside and Greater Manchester in the south, and the sparsely populated rural areas to the north (North West Water Authority, 1975). This contrast is illustrated by the differences in water quality of the two main tributaries entering above Preston near Clitheroe. The Hodder from the north like the Ribble flows through agricultural land and is an important migratory fishery, whereas the Calder from the south flows through heavily industrialised areas and is polluted. Similarly, the waters of the River Darwen and Douglas which enter the estuary from the south are polluted through inputs of sewage and trade effluents. Major improvements are, however, now being made to the sewerage systems and treatment works in the catchments of all three rivers. Although fish are absent from most of the Darwen, the lower reaches of the Calder now support freshwater fish populations, and in the Douglas salmon (Salmo salar L.) and sea trout (Salmo trutta L.) are occasionally reported.

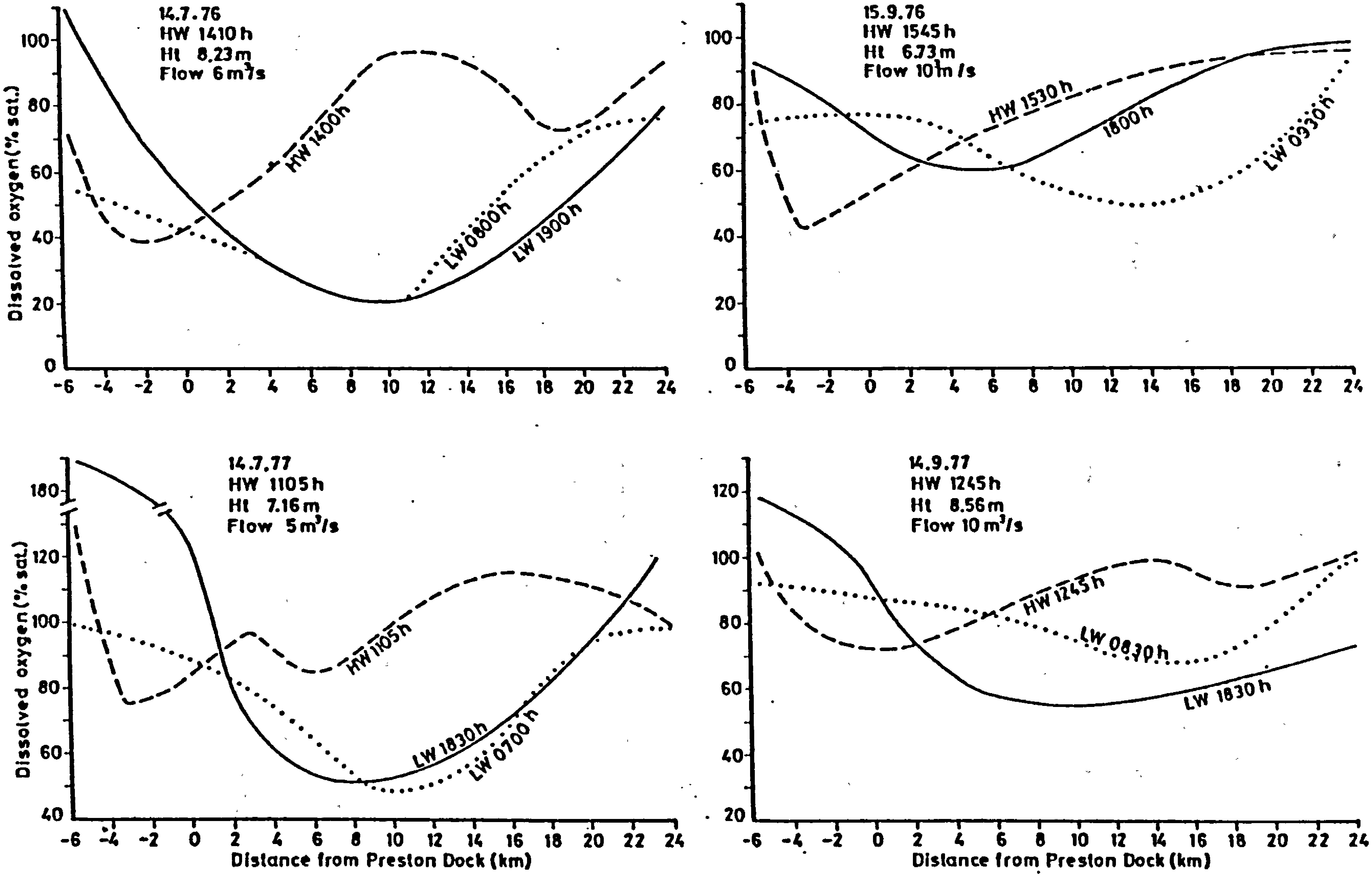
Along its course through Preston and to the sea the estuary receives a large number of outfalls discharging surface water run-off from agricultural land and urban areas, effluent from sewage treatment works, and storm water overflows from the storm-water sewerage system. The most important outfall is from the Clifton Marsh ETW 5 km downstream of Preston Dock. The sewage receives only primary treatment and discharge is on both the flood and ebb tides. Flows average 50-60 Ml/day with a mean biochemical oxygen demand (BOD) of 100 mg/l but occasionally reaching 200 mg/l. There are no direct discharges of effluents to the estuary from industries in Preston, but the estuary does receive an outfall from a British Nuclear Fuels Limited (BNFL) site at Springfields in the north, opening into the estuary 2.6 km below Preston. The effluent contains only negligible amounts of radioactive waste (Dutton, 1966; Hunt, 1980), but does contain a number of other significant components (see below).

A series of boat and helicopter surveys over recent years by North West Water Authority (NWWA) have demonstrated the presence of a dissolved oxygen sag in the estuary. Data from some of these surveys are shown in Figure 1.6 (NWWA, 1977). On 14 June 1976 at low water dissolved oxygen levels were below 30% saturation from 4.5 km to 14.5 km downstream of Preston. This was during a period of low river flows, high water temperatures and high BOD load from Clifton Marsh ETW. However, levels equally as low have also been recorded in other surveys (NWWA, 1979b), and on the three other occasions for which data in Figure 1.6 is presented oxygen concentrations of only 40-50% saturation were observed. It can be seen that at low water the sag is normally located at or below the confluence with the Douglas, whereas at high water the sag is pushed upstream by the tide to near or above the Dock entrance.

FIGURE 1.6

Distribution of dissolved oxygen in the estuary at different states of the tide. Data from North West Water Authority (1977).

FIG. 1.6


14.7.76
HW 1410 h
Ht 8.23 m
Flow 6 m³/s
HW 1400h
LW 0800h
LW 1900h
15.9.76
HW 1545 h
Ht 6.73 m
Flow 10 m³/s
HW 1530 h
1800h
LW 0330h
14.7.77
HW 1105 h
Ht 7.16 m
Flow 5 m³/s
HW 1105h
LW 1830h
LW 0700h
14.9.77
HW 1245 h
Ht 8.56 m
Flow 10 m³/s
HW 1245h
LW 0830h
LW 1830h
Dissolved oxygen (% sat.)
Distance from Preston Dock (km)
0
20
40
60
80
100
120
180
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
24

There is also a high input of ammonia into the estuary with the main sources Clifton Marsh ETW, BNFL, and the River Douglas. Concentrations of 2.0 mg/l NH_3-N and above have been recorded on occasion with the highest values present in the upper estuary from 3 km to 12 km below Preston (NWWA, 1977, 1979b). The levels of the toxic un-ionised form recorded often exceed the safe limit for fish. Similarly, levels of nitrite-nitrogen in the inner estuary are often above values which have been proved lethal to fish in the laboratory (NWWA, 1977). The main source of this form of nitrogen to the estuary is the BNFL outfall.

Compared to many other estuaries the Ribble is also rich in nitrate-nitrogen, phosphate and zinc. Inputs of zinc have, however, now been reduced as a result of the closure of a major industrial unit in Preston.

Migratory fishery

Water quality in the estuary has primarily been of concern because of its possible effect on the run of salmon and sea trout through into the river. On the Ribble the salmonids are fished both by rod and by a small number of commercial netsmen drift netting in the estuary seaward of the Naze.

The history of the salmon and sea trout fisheries on the Ribble has been documented by Houghton (1952). Today catches are variable between years, as are catches nationally, but overall the Ribble can be broadly classified as a good salmon and sea trout river (J. Nott, Fisheries Officer, pers. comm.). In 1980 over 950 salmon were taken by rod with 725 caught in drift nets (NWWA, 1981).

CHAPTER 2

COMPOSITION, SEASONAL PATTERNS OF ABUNDANCE AND DIVERSITY, AND AGE STRUCTURE OF THE FISH POPULATIONS IN THE INNER ESTUARY.

INTRODUCTION

Estuaries are fundamentally physically controlled environments (Sanders, 1968) and organisms are exposed to rapid fluctuations in water levels and salinity, temperature changes, and short-term shifts in current speed and direction (Perkins, 1974). In contrast to other ecotones which are often characterised by increased diversity of species and density of organisms due to overlapping communities, estuaries are marked by reduced species diversity (Muus, 1979).

One of the principal factors controlling community composition and distribution in estuaries is the prevailing salinity regime (Kinne, 1966). On the basis of individual tolerances to changing salinity some species are able to penetrate far into estuaries, whereas others are more restricted in their distribution. Previous studies in Britain, based on power station sampling, have described the fish populations occurring in the outer, marine reaches of estuaries (Huddart, 1971; Hardisty and Huggins, 1975; D'Arcy and Wilson, 1978; Langford et al., 1978; van den Broek, 1979, 1980). There are few data on the species composition and distribution of fish inhabiting the transition zone between fresh water and salt water in the inner sections of estuaries. As will be evident from Chapter 1, fish species in the inner reaches of estuaries are subject to marked temporal and spatial changes in the prevailing salinity conditions. O'Hara (1976) has described fish distribution in the tidal zone of the lower River Dee, North Wales, but principal consideration was given to the freshwater species with only brief reference to the marine and estuarine components of the fish fauna.

Although the unstable and unpredictable environment of estuaries presents many problems to fish species, they are highly productive areas supporting large invertebrate populations (McLusky, 1981). The importance of estuaries as nursery grounds for young marine fish, where they may benefit from the abundant food resources and gain protection from predators, is widely recognised (Haedrich and Hall, 1976). The mass immigration of juveniles followed by their emigration after a period of growth, leads to pronounced fluctuations in abundance (Muus, 1979). Periodic fluctuations in numbers also occur which are correlated with seasonal variation in abiotic factors (Allen and Horn, 1975; Hoff and Ibara, 1977; Quinn, 1980).

In recent studies on estuarine organisms there has been an emphasis on the use of various indices to measure the species richness and diversity of a community, and the similarity between communities. Interest has centred on the measurement of diversity since this is often considered to be associated with other community functions including energy pathways in the food chain and community stability (MacArthur, 1955; Armstrong et al., 1968). Diversity indices have been commonly used to assess environmental quality and the values obtained are often compared with those from studies on other estuaries (Haedrich, 1975; Livingston, 1976).

The present study examines the composition of the fish community in the inner estuary of the Ribble at high water on spring tides. Collections were made at a series of sites downstream from the upper limit of saltwater intrusion, the sites providing a spectrum of saline conditions and enabling determination of the limits of distribution of freshwater and marine-estuarine species along the inner estuary. Seasonal patterns of abundance and diversity are also described, and the age structure of the fish populations is examined.

SECTION A : SPECIES COMPOSITION AND SEASONAL FLUCTUATIONS IN ABUNDANCE AND DIVERSITY OF THE FISH POPULATIONS.

METHODS

Field methods

From April 1978 to April 1980 inclusive monthly samples were taken at five sites along the inner estuary (Figure 2.1). Two of the sites were upstream of Preston Dock (Sites 1 and 2) and three were in the channelised section below the Dock (Sites 3, 4 and 5). In the channelised section samples were collected using a shore seine on the intertidal banks and a bottom trawl pulled down the centre of the channel. Upstream of the Dock only the seine was used as the nature of the bottom prevented the use of the trawl. All samples were collected within one hour of high water on three consecutive days during spring tides.

Samples were also collected at a further site in the channelised section, Site 6, but this region of the inner estuary is exposed to the prevailing winds and especially during the winter months samples could often not be taken. In addition, it was considered that the samples which were collected may not have been representative owing to the currents which prevented the nets fishing as efficiently as at the other sites. Therefore data collected at Site 6 are not included in this study, although the samples are used in later studies on the age composition of the fish populations (Section B of this chapter) and diet (Chapter 4).

During the winter and spring of 1978-79 severe weather made sampling irregular with no samples collected at any site in November 1978 and January 1979.

SECTION A : SPECIES COMPOSITION AND SEASONAL FLUCTUATIONS IN ABUNDANCE AND DIVERSITY OF THE FISH POPULATIONS.

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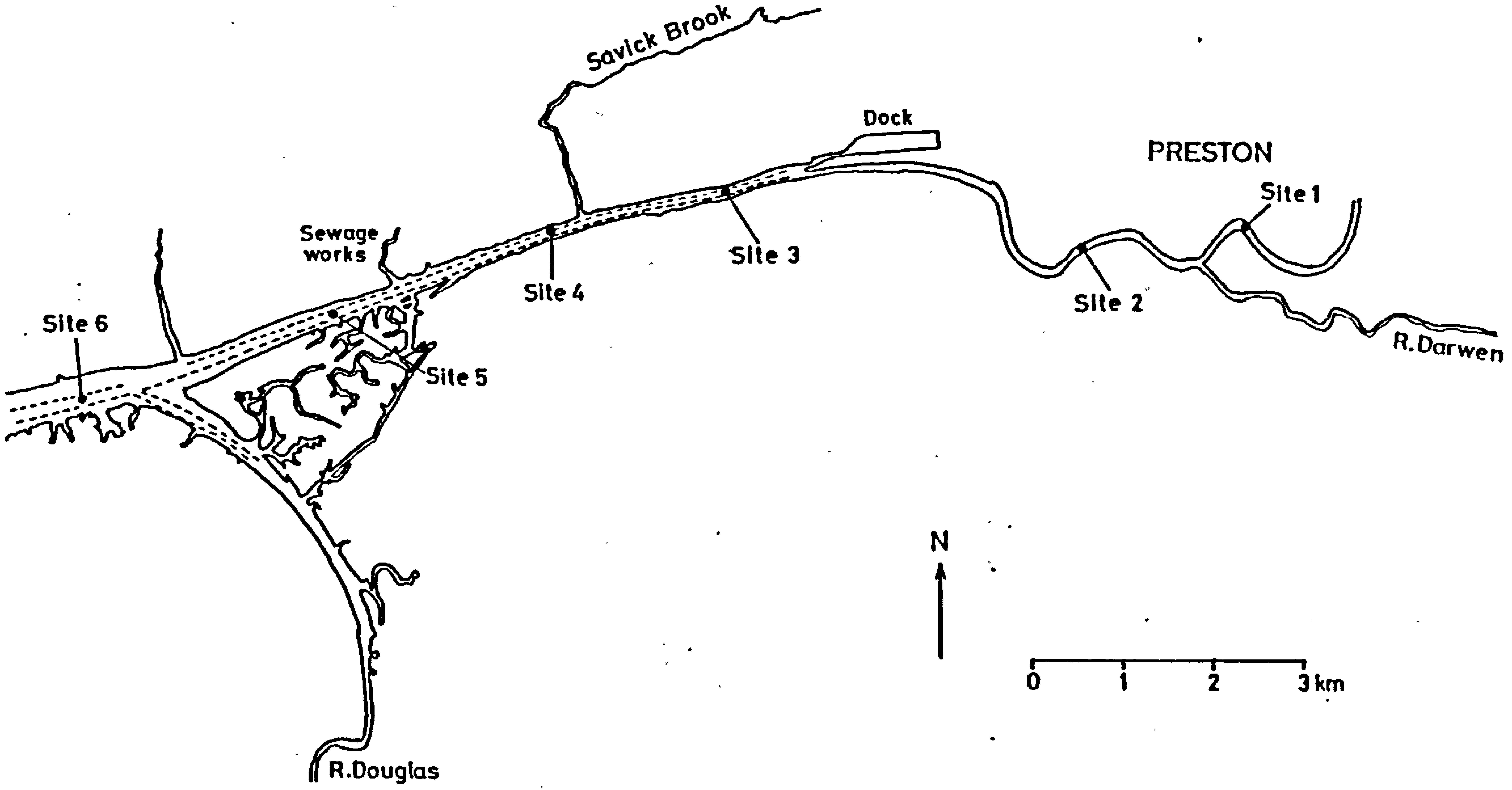
During the winter and spring of 1978-79 severe weather made sampling irregular with no samples collected at any site in November 1978 and January 1979.

FIGURE 2.1

Seine and otter trawl sampling sites in the inner estuary.

Site	National Grid Ref.
1	SD 554 287
2	SD 535 284
3	SD 497 291
4	SD 478 286
5	SD 453 277
6	SD 428 268

FIG. 2.1


Savick Brook
Dock
PRESTON
Site 1
Sewage works
Site 4
Site 3
Site 2
Site 6
Site 5
R.Darwen
N
0
1
2
3 km
R.Douglas

The seine net used measured 17m in length and 2m deep with a mesh diameter of 2mm. Both the seine and trawl net were made of knotless netting. Small seines have been used extensively in American studies of tidal areas (Raney and Massmann, 1953; Kilby, 1955; Jerome et al., 1965; McErlean et al., 1973) but are rarely used in Britain. During a preliminary survey the net was fitted with a light chain as a groundrope and this appeared effective in the capture of demersal species which often avoid capture by a seine net (Raney and Massmann, 1953; Dauble and Gray, 1980). However, the chain dug into the fine sediments on the banks causing retrieval and sorting problems and was therefore replaced by an ordinary lead line. Samples were usually taken by setting the net at a distance of 20 m from the shore.

The trawl used was a small otter trawl based on a design by Ruppe and de Roche (1960) and originally constructed for trawling on a large lake (Butterworth and Coles, 1977). The main body of the net was of 32mm mesh polypropylene leading to a belly of 6.5mm mesh and a codend of 2mm mesh diameter. The length of the groundrope was 2.5m. Sufficient chain was added so that the trawl fished along the bottom with a depth : warp length ratio of 1 : 5 as recommended by Ruppe and de Roche (1960). Trawling was with the current and speed of tow was kept as constant as possible, although this undoubtedly varied according to weather and current conditions. The Port of Preston navigation beacons were used to determine the length of trawl which was usually 750m. If a trawl had to be abandoned before completion due to weather or shipping and could not be repeated, the numbers of fish collected were multiplied by an appropriate factor to the full trawling distance.

When analysing the catch data from the two gears cognisance must be taken of the fact that the area sampled by the trawl was much larger than the area sampled by the seine. As a rough guideline the areas covered by the seine and trawl can be measured as approximately 300 m^2 and 1500 m^2 respectively. However, it is not intended to imply that the two gears were equally efficient and the catches can be directly compared.

Concurrent with the seine and trawl collections at each site, surface water temperature was recorded and water samples were returned to the laboratory for measurement of salinity with a conductivity meter. From April 1979 water samples were also taken for determination of dissolved oxygen concentration by Winkler titration (American Public Health Association, 1965).

Limitations of field methods

Estuarine fish populations present considerable sampling problems (McHugh, 1967; Richkus, 1980) and as pointed out by Cole (1969) it is not possible to sample quantitatively even a small estuary in order to obtain an unbiased estimate of fish abundance. A review of the published work on gear efficiencies by Kjelson and Colby (1977) shows that most of the sampling gears used in estuarine studies are inefficient. Seine netting provides only point samples (Goldstein, 1978) and although trawls are probably the most effective method of sampling a large system (Treasurer, 1978), the trawl used in the present study was small.

Larger versions of the sampling gear employed would have proved relatively more efficient. DeLacy and English (1954) found a 20m seine net took only 50% of the specimens and 75% of the species of a similarly constructed 40m net. Kjelson and Johnson (1978) found the relative catch efficiency of a 6.1m otter trawl was greater than that for a 3m and 4.6m trawl. In the inner estuary however, where the tidal currents changed rapidly and with an often heavy shipping traffic, the primary factors affecting choice of gear were speed and manoeuvrability, since it was considered important to take all samples as close to high water as possible.

How closely the catch agrees with the actual composition of the fish community will depend not only on the type of gear used and its mode of operation, but also on the behaviour of the fish and the environmental conditions (Brandt, 1975). Even if all environmental and gear factors remain constant considerable catch variation may occur owing to the shoaling nature of the fish, a factor which has been investigated by several workers in its application to trawl data (Barnes and Bagenal, 1951; Taylor, 1953; Roessler, 1965; Clark, 1974). While this will have clearly affected catches in the present study, given the rapidly fluctuating physical environment it was not considered practicable or possible to obtain any indication of catch variability. It is therefore emphasised that it was broad population changes, both temporal and spatial, that were investigated in this study, not absolute population numbers.

Laboratory methods

On capture, all fish were preserved in 4% formaldehyde and returned to the laboratory for sorting and identification. Numbers of individuals in each species were then recorded. Measurements taken for age and growth studies are described in Section B of this chapter.

All fish were identified except for large catches of postlarval and small juvenile gobies (less than 20mm standard length), and postlarval clupeids. In these cases a minimum of 100 were randomly selected and identified, and the abundance of the various species in the whole sample was then calculated from their relative abundance in the subsample. The only doubt about identification concerned the small gobies for which vertebral counts were made after staining using the method of Hollister (1934). Gobies were assigned to species on the basis of the vertebral counts using the following guidelines (Dr. P. J. Miller, pers. comm.; Webb, 1980):

Pomatoschistus pictus (Malm) -	30
Pomatoschistus microps (Kroyer) -	31
Pomatoschistus lozanoi (De Buen) -	32
Pomatoschistus minutus (Pallas) -	33

Overlap in vertebral number between species does occur (Dr. P. J. Miller, pers. comm.; Webb, 1980) but this is the only method of separation apart from electrophoretic techniques. Larger juveniles and adults of P. minutus and P. lozanoi were identified on the basis of suborbital papillae patterns according to Fonds (1973) and Webb (1980). The systematic relationships of the latter two members of the Pomatoschistus genus have been comprehensively examined by Webb (1980) and in this study they are regarded as separate species.

Juveniles and adults of all other species were identified according to Wheeler (1969) and postlarvae according to Russell (1976).

Data analysis

The numbers and species composition of a catch may, at least in part, be determined by the selectivity and efficiency of the sampling methods employed. Samples collected by the seine and trawl in the channelised section seaward of Preston Dock were therefore treated separately.

In addition, it was apparent that the fish community upstream of Preston Dock differed from that in the channelised section, and seine catches in the two regions are also presented separately.

Descriptions of estuarine fish communities based on actual catch data may be overwhelmed by the large variation present. If raw catch data is used abundance is often overemphasised and the results dominated by a few extremely high values. In this study the log transformation is used to reduce the variation in catch data, the transformation reduces the importance of high values and increases that of small values (Clifford and Stephenson, 1975).

The overall position of a species in a series of catches can be summarised by relative abundance rankings (Warfel and Merriman, 1944). In this method 10 points are awarded to the most abundant species, 9 to the second most abundant, and so on. The points for each species are then summed and percentages calculated. Relative abundance rankings reduce the effects of infrequent and unusually large catches of particular species which may distort their importance in the catches when measured by actual abundance. However, the system is arbitrary and has no real value in terms of collection except for position (Warfel and Merriman, 1944).

In the comparison of data it was necessary to use nonparametric statistical analyses. The use of parametric statistics requires a large number of samples to be taken at each site in order to obtain information on the underlying distribution (Elliott, 1977). They also assume the parameters of the distribution are the same for each sample. In this study where there was often a wide variability in catch sizes between sites and between months (see Results), the ranking methods employed for nonparametric statistics were considered particularly appropriate.

Diversity indices

Diversity indices are based on the relationship between the number of species in a community and the distribution of individuals among the species. Diversity is maximum when each individual belongs to a different species and minimum when each individual belongs to one species (Wilhm and Dorris, 1968). When a system is exposed to environmental stress the less tolerant species are reduced in number or eliminated, decreasing diversity. Consequently, diversity indices have often been used to assess the impact of pollution on communities (Wilhm and Dorris, 1966; Wilhm, 1967; Bechtel and Copeland, 1970; McErlean et al., 1973; Haedrich and Haedrich, 1974; Livingston, 1975; Hillman et al., 1977).

Various indices of diversity have been proposed and some have been compared for their use in estuarine surveys (McErlean and Mihursky, 1969; Livingston, 1976). In this study the species richness index (Margalef, 1958) was calculated:

$$D = \frac{S - 1}{\log N}$$

where S = number of species

N = number of individuals

This index does not consider community structure and is influenced by sample size (Wilhm and Dorris, 1968).

An information theory index was also calculated. Pielou (1966a, b, 1969) suggested that where all the members of a sample have been identified and counted, the Brillouin index (Brillouin, 1962) is most appropriate:

$$H = \frac{1}{N} \log \left[\frac{N!}{N_1!\, N_2! \ldots N_S} \right]$$

where S = number of species

N = number of individuals

N_i = number of individuals in the ith species

In the calculation of the index the formula given by Lloyd et al. (1968) was used:

$$H = 1/N \left(\log N! - \sum_{i=1}^{S} \log N_i! \right)$$

The species diversity as described by H depends on three factors, N, S, and comparative abundance of the S species (Pielou, 1966a). Changes in any one of these will affect the value of H.

The distribution of individuals among the species can be measured by the evenness index of Pielou (1966b, 1969):

$$J = H/H_{max}$$

where

$$H_{max} = \frac{1}{N}\log\frac{N!}{\left[\frac{N}{S}\right]!^{\,S-r}\qquad\left(\left[\frac{N}{S}\right]+1\right)!}$$

and S = number of species

N = number of individuals

$$\left[\frac{N}{S}\right] = \text{integer part of } \frac{N}{S}.$$

$$r = N - S\left[\frac{N}{S}\right]$$

Logarithms to the base 10 were used throughout the above calculations. Wilhm (1968) and Wilhm and Dorris (1968) consider that instead of numbers of individuals, biomass units should be used in calculations of diversity as these are more closely related to energy distribution among the species in a community. However, as the majority of the individuals captured in the present study were 0-group, numbers are considered sufficient particularly as Dickman (1968) suggests that neither numbers nor biomass are truly representative.

Proportional similarity

To compare the composition of the fish community at different sites the Proportional Similarity Index (Whittaker, 1952; Whittaker and Fairbanks, 1958) was calculated:

$$PS = 1 - 0.5 \sum_{i=1}^{n} \left| p_{xi} - p_{yi} \right| = \sum \min (p_{xi}, p_{yi})$$

where p_{xi} = proportion of species i in sample x

p_{yi} = proportion of species i in sample y

As proportions are utilised it is unimportant if the total numbers in the two samples differ (Kohn and Riggs, 1982). To obviate the effects of infrequent large catches of a species a maximum of 1000 individuals collected in a sample was set.

After calculation of the index values matrices were constructed and sites were clustered by the unweighted pair group-averaged method (Sokal and Sneath, 1963). Dendograms were then drawn.

RESULTS

Physico-chemical parameters

Seasonal fluctuations in surface water temperature are shown in Figure 2.2. The data are presented as the mean temperature over the three days of sampling in each month. The highest mean temperature recorded was 19.5°C in July 1979, with a maximum the previous year of 17.3°C in June. The lowest mean temperature was 1°C in February 1979, but the following winter of 1979-80 was less severe with a minimum of 3.5°C in January 1980 and temperatures in other months remaining above 6°C.

Marked reductions in salinity in the channelised section during December 1978 and December 1979 (Figure 2.3) were a result of very high river flows. Salinities were only slightly above fresh water at all

FIGURE 2.2

Mean water temperatures over the three days of sampling in each month.

FIGURE 2.3

Monthly surface salinity readings at each site.

FIG. 2.2

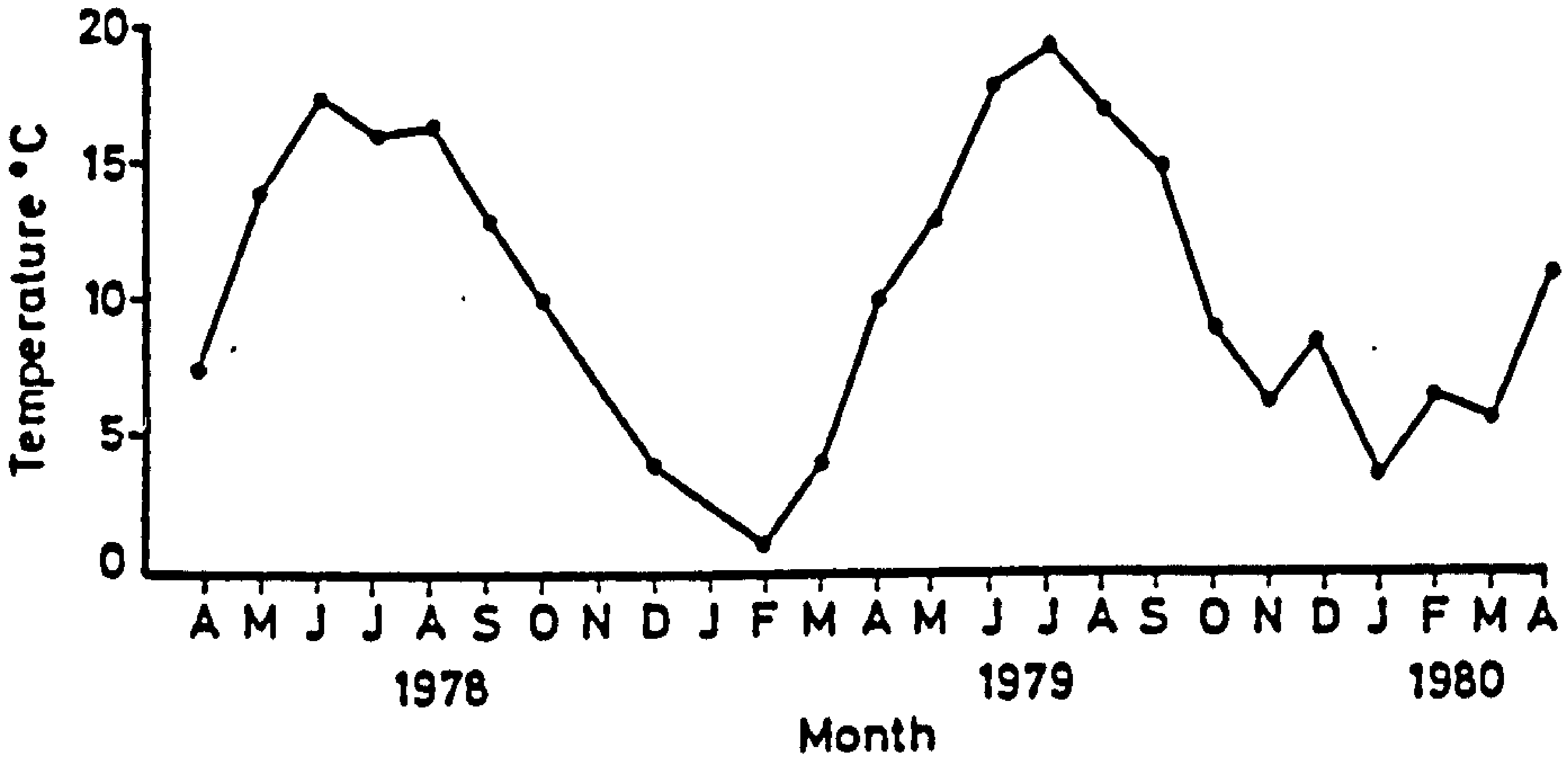

Temperature °C
20
15
10
5
0
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

FIG. 2.3

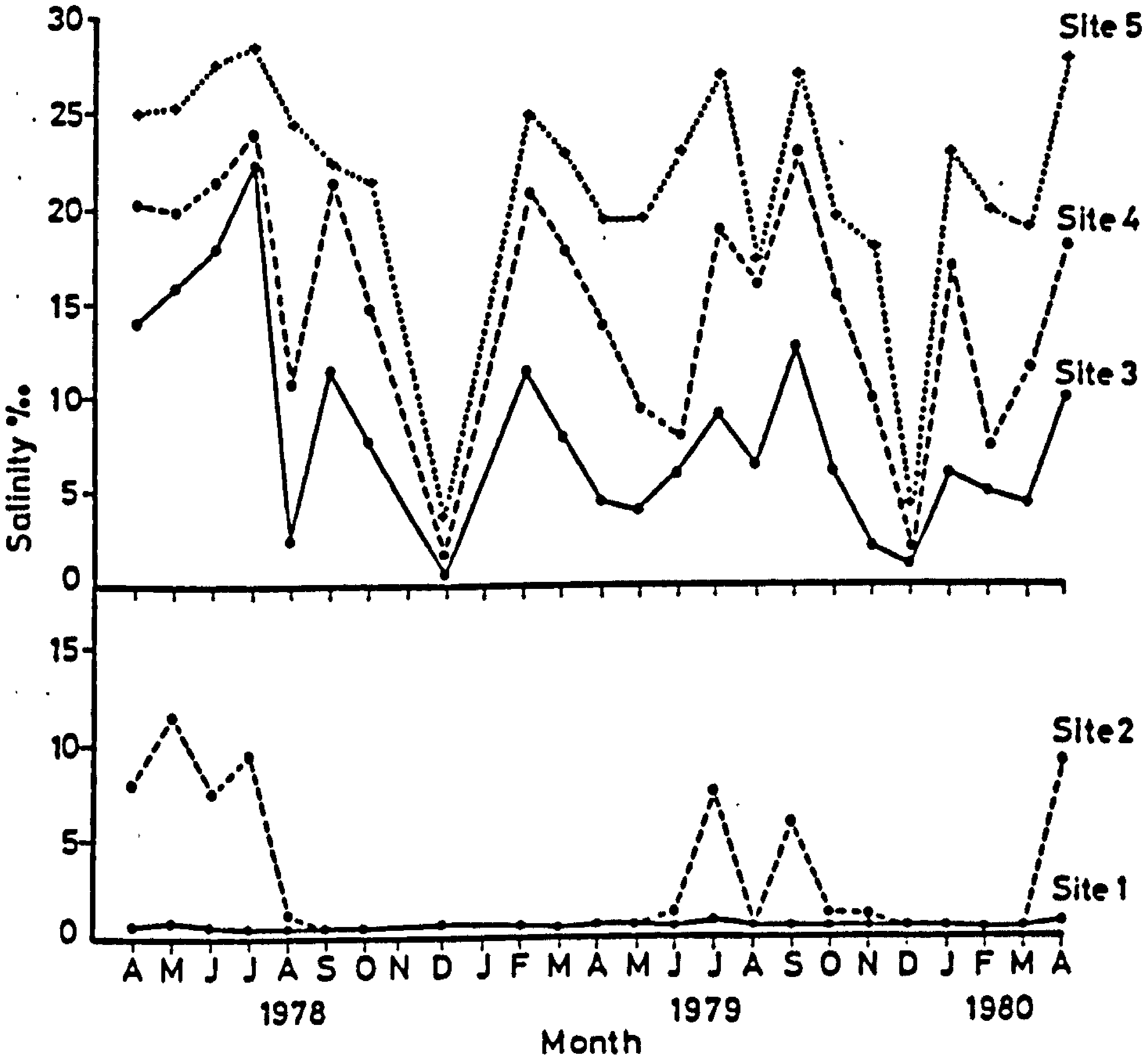
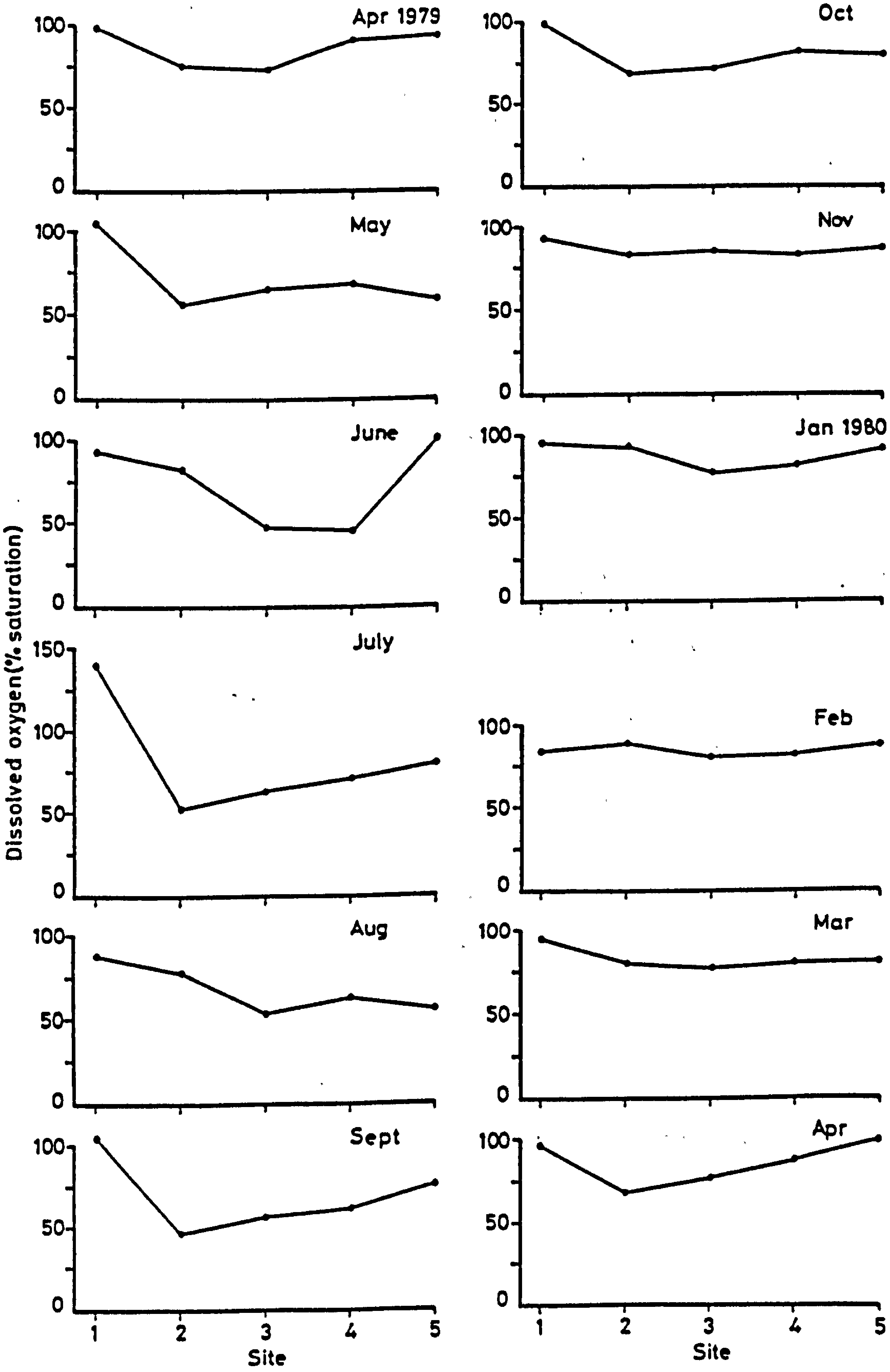

Salinity ‰
30
25
20
15
10
5
0
15
10
5
0
Site 5
Site 4
Site 3
Site 2
Site 1
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

FIGURE 2.4

Dissolved oxygen levels, as percent saturation, at each site from April 1979 to April 1980.

FIG. 2.4


Dissolved oxygen(% saturation)
Apr 1979
May
June
July
Aug
Sept
Oct
Nov
Jan 1980
Feb
Mar
Apr
150
100
50
0
1
2
3
4
5
Site

three channelised sites. Usually however, there was a clear increase in salinity down the channelised section, although since the measurements were not taken simultaneously the salinities at each site cannot be directly compared. Upstream of the Dock entrance at Site 1 the salinity was rarely above fresh water, and the maximum recorded was 0.7 ‰. At Site 2 from late autumn to spring salinities were not measurably above fresh water, but during the summer months when river flows were low surface salinities over 5 ‰ were recorded.

Dissolved oxygen levels, as percent saturation, from April 1979 to April 1980 are presented in Figure 2.4. Concentrations were normally lowest at Sites 2 and 3. The dissolved oxygen sag was most severe in the summer months with a minimum of 46.2% saturation recorded at Site 2 in September 1979.

Species composition of catches

A total of 40755 fish of 32 species were taken in the seine and otter trawl samples. A further 12 species were recorded during the course of other studies documented in this thesis and a complete list of the fish species identified from the inner estuary is shown in Table 2.1. The distribution of individuals among the various species in the seine and trawl samples is shown in Table 2.2. Monthly catch data for each site and method are presented in Appendix A.

Although the number of species captured was large, only a few were abundant and regularly present in the samples. In the channelised section (Table 2.2a, b) catches were dominated by six species: Sprattus sprattus (L.) (sprat), Clupea harengus L. (herring), Platichthys flesus (L.) (flounder), and the three Pomatoschistus species P. minutus, P. lozanoi and P. microps. Ammodytes tobianus L. (sandeel) formed a large proportion of the total seine catch, but as

Table 2.1 List of species recorded from the inner estuary.

Abramis brama (L.)	Bream
Agonus cataphractus (L.)	Pogge
Ammodytes tobianus L.	Sandeel
Anguilla anguilla (L.)	Eel
Aphia minuta (Risso)	Transparent goby
Callionymus lyra L.	Dragonet
Ciliata mustela (L.)	Five-bearded rockling
Clupea harengus L.	Herring
Cyclopterus lumpus L.	Lumpsucker
Dicentrarchus labrax (L.)	Bass
Gadus morhua L.	Cod
Gaidropsarus mediterraneus (L.)	Shore rockling
Gasterosteus aculeatus L.	Three-spined stickleback
Gobio gobio (L.)	Gudgeon
Gymnocephalus cernua (L.)	Ruffe
Lampetra fluviatilis (L.)	River lamprey
Leuciscus cephalus (L.)	Chub
Leuciscus leuciscus (L.)	Dace
Liparis liparis (L.)	Sea snail
Liparis montagui (Donovan)	Montagu's sea snail
Liza ramada (Risso)	Thin-lipped mullet
Merlangius merlangus (L.)	Whiting
Noemacheilus barbatulus (L.)	Stone loach
Osmerus eperlanus (L.)	Smelt
Pholis gunnellus (L.)	Butterfish
Phoxinus phoxinus (L.)	Minnow
Platichthys flesus (L.)	Flounder
Pleuronectes platessa L.	Plaice
Pollachius pollachius (L.)	Pollack
Pomatoschistus lozanoi (de Buen)	Sand goby
Pomatoschistus microps (Kroyer)	Common goby
Pomatoschistus minutus (Pallas)	Sand goby
Pomatoschistus pictus (Malm)	Painted goby
Pungitius pungitius (L.)	Ten-spined stickleback
Rutilus rutilus (L.)	Roach
Salmo salar L.	Salmon
Salmo trutta L.	Trout

Table 2.1 (contd.)

Scophthalmus maximus (L.)	Turbot
Scophthalmus rhombus (L.)	Brill
Solea solea (L.)	Sole
Sprattus sprattus (L.)	Sprat
Syngnathus acus L.	Great pipefish
Trachinus vipera Cuvier	Weever
Trisopterus luscus (L.)	Bib

Table 2.2a Species composition of seine catches in the channelised section.

Species	Numbers	% Act. Ab.	% Rel. Ab.
Sprattus sprattus	9353	47.7	15.0
Pomatoschistus microps	4752	24.2	9.0
Clupea harengus	2004	10.2	13.1
Ammodytes tobianus	1367	7.0	8.9
Pomatoschistus minutus	853	4.3	7.8
Platichthys flesus	443	2.3	10.5
Anguilla anguilla	416	2.1	10.5
Pomatoschistus lozanoi	123	0.6	2.6
Rutilus rutilus	99	0.5	5.4
Leuciscus leuciscus	69	0.4	5.9
Syngnathus acus	62	0.3	1.7
Leuciscus cephalus	44	0.2	2.9
Gasterosteus aculeatus	14	< 0.1	3.3
Gobio gobio	8		< 1.0
Dicentrarchus labrax	7		
Phoxinus phoxinus	3		
Pleuronectes platessa	2		
Solea solea	2		
Liza ramada	1		
Pungitius pungitius	1		
Scophthalmus maximus	1		

Table 2.2b Species composition of otter trawl catches in the channelised section.

Species	Numbers	% Act. Ab.	% Rel. Ab.
Pomatoschistus minutus	3477	31.7	18.7
Sprattus sprattus	3445	31.4	11.5
Platichthys flesus	1613	14.7	20.5
Pomatoschistus lozanoi	1259	11.5	13.2
Anguilla anguilla	637	5.8	6.0
Pomatoschistus microps	188	1.7	5.5
Clupea harengus	104	0.9	5.4
Pleuronectes platessa	88	0.8	6.6
Ammodytes tobianus	43	0.4	4.5
Solea solea	42	0.4	2.1
Gadus morhua	15	0.1	1.7
Merlangius merlangus	15	0.1	<1.0
Gasterosteus aculeatus	5	<0.1	
Pomatoschistus pictus	5		
Aphia minuta	4		
Trisopterus luscus	4		
Syngnathus acus	2		
Trachinus vipera	2		
Agonus cataphractus	1		
Ciliata mustela	1		
Leuciscus cephalus	1		
Noemacheilus barbatulus	1		
Scophthalmus rhombus	1		

Table 2.2c Species composition of seine catches at Sites 1 and 2 upstream of Preston Dock.

Species	Numbers	% Act. Ab.	% Rel. Ab.
Platichthys flesus	3822	37.6	19.9
Leuciscus cephalus	2728	26.8	15.8
Leuciscus leuciscus	1991	19.6	15.1
Rutilus rutilus	655	6.4	9.3
Anguilla anguilla	327	3.2	8.6
Clupea harengus	166	1.6	1.5
Gobio gobio	135	1.3	10.1
Sprattus sprattus	126	1.2	2.3
Pomatoschistus microps	96	0.9	3.9
Phoxinus phoxinus	54	0.5	6.3
Pomatoschistus minutus	43	0.4	< 1.0
Gasterosteus aculeatus	19	0.2	4.2
Noemacheilus barbatulus	11	0.1	1.7
Pomatoschistus lozanoi	3	< 0.1	< 1.0
Abramis brama	1		
Liza ramada	1		

will be seen later A. tobianus was only abundant in the early months of the study period. Anguilla anguilla (L.) (eel) was also common in catches.

The order of the species in the catches differed when ranked by actual and relative abundance. This was the result of infrequent large catches of certain of the species. The actual abundance data for the seine was overwhelmed by a single haul of 7345 sprat (78.5% of the total) at Site 3 in August 1978, and of 4205 P. microps (88.5% of the total) at Sites 3 and 4, also in August 1978. As a consequence, these two species dominated the total seine catch numerically, but when relative abundance is considered several species were important. Infrequent large catches of sprat were also taken in the trawl and by actual abundance sprat ranked second behind P. minutus in the trawl catch, whereas in terms of relative abundance flounder were first followed by P. minutus with sprat ranked fourth. Differences in the catch composition of the seine and trawl were apparent. Overall, species such as flounder, P. minutus and P. lozanoi formed a larger proportion of the trawl catch compared to the seine, in which herring, sandeel and P. microps were more common.

Upstream of Preston Dock at Sites 1 and 2 the principal species in the seine catches (Table 2.2c) were flounder and the freshwater fishes Leuciscus cephalus (L.) (chub), Leuciscus leuciscus (L.) (dace) and Rutilus rutilus (L.) (roach). The relative importance of these species in the total catch was the same by both actual and relative abundance. The marine-estuarine species other than flounder were only occasionally present in the samples.

Seasonal distribution of catches

a) Total numbers of individuals and species

Monthly totals of numbers of species (Figure 2.5) and numbers of

FIGURE 2.5

Numbers of species in monthly samples.

FIG. 2.5

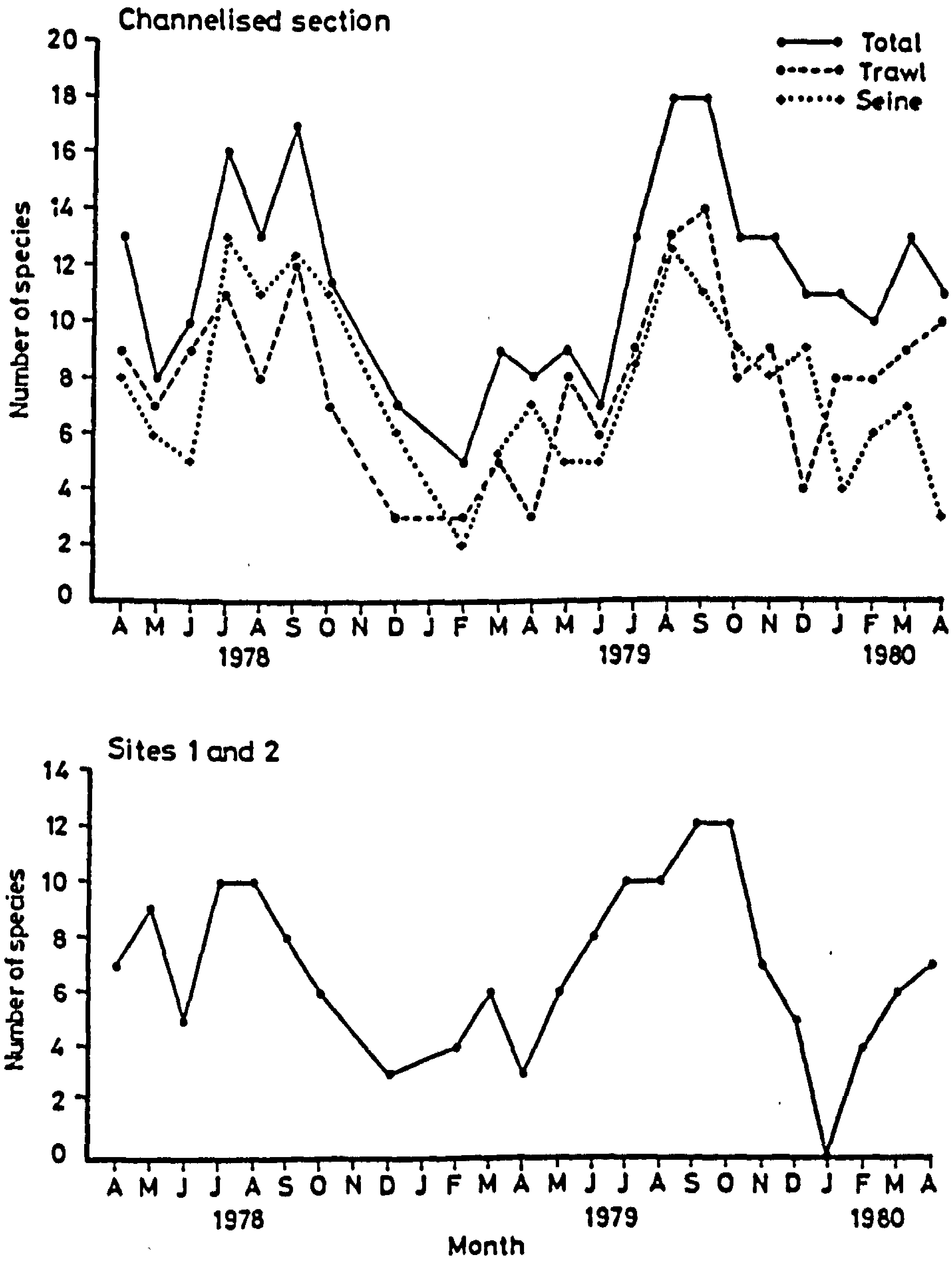

Channelised section
Total
Trawl
Seine
Number of species
0
2
4
6
8
10
12
14
16
18
20
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Sites 1 and 2
Number of species
0
2
4
6
8
10
12
14
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

FIGURE 2.6

Numbers of fish captured in monthly samples; a) seine and otter trawl catches in the channelised section; b) seine catches at Sites 1 and 2 upstream of Preston Dock.

Numbers plotted as log (N + 1).

FIG. 2.6a

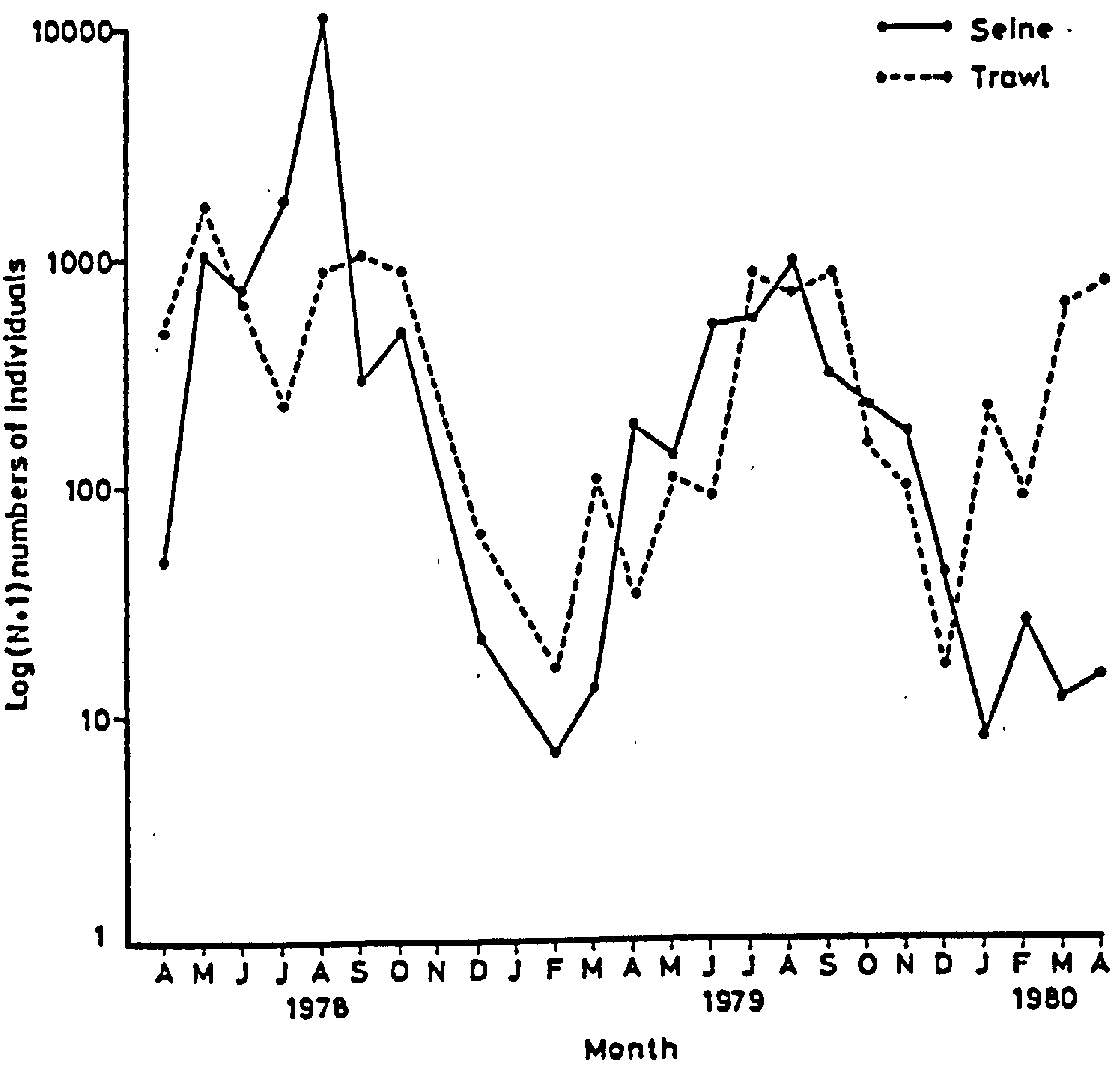

Seine
Trawl
10000
1000
100
10
1
Log(N+1) numbers of individuals
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
1978
1979
1980
Month

FIG. 2.6a

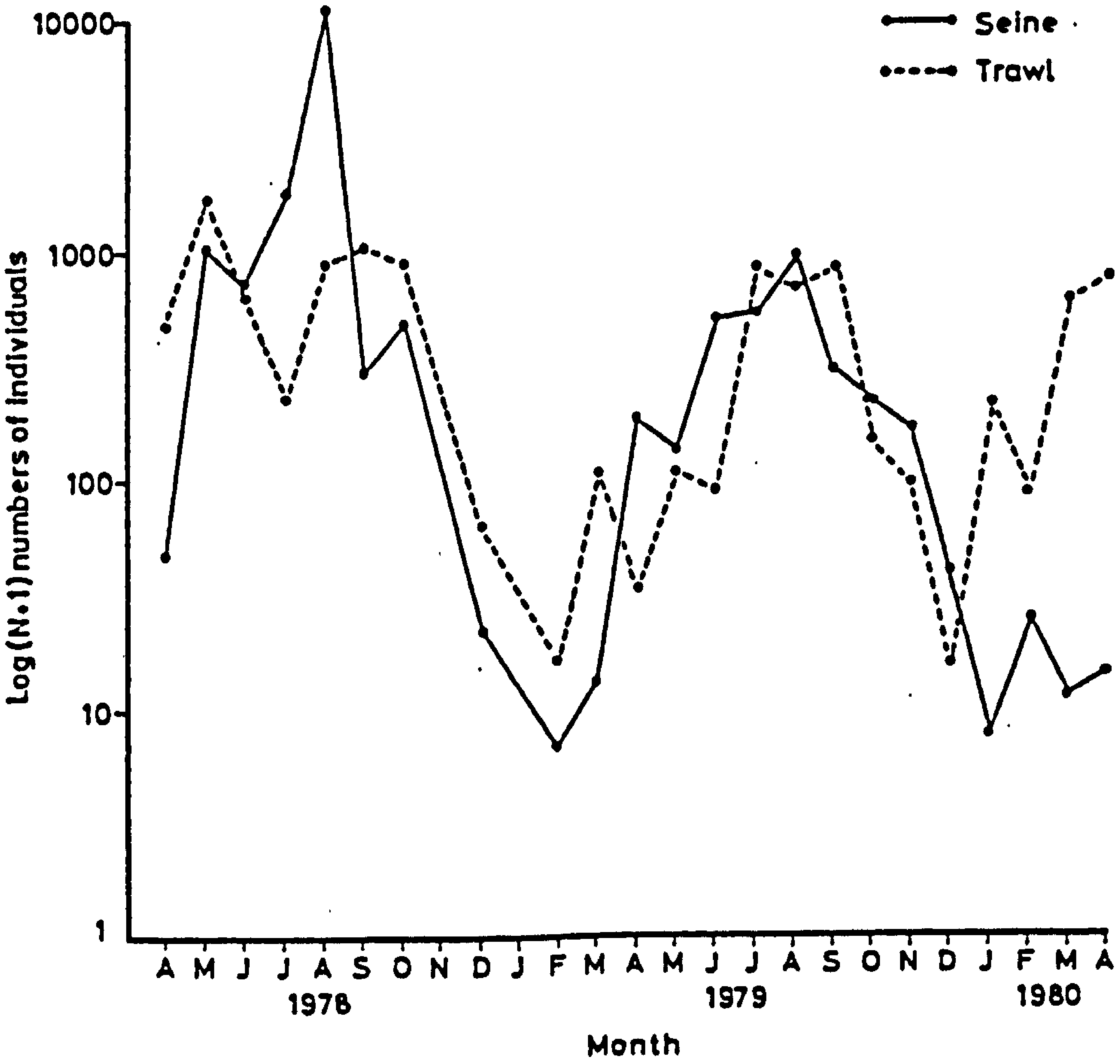

Seine
Trawl
10000
1000
100
10
1
Log (N+1) numbers of individuals
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
1978
1979
1980
Month

FIG. 2.6b


10000
1000
100
10
1
Log(N+1)numbers of individuals
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

individuals (Figure 2.6) often exhibited wide and irregular fluctuations in successive months. This variability persisted even when, as in the latter case, the data was transformed by taking logarithms. However, superimposed on the short-term variation a clear seasonal cycle was evident, and both numbers of species and numbers of individuals reached maximum values in the summer and minimum values in the winter. This pattern was observed at sites in the channelised section and upstream of Preston Dock.

In the early months of 1979 trawl catches were much smaller than in the corresponding months in 1980 when large numbers of fish, principally flounder (see below), were captured. In contrast, seine catches in the channelised section remained generally low in the early months of both years. The peak in channelised seine catches in August 1978 was the effect of the exceptional numbers of sprat and P. microps captured in that month.

b) Percentage composition of monthly samples

In the summer and early autumn seine catches in the channelised section were usually dominated by sprat and herring, although other species were important in some months (Figure 2.7). This was especially the case in May and July 1978 when sandeels composed the largest part of the catches. Sprat were occasionally dominant in the trawl samples during the summer months, but P. minutus was usually the principal species with flounder and P. lozanoi also common. Except in April 1978 and May 1979 P. minutus was always more abundant than P. lozanoi in the trawl catches.

In the winter-spring period of December to March when seine catches were small no one species was consistently more prevalent in the samples in the channelised section. Several of the fish captured during these months belonged to the freshwater species. Freshwater

FIGURE 2.7

Percentage composition of seine and otter trawl catches in the channelised section. The numbers of fish in the catches are shown. ● indicates species comprising less than 2% of the catch.

FIG. 2.7

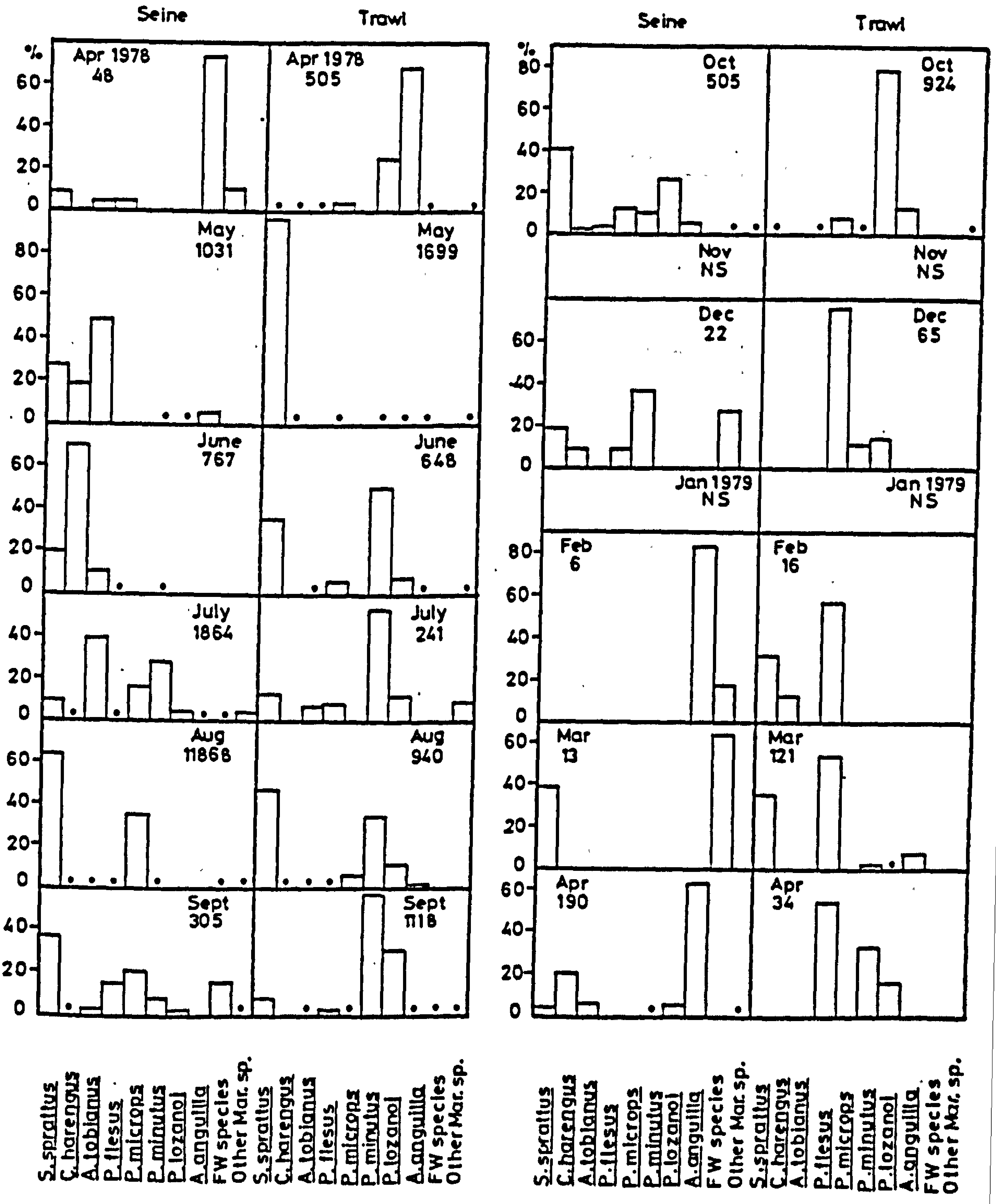

Seine
Trawl
Seine
Trawl
%
Apr 1978
48
Apr 1978
505
May
1031
May
1699
June
767
June
648
July
1864
July
241
Aug
11868
Aug
940
Sept
305
Sept
1118
Oct
505
Oct
924
Nov
NS
Nov
NS
Dec
22
Dec
65
Jan 1979
NS
Jan 1979
NS
Feb
6
Feb
16
Mar
13
Mar
121
Apr
190
Apr
34
0
20
40
60
80
S. sprattus
C. harengus
A. tobianus
P. flesus
P. microps
P. minutus
P. lozanoi
A. anguilla
FW species
Other Mar. sp.

FIG. 2.7 contd.

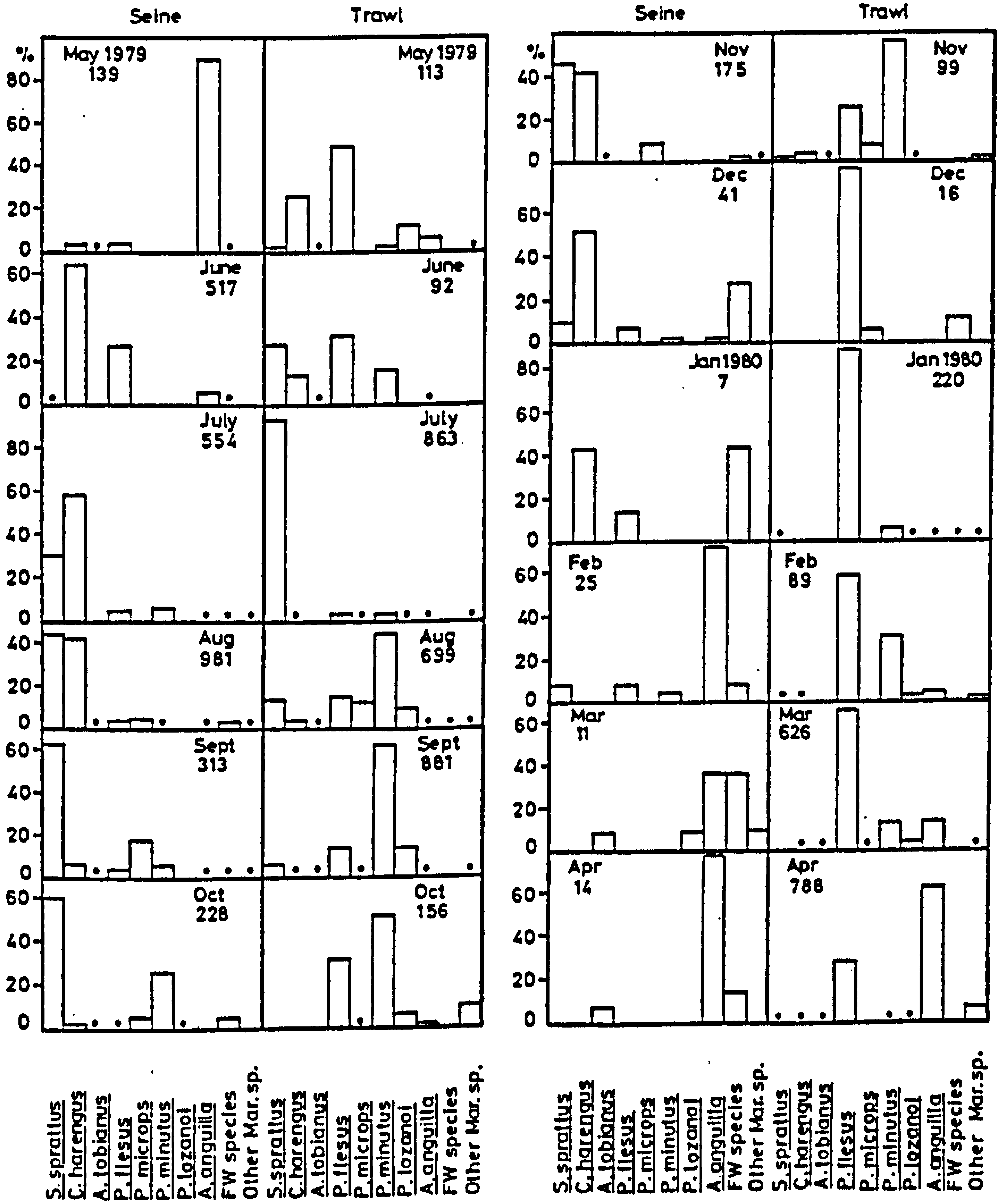
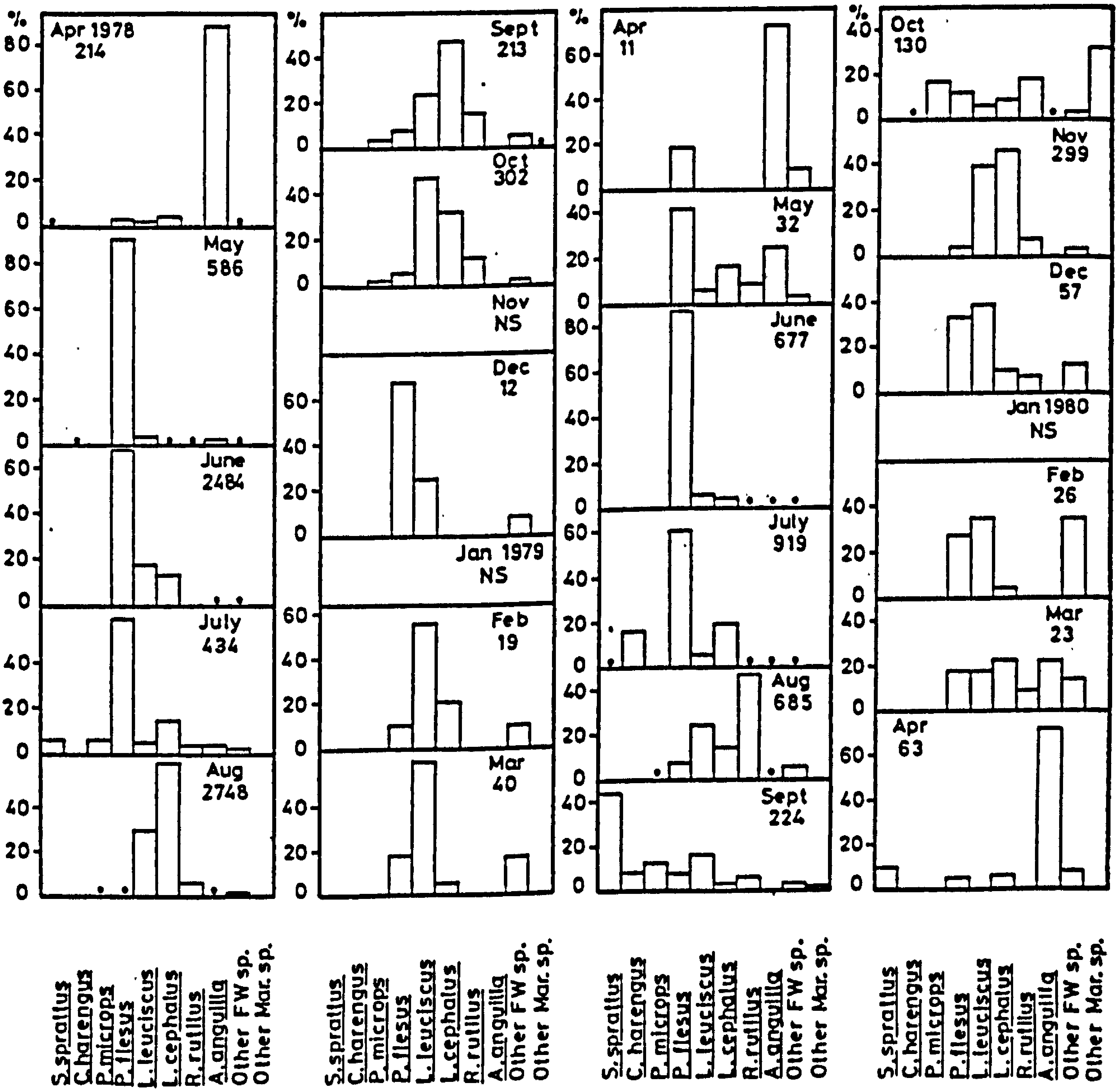

Seine
Trawl
Seine
Trawl
%
May 1979
139
May 1979
113
June
517
June
92
July
554
July
863
Aug
981
Aug
699
Sept
313
Sept
881
Oct
228
Oct
156
Nov
175
Nov
99
Dec
41
Dec
16
Jan 1980
7
Jan 1980
220
Feb
25
Feb
89
Mar
11
Mar
626
Apr
14
Apr
788
0
20
40
60
80
S.sprattus
C.harengus
A.tobianus
P.ilesus
P.microps
P.minutus
P.lozanoi
A.anguilla
FW species
Other Mar.sp.

FIGURE 2.8

Percentage composition of seine catches at Sites 1 and 2 upstream of Preston Dock. The numbers of fish in the catches are shown. ● indicates species comprising less than 2% of the catch.

FIG. 2.8


%
Apr 1978
214
May
586
June
2484
July
434
Aug
2748
Sept
213
Oct
302
Nov
NS
Dec
12
Jan 1979
NS
Feb
19
Mar
40
Apr
11
May
32
June
677
July
919
Aug
685
Sept
224
Oct
130
Nov
299
Dec
57
Jan 1980
NS
Feb
26
Mar
23
Apr
63
0
20
40
60
80
S.sprattus
C.harengus
P.microps
P.flesus
L.leuciscus
L.cephalus
R.rutilus
A.anguilla
Other FW sp.
Other Mar. sp.

fishes were taken in the seine in the channelised section throughout the year, but except in the winter-spring were insignificant compared to the greater numbers of marine-estuarine fishes. Trawl catches in December to March were composed principally of flounder. In April and May elvers (A. anguilla) were often captured in large numbers in both the seine and trawl.

Above the Dock flounder was the most abundant species in the seine catches in the early summer months (Figure 2.8). During the rest of the summer and autumn the freshwater species dace, roach and chub were usually predominant, except in September and October 1979 respectively when sprat and P. minutus (Other Marine Species) were most important. From December to March flounder and the three freshwater species were equally recorded in the catches. As in the channelised section elvers were often abundant in the April and May samples.

c) Seasonal distributions of individual species

Figure 2.9 shows the seasonal abundance of the principal marine-estuarine species. The distribution presented for flounder refers to the abundance of this species in catches in the channelised section, the seasonal distribution of flounder in catches upstream of the Dock entrance is described separately below. Peak numbers of sprat, herring, sandeel and the three Pomatoschistus species occurred in the summer and autumn from May to October. Flounder were regularly taken in the channelised section throughout the year, although again there was a tendency for low catches in some of the late autumn and winter months.

Several of the marine-estuarine species were taken in larger numbers during the summer and autumn of 1978 than in the following year. This was often the result of single large catches of the

FIGURE 2.9

Seasonal abundance of the principal marine-estuarine species. The distribution shown for flounder refers to the numbers of this species taken in catches in the channelised section.

FIG. 2.9

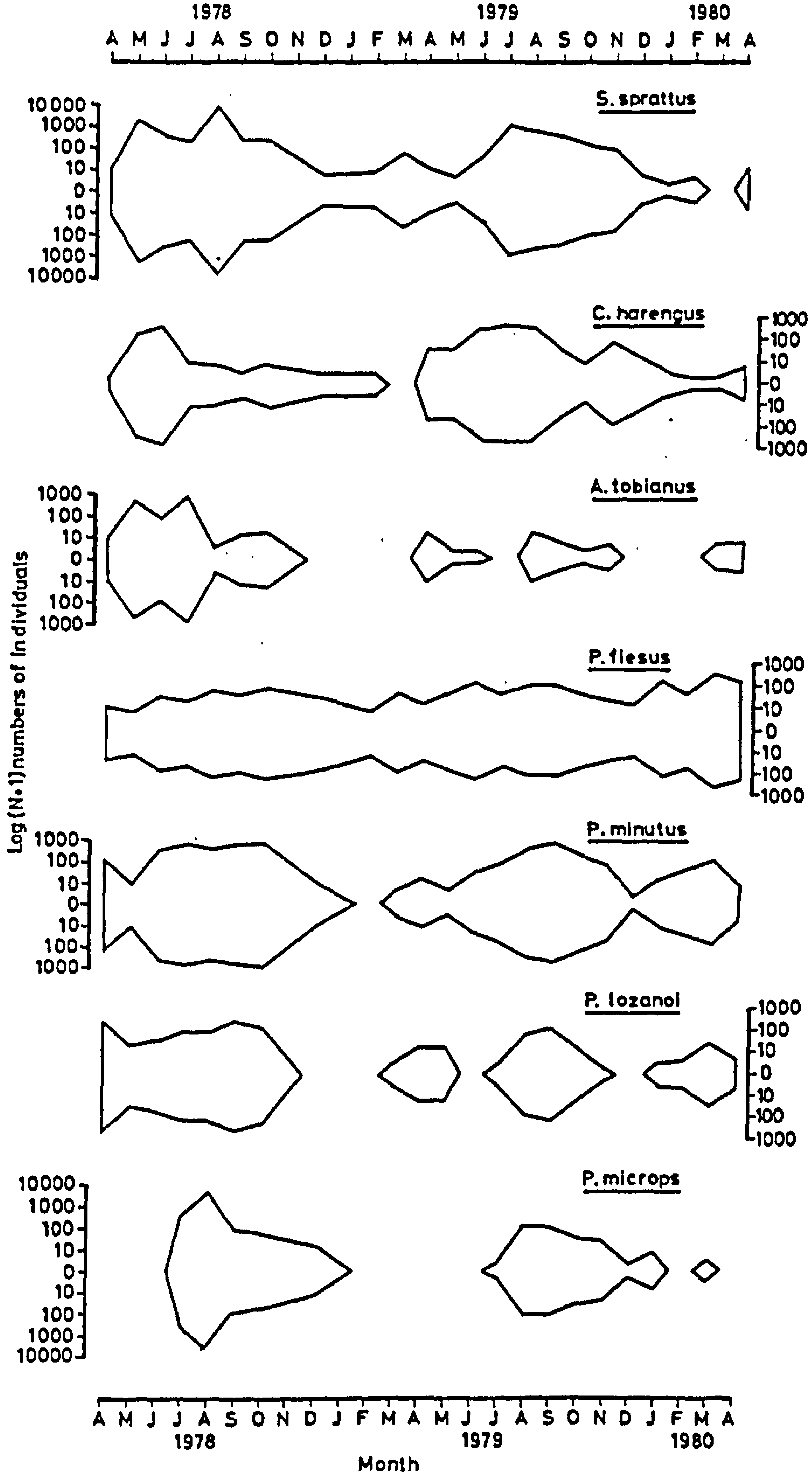

1978
1979
1980
A M J J A S O N D J F M A M J J A S O N D J F M A
S. sprattus
10000
1000
100
10
0
10
100
1000
10000
C. harengus
1000
100
10
0
10
100
1000
A. tobianus
P. flesus
P. minutus
P. lozanoi
P. microps
Log (N+1) numbers of Individuals
Month

FIGURE 2.10

Seasonal abundance of the principal freshwater species, eels, and those flounder taken in catches upstream of Preston Dock.

FIG. 2.10

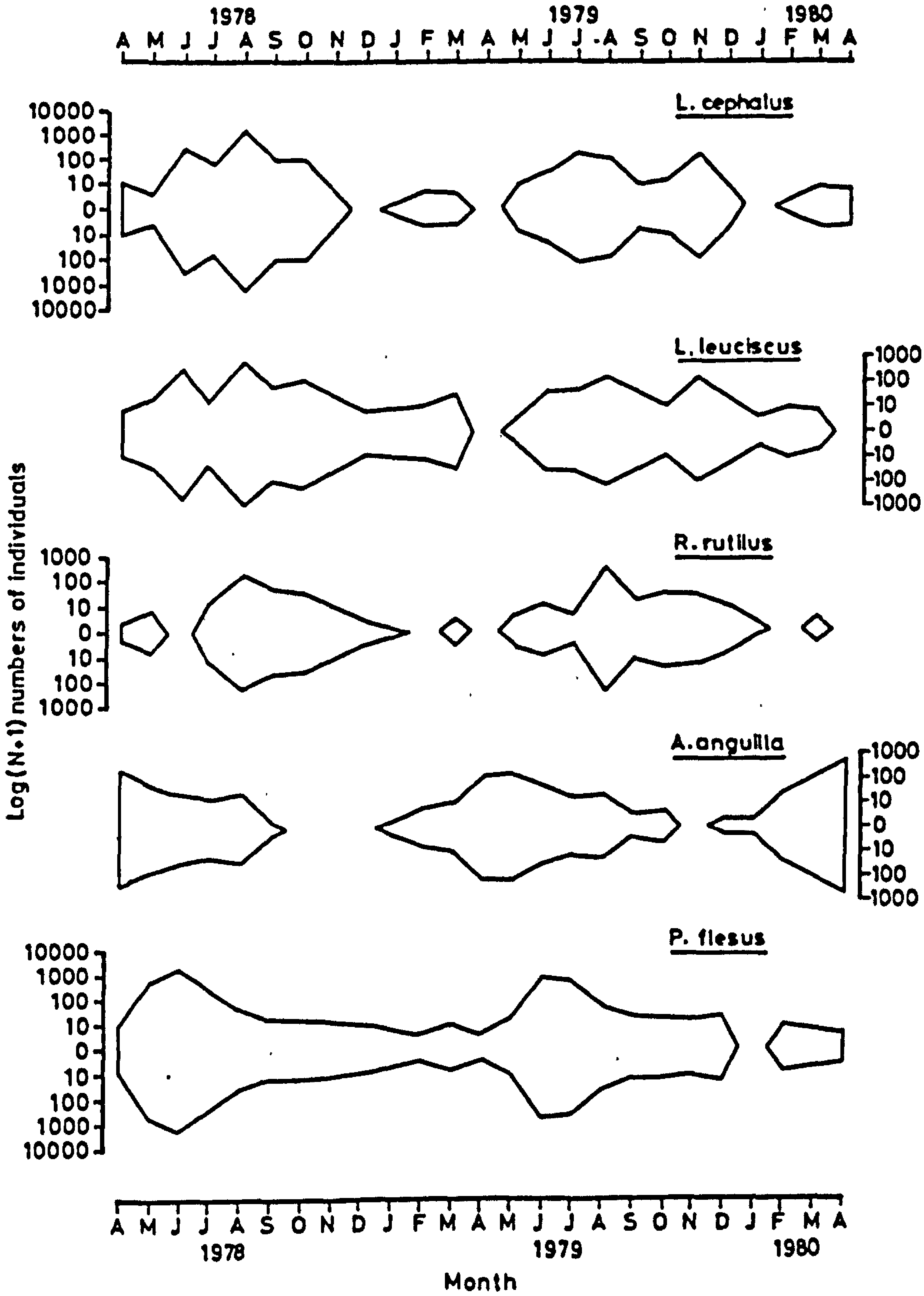
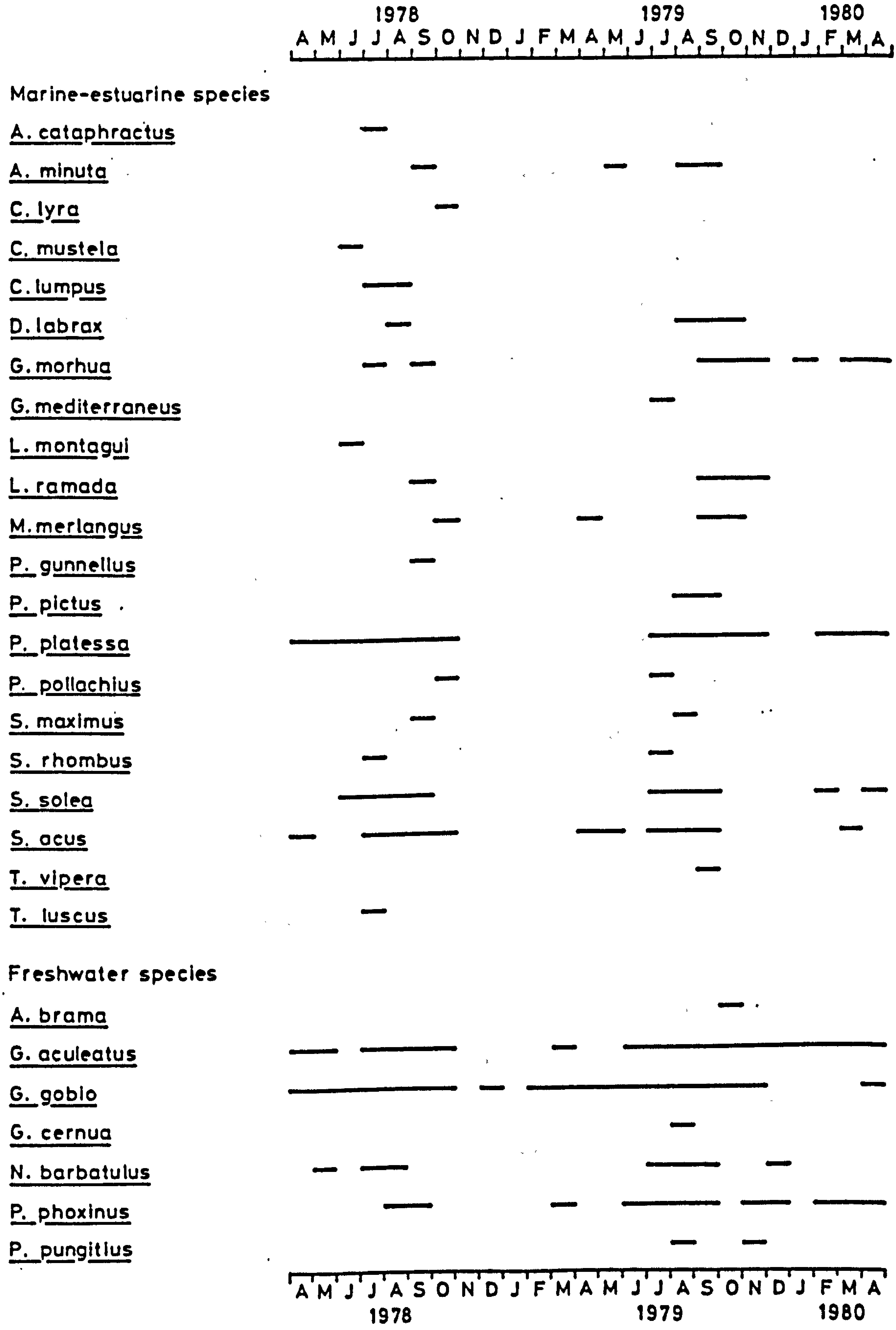

1978
1979
1980
A M J J A S O N D J F M A M J J A S O N D J F M A
L. cephalus
L. leuciscus
R. rutilus
A. anguilla
P. flesus
10000
1000
100
10
0
10
100
1000
10000
Log(N+1) numbers of individuals
Month

FIGURE 2.11

Incidence of the less abundant species in the monthly samples.

FIG. 2.11


1978
1979
1980
A M J J A S O N D J F M A M J J A S O N D J F M A
Marine-estuarine species
A. cataphractus
A. minuta
C. lyra
C. mustela
C. lumpus
D. labrax
G. morhua
G. mediterraneus
L. montagui
L. ramada
M. merlangus
P. gunnellus
P. pictus
P. platessa
P. pollachius
S. maximus
S. rhombus
S. solea
S. acus
T. vipera
T. luscus
Freshwater species
A. brama
G. aculeatus
G. gobio
G. cernua
N. barbatulus
P. phoxinus
P. pungitius
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980

species in 1978. The most striking example, however, was that of A. tobianus which was regularly captured in large numbers during the early summer months of 1978 but was rarely taken in the remainder of the study period. A. tobianus occurs in large shoals in the Irish Sea (Cameron, 1958) and the high numbers in these months may have been due to an abnormal abundance of the sandeels in local inshore waters, some of which then entered the inner estuary.

The seasonal distributions of the principal freshwater fish species, eels, and those flounder taken in catches at Sites 1 and 2 are shown in Figure 2.10. The freshwater species were again most numerous in the summer months with the greatest numbers of eels occurring earlier in the year in April and May, corresponding to the mass immigration of elvers into the estuary. In catches above the Dock flounder showed a clear peak in abundance in May, June and July.

The incidence of all the remaining species which were collected either irregularly or in small numbers is shown in Figure 2.11. It includes a record of their occurrence in all sampling carried out in the inner estuary during the study period, not just in seine and otter trawl samples.

Distribution of species within the inner estuary

a) Distribution with respect to salinity

Table 2.3 shows the distribution of the principal species at sites along the study section. Also shown are the maximum and minimum salinities respectively at which the freshwater and marine-estuarine species were captured. Although sprat, herring and the Pomatoschistus species were mainly abundant in the channelised section, they were also captured at Site 2 and occurred in salinities as low as 1 - 2 ‰. On a small number of occasions P. microps

Table 2.3 Distribution of the principal species in the inner estuary. Also shown are the maximum and minimum salinities respectively at which the freshwater and marine-estuarine species were captured.

Species	Site					Max/min S‰	
	1	2	3	4	5		
L. cephalus	+	+	+	+		11.5	Freshwater species
L. leuciscus	+	+	+			11.5	
R. rutilus	+	+	+	+		11.5	
A. anguilla	+	+	+	+	+	0.5-28.0	- Catadromous species
A. tobianus			+	+	+	6.2	Marine-estuarine species
C. harengus		+	+	+	+	2.0	
P. flesus	+	+	+	+	+	0.5	
P. lozanoi		+	+	+	+	1.0	
P. microps	+	+	+	+	+	0.5	
P. minutus		+	+	+	+	1.0	
S. sprattus		+	+	+	+	2.0	

Table 2.4 Distribution of species in the inner estuary, occurrence at a site shown independent of numbers captured.

Species	Site					
	1	2	3	4	5	
A. brama		+				Freshwater species
G. aculeatus	+	+	+	+	+	
G. gobio	+	+	+			
L. cephalus	+	+	+	+	+	
L. leuciscus	+	+	+	+	+	
N. barbatulus	+				+	
P. phoxinus	+	+	+			
P. pungitius			+			
R. rutilus	+	+	+	+	+	
A. anguilla	+	+	+	+	+	Catadromous species
A. cataphractus					+	Marine-estuarine species
A. tobianus			+	+	+	
A. minuta			+	+	+	
C. mustela					+	
C. harengus		+	+	+	+	
D. labrax			+	+	+	
G. morhua			+	+	+	
L. ramada		+			+	
M. merlangus				+	+	
P. flesus	+	+	+	+	+	
P. platessa			+	+	+	
P. lozanoi		+	+	+	+	
P. microps	+	+	+	+	+	
P. minutus		+	+	+	+	
P. pictus			+		+	
S. maximus				+		
S. rhombus			+			
S. solea			+	+	+	
S. sprattus		+	+	+	+	
S. acus			+	+	+	
T. vipera					+	
T. luscus			+		+	

was found in fresh water at Site 1. The freshwater fish species were captured in salinities up to 11.5 ‰ and although most abundant upstream of the Dock, were taken in the seine at Site 3 and occasionally at Site 4. It is evident therefore that there was a zone, approximately 2 - 5 km in length, where freshwater and marine-estuarine species occurred together on high water of spring tides. Flounder and eels were consistently taken throughout the study area.

In Table 2.3 the occurrence of a species at a site or in water of a certain salinity is only recorded if the species was regularly taken at that site or salinity, or in a group of several individuals. This was clearly a subjective assessment and especially where the freshwater species are concerned, individuals were captured over a greater distance and wider range of salinities than shown. However, these were considered to have been displaced from their normal habitat and are therefore not included in the table. As an example, a single stoneloach (_Noemacheilus barbatulus_ (L.)) was taken in the trawl at Site 5 in December 1979 during a period of high freshwater flows, otherwise stoneloach were only recorded at Site 1. A more generalised diagram of species distribution is shown in Table 2.4 which records the incidence of a species at a site independently of the numbers taken. The three-spined stickleback (_Gasterosteus aculeatus_ L.) is listed as a freshwater species in the table, since all examined were of the leiurus type, which is characteristic of fresh water (Wootton, 1976).

b) Differences between sites

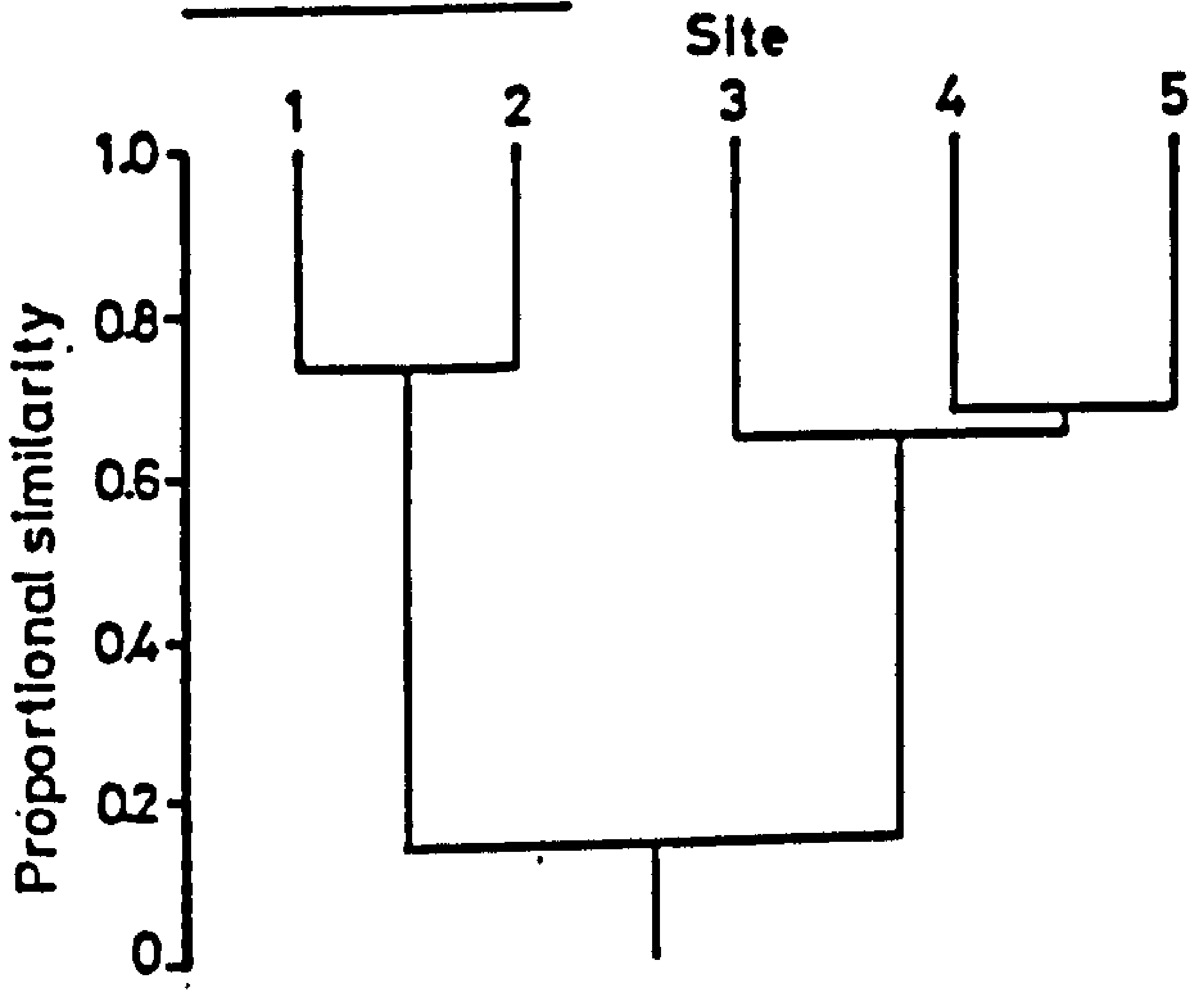
Despite the overlap in freshwater and marine-estuarine species described, the data in Table 2.2 clearly shows a division into freshwater fishes upstream of Preston Dock and marine-estuarine species below. This was reflected in the results of cluster analysis of the pooled seine catches at the sites (Figure 2.12).

FIGURE 2.12

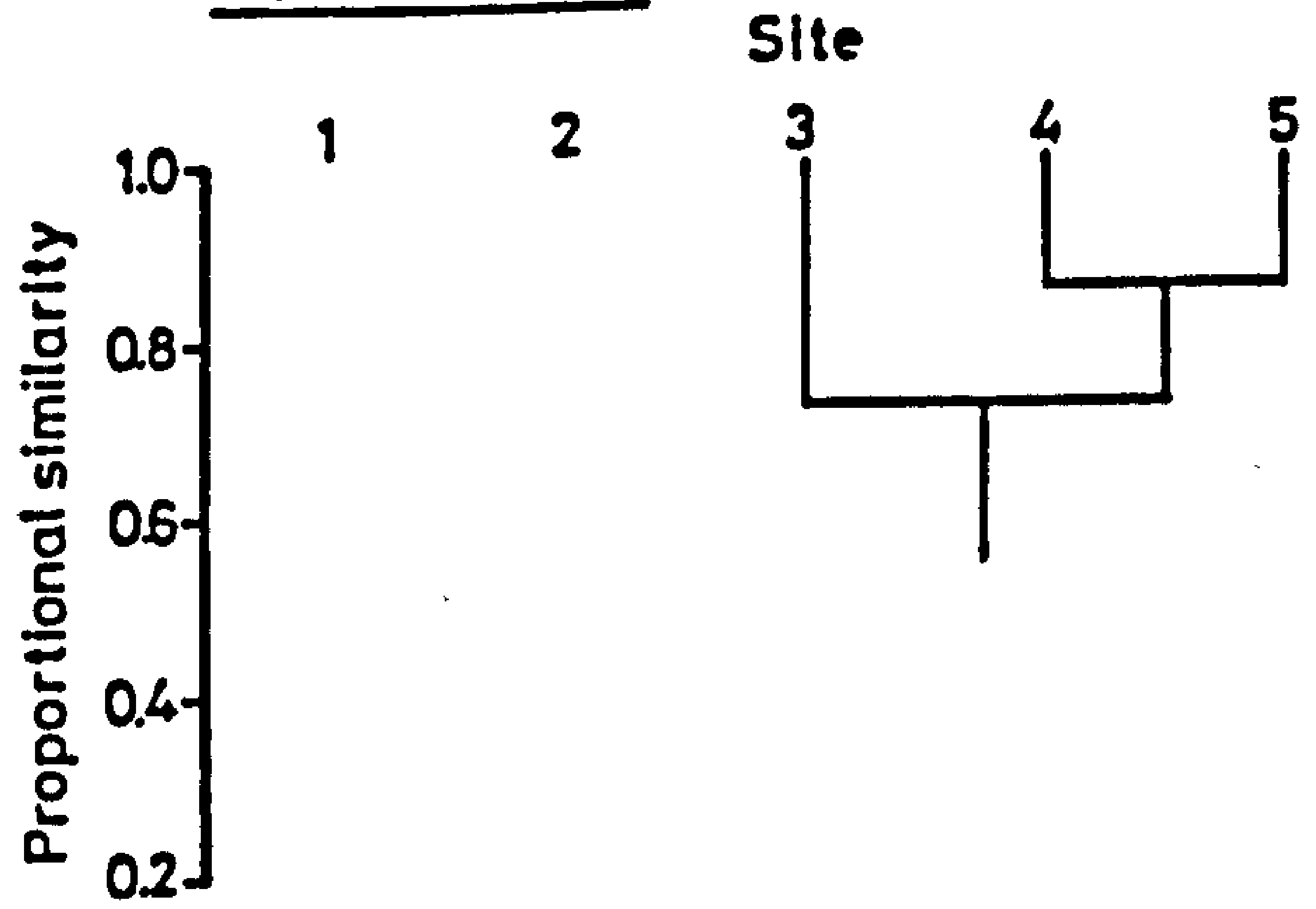
Proportional similarities between sites. Associations in the dendrograms are based on pooled samples over the study period.

FIG. 2.12

Seine catches



Trawl catches



Differences in the total numbers of individuals, numbers of species and the abundance of individual species captured at the three sites in the channelised section were analysed using the Friedman two-way analysis of variance test (Zar, 1974). In each monthly sample the site at which the largest number of individuals or species were captured was assigned a rank of 3, the site at which the second largest number were captured a rank of 2, and the site with the lowest numbers a rank of 1. The ranks were then summed over the study period and the test applied. Where significant differences were detected multiple comparisons were carried out using the Newman-Kuels test (Zar, 1974).

Differences in the rank sums at the sites were apparent and in some of the tests these proved statistically significant ($P < 0.05$) (Table 2.5). However, it is suggested that differences in the numbers of fish captured between the sites were more the result of sampling inefficiencies rather than true differences in abundance. A significant difference was observed between the sites in the trawl catches of sandeels, but as seen earlier the total numbers of sandeels captured in this gear was small. There was no significant difference between the sites in the seine catches of sandeels. A similar contrast in the results for seine and trawl catches occurred in the analysis of the flounder data, seine catches of flounder were significantly lower at Site 3, but in the trawl catches this site had the highest rank sum. The only differences which almost certainly did reflect a variation in species abundance along the channelised section were the greater numbers of dace and roach captured in the seine at Site 3 than at the other sites. Chub were also most frequently captured at Site 3, but because of their low occurrence in the channelised catches generally, the difference was not

Table 2.5a Friedman two-way analysis of variance of seine catches at Sites 3, 4 and 5 in the channelised section. Any two rank sums not underscored by the same line are significantly different at the 5% level (Newman-Kuels test).

Test	Site, Rank sums ( ), and Sign. lines			Sign. level
Total no. individuals	Site 3 (52.0)	Site 4 (44.5)	Site 5 (41.5)	P > 0.05
	———	———	———	
Number of species	Site 3 (52.5)	Site 4 (44.0)	Site 5 (41.5)	P > 0.05
	———	———	———	
S. sprattus	Site 3 (40.5)	Site 4 (34.5)	Site 5 (33.0)	P > 0.05
	———	———	———	
C. harengus	Site 3 (32.5)	Site 4 (35.5)	Site 5 (34.0)	P > 0.05
	———	———	———	
A. tobianus	Site 3 (27.0)	Site 4 (29.5)	Site 5 (27.5)	P > 0.05
	———	———	———	
P. flesus	Site 3 (22.5)	Site 5 (33.5)	Site 4 (40.0)	P < 0.01
		———	———	
	———	———		
P. minutus	Site 3 (24.5)	Site 4 (25.0)	Site 5 (28.5)	P > 0.05
	———	———	———	
P. lozanoi	Site 3 (12.5)	Site 4 (14.0)	Site 5 (15.5)	P > 0.05
	———	———	———	
P. microps	Site 3 (14.5)	Site 4 (19.0)	Site 5 (20.5)	P > 0.05
	———	———	———	
A. anguilla	Site 3 (31.5)	Site 4 (28.5)	Site 5 (24.0)	P > 0.05
	———	———	———	
L. leuciscus	Site 3 (41.0)	Site 4 (23.5)	Site 5 (19.5)	P < 0.001
		———	———	
L. cephalus	Site 3 (22.0)	Site 4 (18.0)	Site 5 (14.0)	P > 0.05
	———	———	———	
R. rutilus	Site 3 (37.5)	Site 4 (22.0)	Site 5 (18.5)	P < 0.001
		———	———	

Table 2.5b Friedman two-way analysis of variance of trawl catches at Sites 3, 4 and 5 in the channelised section. Any two rank sums not underscored by the same line are significantly different at the 5% level (Newman-Kuels test).

Test	Site, Rank sums ( ), and Sign. lines			Sign. level
Total no. individuals	Site 3 (50.5)	Site 4 (43.5)	Site 5 (44.0)	$P > 0.05$
	―――	―――	―――	
Number of species	Site 3 (44.5)	Site 4 (46.5)	Site 5 (47.0)	$P > 0.05$
	―――	―――	―――	
S. sprattus	Site 3 (37.5)	Site 4 (30.5)	Site 5 (40.0)	$P > 0.05$
	―――	―――	―――	
C. harengus	Site 3 (30.0)	Site 4 (26.0)	Site 5 (22.0)	$P > 0.05$
	―――	―――	―――	
A. tobianus	Site 3 (18.5)	Site 4 (26.5)	Site 5 (33.0)	$P < 0.01$
		―――	―――	
	―――	―――		
P. flesus	Site 3 (51.5)	Site 4 (46.5)	Site 5 (40.0)	$P > 0.05$
	―――	―――	―――	
P. platessa	Site 3 (24.0)	Site 4 (24.0)	Site 5 (30.0)	$P > 0.05$
	―――	―――	―――	
P. minutus	Site 3 (47.0)	Site 4 (38.5)	Site 5 (40.5)	$P > 0.05$
	―――	―――	―――	
P. lozanoi	Site 3 (43.0)	Site 4 (32.5)	Site 5 (38.5)	$P > 0.05$
	―――	―――	―――	
P. microps	Site 3 (28.5)	Site 4 (24.5)	Site 5 (25.0)	$P > 0.05$
	―――	―――	―――	
A. anguilla	Site 3 (38.5)	Site 4 (28.0)	Site 5 (29.5)	$P > 0.05$
	―――	―――	―――	

Table 2.6 Results of the Wilcoxon matched-pairs signed-ranks test applied to seine catches at Sites 1 and 2 upstream of Preston Dock.

Test	Relative abundance	Sign. level
Total no. individuals	Site 1 = Site 2	$P > 0.05$
Number of species	Site 1 = Site 2	$P > 0.05$
P. flesus	Site 1 = Site 2	$P > 0.05$
L. leuciscus	Site 1 = Site 2	$P > 0.05$
L. cephalus	Site 1 = Site 2	$P > 0.05$
R. rutilus	Site 1 = Site 2	$P > 0.05$
G. gobio	Site 1 = Site 2	$P > 0.05$
P. phoxinus	Site 1 = Site 2	$P > 0.05$
N. barbatulus	Site 1 > Site 2	$P < 0.05$
G. aculeatus	Site 1 < Site 2	$P < 0.05$
A. anguilla	Site 1 = Site 2	$P > 0.05$

statistically significant ($P > 0.05$).

Upstream of the Dock differences in abundance between Sites 1 and 2 were analysed using the Wilcoxon matched-pairs signed-ranks test (Siegel, 1956). Stoneloach were significantly more abundant at Site 1 and three-spined stickleback significantly more abundant at Site 2 ($P < 0.05$) (Table 2.6). However, these two species were captured in small numbers and no significant differences were observed between the sites in the major species.

Diversity indices

For calculation of the monthly values, catches at all sites were pooled as recommended by Bechtel and Copeland (1970). As observed with total numbers of individuals and numbers of species, the three diversity indices measured often varied widely from month to month (Figure 2.13 and 2.14). The large fluctuations in the indices during the summer months in the channelised section were a consequence of variations in the catches of sprat, their abundance in some months reducing the values. There was often little or no seasonal trend in the indices. Trawl Brillouin (H) values were highest in the summer months with lower values in the winter (Fig. 2.13). Species richness (D) for the trawl also tended to be highest in the summer. Conversely, channelised seine evenness (J) values were maximum in the winter and spring when catches were of a few individuals of many species. On the other hand, seasonal trends in channelised seine H and D, and trawl J were not apparent, and there was also no clear seasonal pattern in any of the three indices for seine catches above the Dock (Fig. 2.14).

Differences in diversity values between the sites were tested for using the procedures outlined in the previous section. There were no significant differences ($P > 0.05$) between the sites either in the channelised section or upstream of the Dock (Tables 2.7 and 2.8).

FIGURE 2.13

Seasonal changes in Brillouin (H), evenness (J), and species richness (D) indices for seine and otter trawl samples in the channelised section.

FIG. 2.13

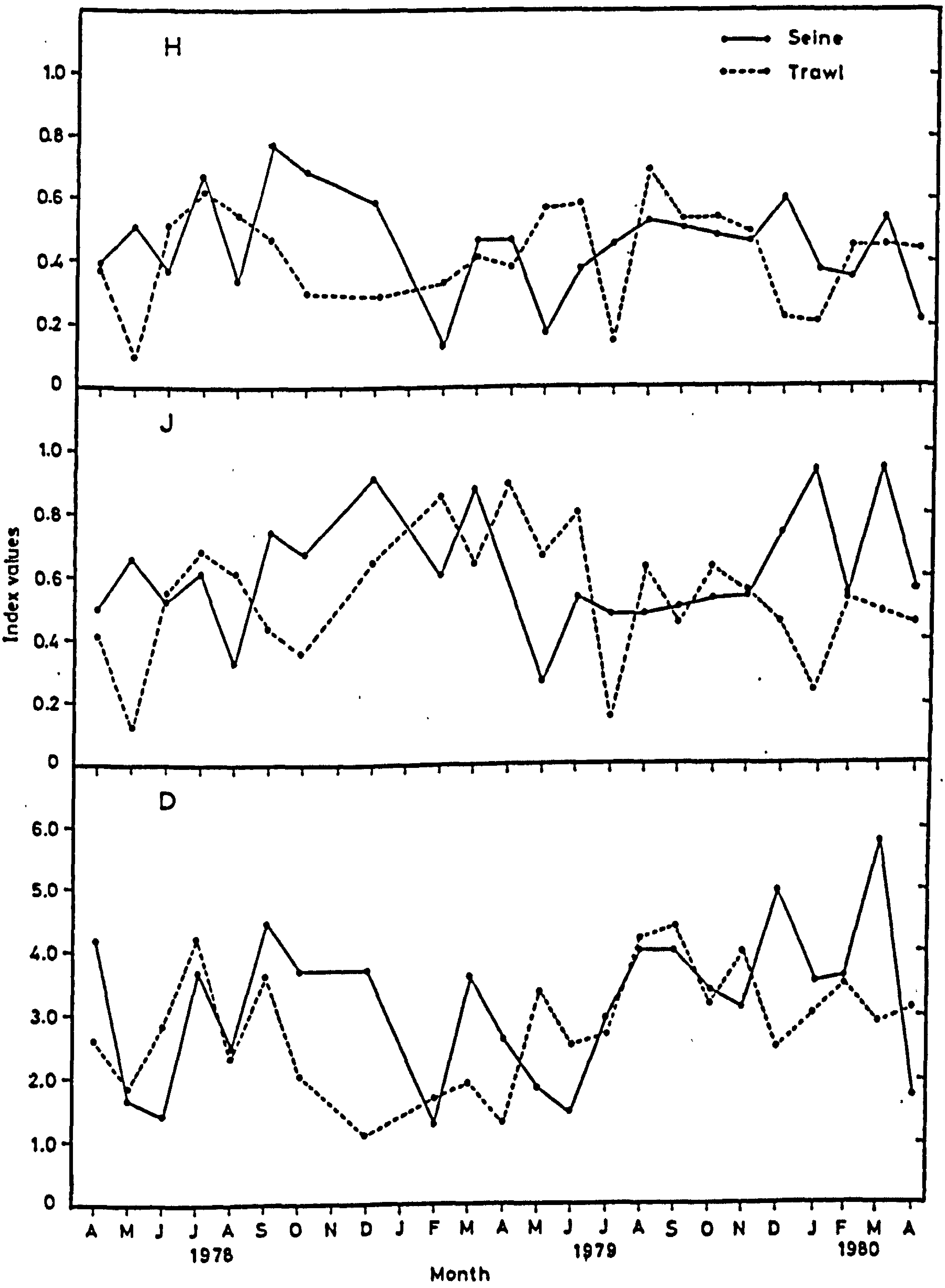

H
Seine
Trawl
J
D
Index values
0
0.2
0.4
0.6
0.8
1.0
1.0
2.0
3.0
4.0
5.0
6.0
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

FIGURE 2.14

Seasonal changes in Brillouin (H), evenness (J), and species richness (D) indices for seine samples upstream of Preston Dock.

FIG. 2.14

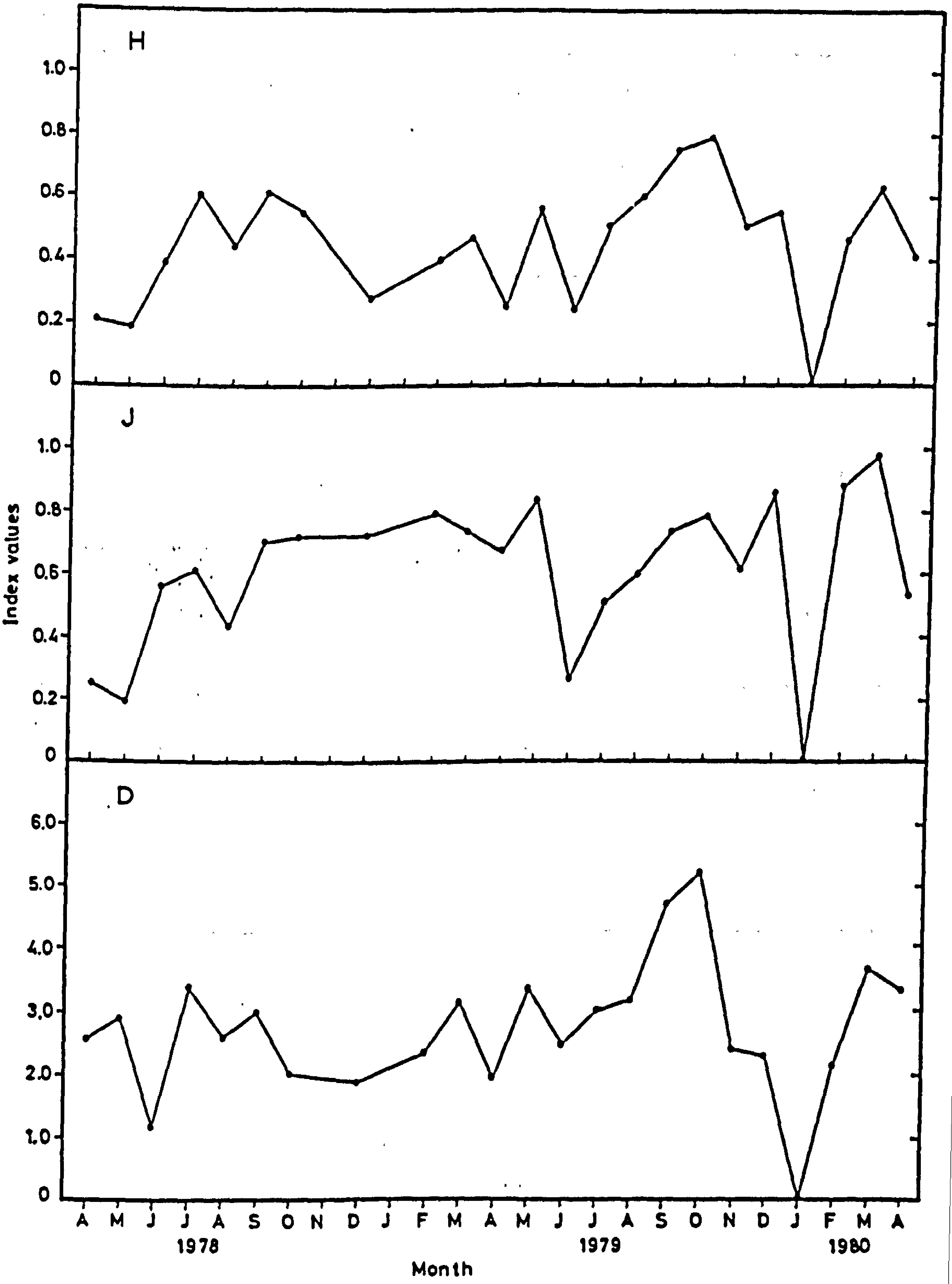

H
J
D
Index values
0
0.2
0.4
0.6
0.8
1.0
0
1.0
2.0
3.0
4.0
5.0
6.0
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Month

Table 2.7 Friedman two-way analysis of variance of diversity indices of seine and trawl catches at Sites 3, 4 and 5 in the channelised section. Underline signifies rank sums not significantly different at 5% level.

Test	Site, Rank sums ( ), and Sign. lines			Sign. level
Seine H	Site 3 (45.0)	Site 4 (45.5)	Site 5 (47.5)	$P > 0.05$
J	Site 3 (44.5)	Site 4 (42.5)	Site 5 (51.0)	$P > 0.05$
D	Site 3 (45.0)	Site 4 (46.5)	Site 5 (46.5)	$P > 0.05$
Trawl H	Site 3 (50.5)	Site 4 (40.0)	Site 5 (47.5)	$P > 0.05$
J	Site 3 (47.0)	Site 4 (44.5)	Site 5 (46.5)	$P > 0.05$
D	Site 3 (39.5)	Site 4 (48.0)	Site 5 (50.5)	$P > 0.05$

Table 2.8 Results of the Wilcoxon matched-pairs signed-ranks test applied to diversity indices of seine catches at Sites 1 and 2

Test	Sites	Sign. level
H	Site 1 = Site 2	$P > 0.05$
J	Site 1 = Site 2	$P > 0.05$
D	Site 1 = Site 2	$P > 0.05$

SECTION B : AGE STRUCTURE OF THE FISH POPULATIONS

METHODS

Members of the principal marine-estuarine (flounder, sprat, herring, P. minutus, P. lozanoi, P. microps) and freshwater (dace, roach, chub) species could often be separated into age groups according to the length-frequency distributions of the samples. However, this method is not completely reliable and where possible age was determined by the examination of otoliths or scales for growth checks. When small numbers of fish were collected all were aged, but if the sample size was large a length-frequency histogram was constructed and fish above the modal length of the 0-group were examined further. No attempt was made to determine the age of individuals of the less abundant species.

Flounder and clupeids were aged by counting the annual rings on their otoliths which were dissected from the auditory capsules and read in creosote against a black background with reflected light. Where necessary, interpretation of the otoliths of large flounder was improved by grinding one surface. The Pomatoschistus species and freshwater fishes were aged by their scales. Gobiid scales were removed from the caudal peduncle of each individual after prior staining in alizarin (Miller, 1975a). P. minutus and P. lozanoi lay down a single growth check each year (Lee, 1974), but P. microps produces an annulus of narrow sclerites on the resumption of growth in the spring and a separate summer annulus, usually laid down in June, corresponding with a retardation of growth during the breeding season (Miller, 1975a). For the ageing of the freshwater species scales were removed from just below and in front of the dorsal fin. The 1st of January was taken as the birthday of the marine-estuarine species, and is the internationally accepted birthday for north temperate marine demersal species (Williams and Bedford, 1974). The freshwater species were assigned a birth date of June 1st (Cragg-Hine and Jones, 1969).

The lengths of all fish captured were recorded. For flounder, in which a detailed examination of seasonal growth was carried out, weights were also taken. All measurements of length were to the nearest millimetre below from the most anterior projection of the closed jaws to the end of the caudal peduncle (standard length), flounder weights were measured to the nearest 0.001g. As a result of preservation in formalin changes in body measurements occurred (Appendix B). There was a small shrinkage in length with most of the decrease taking place within 24 hours, but flounder weight underwent an initial large increase followed by a gradual decline over several months to values approaching live weight. Because of these changes, length and weight measurements of flounder were not taken until the fish had been preserved for 3 months, but length measurements of the other species were recorded after a minimum of 24 hours preservation. Except for flounder all descriptions of size of fish captured are based on length measurements. Length was considered to be a more descriptive indicator of size and growth than weight, and more useful for comparing the results with those of other workers.

Most of the fish used in this study were captured in the regular seine and trawl samples described in Section A of this chapter, but to increase sample size further fish collected during the course of other studies were included in some of the monthly samples. These were collected by the same netting methods or in gear of the same mesh size, and were only included if captured within two days of the regular seine and trawl sampling dates.

Subsampling

When large numbers of O-group sprat or small fish of the other species were caught only a subsample was measured. In an attempt to obtain a random subsample, the whole sample of fish was placed in a container of preservative and stirred vigorously. A small hand net was then used to extract fish until a minimum subsample of 125 fish had been measured.

The effectiveness of this technique for obtaining a representative subsample was examined by comparing the length-frequency distributions and calculated mean lengths of O-group sprat from a subsample with those from the whole sample on three occasions (Table 2:9). All three subsamples did not differ significantly ($P > 0.05$) from the whole samples indicating that the technique did produce representative results.

Gear differences

Data for length-frequency analysis is ideally obtained by non-selective gear which samples the entire length range of fish with equal efficiency. Most fishing gear is, however, selective and the efficiency of the small meshed nets used in the inner estuary can be expected to decrease with increase in fish size. In the channelised section two different methods were employed for sampling. Table 2.10 compares the mean lengths of O-group fish captured in the seine and trawl at all sites along the channelised section; for some of the sprat samples numbers were sufficient to allow a comparison of the two gears at a single location. Catches of the older age groups were too small for an assessment of possible differences in gear selectivity in larger fish. The results show the mean length of flounder and P. minutus taken in the trawl was often significantly greater ($P < 0.05$) than the mean length of fish taken in the seine.

Table 2.9 Comparison of length frequency and mean length of 0-group sprat from a subsample and whole sample on three occasions.

Sample A

Length (mm)	Obs. freq. n=125	Exp. freq. n=755	χ^2
≤ 21	2	1.3	0.377
22	3	4.1	0.295
23	17	12.8	1.378
24	22	23.0	0.043
25	36	38.1	0.116
26	23	25.5	0.245
27	14	11.6	0.496
28	5	6.1	0.198
29	2	1.3	0.377
≥ 30	1	1.2	0.033

Comparison of length distributions:
$\chi^2 = 3.558$; $P > 0.05$

Comparison of mean lengths:
subsample = 25.0
whole sample = 25.1
$t = 0.392$; $P > 0.05$

Sample B

Length (mm)	Obs. freq. n=125	Exp. freq. n=650	χ^2
≤ 26	1	1.2	0.033
27	3	1.5	1.500
28	7	8.1	0.149
29	11	10.6	0.015
30	8	8.6	0.042
31	14	13.9	0.001
32	12	14.2	0.341
33	14	13.7	0.006
34	13	11.9	0.102
35	9	9.0	-
36	5	7.5	0.833
37	7	7.1	0.001
38	6	6.0	-
39	3	2.9	0.003
40	5	2.3	3.169
41	3	1.9	0.637
≥ 42	4	4.6	0.078

Comparison of length distributions:
$\chi^2 = 6.910$; $P > 0.05$

Comparison of mean lengths:
subsample = 33.4
whole sample = 33.3
$t = 0.210$; $P > 0.05$

Sample C

Length (mm)	Obs. freq. n=125	Exp. freq. n=376	χ^2
≤ 40	2	1.0	1.000
41	3	2.3	0.213
42	3	4.7	0.615
43	6	8.7	0.838
44	11	14.0	0.643
45	27	27.3	0.003
46	20	20.7	0.024
47	19	16.7	0.317
48	13	12.7	0.227
49	10	8.0	0.500
50	5	4.0	0.250
51	5	3.7	0.457
≥ 52	1	1.0	-

Comparison of length distributions:
$\chi^2 = 5.087$; $P > 0.05$

Comparison of mean lengths:
subsample = 46.1
whole sample = 46.2
$t = 0.659$; $P > 0.05$

Table 2.10 Comparison of mean lengths of fish captured in the seine and trawl. Sample sizes are shown in parentheses.

a) Sprat

Month	Trawl $\bar{x}$	Seine $\bar{x}$	t	Probability
May 1978	45.7 (200)	46.2 (200)	1.938	$P > 0.05$
June	24.8 (160)	32.0 (72)	10.563	$P < 0.001$
August	32.3 (125)	33.1 (125)	1.805	$P > 0.05$
September	29.6 (110)	33.7 (108)	7.945	$P < 0.001$
July 1979	25.5 (100)	25.6 (55)	0.253	$P > 0.05$
August	32.0 (145)	33.0 (255)	1.736	$P > 0.05$
September	36.3 (53)	37.7 (200)	1.266	$P > 0.05$

b) Flounder

Month	Trawl $\bar{x}$	Seine $\bar{x}$	t	Probability
September 1978	50.9 (14)	44.9 (53)	2.538	$P < 0.05$
October	57.2 (41)	52.7 (68)	2.661	$P < 0.01$
July 1979	27.8 (13)	25.2 (31)	1.184	$P > 0.05$
August	39.1 (40)	36.9 (33)	0.940	$P > 0.05$

c) <u>P. minutus</u>

Month	Trawl $\bar{x}$	Seine $\bar{x}$	t	Probability
July 1978	23.4 (103)	18.4 (100)	9.690	$P < 0.001$
August	28.5 (335)	28.6 (60)	0.037	$P > 0.05$
October	41.3 (713)	39.4 (140)	3.173	$P < 0.01$
July 1979	19.0 (23)	16.7 (33)	2.503	$P < 0.05$
October	47.9 (64)	40.3 (60)	6.470	$P < 0.001$

On the other hand, on two occasions the mean length of sprat captured was significantly greater in the seine than the trawl.

These differences may not, however, necessarily reflect a bias towards different sizes of O-group fish by the two gears. As will be seen in Chapter 3 there was a suggestion that smaller individuals of the demersal species were more common in the shallower depths of water on the intertidal banks sampled by the seine. Considering sprat, on five other occasions when comparisons were made the mean lengths were similar, and the differences recorded in June and September 1978 were most probably the result of the two gears collecting fish from shoals of different sized fish.

Despite the differences observed and the fact that the length distribution of a monthly sample of fish may vary according to whether the majority of the fish were taken in the seine or the trawl, it was necessary to combine the data since the collections were usually too small to be analysed separately.

RESULTS

Marine-estuarine species

Monthly length-frequency distributions of herring, sprat, *P. minutus*, *P. lozanoi* and *P. microps* are shown in Figures 2.15 - 2.18. Data on length and weight of flounder are not included in the figures, the age and growth of this species is considered separately in a following section.

Nearly all of the large numbers of fish taken in catches in the summer and early autumn months were of the O-age group. Herring of the new year class were first captured in April-May as postlarvae with a modal length of 40mm. O-group sprat entered catches later

Length-frequency distributions of marine-estuarine species.

FIGURE 2.15 *C. harengus*

FIGURE 2.16 *S. sprattus*

FIGURE 2.17 *P. minutus* and *P. lozanoi*

FIGURE 2.18 *P. microps*

Histograms in 2mm length groups. The number of individuals in each monthly distribution is shown, no data are presented where less than 5 fish available in a month. Length ranges enclosed in brackets indicate subsample measured with numbers in subsample and whole sample given above bracket. Shade, 1977 year class; white, 1978 year class; hatched, 1979 year class.

FIG. 2.15

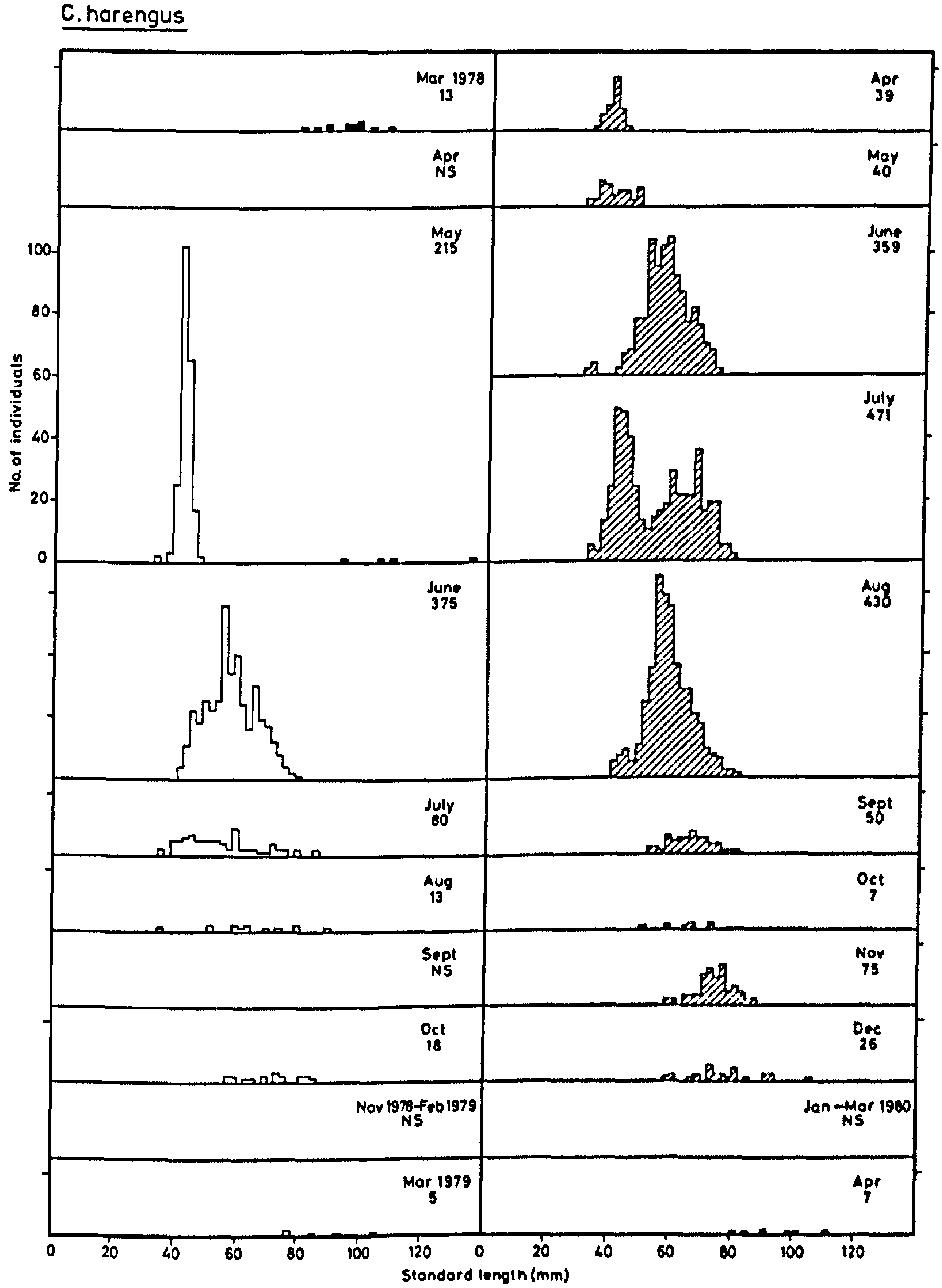

C. harengus
Mar 1978
13
Apr
NS
May
215
June
375
July
80
Aug
13
Sept
NS
Oct
18
Nov 1978–Feb 1979
NS
Mar 1979
5
Apr
39
May
40
June
359
July
471
Aug
430
Sept
50
Oct
7
Nov
75
Dec
26
Jan –Mar 1980
NS
Apr
7
No. of individuals
0
20
40
60
80
100
0
20
40
60
80
100
120
Standard length (mm)

FIG. 2.16

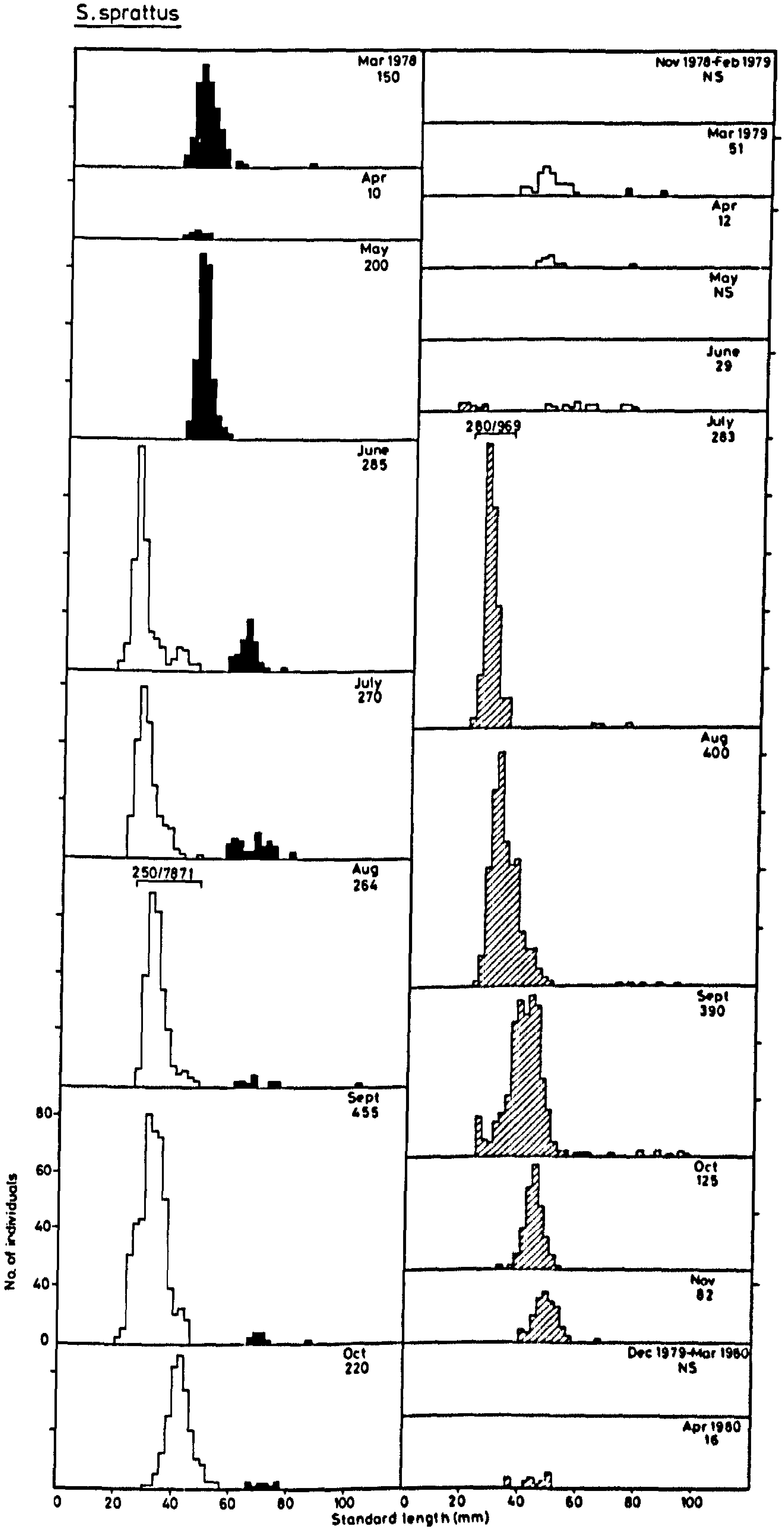

S. sprattus
Mar 1978
150
Apr
10
May
200
June
285
July
270
250/7871
Aug
264
Sept
455
Oct
220
Nov 1978-Feb 1979
NS
Mar 1979
51
Apr
12
May
NS
June
29
280/969
July
283
Aug
400
Sept
390
Oct
125
Nov
82
Dec 1979-Mar 1980
NS
Apr 1980
16
80
60
40
40
0
No. of individuals
0
20
40
60
80
100
0
20
40
60
80
100
Standard length (mm)

FIG. 2.17

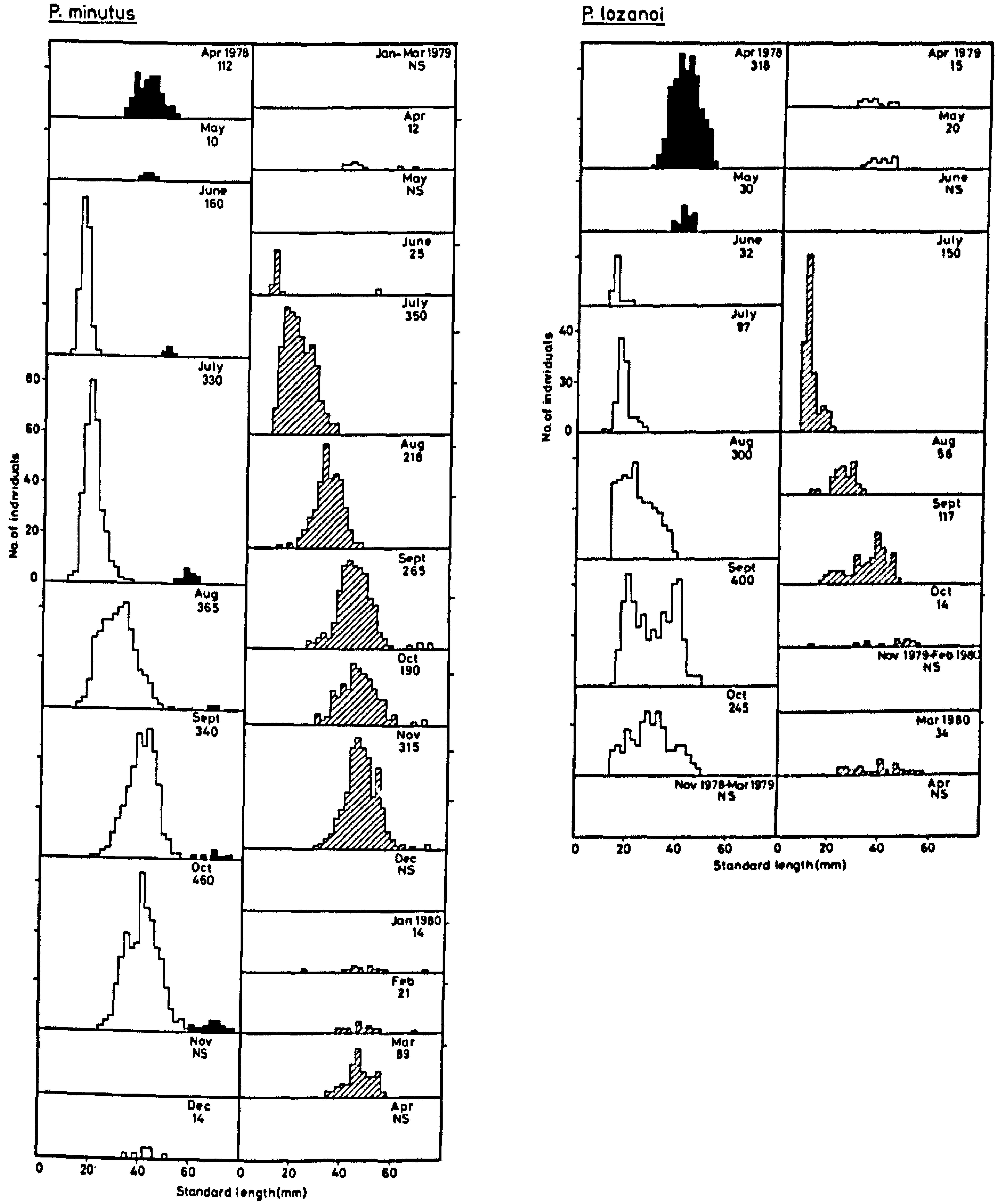

P. minutus
Apr 1978
112
May
10
June
160
July
330
Aug
365
Sept
340
Oct
460
Nov
NS
Dec
14
Jan-Mar 1979
NS
Apr
12
May
NS
June
25
July
350
Aug
218
Sept
265
Oct
190
Nov
315
Dec
NS
Jan 1980
14
Feb
21
Mar
89
Apr
NS
80
60
40
20
0
No. of individuals
0
20
40
60
0
20
40
60
Standard length(mm)
P. lozanoi
Apr 1978
318
May
30
June
32
July
97
Aug
300
Sept
400
Oct
245
Nov 1978-Mar 1979
NS
Apr 1979
15
May
20
June
NS
July
150
Aug
56
Sept
117
Oct
14
Nov 1979-Feb 1980
NS
Mar 1980
34
Apr
NS
40
30
0
No. of individuals
0
20
40
60
0
20
40
60
Standard length (mm)

FIG. 2.18

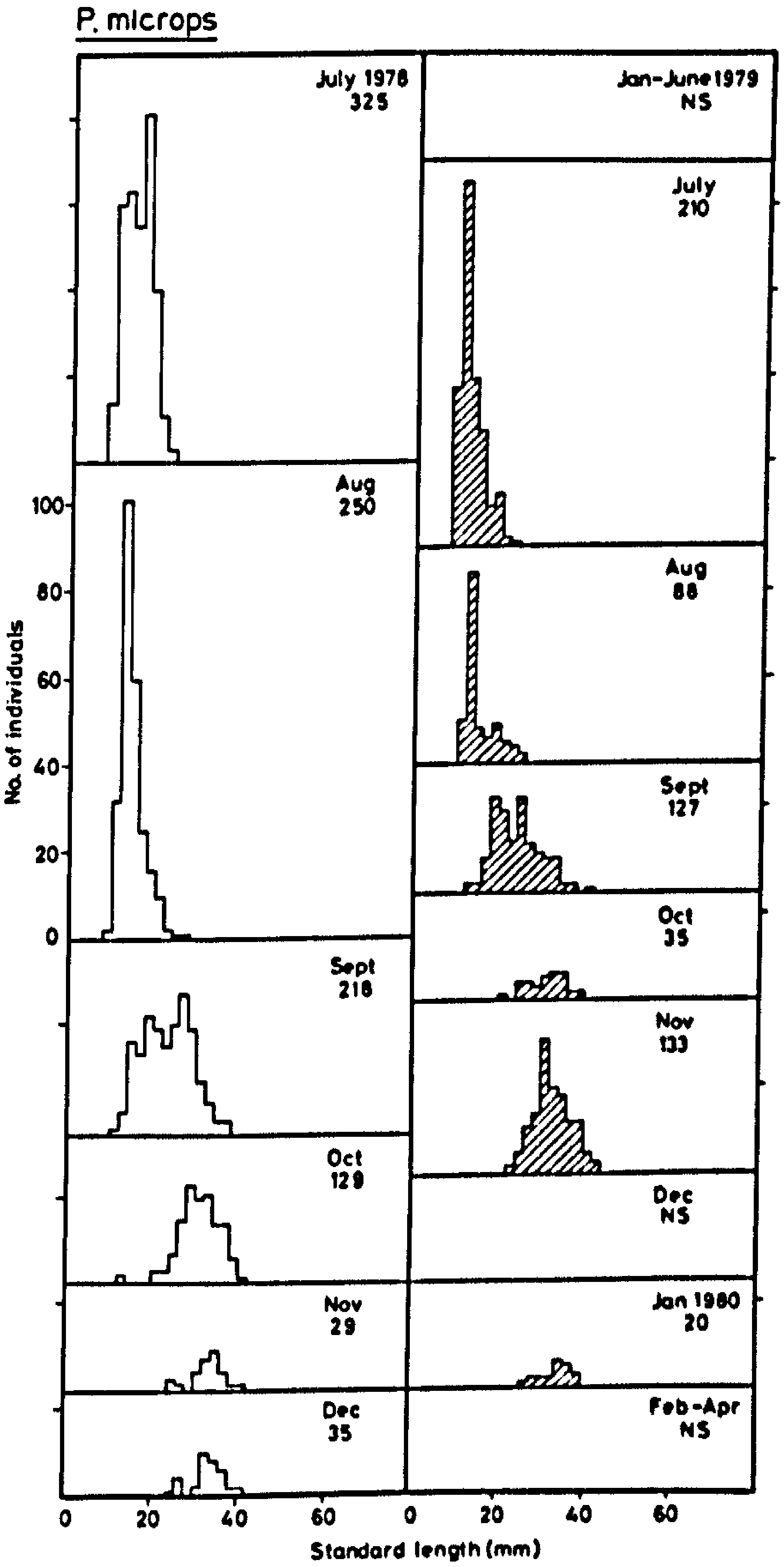
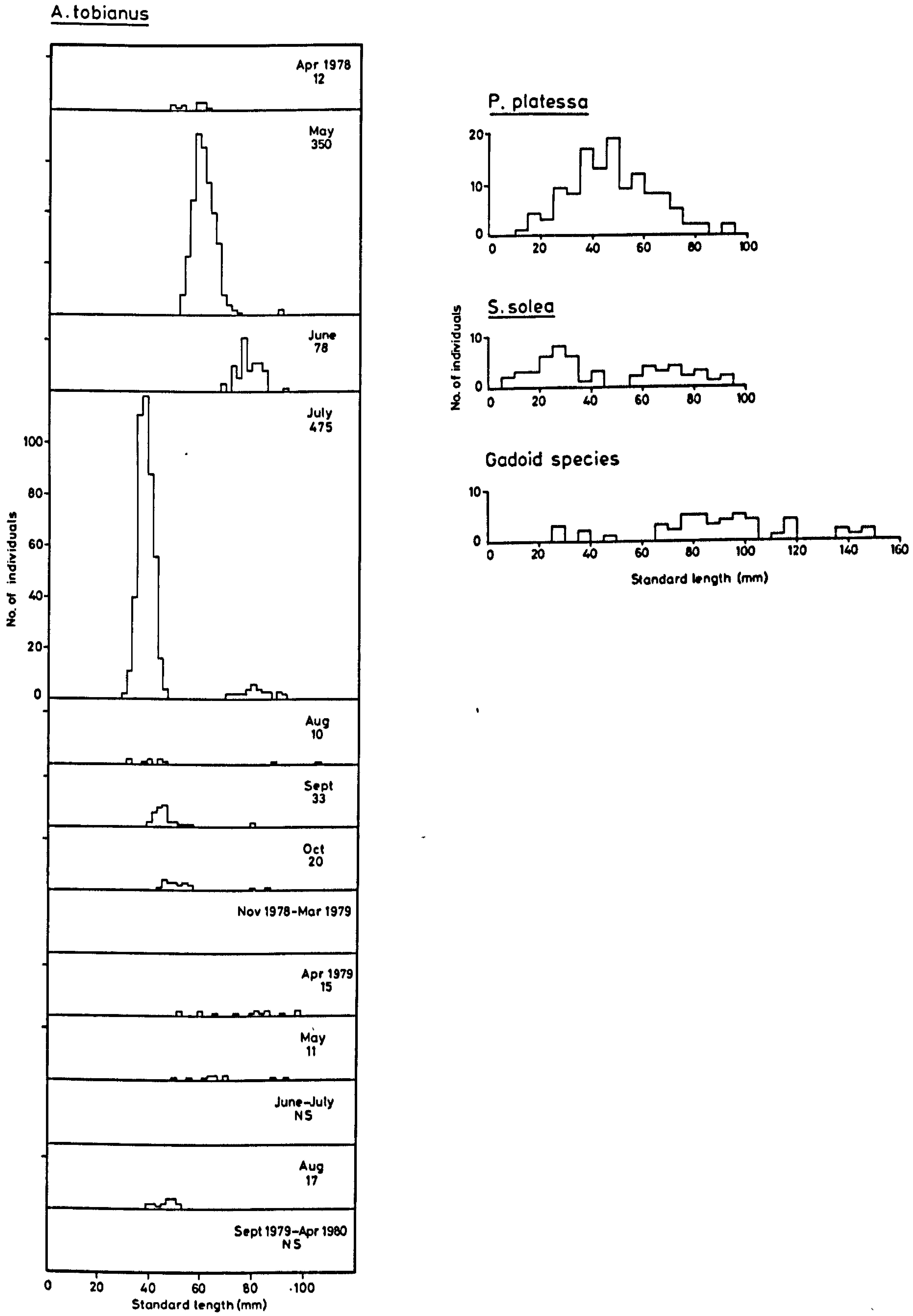

P. microps
July 1978
325
Aug
250
Sept
218
Oct
128
Nov
29
Dec
35
Jan-June 1979
NS
July
210
Aug
88
Sept
127
Oct
35
Nov
133
Dec
NS
Jan 1980
20
Feb-Apr
NS
No. of individuals
100
80
60
40
20
0
0
20
40
60
0
20
40
60
Standard length (mm)

FIGURE 2.19

Length-frequency distributions of monthly samples of A. tobianus, and length distributions of P. platessa, S. solea and gadoid species (G. morhua, M. merlangus, P. pollachius, T. luscus) taken over the entire study period. Histograms for A. tobianus in 2mm length groups, histograms for other species in 5mm length groups. The fish were not aged.

FIG. 2.19


A. tobianus
Apr 1978
12
May
350
June
78
July
475
Aug
10
Sept
33
Oct
20
Nov 1978-Mar 1979
Apr 1979
15
May
11
June-July
NS
Aug
17
Sept 1979-Apr 1980
NS
No. of individuals
0
20
40
60
80
100
0
20
40
60
80
100
Standard length (mm)
P. platessa
20
10
0
0
20
40
60
80
100
S. solea
No. of individuals
10
0
0
20
40
60
80
100
Gadoid species
10
0
0
20
40
60
80
100
120
140
160
Standard length (mm)

than herring in June. These were also mainly postlarval fish of 15-30mm length. In 1978 O-group P. minutus and P. lozanoi were first taken in June. In 1979 a small number of O-group P. minutus were taken in the June sample, but P. lozanoi was not recorded until July. Postlarval and small juvenile P. microps were not collected in the inner estuary until July of both years.

Small fish of the species continued to be taken through the summer months. The marked bimodality in the length distribution of O-group herring in July 1979 was caused by the capture of a large number of small fish with a modal length almost the same as that of the sample collected in the previous April. These small herring were probably from a late spawning (Bowers, 1952). In August 1979 the distribution again showed only one mode, positioned between the two modes of the previous month's sample. The length distribution of P. lozanoi in September 1978 was also bimodal, but reverted to a unimodal form in the October sample. As nearly all of the P. lozanoi were taken in the trawl the bimodal distribution was not an effect of a combination of samples from shallow and deep water (see Methods).

The marine-estuarine species were aged from 1 January and on this date the O-group fish were promoted to age group I, this being the dominant age group until the arrival of the next year class in the summer months. Only a small number of I-group herring were recorded in samples, and all were collected in the early months of the year. In contrast, I-group sprat were regularly taken through the year, although in low numbers after the early summer months. A few sprat of age group II were also collected. Of the two sand goby species I-group P. minutus were present through the year, but I-group P. lozanoi were not taken in samples after May. Age group I P. microps were rare in the inner estuary throughout the year.

Length-frequency distributions of other marine-estuarine species taken in catches, but which were not aged, are shown in Figure 2.19. The length distributions of sandeels (A. tobianus) in the spring and early summer of 1978 when they were common in catches shows two distinct series of modes. A. tobianus has separate spring- and autumn-spawning groups (Cameron, 1958; Reay, 1973) and the different modes probably correspond with the juveniles of the two groups. Figure 2.19 includes length distributions for plaice (Pleuronectes platessa L.) and sole (Solea solea (L.)) taken over the whole study period. A similar composite is shown for the large gadoid species captured (Gadus morhua L., Merlangius merlangus (L.), Pollachius pollachius (L.), Trisopterus luscus (L.)). Although the fish were not aged, the length distributions indicate most were of the O- and I-age groups.

Freshwater species and eels

Fish of the O-age group also dominated the catches of the freshwater species (Figures 2.20 and 2.21) with the new year class of dace preceding the appearance of O-group roach and chub during the early summer. The small number of older individuals taken were captured at the two sites upstream of Preston Dock, all of the freshwater fish captured in the channelised section were O-group.

Figure 2.22 shows the length distributions of eels taken in catches. Most were elvers immigrating through the estuary into the freshwater reaches during the spring and early summer. The length range up to 230mm shown on the histograms included the majority of the eels captured. Fish of greater length were captured, but in very small numbers and they are not represented diagrammatically.

Length-frequency distributions of freshwater species.

FIGURE 2.20 <u>L. leuciscus</u>

FIGURE 2.21 <u>R. rutilus</u> and <u>L. cephalus</u>

Histograms in 2mm length groups. The number of individuals in each monthly distribution is shown. No data are presented where less than 5 fish available in a month. Shade, 1977 year class; white, 1978 year class; hatched, 1979 year class.

FIG. 2.20

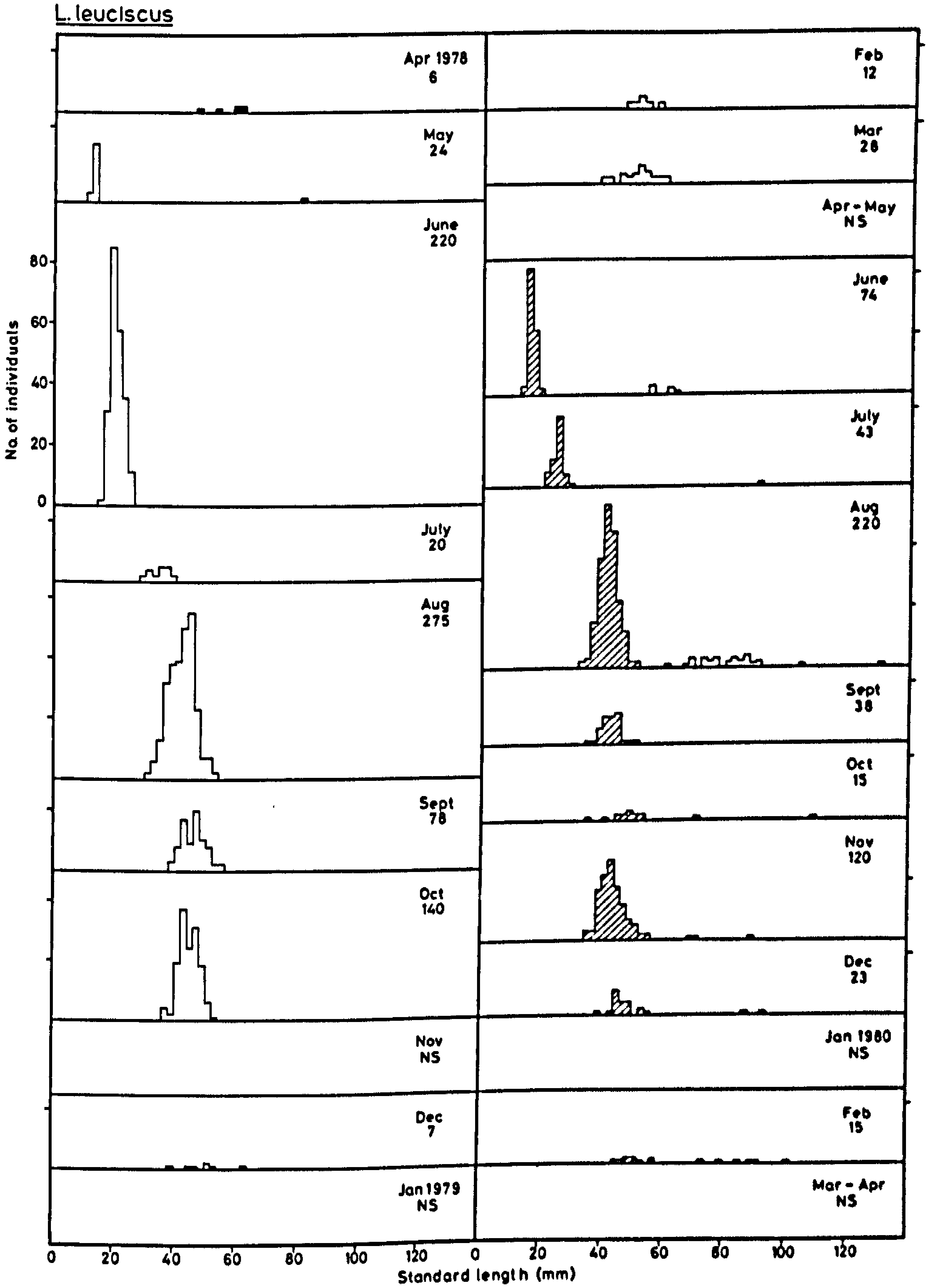

L. leuciscus
Apr 1978
6
May
24
June
220
July
20
Aug
275
Sept
78
Oct
140
Nov
NS
Dec
7
Jan 1979
NS
Feb
12
Mar
28
Apr - May
NS
June
74
July
43
Aug
220
Sept
38
Oct
15
Nov
120
Dec
23
Jan 1980
NS
Feb
15
Mar - Apr
NS
No. of individuals
0
20
40
60
80
0
20
40
60
80
100
120
0
20
40
60
80
100
120
Standard length (mm)

FIG. 2.21

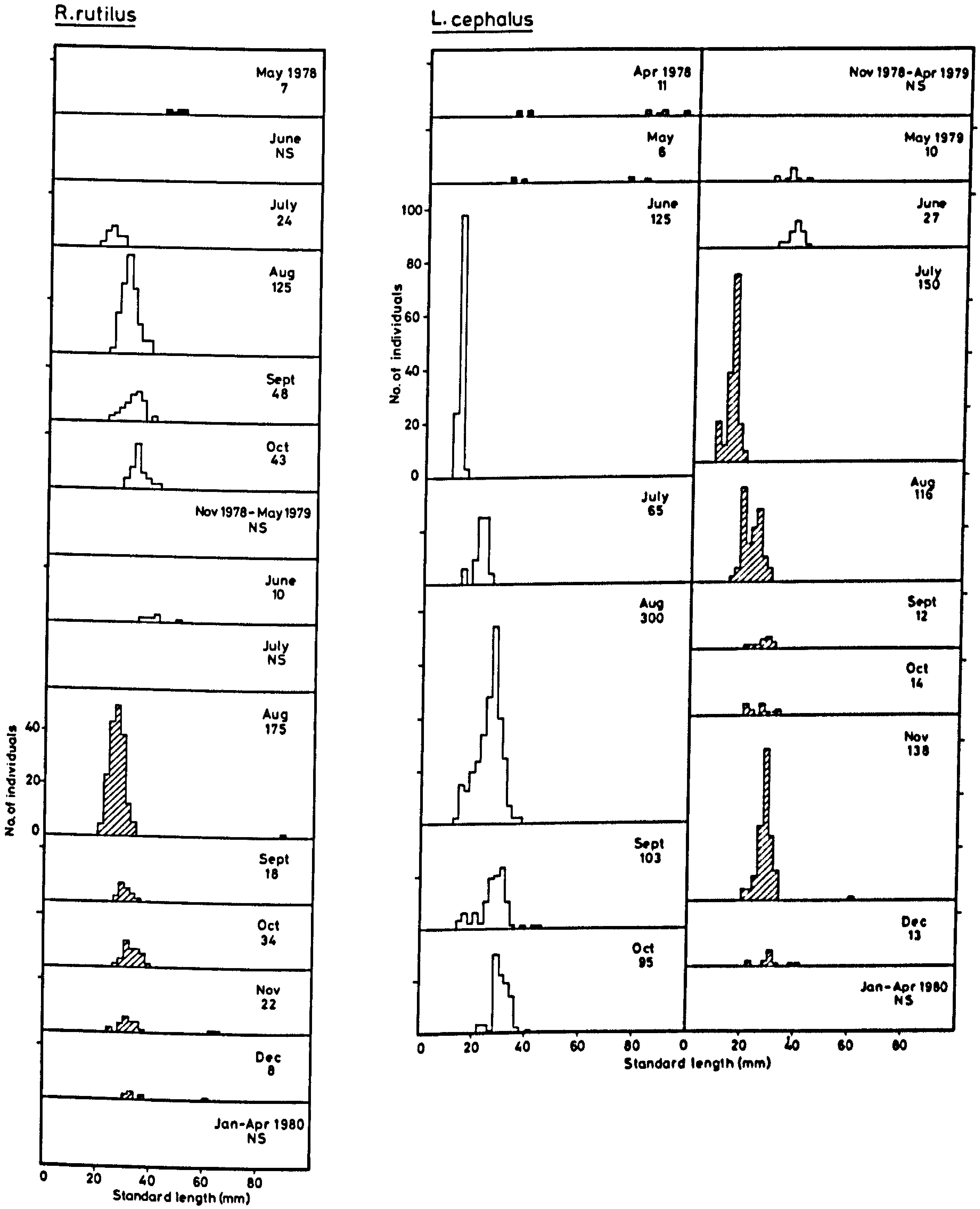

R.rutilus
May 1978 7
June NS
July 24
Aug 125
Sept 48
Oct 43
Nov 1978-May 1979 NS
June 10
July NS
Aug 175
Sept 18
Oct 34
Nov 22
Dec 8
Jan-Apr 1980 NS
No. of individuals
0
20
40
0 20 40 60 80
Standard length (mm)
L. cephalus
Apr 1978 11
May 6
June 125
July 65
Aug 300
Sept 103
Oct 95
No. of individuals
0
20
40
60
80
100
Nov 1978-Apr 1979 NS
May 1979 10
June 27
July 150
Aug 116
Sept 12
Oct 14
Nov 138
Dec 13
Jan-Apr 1980 NS
0 20 40 60 80 0 20 40 60 80
Standard length (mm)

FIGURE 2.22

Length-frequency distributions of A. anguilla. Histograms in 2mm length groups. Only individuals up to 230mm standard length are shown. The number of individuals in each monthly distribution is shown, no data are presented where less than 5 fish available in a month. The fish were not aged.

FIG. 2.22

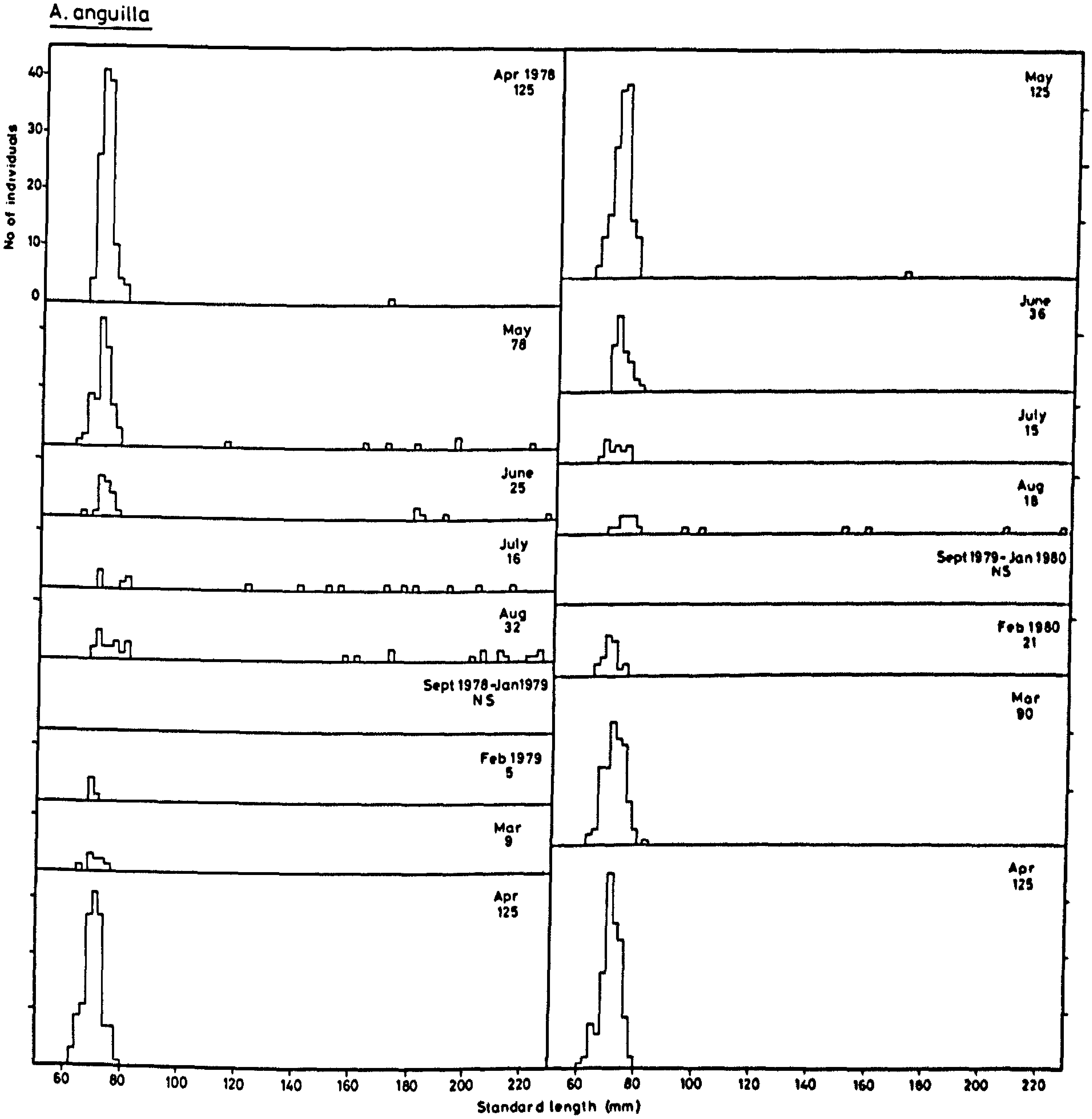

A. anguilla
No of individuals
0
10
20
30
40
Apr 1978
125
May
78
June
25
July
16
Aug
32
Sept 1978-Jan1979
NS
Feb 1979
5
Mar
9
Apr
125
May
125
June
36
July
15
Aug
18
Sept 1979-Jan 1980
NS
Feb 1980
21
Mar
90
Apr
125
60
80
100
120
140
160
180
200
220
60
80
100
120
140
160
180
200
220
Standard length (mm)

FIGURE 2.23

Length-frequency distributions of flounder from the channelised section. Histograms in 2mm length groups. Only fish up to 180mm standard length are included. The number of individuals in each monthly distribution is shown. Stippled, 1976 year class; shade, 1977 year class; white, 1978 year class; hatched, 1979 year class.

FIGURE 2.24

Seasonal changes in mean length and weight (± 95% confidence limits) of the principal year classes of flounder from the channelised section.

Growth of flounder

a) Length distributions

Length-frequency distributions of flounder from the channelised section and upstream of Preston Dock are presented in Figures 2.23 and 2.25 respectively, with seasonal changes in mean length and weight of the principal year classes shown in Figures 2.24 and 2.26. Most of the flounder belonged to the 0- and I-age groups, but a small number of fish of older age groups were taken in the channelised section (Table 2.11). On the length-frequency distributions for flounder from the channelised section, only fish up to 180mm are shown. This length range included all fish of the age groups 0-II, but larger individuals of the older age groups are not presented. The length-frequency distributions for flounder upstream of the Dock includes all fish captured.

0-group flounder first entered the estuary in the latter part of May, a series of samples every few days at Sites 1 and 2 indicated they arrived on or just after 20 May of both years. The majority of the fish were metamorphosing or newly metamorphosed and the appearance of the 0-group is shown on the length-frequency distributions by the new mode at 8-16mm. The influx of small flounder continued until late July with newly metamorphosed fish of 14-15mm still present in catches in September in 1979. While these young fish were captured in large numbers at the two sites upstream of Preston Dock, generally, they were taken in much smaller numbers in the regular seine and trawl samples in the channelised section. Most of the young flounder shown on the length-frequency distribution for June 1978 in the channelised section were taken in low water trawls carried out in the estuary.

At the start of the flounder immigration in June 0-group fish

FIG. 2.23

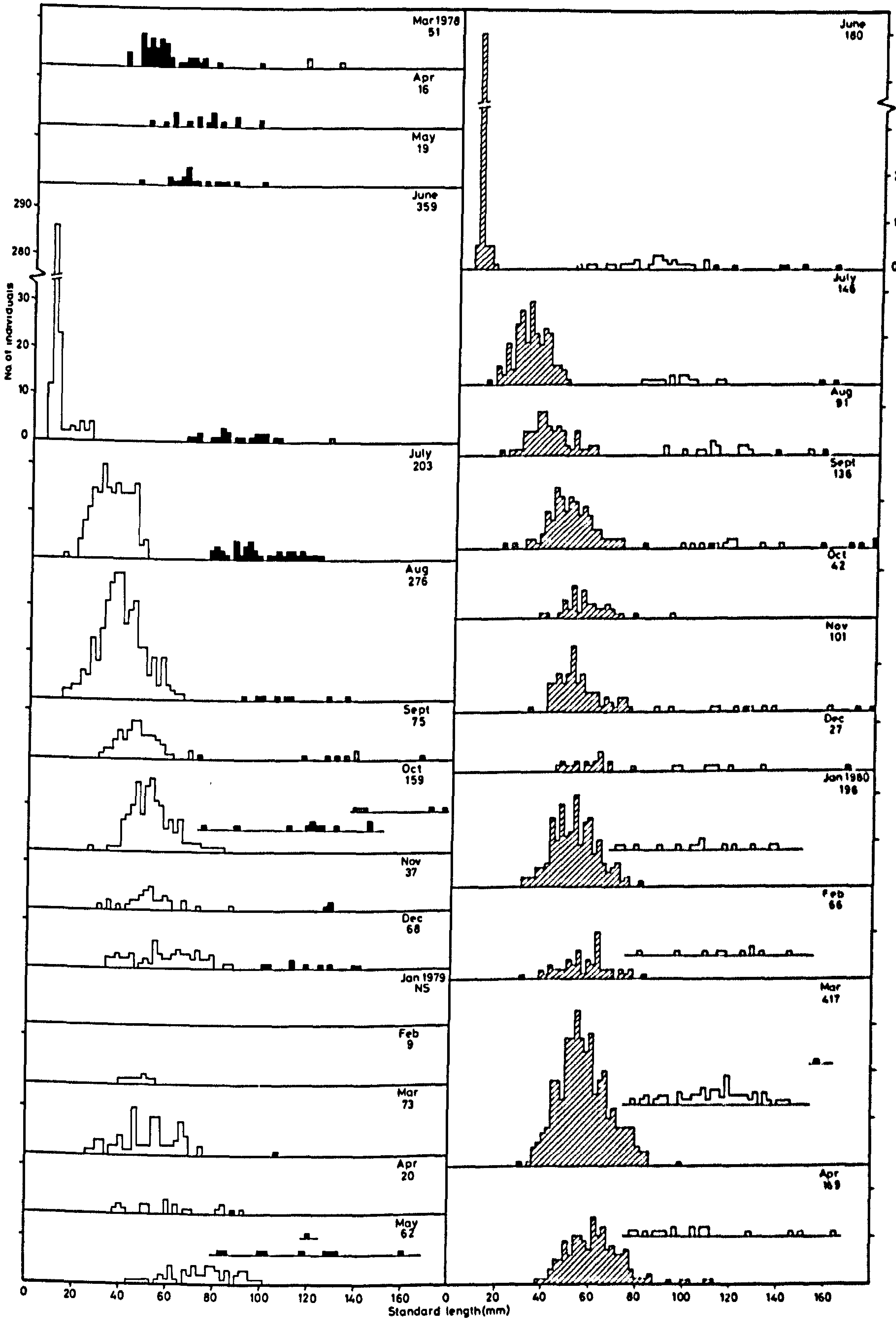

Mar 1978
51
Apr
16
May
19
June
359
July
203
Aug
276
Sept
75
Oct
159
Nov
37
Dec
68
Jan 1979
NS
Feb
9
Mar
73
Apr
20
May
62
290
280
30
20
10
0
No. of individuals
June
180
July
146
Aug
91
Sept
136
Oct
42
Nov
101
Dec
27
Jan 1980
196
Feb
66
Mar
417
Apr
169
130
120
30
20
10
0
0
20
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160
Standard length(mm)

FIG. 2.24

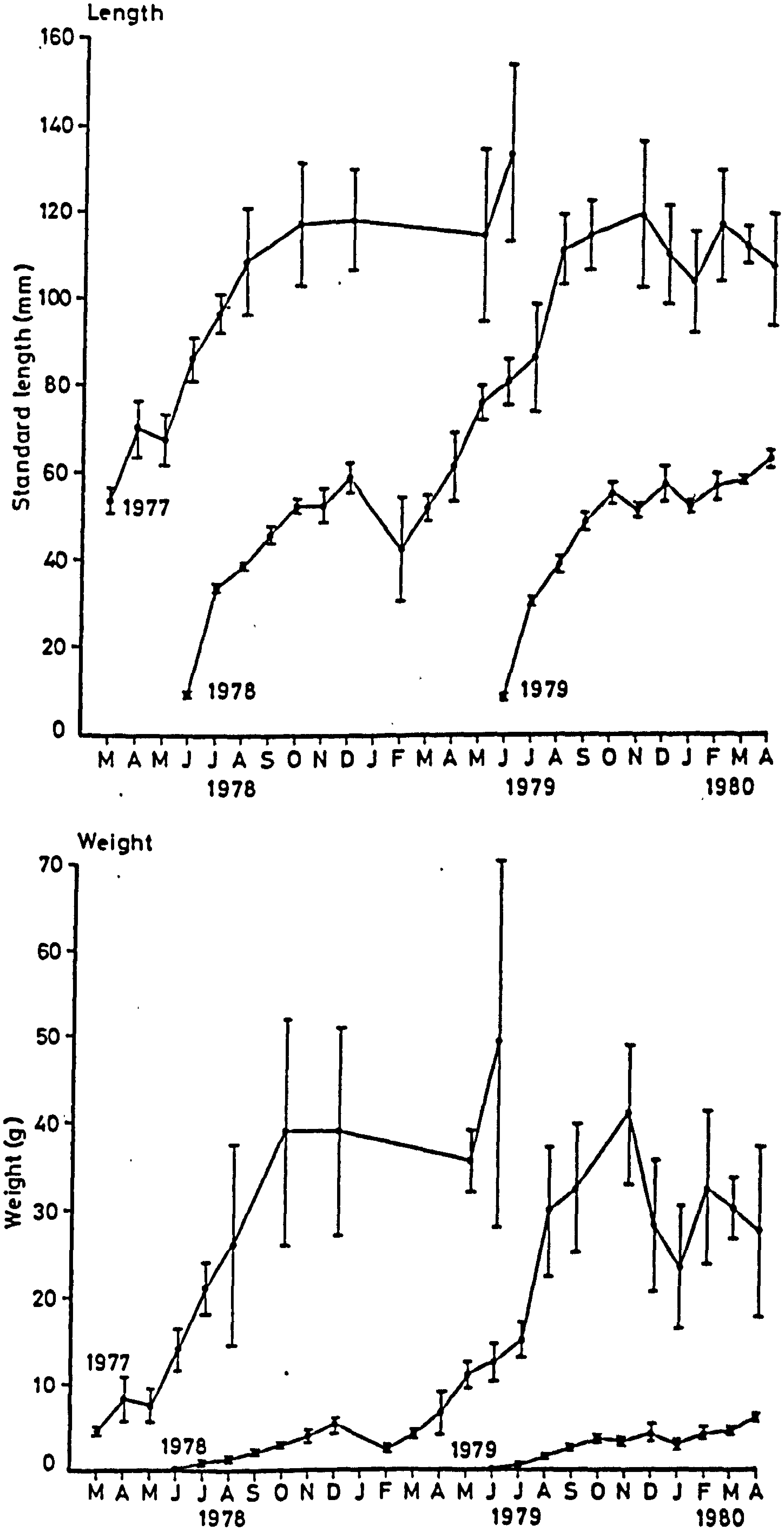

Length
Standard length (mm)
160
140
120
100
80
60
40
20
0
1977
1978
1979
M A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Weight
Weight (g)
70
60
50
40
30
20
10
0
1977
1978
1979
M A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980

FIGURE 2.25

Length-frequency distributions of flounder from upstream of Preston Dock. Histograms in 2mm length groups. The number of individuals in each monthly distribution is shown, no data are presented where less than 5 fish available in a month. Length ranges enclosed in brackets indicate subsample measured with numbers in subsample and whole sample given above bracket. Shade, 1977 year class; white, 1978 year class; hatched, 1979 year class.

FIGURE 2.26

Seasonal changes in mean length and weight (± 95% confidence limits) of the principal year classes of flounder from upstream of Preston Dock.

FIG. 2.25

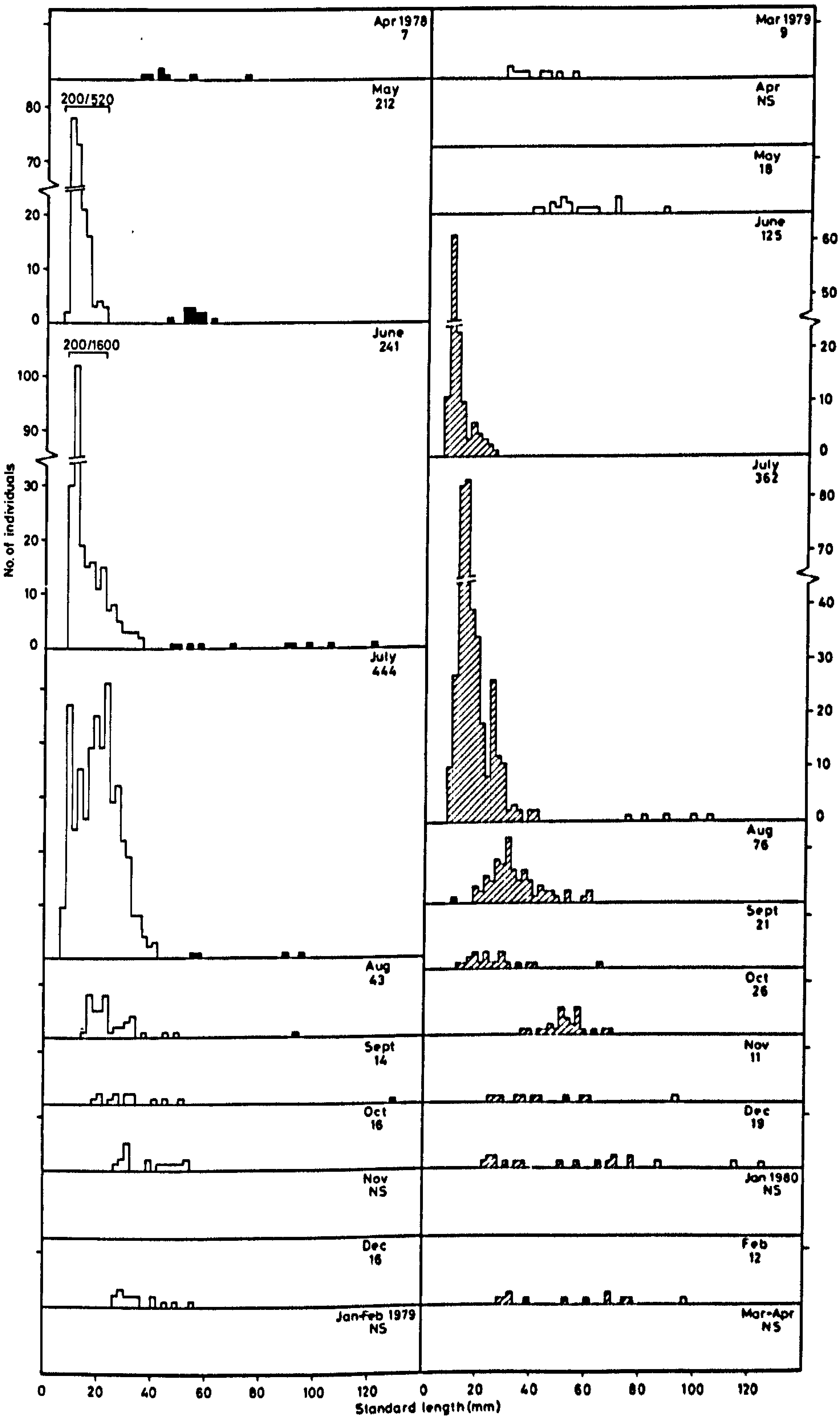

Apr 1978
7
May
212
200/520
80
70
20
10
0
June
241
200/1600
100
90
30
20
10
0
No. of individuals
July
444
Aug
43
Sept
14
Oct
16
Nov
NS
Dec
16
Jan-Feb 1979
NS
Mar 1979
9
Apr
NS
May
18
June
125
60
50
20
10
0
July
362
80
70
40
30
20
10
0
Aug
76
Sept
21
Oct
26
Nov
11
Dec
19
Jan 1980
NS
Feb
12
Mar-Apr
NS
0
20
40
60
80
100
120
0
20
40
60
80
100
120
Standard length (mm)

FIG. 2.26

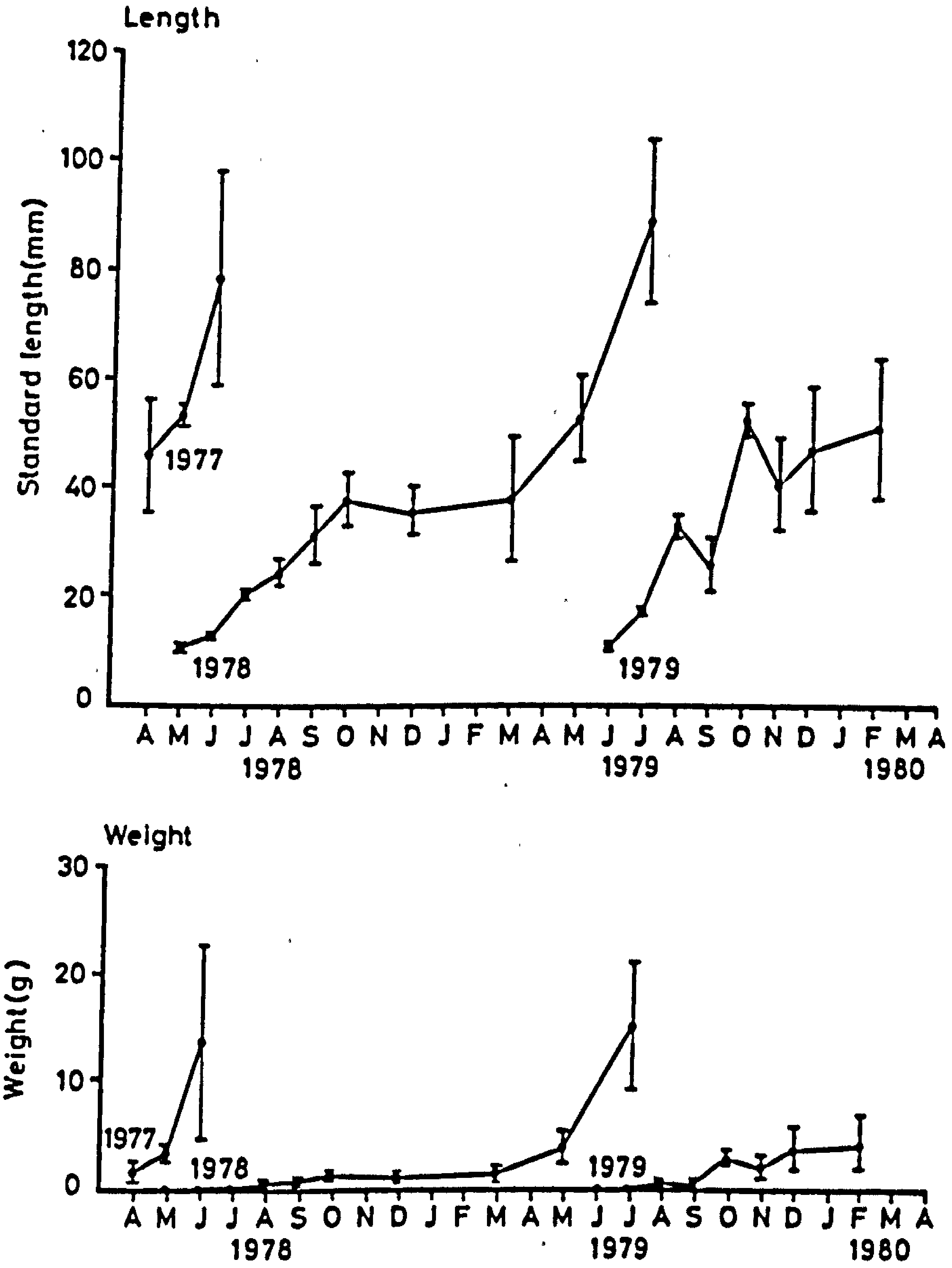

Length
Standard length(mm)
120
100
80
60
40
20
0
1977
1978
1979
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
Weight
Weight(g)
30
20
10
0
1977
1978
1979
A M J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980

Table 2.11 Percentage age composition of flounder from the channelised section.

Month	n	Age group					
		0	I	II	III	IV	>V
1978							
March	54		89.0	5.5	5.5		
April	16		100.0				
May	19		100.0				
June	361	93.0	6.1	0.3	0.6		
July	206	79.6	18.9		1.5		
August	277	96.6	3.0		0.4		
September	76	88.2	3.9	6.6	1.3		
October	165	86.1	7.3	3.0	3.0		0.6
November	37	91.9	8.1				
December	68	86.8	11.8	1.4			
1979							
January	NS						
February	9		100.0				
March	73		98.6	1.4			
April	20		95.0	5.0			
May	62		83.9	14.5	1.6		
June	181	80.7	15.5	3.3	0.5		
July	147	87.8	10.2	1.4		0.6	
August	96	76.0	16.8	2.0	3.2	2.0	
September	138	86.3	8.0	3.6	0.7	0.7	0.7
October	42	97.6	2.4				
November	101	88.1	8.9	3.0			
December	27	70.4	25.9		3.7		
1980							
January	196		92.4	7.6			
February	67		83.6	14.9		1.5	
March	417		86.8	13.0	0.2		
April	170		88.8	10.6		0.6	

throughout the study section were of a similar size. However, after this early period size distributions of flounder captured above and below the Dock began to differ. Even a cursory comparison of the mean lengths and weights of fish taken in the two areas shows flounder upstream of the Dock were generally of a smaller size. Although seine netting was the only method used to capture fish at the two upper sites, it is considered the differences were too large to be solely a result of a size distribution with depth.

Overall, the growth pattern of the juvenile flounder was of an increase in size through the summer months with a slowing or cessation of growth in the late autumn and winter, growth commencing again in April-May. In some of the winter months a reduction in mean size was observed.

b) Length-weight relationships

The relationship between the length and weight of a fish can usually be expressed as:

$$w = al^b \qquad \text{(Bagenal and Tesch, 1978)}$$

or $$\log w = \log a + b \log l$$

where w = weight, l = length, 'a' is a constant, and 'b' is an exponent with a value between 2 and 4. Where b = 3 growth is isometric and weight increases as the cube of the length, values other than 3 indicating allometric growth (Bagenal and Tesch, 1978).

For each monthly sample of O- and I-group flounder log weight was plotted against log length and linear regression lines were calculated by the method of least squares. Values of b (regression coefficient) and log a (intercept) are given in Tables 2.12-2.14. Only small numbers of I-group flounder were captured in the monthly samples upstream of the Dock and length-weight regressions were not calculated

Table 2.12 Length-weight relationships of 0-group flounder from the channelised section. Statistical significance of b from 3 (isometric growth): $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Month	n	$\log_{10} a$	b	95%CL of b	
				L95 CL	U95 CL
June 1978	75	-5.223	3.414^{***}	3.279	3.549
July	164	-4.890	3.111^{**}	3.038	3.184
August	127	-4.636	2.964	2.904	3.024
September	67	-5.100	3.204^{**}	3.085	3.323
October	137	-4.972	3.155^{***}	3.072	3.238
November	34	-4.790	3.088	2.954	3.222
December	59	-4.681	3.008	2.943	3.073
June 1979	50	-5.268	3.454^{***}	3.194	3.714
July	64	-5.064	3.242^{***}	3.161	3.323
August	73	-4.873	3.107^{*}	3.024	3.190
September	120	-4.916	3.137^{***}	3.074	3.200
October	41	-4.687	2.990	2.880	3.110
November	89	-4.739	3.024	2.915	3.133
December	19	-4.864	3.107	2.874	3.340

Analysis of covariance

June - Dec. 1978 : Between slopes $F = 14.426$; df = 6,649; $< P$ 0.001

June - Dec. 1979 : Between slopes $F = 5.008$; df = 6,442; $< P$ 0.001

Table 2.13 Length-weight relationships of I-group flounder from the channelised section. Asterisk indicates b significantly different from 3 (isometric growth) at 5% level.

Month	n	$\log_{10}a$	b	95%CL of b	
				L95 CL	U95 CL
April 1978	16	-4.845	3.102	2.848	3.356
May	19	-4.795	3.071	2.839	3.303
June	22	-4.875	3.102	2.709	3.496
July	39	-4.786	3.064	2.890	3.238
August	8	-4.906	3.132	2.828	3.436
September	NS				
October	14	-4.865	3.096	2.842	3.350
November	NS				
December	9	-5.202	3.267	2.605	3.929
January 1979	NS				
February	9	-3.915	2.552	2.051	3.053
March	72	-4.606	2.965	2.879	3.051
April	19	-5.037	3.198	2.934	3.462
May	52	-4.862	3.114*	3.018	3.210
June	29	-4.345	2.830*	2.668	2.992
July	10	-4.621	2.962	2.250	3.674
August	15	-4.454	2.896	2.474	3.318
September	11	-4.535	2.926	2.270	3.582
October	NS				
November	9	-4.405	2.862	2.254	3.470
December	7	-4.115	2.717	2.056	3.378
January 1980	180	-4.550	2.918*	2.840	2.996
February	56	-4.744	3.031	2.940	3.122
March	362	-4.589	2.948*	2.904	2.992
April	152	-4.532	2.925	2.846	3.004

Analysis of covariance

April 1978 - March 1979: Between slopes $F = 0.918$; df = 8,190; $p > 0.05$

Between intercepts $F = 0.988$; df = 8,190; $p > 0.05$

April 1979 - March 1980: Between slopes $F = 1.869$; df = 11,878; $p > 0.05$

Between intercepts $F = 7.501$; df = 11,878; $p < 0.001$

Table 2.14 Length-weight relationships of 0-group flounder from upstream of Preston Dock. Statistical significance of b from 3: * $P < 0.05$, ***$P < 0.001$.

Month	n	$\log_{10}$ a	b	95%CL of b	
				L95 CL	U95 CL
May 1978	100	-5.122	3.358***	3.276	3.440
June	175	-5.205	3.399***	3.322	3.476
July	200	-5.137	3.335***	3.290	3.380
August	42	-4.991	3.184***	3.100	3.268
September	13	-4.671	3.013	2.844	3.182
October	12	-4.777	3.059	2.906	3.212
November	NS				
December	16	-4.585	2.949	2.755	3.143
June 1979	75	-5.418	3.640***	3.516	3.764
July	170	-4.951	3.190***	3.093	3.287
August	76	-4.802	3.036	2.934	3.138
September	21	-4.854	3.101*	3.002	3.200
October	26	-4.887	3.112	2.895	3.329
November	10	-4.751	3.063	2.902	3.224
December	16	-4.791	3.088	2.974	3.202

Analysis of covariance

May - Dec. 1978: Between slopes $F = 3.238$; df = 6,544; $P < 0.01$

June- Dec. 1979: Between slopes $F = 9.060$; df = 6,380; $P < 0.001$

for these fish. Analysis of covariance (Zar, 1974) was used to test for statistically significant differences between the regression coefficients and if homogenous the analysis was continued to test for differences between the intercepts.

Significant differences in the regression coefficient b were found among the monthly samples of O-group flounder ($P < 0.05$) both in 1978 and 1979, and both in the channelised section and upstream of the Dock. The regression coefficients tended to be highest in the samples containing large numbers of metamorphosing and newly metamorphosed fish with high log a values also recorded. This may reflect the fact that the length-weight characteristics of postlarval and metamorphosing fish are often different from those of older fish (Le Cren, 1951; Macphee, 1960; Kuipers, 1977). The regression coefficient was significantly greater than 3 in many of the samples indicating the fish were increasing in weight at a rate greater than required to maintain constant body proportions (Ricker, 1979).

For I-group flounder from the channelised section there was no significant difference ($P > 0.05$) in the samples between April 1978 and March 1979, but in the following period of April 1979 to April 1980 log a values were significantly different although b was not. There was no clear explanation for the differences and since the determination of intercept values requires extrapolation beyond the data points, too much emphais should not perhaps be placed on them, especially as sample sizes were variable and often small.

Analysis of covariance was also used to compare the length-weight relationships of O-group flounder from the channelised section and upstream of Preston Dock in the same month. In most of the tests there was no significant difference in b (Table 2.15), but

Table 2.15 Comparison of length-weight relationship regression coefficients of monthly samples of 0-group flounder from the channelised section and upstream of Preston Dock, by analysis of covariance. Sample sizes are given in parentheses.

Month	Channelised b	Upstream of Dock b	F-test
1978			
June	3.414 (75)	3.399 (175)	$P > 0.05$
July	3.111 (164)	3.335 (200)	$P < 0.001$
August	2.964 (127)	3.184 (42)	$P < 0.001$
September	3.204 (67)	3.013 (13)	$P > 0.05$
October	3.155 (137)	3.059 (12)	$P > 0.05$
November	-	-	-
December	3.008 (59)	2.949 (16)	$P > 0.05$
1979			
June	3.454 (50)	3.640 (75)	$P > 0.05$
July	3.242 (64)	3.190 (170)	$P > 0.05$
August	3.107 (73)	3.036 (76)	$P > 0.05$
September	3.137 (120)	3.101 (21)	$P > 0.05$
October	2.990 (41)	3.112 (26)	$P > 0.05$
November	3.024 (89)	3.063 (10)	$P > 0.05$
December	3.107 (19)	3.088 (16)	$P > 0.05$

Table 2.16 Comparison of length-weight relationship intercept values of monthly samples of 0-group flounder from the channelised section and upstream of Preston Dock, by analysis of covariance. Sample sizes are given in parentheses.

Month	Channelised $\log_{10}$ a	Upstream of Dock $\log_{10}$ a	F-test
1978			
June	-5.223 (75)	-5.205 (175)	$P > 0.05$
July	-4.890 (164)	-5.137 (200)	$P < 0.001$
August	-4.636 (127)	-4.991 (42)	$P < 0.001$
September	-5.100 (67)	-4.671 (13)	$P < 0.001$
October	-4.972 (137)	-4.777 (12)	$P < 0.01$
November	-	-	
December	-4.681 (59)	-4.585 (16)	$P > 0.05$
1979			
June	-5.268 (50)	-5.418 (75)	$P > 0.05$
July	-5.064 (64)	-4.951 (170)	$P < 0.05$
August	-4.873 (73)	-4.802 (76)	$P < 0.001$
September	-4.916 (120)	-4.854 (21)	$P > 0.05$
October	-4.687 (41)	-4.887 (26)	$P > 0.05$
November	-4.739 (89)	-4.751 (10)	$P < 0.001$
December	-4.864 (19)	-4.791 (16)	$P < 0.05$

in the comparisons of log a the differences were usually statistically significant (Table 2.16). However, there was no consistent trend in the differences.

c) Mathematical description of seasonal growth of O-group flounder

The von Bertalanffy growth equation was used to fit a curve to the data on the increase in mean length of flounder through their first year of life. The principal reason for constructing growth models is that they allow a generalised description of the pattern of growth so that comparisons can be made within the species and between species (Dickie, 1978). The von Bertalanffy model, though probably the most widely used, is only one of a series of growth models, but was chosen for its ease of use and, more importantly, because it was found to fit the results with a good degree of accuracy. For reasons which will be considered in the Discussion only the data on flounder growth in the channelised section were used.

The von Bertalanffy growth model is described by:

$$l_t = L_1(1 - e^{-k(t-t_o)})$$

where l_t = length at any given time t

L_1 = asymptotic length achieved after first year growth

k = growth rate constant

t_o = a parameter equivalent to the hypothetical time at which the fish would have been zero size if it had always grown according to the above equation

The growth curve was fitted to the observed mean lengths of the O-group flounder following the procedure outlined by Lockwood (1974a). Table 2.17 gives the mean lengths of each sample of flounder during 1978 and 1979 and the parameters L_1 and k were computed from the

Table 2.17 The computation of the growth parameters k, L_1 and $\bar{t}_o$ for 0-group flounder from the channelised section 1978-79. Derived values of l_t from the von Bertalanffy equation are shown.

	Days from 20 May t	Mean length of popn. l (mm)	Median length for time interval t $(l_1 + l_2)/2$ (mm)	Increase in length per unit time $l/\ t$ (mm)	t_o	Calculated length l_t (mm)
1978						
June	33	9.2			22.92	5.5
			21.3	0.835		
July	62	33.4			13.23	26.4
			35.9	0.161		
August	93	38.4			32.01	40.1
			42.3	0.269		
September	122	46.2			35.28	48.1
			49.5	0.217		
October	152	52.6			31.34	53.2
			52.6	0.000		
November	185	52.5			65.04	56.6
			55.8	0.275		
December	209	59.1			5.00	58.1
1979						
June	23	8.5			13.74	-
			19.5	0.730		
July	53	30.4			10.55	21.0
			34.6	0.290		
August	82	38.8			19.92	36.0
			43.8	0.309		
September	114	48.7			16.12	46.2
			52.0	0.156		
October	157	55.4			12.55	53.8
			53.5	-0.134		
November	186	51.5			72.65	56.6
			54.5	0.454		
December	199	57.4			29.36	57.5

Regression of increase in length per unit time on median length for time interval t :

$$y = -0.0161x + 0.9880 \qquad (r = -0.746)$$

$$k = 0.0161$$

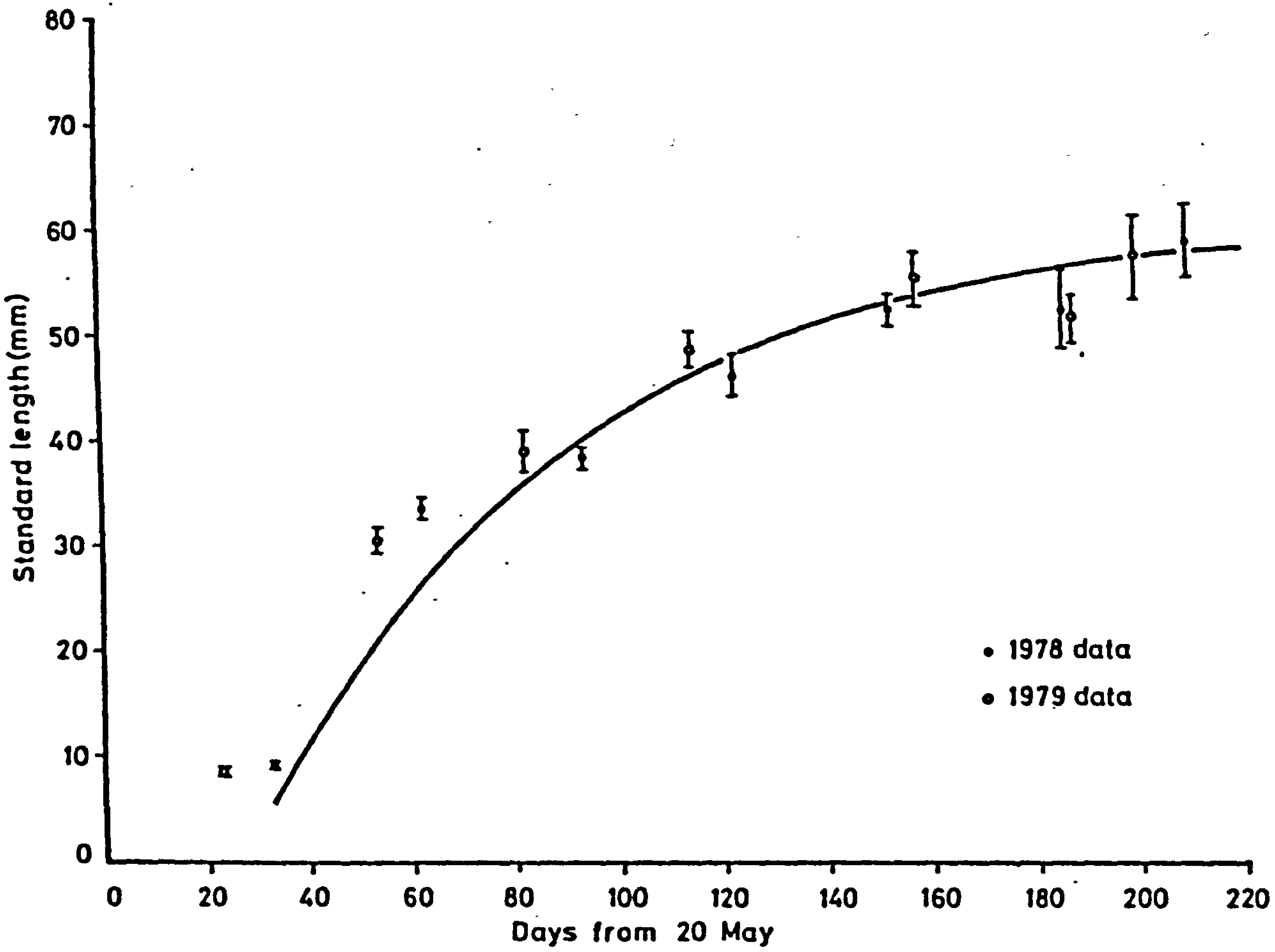
$$L_1 = 61.4$$

$$\bar{t}_o = 27.12$$

FIGURE 2.27

Von Bertalanffy growth curve fitted to the growth in length data of O-group flounder from the channelised section, 1978-79. The observed mean lengths (± 95% confidence limits) are shown.

FIG. 2.27



Standard length (mm)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
180
200
220
Days from 20 May
• 1978 data
• 1979 data

regression of the increase in length per unit time $(\bar{l}_2 - \bar{l}_1/t_2 - t_1)$ on the median length for time interval $t_2 - t_1((\bar{l}_1 + \bar{l}_2)/2)$. Time t was measured in days from 20 May when the young flounder were thought to be first entering the estuary (see earlier). The remaining parameter t_o was estimated by substitution of the computed values L_1 and k, and the observed mean lengths in the re-arranged equation

$$t_o = t + (1/k)l_n(1 - l_t/L_1)$$

and then taking the mean value. To provide a model which describes growth over both seasons the length data from both years of sampling were used. There were no clear differences in growth between the two years which would invalidate this combination, the observed mean lengths in December were very similar as were the calculated L_1 values (1978 : L_1 = 59.6mm; 1979 : L_1 = 63.1mm). The values of all the parameters and the predicted lengths at each age are given in Table 2.17 with the fitted growth curve shown in Figure 2.27. The fit of the curve to the observed mean lengths was generally good with the observed means for July showing the greatest deviation from the curve.

DISCUSSION

A large number of marine and estuarine fish species were recorded from the inner estuary, but only a few were abundant and regularly present in catches. Species such as plaice and sole, for which the outer estuary of the Ribble is known to be an important nursery ground (Corlett, 1967; Holden et al., 1975), were represented in small numbers. These species are probably limited in their physiological capacity to penetrate into the low and fluctuating salinities present in the inner estuary. The dominant species: flounder, sprat, herring, P. minutus, P. lozanoi and P. microps, are all able to tolerate a wide range of salinities (Brawn, 1960; Holliday and Blaxter, 1960, 1961; Motais et al., 1966; Fonds, 1973). In a brief study on the distribution of flatfishes in the estuary downstream of the Douglas confluence, Hiscock (1971) noted the successive appearance of plaice, sole and dab (Limanda limanda (L.)) in more seaward reaches, the latter species not recorded except at the estuary mouth. He suggested tolerance to salinity was probably a major determinant controlling the distributions. Popham (1966a) has discussed the influence of salinity on the distribution of marine and estuarine invertebrates in the estuary.

A high level of dominance by a small number of species is a common feature of studies on estuarine and inshore fish (Allen and Horn, 1975; Livingston, 1976; Quinn, 1980; Nash and Gibson, 1982). It should be remembered that in any community the individuals tend to be distributed among the component species according to a lognormal or similar law (Pielou, 1969). However, species dominance can be expected to increase the more rigorous the physical environment (Odum, 1971).

The accepted presentation of faunal diversity in aquatic environments of different salinities is of a minimum number of species in the lower mesohaline range (Remane and Schlieper, 1971; Kinne, 1971), usually considered a result of the high susceptibility of most freshwater organisms to slight increases in salt concentration (Remane and Schlieper, 1971). However, freshwater fishes were recorded in salinities up to 11.5 ‰ in the inner estuary. This salinity is in fact similar to that reported for freshwater fishes in other European waters (Nellen, 1965; Remane and Schlieper, 1971; O'Hara, 1976; Schofer, 1979; Muller and Berg, 1982). Most of the observations relate to the occurrence of freshwater fish in the stable salinities of brackish water seas, an environment not directly comparable to the tidal regime of an estuary (O'Hara, 1976). Fluctuations in salinity are just as important biologically as the overall average salinity (Sanders et al., 1965; Perez, 1969; Heerebout, 1970). However, variation in salinity regime may in fact aid the colonisation of a region by freshwater fishes since high salinities are not necessarily deleterious provided they are present for a limited period (Renfro, 1960), a point demonstrated experimentally by O'Hara (1976).

There was considerable variation in the numbers of fish taken in successive months. Short-term fluctuations in catch are often found in estuarine studies (Hardisty and Huggins, 1975; Langford et al., 1978; Shenker and Dean, 1979; van den Broek, 1979, 1980; Quinn, 1980). In this study they were a consequence of the sampling methods employed and the contagious distribution of the species, in addition to probable variation in actual fish numbers in the inner estuary. Superimposed on the variation was a seasonal pattern of maximum numbers of individuals and species in the summer and minimum in the winter, both of the freshwater and marine-estuarine species.

The rise to maximum abundance in the summer months was a consequence of the appearance of fish of the new year class in the catches. The subsequent decline in numbers during the later months of the year may have been correlated with the decrease in water temperatures. Several studies on estuarine and shallow coastal fish populations in North America have shown decreases in abundance with the onset of lower seasonal temperatures (Dahlberg and Odum, 1970; Recksieck and McCleave, 1973; Allen and Horn, 1975; Subrahmanyam and Drake, 1975; Hoff and Ibara, 1977). Water temperatures in estuaries are fundamentally controlled by the temperature of the sea and the freshwater inflow (Day, 1950) and in winter upper estuary waters may be cooler than those at the mouth. Sprat have been found to collect in regions of warmer water during the winter (Molander, 1952), although Johnson (1970) discounted hydrological conditions as important in the location of overwintering sprat concentrations in the Wash and Thames Estuary. Decreasing temperatures are almost certainly implicated in the late autumn decline of the Pomatoschistus species in the inner estuary (Jones and Miller, 1966; Fonds, 1973; Miller, 1975a; Hesthagen, 1975, 1977, 1979). A winter emigration of flounder from estuaries has also been documented by a number of authors (Hartley, 1940; Williams et al., 1965; Muus, 1967; Summers, 1979). Corlett (1967) noted a winter emigration of juvenile sole from the outer estuary of the Ribble with an offshore movement of plaice also known to occur on the north west coast (Holden et al., 1975).

Different species vary in their response to low temperatures (Fonds and Creutzberg, 1971) and not all of the marine-estuarine fishes may have been affected by the winter temperature conditions in the inner estuary to the same extent. It may also be expected that the numbers recorded during a particular winter will depend on the temperatures in that year. The lower catches in the channel during the early months of 1979 compared to in 1980 may have been due to the lower temperatures in the former period. It was noticeable that P. minutus was common in the channel in February and March 1980 but rarely taken in these months in 1979. However, the catches in 1980 were mainly of flounder and the numbers were larger than usually taken at any other time of year. Further sampling would be required to establish whether this apparent influx of flounder was a regular occurrence in mild winters. A similar winter-spring influx of flounder into the Medway Estuary was described by van den Broek (1977).

It seems probable that the small numbers of the freshwater fishes captured after the autumn was also related to the fall in temperature. The movement of freshwater fish into deeper water for overwintering is well documented (Nikolskii, 1963; Hynes, 1970; Norman, 1975). Mathews (1971) and Sadler (1980) found catches of cyprinids declined rapidly in the late autumn and considered the fish had moved into deeper water or elsewhere. Hynes (1970) suggests the movement is probably a general pattern of behaviour associated with reduced activity in cold water.

The seasonal changes in abundance of the marine-estuarine species in the inner estuary contrast with the findings of the power station intake studies conducted in other British estuaries (Huddart, 1971; Hardisty and Huggins, 1975; Langford _et al._, 1978; van den Broek, 1979, 1980) where maximum numbers of individuals and species were recorded in the late autumn to early spring. In the middle and outer reaches of the estuaries where the studies were carried out, several marine fish species were seasonally abundant during the colder months. However, some of the principal species in the inner estuary were also recorded in maximum numbers during the winter in the power station studies, in some instances they dominated the catches. This presumably reflected less rigorous winter temperature conditions in the outer reaches of these estuaries compared to in the present study area. The presence of a peak in catches of the species in the winter may have indicated a migration of fish into the area where the intakes were sited. However, a contributory factor, explaining the often small numbers of the species collected in the summer, was probably a size bias against small fish by the intake screens. Huddart (1971) noted that only a proportion of the total sprat population was sampled by the intake screens of a Thames power station, with sprat less than 45mm rarely collected. Similarly, if the data of van den Broek (1979, 1980) are examined, nearly all of the fish taken were above 40mm standard length which can be compared with the large numbers of fish as small as 10mm collected during the summer in this study. It is also possible that catches in winter were increased as a result of reduced activity of the fish at the lower temperatures making them more susceptible to entrainment (Grimes, 1975).

The fish community present in an estuary on the north west coast has been the subject of previous research. D'Arcy and Pugh Thomas (1978) and D'Arcy and Wilson (1978) studied the composition and seasonal fluctuations in catches taken from power station intake screens on the tidal Manchester Ship Canal, which opens onto the outer Mersey Estuary. Maximum catches were taken in the winter, mainly due to large numbers of sprat and P. minutus. However, analysis of temporal fluctuations was complicated by variations in the volume of water drawn into the Canal from the estuary. Overall diversity was low, restricted by poor water quality in the Canal and estuary.

There was little or no seasonal trend in the three diversity indices measured. In the literature the diversity of a system is often compared with values obtained in studies on other estuaries as an assessment of environmental quality. Haedrich and Haedrich (1974) suggest certain diversity levels may be characteristic of temperate estuaries, however, differences in sampling procedures, faunal biogeography, and estuarine physiography (Livingston, 1976; Moore, 1978; Shenker and Dean, 1979; Gilbert, 1980) mean direct comparisons are probably of little use. Low diversity values may be/consequence of the natural environmental stresses present in estuaries limiting the fauna, rather than the effect of some form of pollution. Studies have shown diversity values to vary inversely with levels of pollution (Wilhm and Dorris, 1966; Bechtel and Copeland, 1970; Boesch, 1972; Rowe *et al.*, 1972; Tsai, 1973), but pollution may also result in population changes which do not cause diversity decreases (Tramer and Rodger, 1973; Livingston, 1975).

Although diversity indices are widely employed, their use has been questioned by some authors. Hurlbert (1971) has criticized the indices most commonly used suggesting the 'diversity' they measure has no biological interpretation, a view supported by Goodman (1975). There is also controversy over the significance of diversity in communities. Based on the argument by MacArthur (1955) that trophic diversity may be equated with community stability it is often considered that high diversity leads to increased stability. However, this premise may not necessarily be true (May, 1971; Goodman, 1975; Zaret, 1982). In a study on an unpolluted estuarine system Livingston (1976) observed large annual variations in species richness and diversity, but despite these variations the system was stable and productive.

In the present study calculation of the diversity indices provided few worthwhile data. Generally, they did not reflect the large changes in the fish community which occurred seasonally and careful analysis was often required in the interpretation of the values. Although diversity indices may provide a useful means of summarising data in some instances, as suggested by certain authors analysis of a community by the simple methods of numbers of species or species present may be just as informative (Williamson, 1972; Moore, 1978).

Except for the division into freshwater fishes upstream of the

Dock and marine-estuarine species below, there were no clear differences in species abundances between the sites. The zone where the marine-estuarine and freshwater species overlap will vary according to tidal height and freshwater discharge. At spring tides, or low river flow, the upper limit of salt water will be above Preston Dock, whereas on neap tides, or at high river flows, tidal intrusion will be reduced. These variations will have corresponding effects on the distribution of the two groups of species. It is probably not salinity directly which governs the upper distributional limit of the marine-estuarine species, but rather the tidal currents associated with the salinity intrusion (see below and Chapter 3). Given the relatively small tidal volume of the inner section (Chapter 1) it will be evident that high flood flows from the river may affect the abundance and distribution of marine-estuarine species throughout the inner estuary. Weinstein _et al_. (1979) observed that during river floods marine species normally found in the upper reaches of the Cape Fear Estuary were swept downstream to the lower estuary. The extent to which freshwater fishes found in the channelised section were displaced individuals, albeit they were often present in large numbers, which would have been eventually washed out to sea is not known. In the River Dee O'Hara (1976) found dace present in the tidal reaches moved back into fresh water, but these were two and three year old fish compared to the small 0-group individuals captured below Preston Dock in this study.

There was no evidence of decreased fish numbers at Sites 2 and 3 where at high water the dissolved oxygen sag is located. During the present study, from April 1979 to April 1980 when determinations of oxygen concentrations were made, levels were usually above 50% saturation.

The position of the oxygen sag over the tidal cycle is governed by the tidal currents (Chapter 1) and the currents will also have influenced fish distribution. Fish may have been carried into the area where the sag was situated, or vice versa. Unless fish death had occurred no deleterious effects of the low oxygen levels may have been expected to be observed. There is conflicting evidence on whether acclimation to low oxygen concentrations can occur (Shepard, 1955; Moss and Scott, 1961; Burton _et al._, 1980), but fish moving into the oxygen sag will have experienced a rapid decrease in concentrations.

Distribution of benthic species may be affected by substrate characteristics, often indirectly through its influence on the composition and density of the available food resources (De Sylva, 1975; Pearcy, 1978; Weinstein _et al._, 1980). In the outer estuary of the Ribble Hiscock (1971) suggested a correlation between abundance of sole and substrate. In the inner estuary there was a change from mud and allochthonous material in the channel at and just below the Dock entrance, to sand in more seaward reaches (Chapter 1). Differences in diet composition along the study section are described fully in a later chapter and while there was a slightly higher prevalence of freshwater organisms in the diet of fish at Site 3, they were a minor food item overall.

The fish populations in the inner estuary were dominated by fish of the O-age group. During the summer and autumn months I-group and older fish formed only a small proportion of the total numbers. The small numbers of I-group herring and sprat were probably the result of a migration to deeper water with increasing size (Robertson, 1938; Wood, 1959; Parrish and Saville, 1965; van den Broek, 1979b). This emigration may have been responsible for the decrease in abundance of

O-group herring in the late summer months, well before water temperatures began to decline. The majority of P. minutus and P. lozanoi die after breeding in the spring (Fonds, 1973). Small numbers of I-group P. minutus were taken during the summer and autumn, but I-group P. lozanoi were not recorded after May. P. lozanoi is a more neritic species than P. minutus (Fonds, 1973) and its ability to tolerate estuarine conditions may decrease on reaching sexual maturity. The absence of I-group P. microps during the spring and early summer was probably due to breeding in the more outer reaches of the estuary (Miller, 1975a), but there is no clear explanation for their very low numbers during the remainder of the summer months.

A low water electrofishing survey upstream of Preston Dock showed that adult freshwater fish were common at the two upper sites. Decreased catch efficiency for large individuals must be considered a reason for the small numbers of freshwater fish older than the O-group taken in the seine samples. Remane and Schlieper (1971) noted that raised salinities do not appear to inhibit growth of freshwater fish and frequently brackish water populations have been considered to have grown particularly well. O'Hara (1976) found no obvious differences in the growth of two and three year old dace and roach in tidal and freshwater sections of the lower River Dee.

Size bias against large fish by the nets used in this study must also be borne in mind when examining the age structure of the flounder catches. Members of the older age groups may be under represented. At the beginning of December of both years O-group flounder from the channelised section had attained a mean length of 57-59 mm. This is similar to the mean length reported for flounder from the Ythan Estuary at the end of the first year of life (Summers, 1979), but less than for flounder in the Medway Estuary (van den Broek, 1980). Differences in growth rate between areas can probably be attributed to differences in water temperature, fish density and food availability (Steele and Edwards, 1970; Lockwood, 1972; Rosenberg, 1982; Zijlstra et al., 1982).

In the inner estuary there were clear differences in the size of flounder from the channelised section and upstream of Preston Dock. Young O-group flounder use selective tidal stream transport for immigration into estuaries (Johnston, 1981). A simple field experiment in which a fine meshed conical net was suspended 1 m below the water surface over the tidal cycle demonstrated that small flounder were migrating through the inner estuary in the water column, with larger catches taken on the flood tide. (Table 2.18). The tidal migration probably explains the usually low numbers of metamorphosing and newly metamorphosed flounder captured in the seine and trawl in the channelised section compared to in seine samples above the Dock. In the latter section the rising bed levels and increased resistance of the river flow will have led to a slowing of the tidal currents and settlement of the migrating fish. The variation in the relative availability of the small flounder to the sampling methods in the two areas may partly account for the differences in mean length in the early summer months during the period of the immigration. It does not, however, explain the continuing differences observed in later months.

In the upper tidal and freshwater reaches of the River Dee Johnston (1981) found an increase in mean length of O-group flounder with distance upstream and he suggested there was a progressive upriver movement of larger flounder. A similar movement of larger flounder from above the Dock into the river could explain the size

Table 2.18 Numbers of fish captured in a 0.6m diameter conical net (mesh size 1mm) suspended 1m below the water surface on flood and ebb tides. Length ranges of fish captured are shown. NS indicates no sample collected.

		Date								
Species	Tide	8/6/80	9/6/80	10/6/80	11/6/80	2/7/80	23/8/80	29/8/80	30/8/80	Length range
<u>P. flesus</u>	Flood	12	48	280	556	436	3			7 - 24 mm
	Ebb	0	24	84	282	54	0			
<u>P. microps</u>	Flood					158	72	56	37	8 - 27 mm
	Ebb					28	31	NS	NS	
<u>P. minutus</u>	Flood							82	118	13 - 50 mm
	Ebb							NS	NS	
<u>P. lozanoi</u>	Flood							31	63	12 - 48 mm
	Ebb							NS	NS	
<u>S. sprattus</u>	Flood				0	130	140	59	151	20 - 42 mm
	Ebb				3	96	289	NS	NS	
<u>A. tobianus</u>	Flood					5	0	3	11	33 - 54 mm
	Ebb					8	21	NS	NS	
Cyprinid fry	Flood		0	6	8		0			7 - 29 mm
	Ebb		3	0	12		3			

differences observed in this study. For the differences to be maintained would require there to be little interchange between the flounder populations in the two areas, at least not in the direction channelised section to above the Dock. This is perhaps surprising since tidal migration is not restricted to small flounder (De Veen, 1978), although larger fish may be more selective in their use of the currents (Creutzberg et al., 1978). It is also possible that during the immigration there was a 'build-up' of young flounder in the upper section in preparation for subsequent movement into the river. If densities were high this may have affected growth rates.

The suggested upstream movement of larger flounder illustrates the problems of making growth determinations in estuarine fish populations. Both the emigration of larger individuals and the prolonged spawning seasons of the marine-estuarine species with small fish continually entering the populations, have the effect of reducing observed growth rates as shown by changes in mean length. Mixing of different groups of fish which have been feeding and growing in separate areas may also occur (Titmus et al., 1978). The reductions in mean size of flounder observed during the winter in the channelised section were in many instances probably a consequence of small sample sizes rather than changes in the population. However, the size reductions recorded in age group II flounder in the early months of 1980 did appear to be the result of an influx of smaller individuals.

In conclusion, this study has described the composition and seasonal variations of the fish community in the inner estuary. It forms a basis for the investigations into more detailed aspects of the ecology of the fishes documented in subsequent chapters. The study has described the fish community present at high water on spring tides, however, as will be observed in later chapters, the community at low water or at high water of neap tides may be markedly different.

CHAPTER 3

INTERTIDAL DISTRIBUTION AND MOVEMENTS

INTRODUCTION

In comparison with the extensive areas of sand and mud flats in the more seaward reaches of the estuary the intertidal area of the inner estuary is relatively small. However, even in this inner section there are large areas of mud banks which are only covered by the tide at high water. Many studies have shown that fish inhabiting shallow coastal waters move onto the intertidal zone with the flood tide (Merriman, 1947; Butner and Brattstrom, 1960; Zenkevitch, 1963; Williams _et al._, 1965; Edwards and Steele, 1968; Wells _et al._, 1973; Wolff _et al._, 1981). This movement may be on large scale, for example, in the western part of the Wadden Sea Kuipers (1973) found almost the entire juvenile plaice population moved from the low water channels onto the intertidal sand flats with the tide. Not all species migrate intertidally however. Gibson (1973a) examined changes in the distribution and abundance of young fish on a sandy beach in Scotland and found that whereas species such as plaice, juvenile cod (_Gadus morhua_ L.) and young bull rout (_Myoxocephalus scorpius_ (L.)) moved onto the shore with the flood tide, O-group dab (_Limanda limanda_ (L.)) and young pogge (_Agonus cataphractus_ (L.)) remained in the sublittoral and were rarely found above low water spring tide mark. In his study Gibson clearly demonstrated that the movement of fish species onto and off the intertidal zone is not a random movement. This has also been shown by Tyler (1971a) who studied the intertidal movements of winter flounder (_Pseudopleuronectes americanus_ (Walbaum)) using an underwater television camera. He observed that movement onto the intertidal zone occurred 2 - 2.5 hours after low water, and movement off the shore occurred 2.5 - 0.5 hours before the next low water. It was estimated that 70% of the winter flounder which moved onto the intertidal zone occupied it for more than 7 hours of the 12 hour tidal cycle.

In the inner estuary it was readily apparent that fish were distributed on the intertidal banks at high water since they were taken in the seine (Chapter 2). The detailed investigations on intertidal movements so far conducted have examined the movements of fish on the coast and there are no comparable data available on the intertidal movements of fish in the more confined reaches of estuaries. Therefore the aim of this study was to examine the distribution of fish on the intertidal banks of the inner estuary, and to determine their movements over the tidal cycle.

METHODS

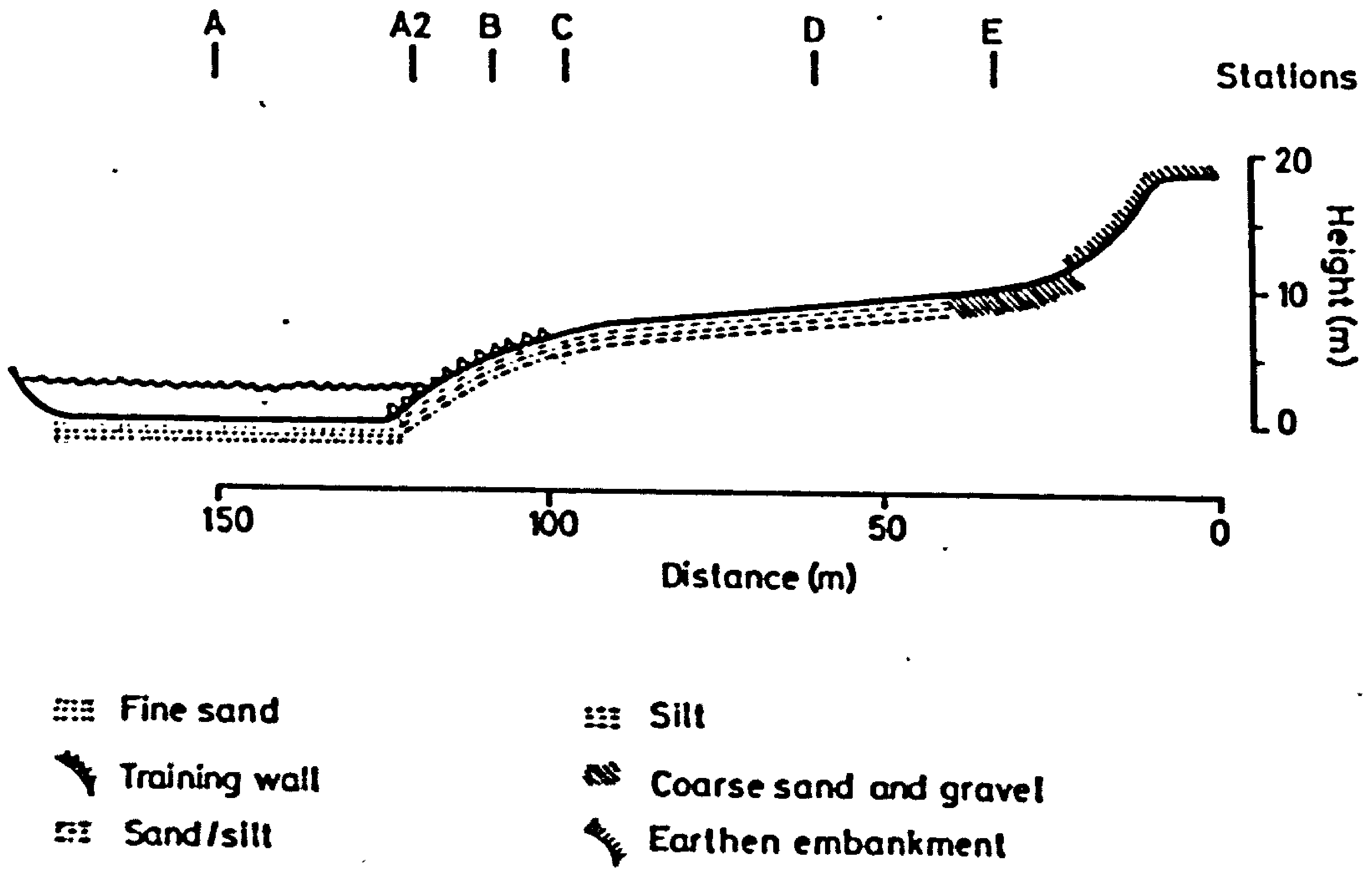
Changes in the distribution and abundance of fish on the intertidal area over the tidal cycle were investigated by a series of trawls taken parallel to the central low water channel. The study was confined to a 250m length of the inner estuary 2.8 km seaward of the Dock entrance. All intertidal samples were taken on the south bank of the estuary. A cross-section of the study area is shown in Figure 3.1. Over most of the intertidal area there was only a slight gradient so that at high water there was a gradual increase in depth with distance from the shore. The banks of the central low water channel had, however, a much steeper gradient. The substrate changed from fine sand in the centre of the channel to a mixture of sand and silt in between the rocks of the training wall, to fine silt on the gently sloping intertidal flats. At the top of the shore above MHWNT coarse sand was overlain by small and medium sized pebbles. The training wall was less extensive than in other parts of the inner estuary.

As the water moved onto and off the intertidal area samples were

FIGURE 3.1

Cross-sectional profile of the intertidal movement study. Approximate positions of the sampling stations are shown.

FIG. 3.1


A
A2
B
C
D
E
Stations
20
10
0
Height (m)
150
100
50
0
Distance (m)
Fine sand
Training wall
Sand/silt
Silt
Coarse sand and gravel
Earthen embankment

taken once every hour (± 15 min) at those of the following stations which were immersed:

Station A - mid-channel
Station A2 - side of channel at low water, water depth 0.25m-1.5m
Station B - corresponding to 0.5m depth of water at LW + 0.5h.
Station C - " " " " " " " LW + 1 h.
Station D - " " " " " " " LW + 2 h.
Station E - " " " " " " " HW

The approximate positions of these stations on the study area are shown in Figure 3.1, but these of course varied according to the height of the tide. In the field the positions of the stations were marked by buoys. When time allowed trawls were also made in between the above stations in order to obtain samples from as many different depths as possible. The obstruction to trawling caused by the rocks of the training wall meant that Station A2 was only sampled at low water when the water was shallow and the trawl could be accurately positioned by hand. Similarly, sampling at Station B located in the upper part of training wall was also restricted.

The sampling gear used was a 1.8m beam trawl fitted with a net of outer mesh 10mm knot to knot, and a codend of 2mm diameter knotless netting. In water deeper than 0.75m the trawl was pulled by a boat fitted with an outboard motor. In shallower water the net was set at the required depth, the trawl rope laid out along the bank, and the net was then pulled over the trawling distance by hand. The standard length of a trawl was 125m and distances were measured by reference to marker posts on the shore. The towing speed was kept as constant as possible at approximately 0.5m/sec as recommended by Riley and Corlett (1966) as being most effective for a similar net. Sampling depth was measured immediately before and after each trawl.

When trawling in shallow water it is possible the disturbance caused by the passage of the boat and outboard may have chased fish out of the path of the net causing a reduction in catch (Kuipers, 1975a). To investigate whether a difference in catch did exist between hand and boat pulled trawls, pairs of trawls were made in 1m depth of water. Trials were made on four separate dates and all hauls were made within one hour of high water. The Chi-square statistical analysis was used to compare the numbers of fish of each species captured in the pairs of trawls. The results for flounder, P. minutus and P. microps are given in Table 3.1. In only one pair of trawls was there a statistically significant difference ($P < 0.05$) in the numbers of fish caught, this was P. minutus on 20 October 1978. In addition, for each sampling date collections of fish taken by the separate methods were combined and a further test was carried out to determine whether there was any difference in the mean length of fish captured. The results of the analyses are presented in Table 3.2. The mean length of fish captured by boat and hand trawl were significantly different on one occasion for flounder. In all other tests, however, there was no significant difference ($P > 0.05$). It was therefore considered justified to examine the intertidal distribution and movement of the fish species using these two different trawling methods.

Sampling on the flood and ebb tides was usually carried out on separate occasions and only the day tides were worked as night trawling was too dangerous to be undertaken. Sampling was also confined to tides of 7.5m or higher as lower tides did not cover an appreciable area of the intertidal zone above the training wall. Because of the restrictions imposed on trawling by the training wall samples on the ebb tide were not taken after HW + 4 - 5h. The catch from each trawl was preserved in 4% formaldehyde and returned to the laboratory for

Table 3.1 Comparison of the numbers of fish captured when the beam trawl was pulled by boat and by hand in water of 1m depth.

a) P. microps

Date and sample no.	Boat trawl	Hand trawl	χ^2 test
20/10/78	6	5	0.091 ; $P > 0.05$
7/11/79 1	9	8	0.059 ; $P > 0.05$
2	20	16	0.444 ; $P > 0.05$
3	10	7	0.529 ; $P > 0.05$
4	8	11	0.474 ; $P > 0.05$
5	9	15	1.500 ; $P > 0.05$

b) P. minutus

Date and sample no.	Boat trawl	Hand trawl	χ^2 test
20/10/78	134	213	17.985 ; $P < 0.01$
7/11/79 1	10	9	0.053 ; $P > 0.05$
2	23	22	0.022 ; $P > 0.05$
3	35	23	2.483 ; $P > 0.05$
4	10	16	1.385 ; $P > 0.05$
5	22	32	1.852 ; $P > 0.05$

c) P. flesus

Date and sample no.	Boat trawl	Hand trawl	χ^2 test
24/8/78 1	35	34	0.014 ; $P > 0.05$
2	56	42	2.000 ; $P > 0.05$
3	48	37	1.424 ; $P > 0.05$
4	10	11	0.048 ; $P > 0.05$
5	5	11	2.250 ; $P > 0.05$
20/10/78	10	6	1.000 ; $P > 0.05$
27/7/79 1	14	17	0.290 ; $P > 0.05$
2	12	16	0.571 ; $P > 0.05$
3	28	37	1.246 ; $P > 0.05$
4	35	44	1.025 ; $P > 0.05$
5	42	40	0.049 ; $P > 0.05$
7/11/79 1	9	8	0.059 ; $P > 0.05$
2	9	11	0.200 ; $P > 0.05$
3	6	5	0.091 ; $P > 0.05$
4	9	7	0.250 ; $P > 0.05$
5	5	11	2.250 ; $P > 0.05$

Table 3.2 Comparison of the mean length of fish captured when the beam trawl was pulled by hand and by boat in water of 1m depth. Significant differences in mean length were tested for using the two-tailed t-test; variances were tested by the two-tailed variance ratio test (F-test). Sample sizes are shown.

Species	Sample date	Boat trawl			Hand trawl			F-test	t-test
		N	Mean	Variance	N	Mean	Variance		
<u>P. microps</u>	7/11/79	56	32.5	18.7	57	31.9	17.2	1.09 ; $P>0.05$	0.753 ; $P>0.05$
<u>P. minutus</u>	20/10/78	134	41.8	39.0	213	40.8	37.4	1.04 ; $P>0.05$	1.253 ; $P>0.05$
	7/11/79	100	45.0	30.4	102	45.5	24.7	1.23 ; $P>0.05$	0.555 ; $P>0.05$
<u>P. flesus</u>	24/8/78	154	42.4	66.6	135	39.5	57.3	1.16 ; $P>0.05$	3.093 ; $P<0.01$
	27/7/79	131	35.9	32.9	154	36.1	31.7	1.04 ; $P>0.05$	0.296 ; $P>0.05$
	7/11/79	38	51.2	47.6	42	50.6	51.1	1.07 ; $P>0.05$	0.210 ; $P>0.05$

sorting. Fish were identified, aged and standard length recorded.

The intertidal distribution and movements of fish in the inner estuary were studied over a total of eleven flood tides and five ebb tides during the period July 1978 to November 1978, and July 1979 to January 1980.

RESULTS

Species composition

The intertidal movements of four species are described: flounder, *P. microps*, *P. minutus* and *P. lozanoi*. Most of the other species were too rare in catches for a study of their intertidal distribution and movements to be made. A complete list of the numbers of fish of each species collected during the study is shown in Table 3.3; nearly all the fish were O-group. Sprat and herring were abundant in catches but are not considered further as the fishing method employed only sampled the bottom 0.4m of the water column and therefore probably did not provide representative data on the distribution of pelagic fish. Most of the dace, roach and chub taken were captured on one occasion when there was a large freshwater flow into the estuary after heavy rainfall. Normally, freshwater fish were rare in catches in the study area.

Catches of the four species considered varied over the sampling dates, on some occasions only one or two of the species were taken in sufficient numbers to provide meaningful data.

Movements of O-group flounder

Tidal changes in the distribution of O-group flounder over the study area are shown in Figure 3.2a and b for flood and ebb tides respectively. The figure shows the number of flounder collected at each sampling depth on the different occasions. In this and the following figures the stations are shown equally spaced apart and

Table 3.3 Species composition of the intertidal movement catches.

Species	Total numbers
Sprattus sprattus	13566
Pomatoschistus minutus	5285
Pomatoschistus microps	4983
Platichthys flesus	3997
Pomatoschistus lozanoi	3520
Clupea harengus	728
Ammodytes tobianus	220
Rutilus rutilus	83
Leuciscus cephalus	62
Leuciscus leuciscus	53
Pleuronectes platessa	46
Syngnathus acus	30
Solea solea	24
Gasterosteus aculeatus	24
Anguilla anguilla	19
Dicentrarchus labrax	11
Scophthalmus rhombus	4
Merlangius merlangus	2
Cyclopterus lumpus	2
Liza ramada	2
Pungitius pungitius	2
Liparis montagui	1
Trisopterus luscus	1
Pollachius pollachius	1
Agonus cataphractus	1
Gobio gobio	1

FIGURE 3.2

Changes in the intertidal distribution and abundance of 0-group flounder over the tidal cycle; a) flood tide; b) ebb tide: ●—● numbers of fish; ●--● depth of water. Station A2 when sampled is denoted on the graphs for LW by the depth symbol at 0.5m. NS indicates no samples collected.

FIG. 3.2a

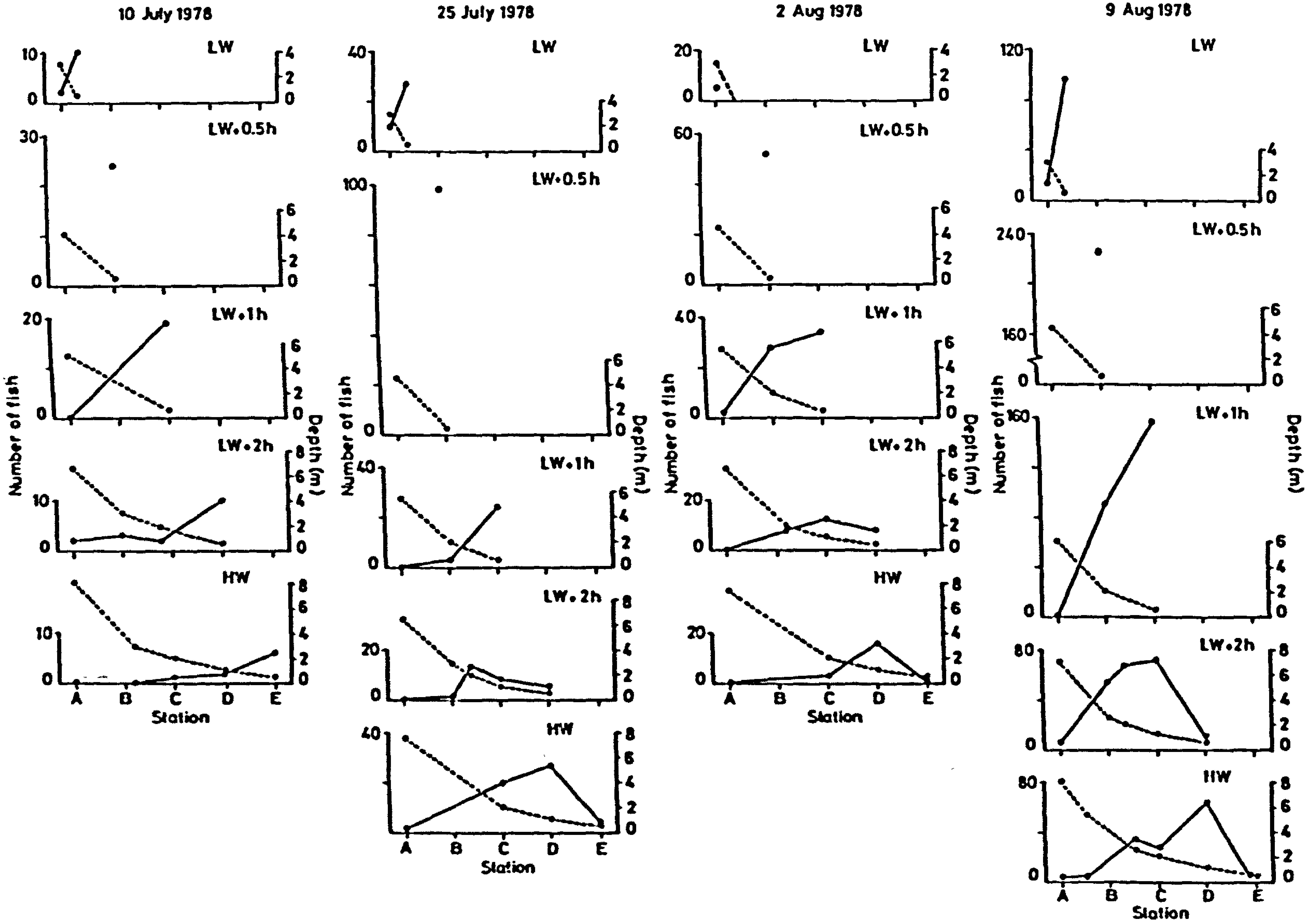

10 July 1978
25 July 1978
2 Aug 1978
9 Aug 1978
LW
LW•0.5h
LW•1h
LW•2h
HW
Number of fish
Depth (m)
Station
A
B
C
D
E

FIG. 3.2a contd.

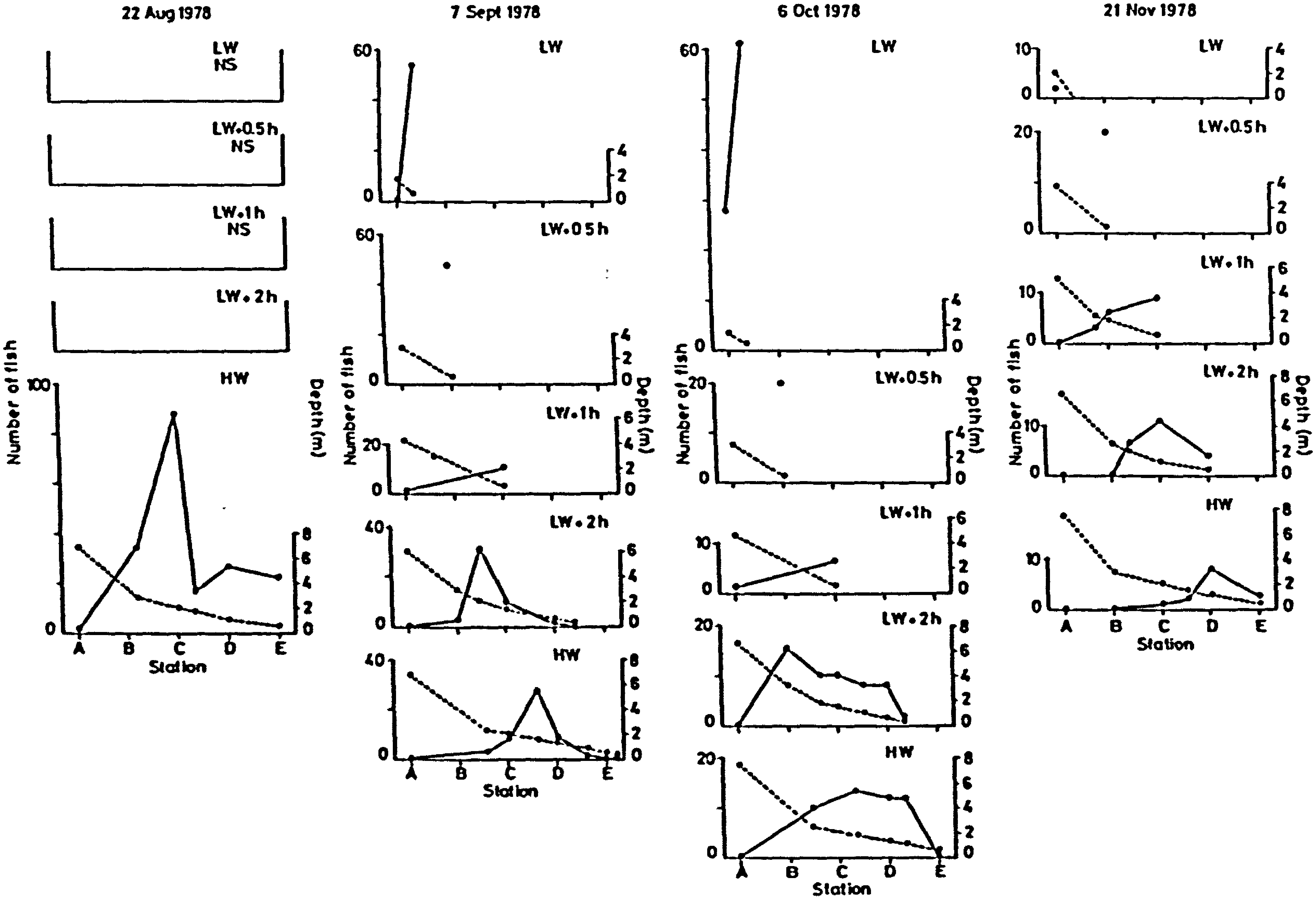


FIG. 3.2a contd.

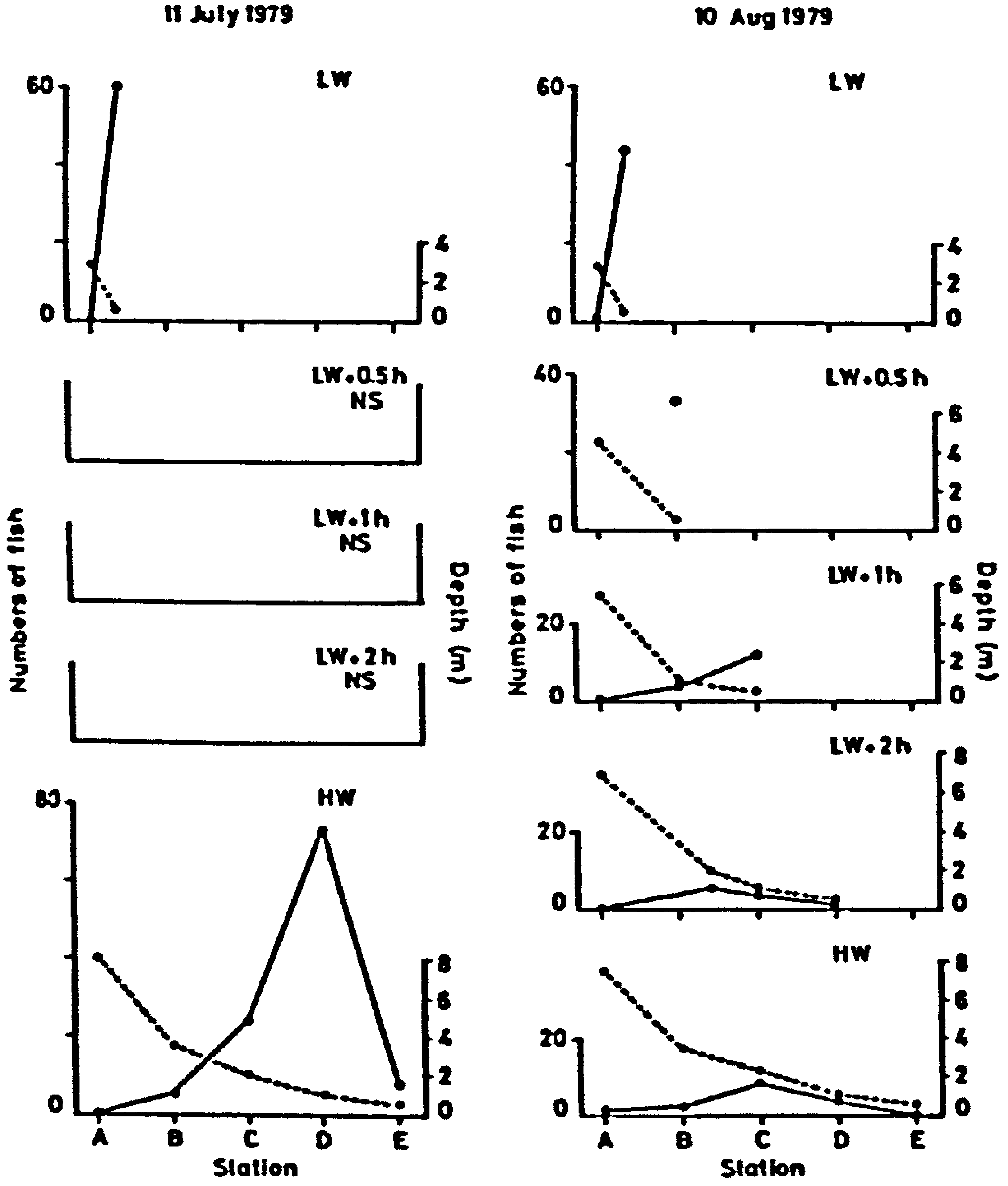


FIG. 3.2b

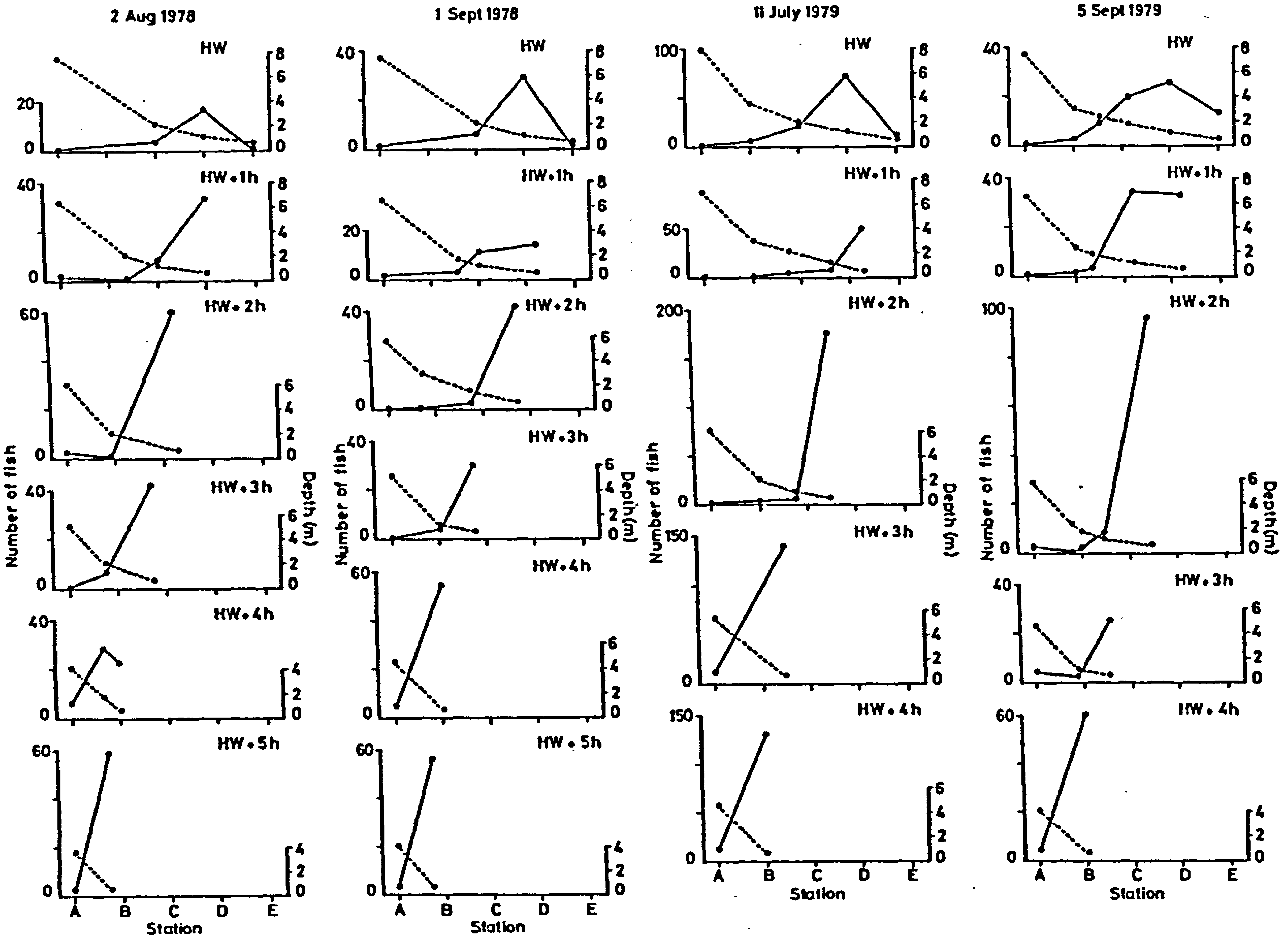

2 Aug 1978
1 Sept 1978
11 July 1979
5 Sept 1979
HW
HW+1h
HW+2h
HW+3h
HW+4h
HW+5h
Number of fish
Depth (m)
Station
A
B
C
D
E
0
2
4
6
8
20
40
50
60
100
150
200

Table 3.4 Numbers of O-group flounder in mid-channel (Station A) and side-channel (Station A2) trawls. The paired data was analysed using the Chi-square statistical analysis. The null hypothesis was that equal numbers of fish were captured in the paired trawls.

Sampling date	Mid-channel trawl	Side-channel trawl	Chi-square	Significance
10/7/78	2	10	5.333	$P < 0.05$
25/7/78	10	26	7.111	$P < 0.01$
9/8/78	13	94	61.318	$P < 0.001$
7/9/78	0	54	54.000	$P < 0.001$
6/10/78	28	62	12.844	$P < 0.001$
11/7/79	0	60	60.000	$P < 0.001$
10/8/79	1	44	41.089	$P < 0.001$

reference should be made to Figure 3.1 for their relative positions on the study area.

At low water the flounder were most abundant at the side of the channel (Fig. 3.2a). Numbers in mid-channel trawls were always significantly smaller ($P < 0.05$) than at the side (Table 3.4). During the early stages of the flood tide flounder closely followed the edge of the rising water onto the intertidal banks and at LW + 0.5h large numbers were taken in shallow water of 0.5m depth, although since this was the only sample taken at this time comparative data on numbers at greater depths are not known. At LW + 1h the numbers at 0.5m depth had decreased but catches were higher than at other depths. By LW + 2h the majority of the intertidal banks had been covered by the tide and flounder were now generally most abundant in water of 1 - 2m depth. The abundance at this depth was maintained at high water showing that the fish had continued to move up the banks from their position at LW + 2h. Even though the depth range at which the juvenile flounder were most abundant at LW + 2h and high water was relatively narrow, the gently sloping profile of the major part of the intertidal banks (Fig. 3.1) meant they were spread over a large area. The exception to the above pattern was on 10 July 1978 when throughout the flood tide flounder were most abundant in 0.5m depth.

Movement off the intertidal banks on the ebb tide was the reverse of the flood tide movement. The juvenile flounder apparently moved off the intertidal banks just in front of the water's edge and as the tide receded they became increasingly concentrated in water of 0.5m depth. Two hours after high water the flounder distribution resembled that at the start of the flood tide. Catches in mid-channel trawls remained small but did increase slightly.

Movements of O-group P. microps

The intertidal distribution and movements of O-group P. microps followed the same pattern as that of flounder (Figure 3.3a and b). At low water P. microps was considerably more abundant at the side of the channel than in the mid-channel (Fig. 3.3a, Table 3.5), indeed the differences were so great it was not considered necessary to test the data statistically. P. microps moved onto and off the intertidal banks in shallow water, but at LW + 2h and high water the fish were again generally most abundant in water of 1 - 2m depth. This was except on 7 September and 6 October 1978 when at LW + 2h the greatest numbers were found at 0.5m. On some of the sampling dates in the summer months large catches were also made in deeper water including in the mid-channel. The majority of these fish were postlarvae or very small juveniles which had probably been carried into the estuary by the tidal currents and as these slackened the fish had settled to the bottom; they were therefore most abundant in deeper water near and in the central channel where the main tidal flow occurred.

Movements of O-group P. minutus

Changes in the distribution and abundance of O-group P. minutus over the tidal cycle are shown in Figure 3.4a and b. On the sampling dates in July 1978 very large numbers of P. minutus were captured at low water, but on the other occasions only small numbers were present or they were absent from catches, both at the side of the channel and in the mid-channel (Fig. 3.4a). There was no obvious explanation for the exceptional catches taken in July 1978. At LW + 2h and high water however, P. minutus was abundant in the catches. Like flounder and P. microps the sand goby was mainly found on the intertidal banks and only small catches were taken in the channel. P. minutus was generally most abundant in water of 1.5 - 3m depth with the greatest numbers

FIGURE 3.3

Changes in the intertidal distribution and abundance of 0-group *P. microps* over the tidal cycle; a) flood tide; b) ebb tide: •—• numbers of fish; •--• depth of water. Station A2 when sampled is denoted on the graphs for LW by the depth symbol at 0.5m. NS indicates no samples collected.

FIG. 3.3a

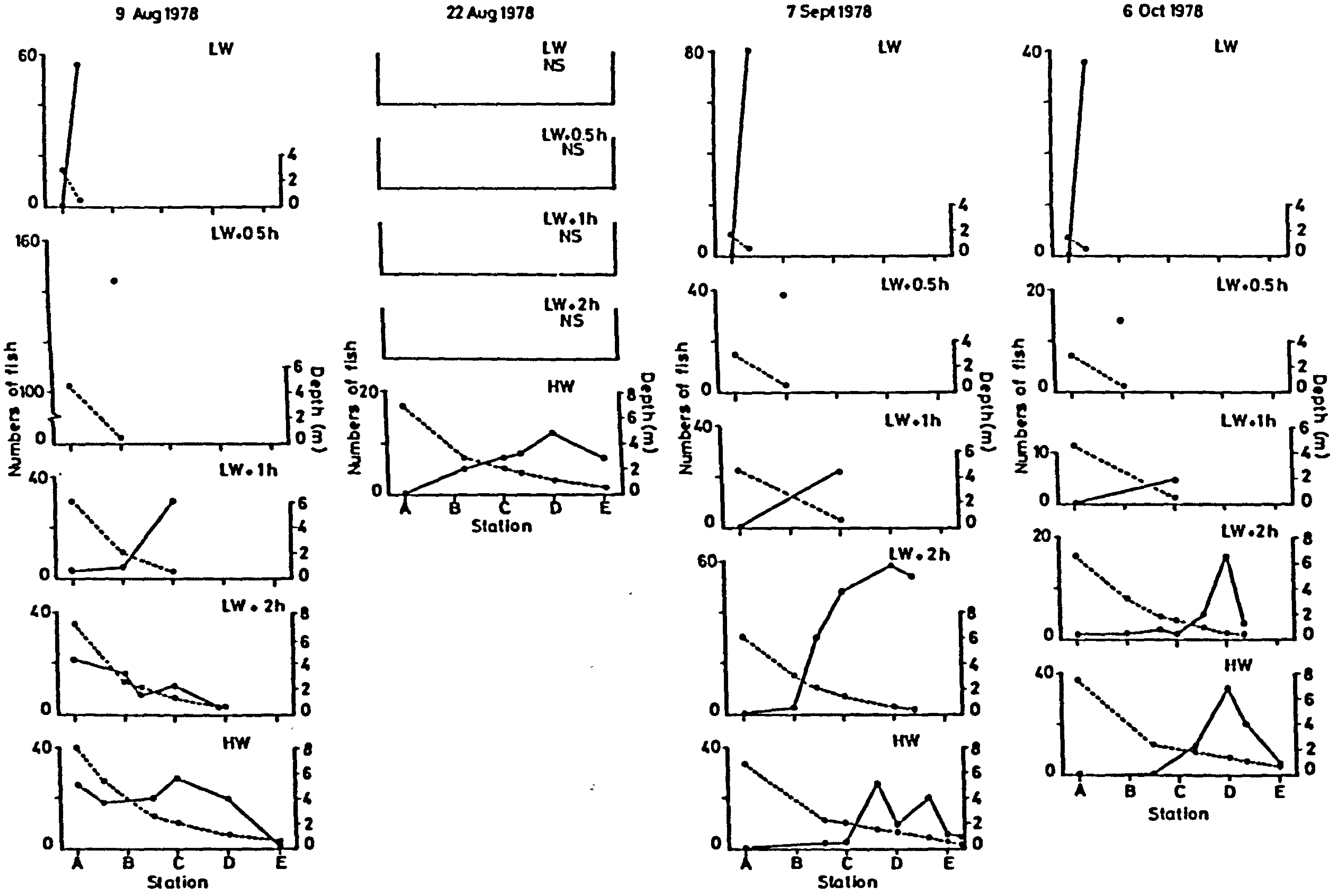
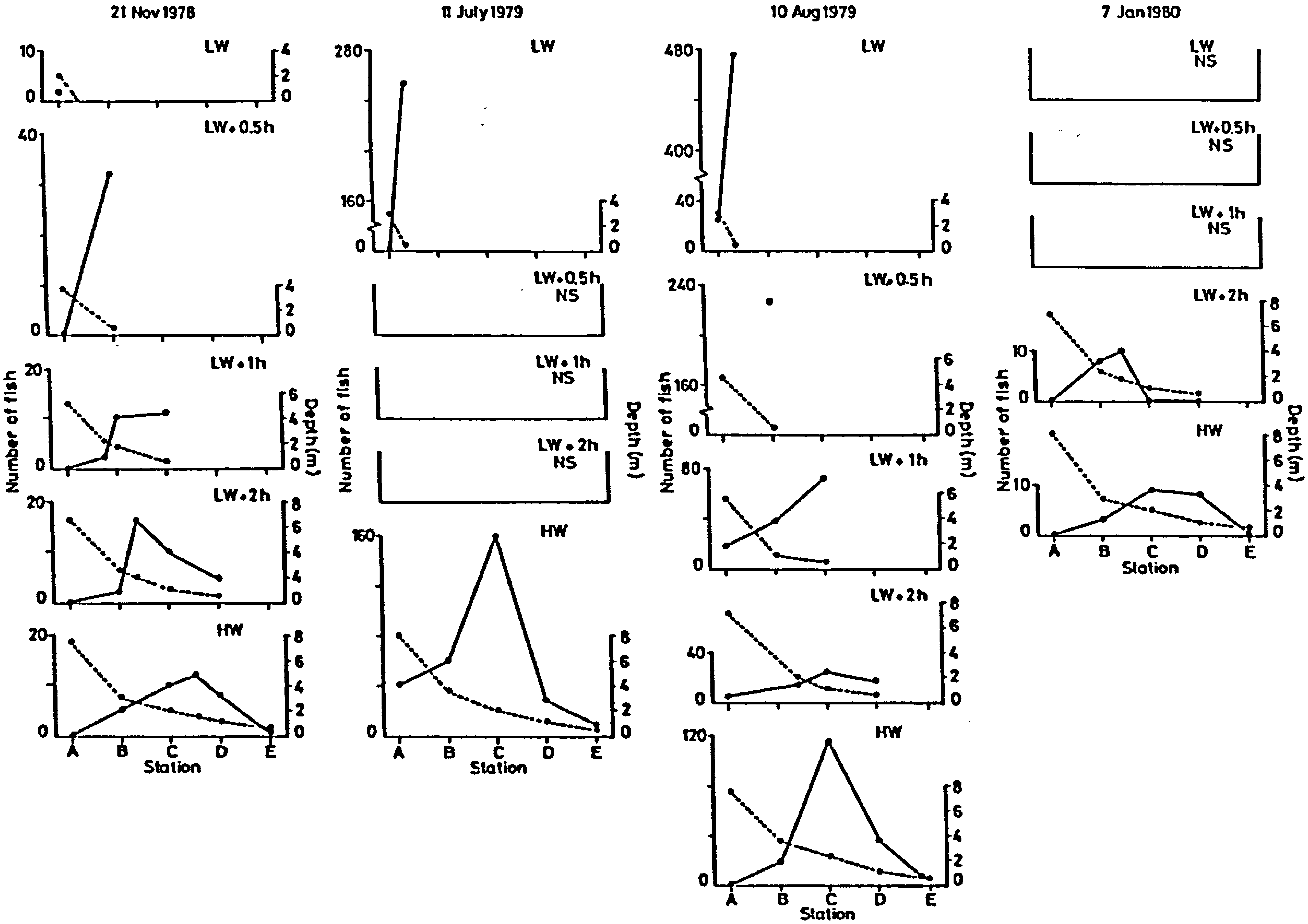

9 Aug 1978
22 Aug 1978
7 Sept 1978
6 Oct 1978
LW
LW.0.5h
LW.1h
LW.2h
HW
NS
Numbers of fish
Depth (m)
Station
A
B
C
D
E
0
20
40
60
80
100
160
10
2
4
6
8

FIG. 3.3a contd.



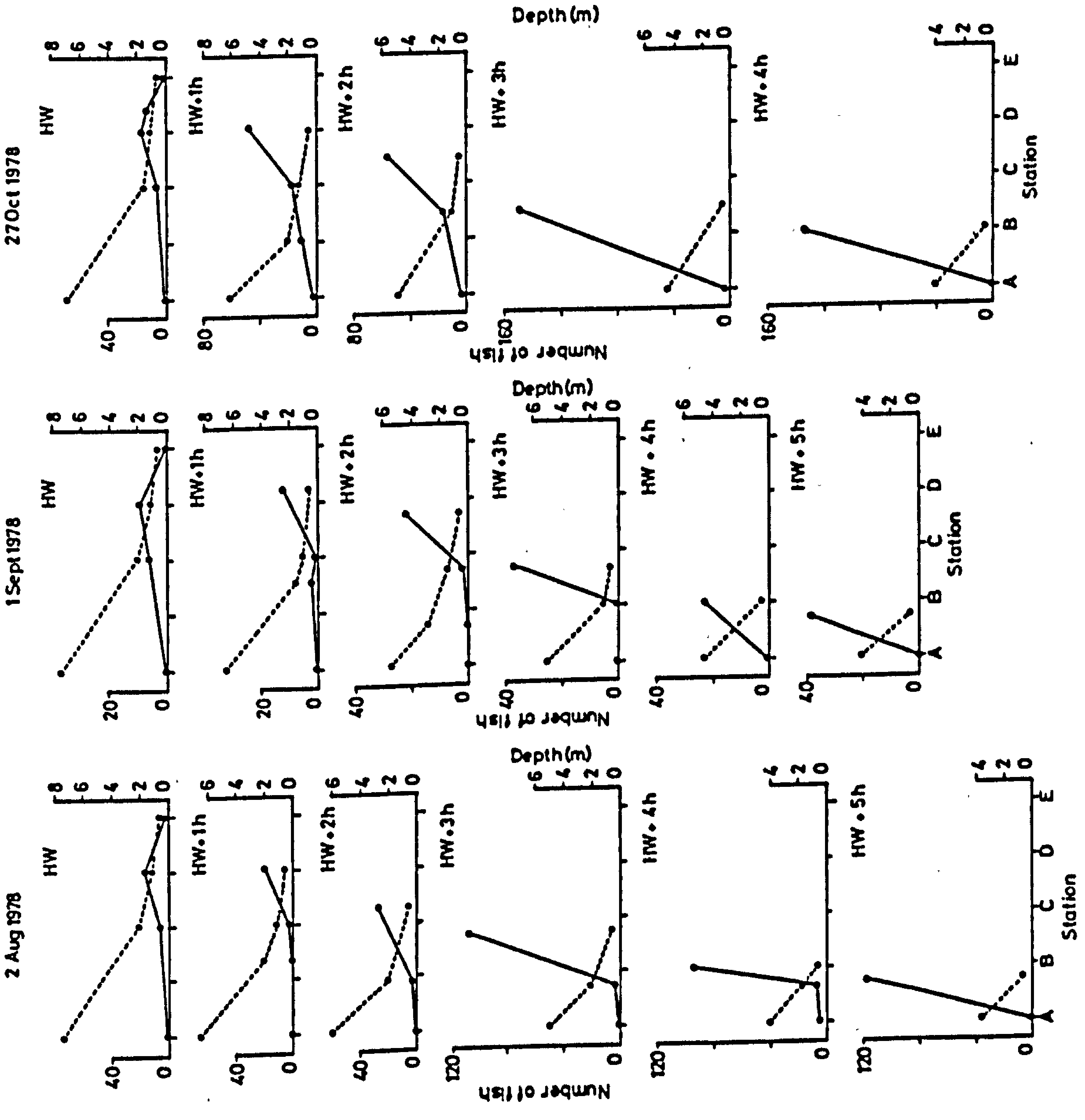

27 Oct 1978
1 Sept 1978
2 Aug 1978
HW
HW.1h
HW.2h
HW.3h
HW.4h
HW.5h
Depth (m)
Number of fish
Station
A
B
C
D
E

FIG. 3.3b

FIG. 3.3b contd.

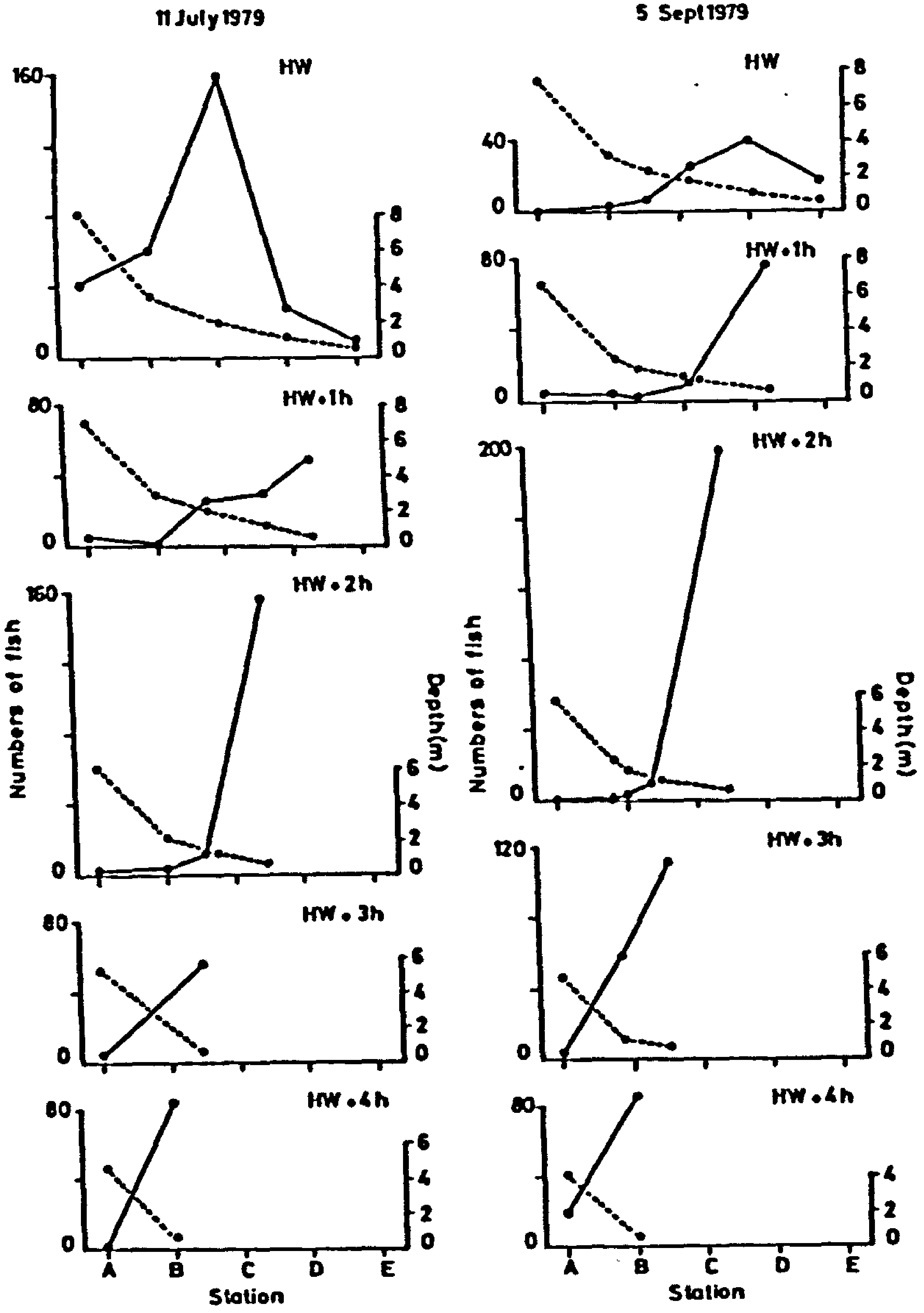


Table 3.5 Numbers of O-group P. microps in mid-channel (Station A) and side-channel (Station A2) trawls.

Sampling date	Mid-channel trawl	Side-channel trawl
9/8/78	0	56
7/9/78	0	81
6/10/78	0	38
11/7/79	2	253
10/8/79	26	475

FIGURE 3.4

Changes in the intertidal distribution and abundance of O-group P. minutus over the tidal cycle; a) flood tide; b) ebb tide : ●—● numbers of fish; ●--● depth of water. Station A2 when sampled is denoted in the graphs for LW by the depth symbol at 0.5m. NS indicates no samples collected.

FIG. 3.4a

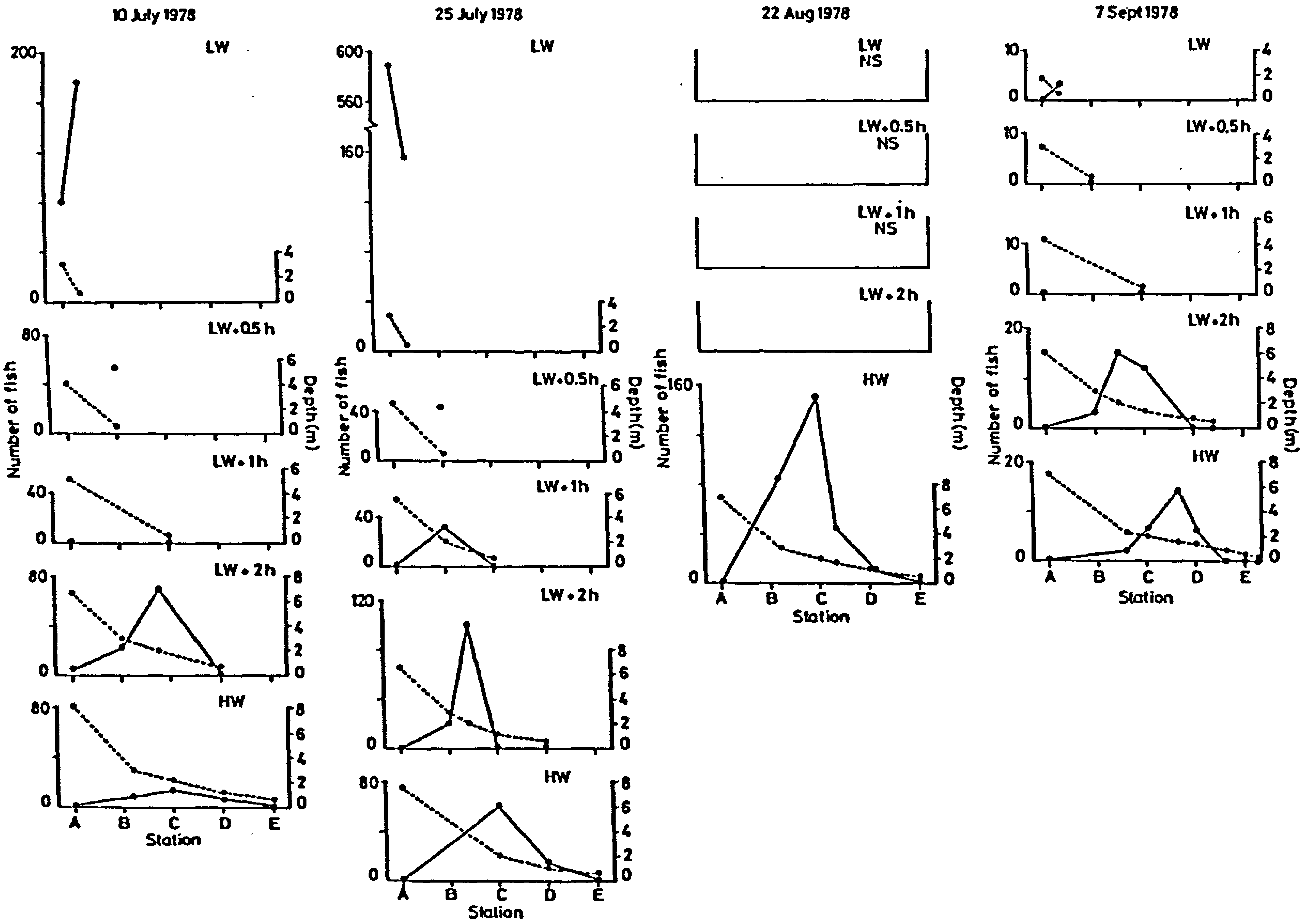

10 July 1978
25 July 1978
22 Aug 1978
7 Sept 1978
LW
LW+0.5h
LW+1h
LW+2h
HW
NS
Number of fish
Depth (m)
Station
A
B
C
D
E
200
600
560
160
120
80
40
20
10
0
8
6
4
2

FIG. 3.4a contd.

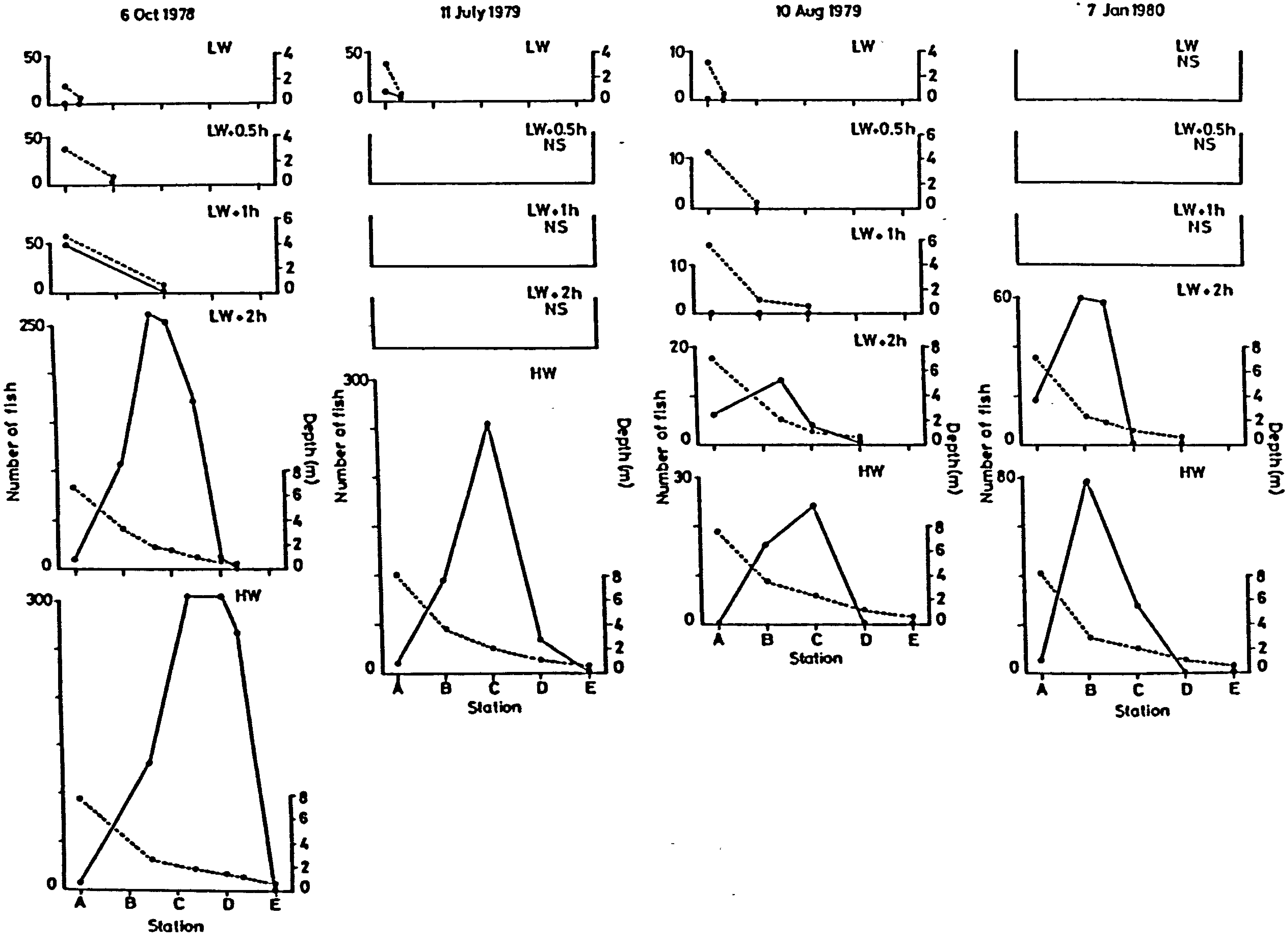
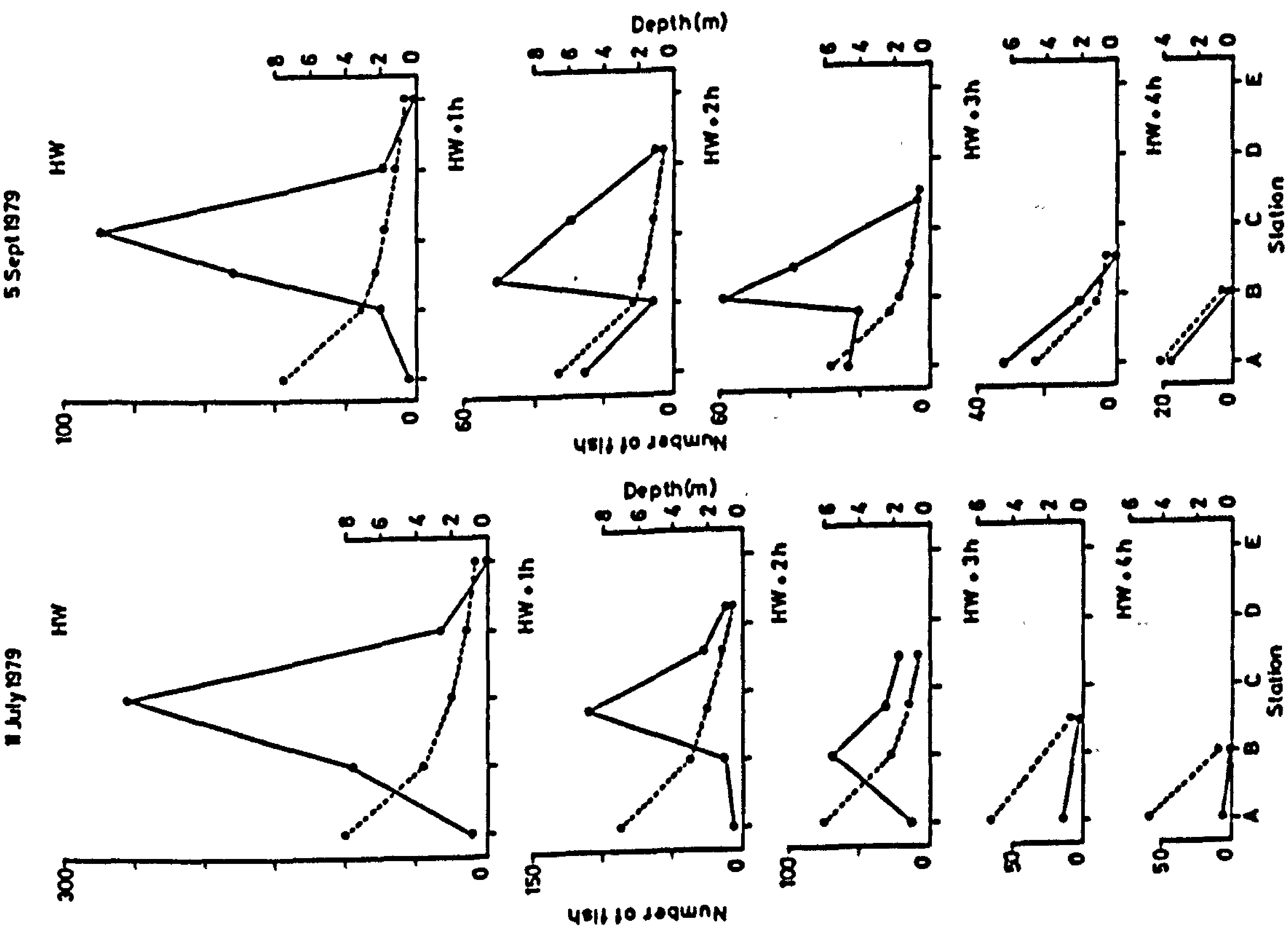


FIG. 3.4b


11 July 1979
5 Sept 1979
HW
HW+1h
HW+2h
HW+3h
HW+4h
Number of fish
Depth(m)
Station
A
B
C
D
E
300
150
100
60
50
40
20
8
6
4
2
0

usually taken at 2m depth.

Because of the restrictions placed on trawling by the training wall the distribution and intertidal movements of P. minutus during the early stages of the flood tide before LW + 2h are not known, however, it appeared that unlike flounder and P. microps they did not move onto the intertidal banks in shallow water. There was an exception to this in July 1978 when P. minutus was taken in large numbers in low water trawls, and at the start of the flood tide they were common in 0.5m depth. At LW + 1h however, they were absent from samples at this depth.

Information on the distribution and movements after high water was also limited since on the ebb tide sampling dates the sand goby was abundant on only two occasions (Fig. 3.4b). The results suggested that P. minutus moved down the intertidal banks maintaining their concentration in water of 2m depth, and at HW + 2h when samples could still be taken at a series of depths, the depth distribution of the fish resembled that at high water. Numbers in shallow water of 0.5m depth did increase slightly but unlike flounder and P. microps the bulk of the sand gobies moved down the shore well in advance of the water's edge. In September 1979 large catches of P. minutus were also taken in the mid-channel.

Movements of O-group P. lozanoi

The intertidal movements of P. lozanoi were closely similar to those of P. minutus (Figure 3.5a and b). Again, except on the sampling date in July 1978, at low water only small numbers of P. lozanoi were captured or they were absent from catches, but at LW + 2h and high water the sand goby was common on the intertidal banks. There was little difference in the depth distributions of P. minutus and P. lozanoi at LW + 2h and high water.

FIGURE 3.5

Changes in the intertidal distribution and abundance of O-group *P. lozanoi* over the tidal cycle; a) flood tide; b) ebb tide : •—• numbers of fish; •--• depth of water. Station A2 when sampled is denoted on the graphs for LW by the depth symbol at 0.5m. NS indicates no samples collected.

FIG. 3.5a

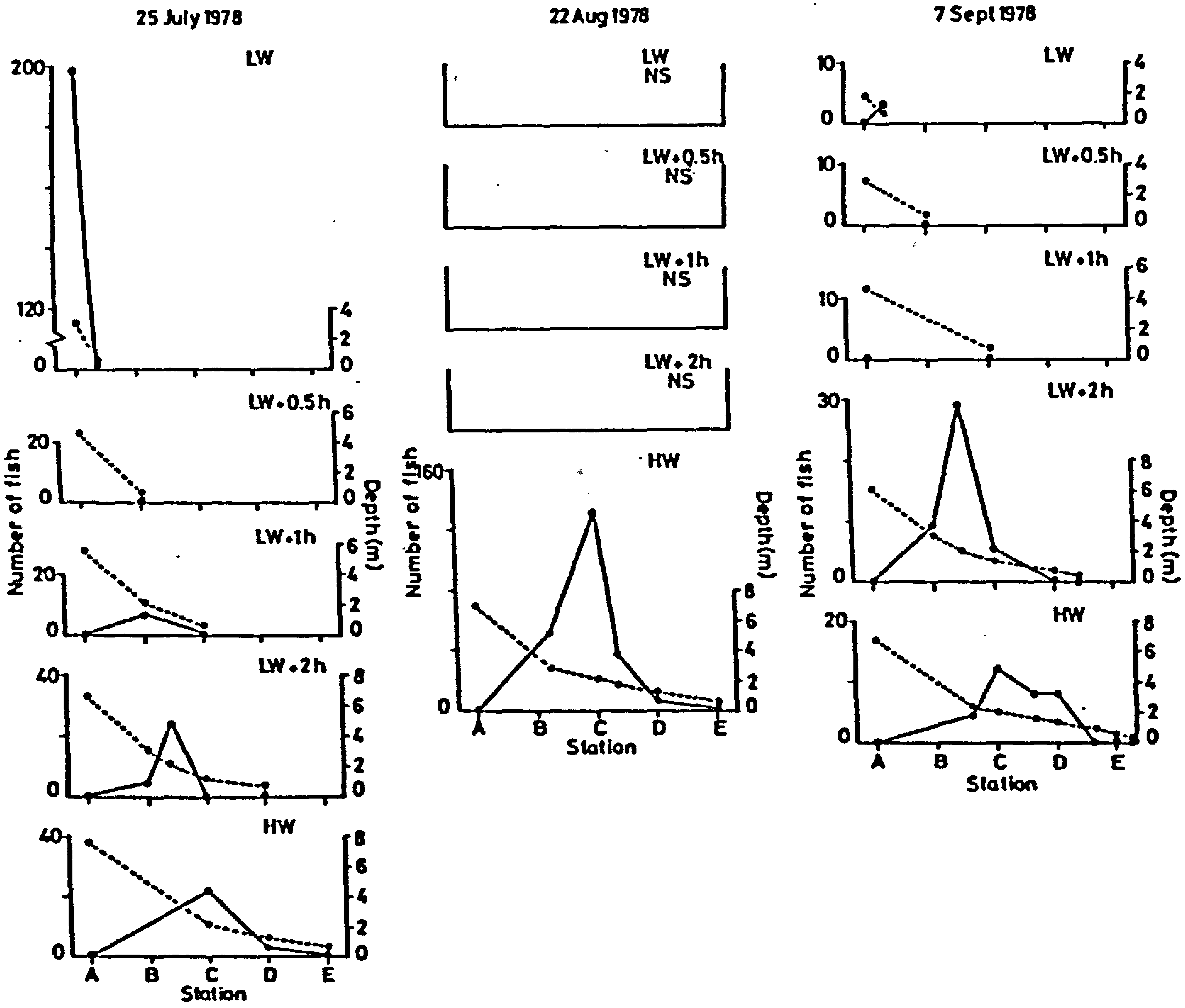

25 July 1978
22 Aug 1978
7 Sept 1978
LW
LW NS
LW+0.5h
LW+0.5h NS
LW+1h
LW+1h NS
LW+2h
LW+2h NS
HW
Number of fish
Depth (m)
Station
A
B
C
D
E
200
120
160
40
30
20
10
8
6
4
2
0

FIG. 3.5a contd.

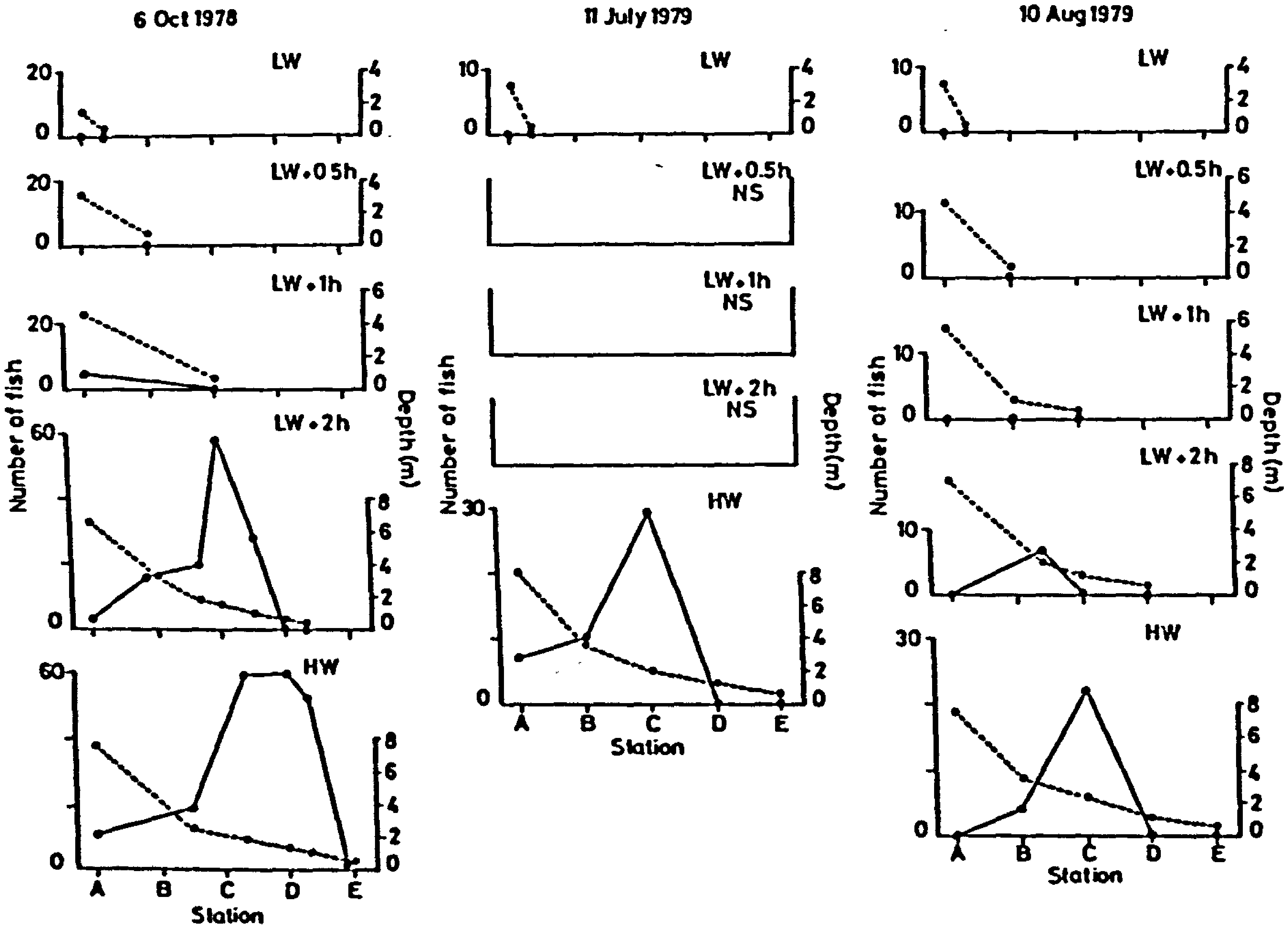
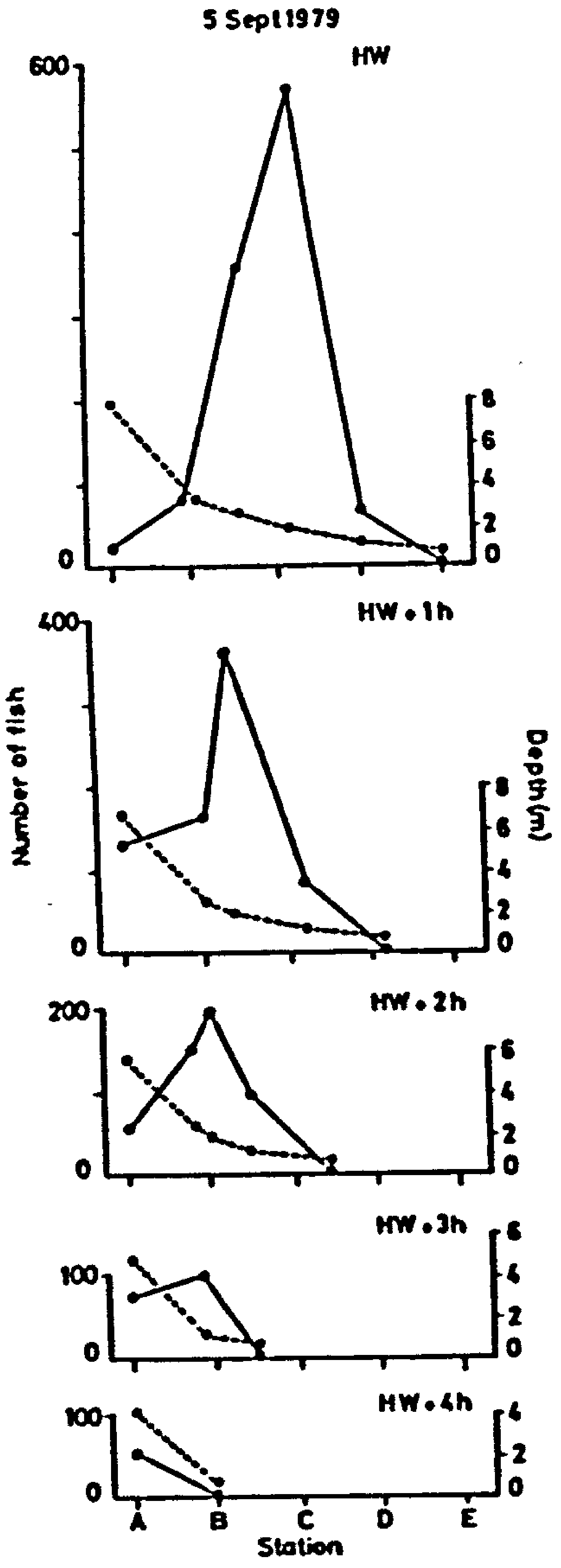


FIG. 3.5b


5 Sept 1979
HW
HW + 1h
HW + 2h
HW + 3h
HW + 4h
Number of fish
Depth (m)
600
400
200
100
100
0
8
6
4
2
0
A
B
C
D
E
Station

On the one occasion when P. lozanoi was abundant on the ebb tide sampling dates (Fig. 3.5b), the results suggested the fish moved down the intertidal banks with greatest numbers in 2m depth.

Size distribution with depth

Figures 3.6 - 3.9 show the mean length of O-group fish of the four species at each sampling depth on the intertidal banks on the separate sampling occasions. Only those fish taken at LW + 2h and high water when a series of depths could be sampled were included in the analysis.

There was no obvious relationship between mean length of fish and depth, and as can be seen from the 95% confidence limits of the means there was usually a large variation in individual fish length at a given depth. On some occasions the samples showed a tendency for an increase in mean length with increase in depth, but on the evidence available it is not possible to suggest whether this reflected the presence of a real trend for an increase in size with depth on the intertidal banks. P. microps showed a decrease in mean length with depth on the July and September 1979 sampling dates. This was the result of an abundance of postlarval and small juvenile fish at the deeper depths, a feature which has been discussed when the intertidal distribution and movements of P. microps was described. Also in July 1979, a large number of small juvenile P. minutus were present in deeper water and the mean length of fish at 2m and 3.5m was less than at 1.2m depth.

A small number of I-group flounder and P. minutus were taken in the samples on the intertidal banks, but the numbers were too few for any conclusions to be drawn on whether they had a different depth distribution to the O-group fish. The overall impression was that they followed the same pattern of abundance with depth as the O-group fish.

Mean length of fish at each sampling depth on the intertidal banks. All fish from samples collected at LW + 2 h and high water. Sample sizes and 95% confidence limits are shown. No data are presented where less than five fish collected at a depth, or for those sampling dates when sufficient fish were only available from one depth.

FIGURE 3.6 - Flounder
FIGURE 3.7 - *P. microps*
FIGURE 3.8 - *P. minutus*
FIGURE 3.9 - *P. lozanoi*

FIG. 3.6

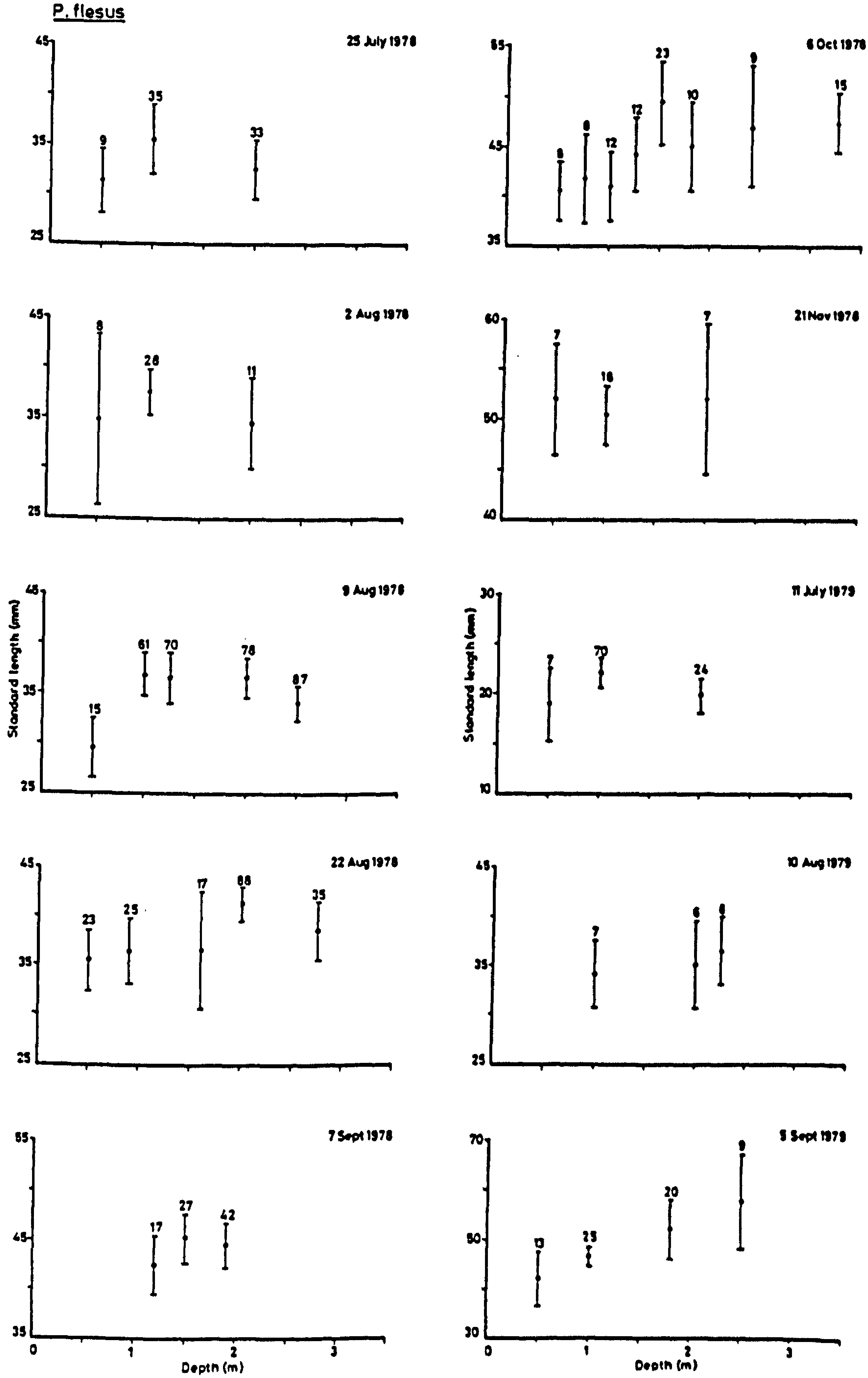

P. flesus
25 July 1978
45
35
25
9
35
33
6 Oct 1978
55
45
35
8
8
12
12
23
10
9
15
2 Aug 1978
45
35
25
8
28
11
21 Nov 1978
60
50
40
7
18
7
9 Aug 1978
45
35
25
Standard length (mm)
15
61
70
78
87
11 July 1979
30
20
10
Standard length (mm)
7
70
24
22 Aug 1978
45
35
25
23
25
17
88
35
10 Aug 1979
45
35
25
7
6
8
7 Sept 1978
55
45
35
17
27
42
0
1
2
3
Depth (m)
5 Sept 1979
70
50
30
13
25
20
9
0
1
2
3
Depth (m)

FIG. 3.7

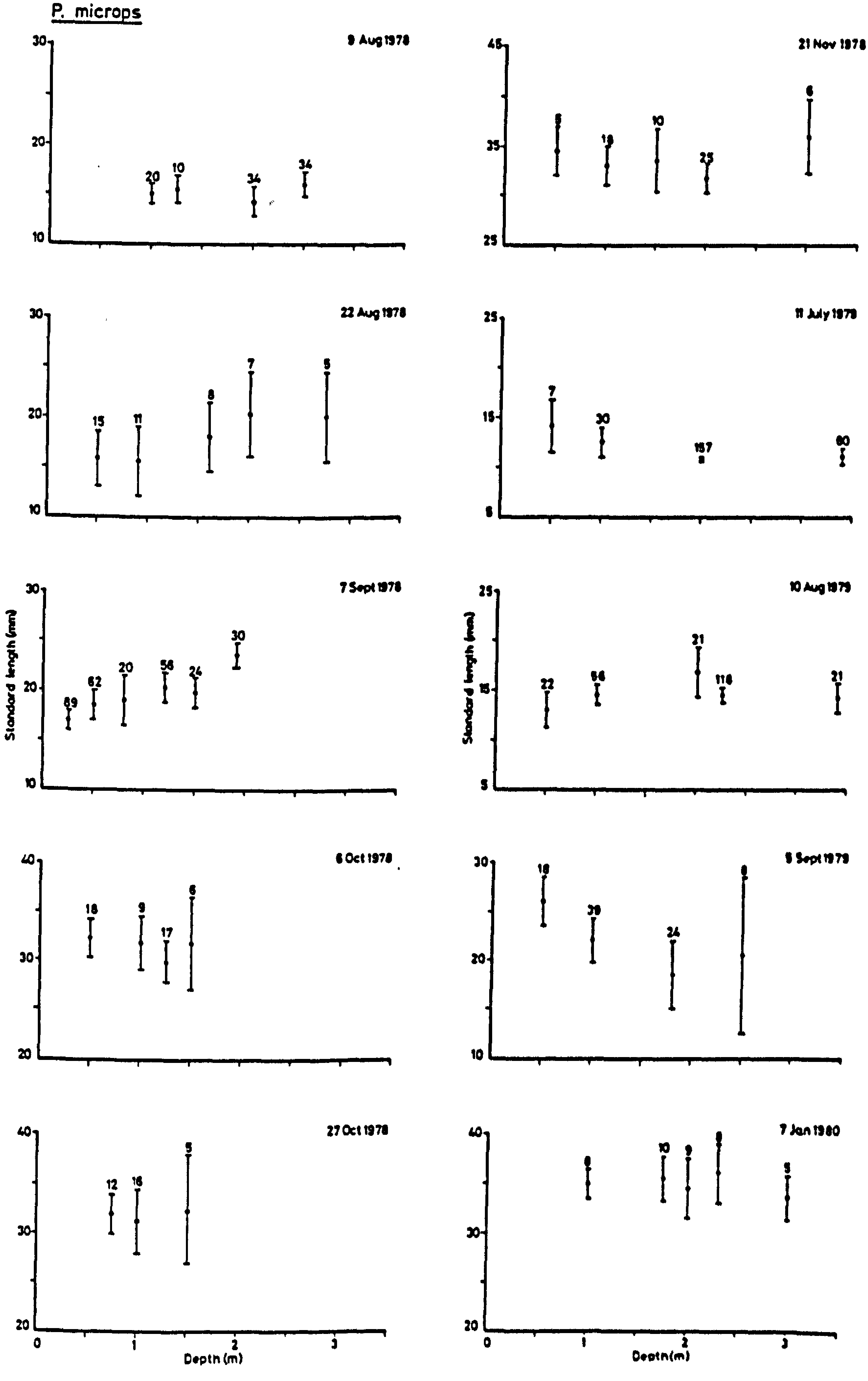

P. microps
9 Aug 1978
20
10
34
34
21 Nov 1978
8
18
10
25
6
22 Aug 1978
15
11
8
7
5
11 July 1979
7
30
167
60
7 Sept 1978
89
62
20
56
24
30
10 Aug 1979
22
56
21
118
21
6 Oct 1978
18
9
17
6
5 Sept 1979
18
39
24
8
27 Oct 1978
12
16
5
7 Jan 1980
8
10
9
8
5
Standard length (mm)
Depth (m)
0
1
2
3

FIG. 3.8

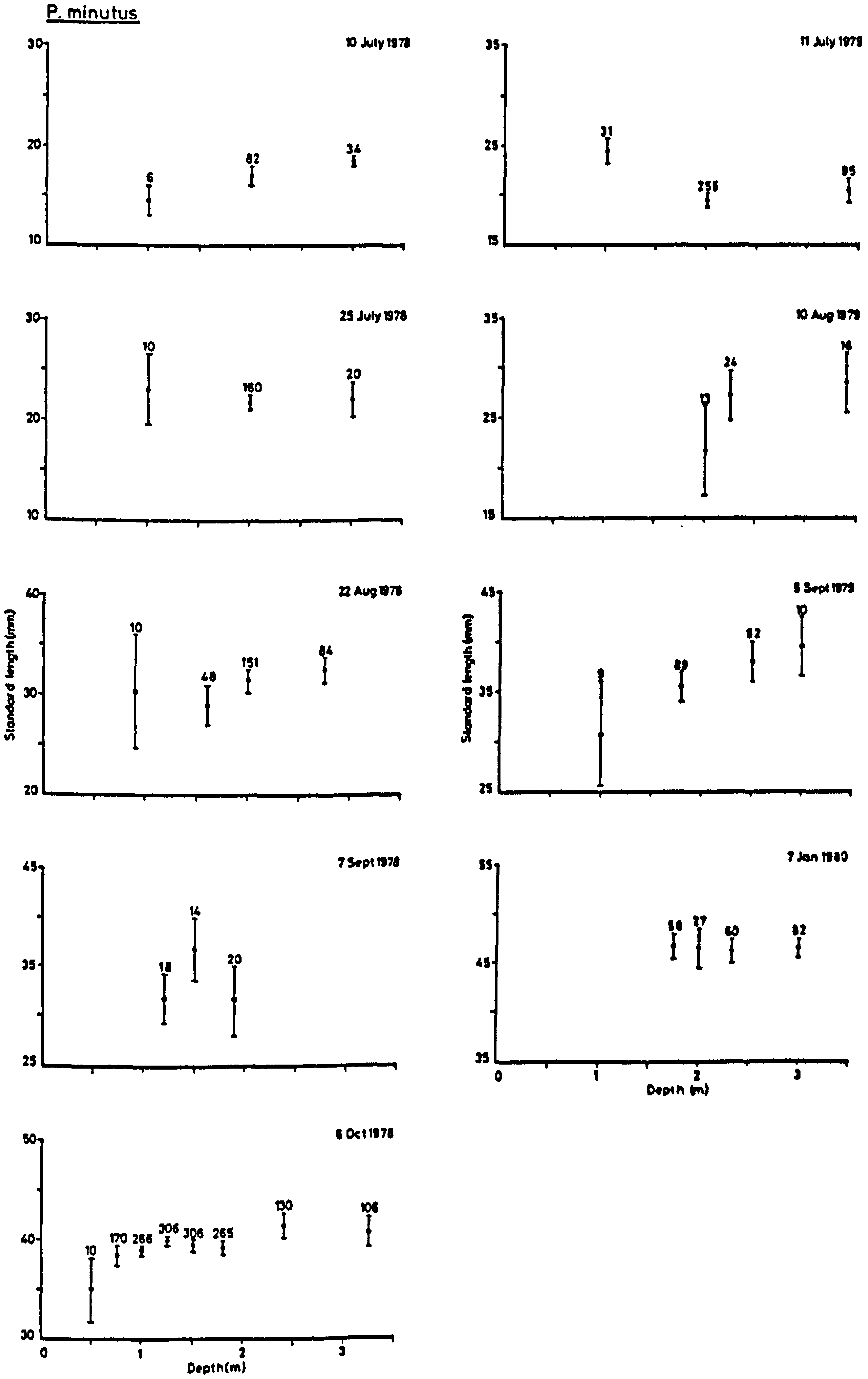
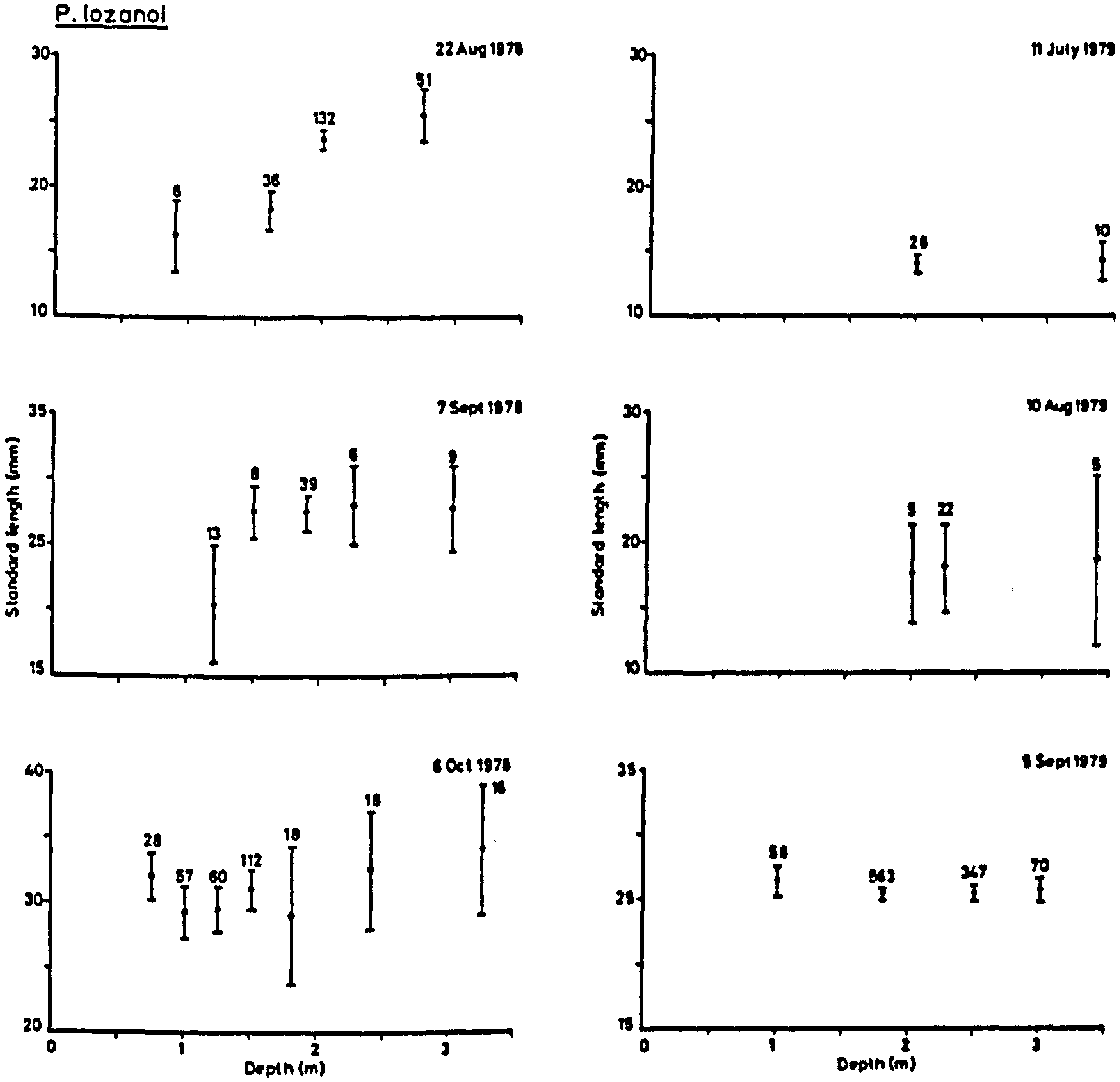

P. minutus
10 July 1978
30
20
10
6
82
34
11 July 1979
35
25
15
31
258
95
25 July 1978
30
20
10
10
160
20
10 Aug 1979
35
25
15
13
24
16
22 Aug 1978
Standard length (mm)
40
30
20
10
48
151
84
5 Sept 1979
Standard length (mm)
45
35
25
9
89
52
10
7 Sept 1978
45
35
25
18
14
20
7 Jan 1980
55
45
35
58
27
60
82
0
1
2
3
Depth (m)
6 Oct 1978
50
40
30
10
170
286
306
306
265
130
106
0
1
2
3
Depth(m)

FIG. 3.9


P. lozanoi
22 Aug 1978
11 July 1979
7 Sept 1978
10 Aug 1979
6 Oct 1978
5 Sept 1979
Standard length (mm)
Depth (m)
30
20
10
35
25
15
40
0
1
2
3
6
36
132
51
28
13
8
39
9
5
22
57
60
112
18
16
58
563
347
70

DISCUSSION

The description of the distribution and movements of flounder, P. microps, P. minutus and P. lozanoi in the present study must be tempered with the lack of detailed information on the distribution of fish during the early stages of the flood tide and the later stages of the ebb tide, a consequence of the restrictions placed on sampling by the training wall. There was in fact an absence of data on the numbers of fish in the training wall throughout nearly the whole of the tidal cycle. However, the results clearly show a positive movement of the species onto and off the intertidal banks with the tide, and a pattern to their distribution on the major part of the banks. This was not a passive movement of the fish with the currents since the main tidal flow was at 90° to the direction of movement.

The principal reason why fish move onto the intertidal zone appears to be for feeding; the movement enables the fish to feed on prey populations which are only available when they are immersed by the tide (Merriman, 1947; Smidt, 1951; Zenkevitch, 1963; Edwards and Steele, 1968; Tyler, 1971a; Gibson, 1973a; Kuipers, 1973; Gibson, 1980; Wolff et al., 1981). The importance of the intertidal banks in the inner estuary as a feeding ground for juvenile fish will be discussed in Chapter 4.

The intertidal movements of P. minutus and P. lozanoi differed from those of flounder and P. microps. The movements of the former two species resembled those of O-group plaice and the juveniles of several less abundant demersal species described by Gibson (1973a). This author found each of the species moved up and down a sandy beach in a relatively well defined band and the movement appeared to be related to a depth preference, the species were concentrated at certain depths and they maintained the depth distribution over the tidal cycle. Likewise, the results of the present study suggested P. minutus and P. lozanoi migrated over the intertidal banks in water of approximately the same depth, although this could only be confirmed for the period 1 - 1.5 hours before high water to 2 - 2.5 hours after high water. A small number of P. minutus were collected by Gibson and they were mainly found in water of 1 - 3m depth, a depth distribution similar to that observed in this study.

In contrast, the depth of greatest abundance of flounder and P. microps in the inner estuary changed over the tidal cycle. The pattern of movement shown by these two species would seem the most appropriate for foraging on intertidal prey populations in the inner estuary. By moving onto and off the intertidal banks in shallow water with large numbers of fish in water of 0.5m depth or less, the two species were maximising the time they were present intertidally. The greater numbers of flounder and P. microps found at the side of the channel at low water can be considered as part of this overall pattern of movement in shallow water. As the banks were increasingly immersed on the flood tide and a much larger area was available to the fish, the two species became spread over the banks and were most abundant at a depth of 1 - 2m. It may in fact have been expected that the fish would have become even more uniformly distributed, foraging over the whole of the intertidal area. The usually small catches in 0.5m depth during the later stages of the flood tide and at high water may at least probably be explained by differences in the distribution of prey organisms. As will be discussed in Chapter 4 the highest densities of benthic prey were thought to be associated with the fine sediments and at the top of the banks where the substrate was coarse sand and pebbles there was probably little food for the fish. The lower numbers of flounder and P. microps in water deeper than 1 - 2m however, suggests a preference for shallow depths. The samples collected by Gibson (1973a) included a small number of O-group flounder with the majority present in water of 1m depth or less, shallower than the bulk of the plaice population. Studies by Williams et al. (1965) and Wolff et al. (1981) have also found flounder generally occur in shallower water on the shore than plaice. In the inner estuary it is possible that were there not a change in the nature of the sediment at the top of the intertidal banks, flounder would have been more abundant in water less than 1 - 2m depth at LW + 2h and high water than was observed. This will equally apply to the distribution of P. microps.

The different movements of P. minutus and P. lozanoi, and flounder and P. microps resulted in a separation of the bulk of the two groups of fish when they were moving onto and off the intertidal banks. If competition for food existed this may have been reduced by the different patterns of movement, although during the later stages of the flood tide and at high water there was a considerable overlap in the distributions. On some of the sampling dates there was a tendency for the greatest numbers of sand gobies to be found in slightly deeper water than flounder and P. microps at LW + 2h and high water, but on other occasions there was no apparent difference. A discrete zonation of the species was not to be expected however, and even slight differences in distribution if present may still have led to reduced competition. Several workers have suggested that differences in depth distribution may help lessen competition between species with similar diets, and this has often been discussed in relation to the distribution of juvenile plaice and dab on the shore (Macer, 1967; Edwards and Steele, 1968;

Gibson, 1973a; Wolff et al., 1981). Where these two species are concerned there is a large degree of separation since unlike plaice, juvenile dab are only rarely (Poxton et al., 1982) found to move intertidally. The shallower depth distribution of flounder than plaice has also been suggested as resulting in the two species avoiding competition (Williams et al., 1965; Wolff et al., 1981). However, whether or not reduction in competition is actually a factor affecting the intertidal distribution and movements of fish species can only be conjecture.

While there was no clear evidence of a size distribution with depth on the intertidal banks, an increase in size with depth is generally acknowledged as occurring in juvenile plaice inhabiting shallow coastal waters (Bregnballe, 1961; Macer, 1967; Edwards and Steele, 1968; Hill, 1971; Gibson, 1973a; Lockwood, 1974) and has also been shown in juvenile dab (Gibson, 1973a). Muus (1967) found some evidence of larger O-group flounder inhabiting deeper water and in addition observed an increase in the length of P. microps with depth. However, as with the present study where variable results were obtained many of these studies have also shown often small increases with depth and a large variability in fish length at a given depth. In addition the data are often presented in the form of length-frequency histograms at a few depths and for only one occasion so it is difficult to assess the consistency of the patterns described. The studies of Gibson (1973a) and Lockwood (1974) did investigate the size-depth relationship of juvenile plaice in more detail, although in his study Lockwood gave no indication of variability about mean lengths, and described seasonal changes. Gibson suggested that zonation by size may reduce intraspecific competition and cannabalism, and observed that the juvenile plaice maintained the differential size distribution as they moved over the shore with the tide. If a size distribution with depth was present in flounder and P. microps on the intertidal banks at high water, then presumably when the fish were moving onto and off the banks mainly in shallow water they will have been mixed irrespective of size. As will be discussed later, it was apparent that fish were also moving into and out of the inner estuary as a whole with the tide, and therefore it is perhaps less likely that a size distribution with depth similar to that observed on the coast, where fish are simply moving up and down the shore, would be formed on the intertidal banks. A more thorough investigation into a possible size-depth relationship in the inner estuary would have required samples from a much wider range of depths, however, because of the training wall and the cross-sectional profile of the study area these could not be obtained.

As stated at the start of this discussion it is generally considered that the function of intertidal movement is to facilitate feeding. Although a detailed study of the intertidal movements of fish on night tides was not undertaken in the present investigation, shallow water trawls made during the 24 hour feeding study (Chapter 4) showed that large numbers of juvenile flounder and P. microps were present on the intertidal banks at night. However, the same study showed that flounder and P. microps only fed during the hours of daylight. Intertidal movement purely as a feeding migration would therefore not account for the movement of fish intertidally on the night tides. Similarly, Gibson (1973a) found juvenile plaice moved onto the shore on both day and night tides, but food intake followed a diurnal rhythm with a low level of feeding during the hours of darkness. He suggested the movement at night may have enabled the young plaice to avoid predation by larger fish which moved inshore at this time. In the inner estuary however, it was not thought that the fish were subject to any major predation by other fish species. Species such as juvenile cod, lesser weever (Trachinus vipera Cuvier) and large plaice which are active predators on other fish on the open coast (Riley and Corlett, 1966; Macer, 1967; Edwards and Steele, 1968; Lockwood, 1972) rarely entered the inner estuary (Chapter 2). The trawls taken during the 24 hour feeding study did not indicate whether P. minutus and P. lozanoi also moved onto the intertidal banks at night. Only a small number of individuals of the two sand gobies were taken in the samples during either the day or night, and this was probably because the trawls were taken in water of 0.5 - 1m depth which was shallower than where the sand gobies were mainly found, at least on the day tides.

It seems probable that the intertidal movements of fish are at least partly controlled by an endogenous rhythm of activity which in tidal conditions is phased with the tidal cycle. Gibson (1973b, 1975, 1976) and Gibson et al. (1978) have carried out detailed laboratory investigations of this activity rhythm in plaice and have discussed the findings in relation to the activity of plaice on the shore. Similar activity rhythms have been shown in juvenile flounder (Gibson, 1976) and P. minutus (Gibson and Hesthagen, 1981), and are in fact common in many species of fish (Gibson, 1978) and invertebrates (Palmer, 1974, 1976; Enwright, 1975) inhabiting intertidal and shallow subtidal areas. However, the presence of an innate circa-tidal rhythm of activity does not completely account for the intertidal movements of fish. Gibson (1975) has shown that the activity of young plaice in the laboratory is not fully representative of the activity of fish on the shore. The function of the endogenous rhythm seems to be to ensure that the timing of the fishes' downshore migration on the ebb tide is correctly phased. The directionality of movement is also particularly well synchronised on the ebb tide (Gibson, 1980). Gibson (1973a) has discussed various environmental cues which a fish may use to migrate over the intertidal zone and one environmental factor which does appear important in controlling intertidal movement is the change in hydrostatic pressure which occurs with the rise and fall of the tide (Gibson et al., 1978; Gibson, 1982).

Trawls taken during this study indicated that normally there was only a small population of P. minutus and P. lozanoi present in the inner estuary at low water. Samples collected during the dredging survey (Chapter 5) confirmed this finding. In fact the only species which were abundant in the channelised section throughout the tidal cycle were flounder and P. microps, the other marine-estuarine fishes moving in and out with the tide.

The movement of fish species with tidal currents is well documented (see review by Arnold, 1981). Most emphasis has centred on the unidirectional movement of fish, for example adults to spawning grounds or postlarvae to nursery areas. The immigration of young O-group flounder into the estuary by tidal transport comes within this category and has been discussed in Chapter 2. It is evident, however, that fish may also use currents for movement to and from an area within a tidal cycle. While it is not suggested that the tidal migration of P. minutus and P. lozanoi affected their pattern of intertidal movement, it would seem advantageous for the fish to move off the banks early on the ebb tide when the outgoing currents were still strong, thereby reducing the energy costs of the migration to more seaward reaches. The large catches of sand gobies in the channel on the ebb tide in September 1979 may have indicated a movement off the banks into the central channel, and then out of the inner estuary.

It is probable that the numbers of fish entering the inner estuary with the flood tide are correlated with tidal height. This may at least partly account for the short-term fluctuations in high water abundance of the marine-estuarine species observed in Chapter 2 and also apparent in this study. Although the use of tidal currents provides a rapid and energy saving means of transport (Weihs, 1978), both the tidal migration into and out of the inner estuary and the movement onto the intertidal raises interesting questions on the energetics and advantages of the movements.

CHAPTER 4

FOOD AND FEEDING HABITS OF FISHES IN THE INNER ESTUARY

INTRODUCTION

The food and feeding habits of estuarine and marine fishes have been the subject of numerous studies. In most of these the workers have analysed the diet of a single or two closely related species. An increasing number of studies are, however, now being published which consider feeding relationships within the community of fishes and the extent to which the available food resources are partitioned between the various community members (Tyler, 1972; Kislalioglu and Gibson, 1977; Hacunda, 1981; Thorman, 1982). This chapter examines the diet composition and feeding relationships of the marine-estuarine fishes present in the inner estuary. Five species were included in the study, these were flounder, P. minutus, P. lozanoi, P. microps and sprat. At high water these species numerically dominated the fish fauna of the channelised section (Chapter 2).

In Chapter 3 it was suggested that the movement of fish species onto the intertidal zone is generally regarded as a feeding migration. As was clearly demonstrated, there was a directed movement of fishes onto the intertidal banks of the inner estuary with the tide. A major aspect of this study of diet, therefore, was the question of whether there were differences in the feeding of fish on the intertidal banks and in the channel. In connection with this an investigation was also made of the feeding chronology of fishes in the inner estuary. If the main food sources were located intertidally then it was expected that feeding activity would follow a tidal pattern.

The results presented in this chapter are principally concerned with the feeding habits of fishes in the channelised section of the inner estuary and although sprat and the goby species did occasionally penetrate upstream of Preston Dock (Chapter 2), their diet in this section of the study area was not examined. However, flounder were abundant at each of the two sites sampled above the Dock and in this species a study was conducted. Compared to the extensive literature on flounder diet in estuarine and coastal habitats there are few accounts of the food of flounder in freshwater.

The food habits of fish species in the Ribble Estuary have been considered in a number of earlier studies. At the turn of the century workers from the Lancashire Sea Fisheries Laboratory listed the food organisms found in the stomachs of several commercial and non-commercial species from locations on the north west coast including the outer estuary of the Ribble (Herdman, 1893, 1894; Herdman and Scott, 1895). The stomachs of a wide variety of species were examined, although the number of individuals was small. A more detailed and far more recent study was conducted by Hiscock (1971) on the diet of flounder and plaice collected from the channel in the middle and outer estuary seaward of the confluence with the River Douglas. Hiscock also examined the diet of plaice and dab taken just offshore of the estuary mouth. However, the study was of limited duration and the total number of samples collected was small. All of these earlier studies examined the diet of fishes in the more outer regions of the estuary and there are no previous accounts of the feeding of fishes in the inner estuary.

METHODS

Feeding habits in the inner estuary were studied using the stomachs of fish taken in the monthly seine and trawl samples (Chapter 2). These provided a collection of stomachs taken over a 2 - 3 day period of each month at a series of locations along the study section, both from the channel and on the intertidal banks in the channelised section, and at the two sites upstream of Preston Dock. Samples of fish collected at Site 6 were included in this study.

The diet of flounder was examined from April 1978 to April 1980, and that of P. minutus, P. lozanoi, P. microps and sprat from July to October 1978 when their numbers in the catches were highest. In the channelised section P. lozanoi was rarely taken in the seine and P. microps rarely in the trawl, their diets in these two areas were therefore not investigated. As noted in the Introduction analysis of diet upstream of the Dock was restricted to flounder. Where possible 30 fish were examined from each monthly sample at each site, although numbers were usually much lower than this. Samples of I-group sprat and P. minutus were supplemented by material collected during the progress of other studies in this period.

Only the contents of the stomach were considered, because these indicate the types of food most recently consumed. Each stomach was examined individually. When no identifiable material was present a stomach was said to be empty. The contents of those stomachs containing food were examined under a binocular microscope and the food items identified, counted and their volume measured. Many of the fish had eaten large numbers of copepods and the numbers of these were estimated by subsampling. Volumes were measured by water displacement for large items and for smaller ones by the area of mm graph paper covered between two glass plates a known distance (approximately 1mm) apart (Chubb, 1961). The stomachs of metamorphosing and small juvenile fish were removed and opened under the binocular microscope and the contents examined under a compound microscope. For these fish the percentage that each food item contributed to the total volume of the contents was estimated, as direct measurement was not practicable.

The results were analysed using the percentage occurrence and the average of the volume percentages methods (Wallace, 1981). The former gives the percentage of all the stomachs containing food in which a particular item occurs, and the latter is the average percentage that each item contributed to the total volume of food in each stomach. Reference will be made to the numbers of prey eaten by individual fish in the Results, but the difficulty of assessing the numbers of whole tubificids consumed precluded any further analysis by this method. The frequency of occurrence of some rare small items in the diet may have been underestimated. For example, at certain times of the year an individual flounder stomach often contained several thousand calanoid copepods with one or two harpacticoid or cyclopoid copepods also occasionally present. These were easily missed amongst the much larger numbers of calanoids and their frequency of occurrence minimised, however, such items were insignificant in terms of volume.

All measures of dietary analysis have advantages and disadvantages which have been variously discussed (Hynes, 1950; Windell and Bowen, 1978; Berg, 1979; Hyslop, 1980; Wallace, 1981). The occurrence and volumetric methods used in the present study were considered to adequately describe the diets of fish in the inner estuary. Wallace (1981) considered the average of volume percentages methods to be the most suitable to use when determining dietary overlap. The major disadvantage of this method is that a single copepod in an otherwise empty stomach is equal to several mysids which distend the stomach of a fish of a comparable size.

Similarity between diets was measured using the Proportional

Similarity Index (Whittaker, 1952; Whittaker and Fairbanks, 1958):

$$PS = 1 - 0.5 \sum_{i=1}^{n} \left| p_{xi} - p_{yi} \right| = \sum \min (p_{xi}, p_{yi})$$

where p_{xi} is the proportion of food category i in diet x

p_{yi} is the proportion of food category i in diet y

This index has been used to compare species resource utilisation in a number of recent diet studies (Schoener, 1970; Werner and Hall, 1977; Leviten, 1978; Sabo and Whittaker, 1979). Wallace (1981) suggests this is the appropriate index to use when no information on resource availability has been collected. The average percentage volume data was used in the calculation of PS values, but with the data recalculated to exclude the indeterminate components of the stomach contents. As will be observed in the Results the stomachs were often found to contain small amounts of inorganic and plant material. They had probably been ingested accidentally during other feeding and these categories were also excluded from the calculations. Zaret and Rand (1971) and Mathur (1977) consider dietary overlap is ecologically significant when the index value obtained exceeds 0.60.

Daily feeding activity

To determine the feeding periodicity of fish in the inner estuary samples were taken at regular intervals over three 24 hour periods in August 1980 and changes in stomach fullness monitored. Samples were collected using a beam trawl on the intertidal movement study area (Chapter 3). Trawls were made every hour, and the fish were killed and preserved within 15 minutes of a haul commencing. On some occasions only a few or no fish were captured and the interval between samples was longer. Each 24 hour series began at 20.00h and continued until 20.00h the next day. Where possible a minimum of 10 fish of each species were taken from a sample and the stomach contents and body of the individual fish dried separately in a hot air oven at 65°C for 72 hours (trials showed that fish of the size range used achieved constant weight after this period). After cooling in a desiccator for 24 hours the fish and stomach contents were weighed to the nearest 0.1 mg. Dry weights were taken in order to eliminate errors associated with the blotting dry of fish and stomach contents which would have occurred if wet weights had been used. Stomach fullness was expressed as:

$$SF = \frac{\text{dry weight of ingested food}}{\text{dry weight of fish}} \times 100$$

To normalise the data the individual stomach fullness values were transformed using the arcsine transformation (Zar, 1974). The mean and 95% confidence limits of each sample were then calculated and the values back transformed to the original scale.

To analyse the effect of both the light-dark period and tidal state on feeding activity the three sampling dates were chosen so that the time of high water varied on each occasion. However, because the tidal regime is 3 hours flood and 9 hours ebb the sample series could not be exactly reversed with respect to the tidal cycle which is the normal practice in coastal marine feeding studies (e.g. Healey, 1971; Thijssen et al., 1974).

The trawls were made in shallow water of 0.5 - 1 m depth and the position at which the samples were taken therefore moved over the intertidal banks with the rise and fall of the tide. This was necessary since the use of a boat at night for trawling was considered too dangerous and all trawls had to be made in water of wadable depth. Attempts were made to collect fish from the central channel over the tidal cycle during the day, but insufficient numbers were collected for analysis. The shallow depth at which the samples were taken meant that fish other than flounder and P. microps were rare in the catches (see Chapter 3) and the study was therefore limited to these two species.

RESULTS

Diet of fish in the channelised section : fish from the channel

a) Flounder

Overall composition of diet

Table 4.1 shows the diet composition of O- and I-group flounder from the channel over the study period, fish from all sites combined. By far the most important component was the calanoid copepod Eurytemora affinis (Poppe). Larger crustaceans including the marine and estuarine species Neomysis integer (Leach) and Crangon crangon L., and the freshwater species Asellus aquaticus (L.) were eaten, however, in the total diet they were minor items compared to E. affinis. Chironomid larvae and pupae formed a large part of the diet and were the second most important item after E. affinis, comprising 9.2% and 8.9% of the volume of the O- and I-group stomach contents respectively. A variety of other taxa of insect larvae and nymphs were consumed, but were of little consequence in the diet. Some of the fish had consumed tubificids, however, they were a minor food of flounder from the channel, a finding which can be contrasted with their importance in the diet of flounder on the intertidal banks (see later).

Diet at each site

Figures 4.1 and 4.2 show the diet of O- and I-group flounder

Table 4.1 Overall composition of the diet of O- and I-group flounder from the channel. Number of stomachs examined with food: O-group = 151; I-group = 407.

	O-GROUP		I-GROUP	
Food item	% Occ.	% Vol.	% Occ.	% Vol.
Eurytemora affinis	76.2	72.6	83.5	67.8
Cyclopoid copepoda	3.3	+	2.2	+
Harpacticoid copepoda	6.6	+	2.7	+
Ostracoda	2.6	+	0.5	+
Cladocera	0.7	0.1	0.5	+
Neomysis integer	3.3	2.9	9.6	2.9
Crangon crangon	0.7	0.3	4.7	2.8
Corophium volutator	2.6	0.7	3.4	0.6
Gammarus spp.	1.3	0.7	2.2	0.6
Asellus aquaticus	3.3	1.2	6.1	3.5
Indeterminate Crustacea	2.0	1.3	0.7	0.1
Macoma balthica			0.5	0.2
Tubificidae	8.6	4.8	8.6	1.5
Nereis diversicolor	0.7	0.1	0.7	0.4
Lumbricidae	0.7	0.2	0.3	0.2
Hirudinea			0.5	0.1
Chironomidae larvae/pupae	20.5	9.2	41.6	8.9
Psychodidae larvae	0.7	0.1		
Simulidae larvae			0.3	+
Ceratopogonidae larvae			0.5	0.2
Tipulidae larvae			0.5	+
Dolichopodidae larvae			0.7	0.1
Indet. Diptera larvae	1.3	0.6	1.7	0.8
Trichoptera larvae			0.5	+
Plecoptera nymphs			1.0	0.3
Ephemeroptera nymphs	1.3	1.1	1.3	0.2
Flounder postlarvae	0.7	0.2	2.5	0.8
Pomatoschistus spp.			0.5	0.5
Indeterminate Pisces	0.7	0.7	0.7	0.5
Inorganic material	34.4	1.9	64.6	3.8
Plant material	33.8	1.3	56.5	3.2

+ = Food items < 0.1%

FIGURE 4.1

Diet of O-group flounder from the channel by site.

FIGURE 4.2

Diet of I-group flounder from the channel by site.

Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.1


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
142
50
94
60
42
26
21
12
0
80
100
80%
Inorganic material
Plant material
E. affinis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
Cladocera
N. integer
C. crangon
C. volutator
Gammarus spp.
A. aquaticus
Indet. Crustacea
Tubificidae
N. diversicolor
Lumbricidae
Chironomid larv/pup
Oth. insect larv/nym
P. flesus postlarvae
Indet. Pisces
E. affinis
A. aquaticus
Tubificidae
Chironomid larv/pup
Oth. insect larv/nym
Others (<2%)
E. affinis
Indet. Crustacea
Others (<2%)
E. affinis
N. integer
Chironomid larv/pup
Indet. Pisces
E. affinis
C. volutator
Tubificidae
Chironomid larv/pup
Oth. insect larv/nym
Inorganic mat.
Plant mat.
Others (<2%)

FIG. 4.2


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
244
85
169
31
171
73
29
17
0
100
100 %
Inorganic material
Plant material
E. affinis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
Cladocera
N. integer
C. crangon
C. volutator
Gammarus spp.
A. aquaticus
Indet. Crustacea
M. balthica
Tubificidae
N. diversicolor
Lumbricidae
Hirudinea
Chironomid larv/pup
Oth. insect larv/nym
P. flesus postlarvae
Pomatoschistus spp.
Indet. Pisces
E. affinis
N. integer
C. crangon
A. aquaticus
Tubificidae
Chironomid larv/pup
Plant mat.
Others (<2%)
C. crangon
A. aquaticus
Chironomid larv/pup
Inorganic mat.
Plant mat.
Others (<2%)
N. integer
Chironomid larv/pup
Oth. insect larv/nym
Inorganic mat.
Others (<2%)
Chironomid larv/pup
Inorganic mat.
Others (< 2%)

collected at each site. The number of stomachs examined from each site which contained food was often small and effectively only allowed a comparison of the diets of O-group fish at Sites 3 and 4, and I-group fish at Sites 3, 4 and 5. Similarity of diet at these sites was compared using the Proportional Similarity Index and the average percentage volume data.

O-group diets:

Site 3 vs Site 4 PS = 0.77

I-group diets:

Site	3	4	5
4	0.78	-	0.88
5	0.81	0.88	-

The calculated values of overlap indicate no major differences in the overall diet of flounder at each site. Considering the dominance of E. affinis in the diets this is not surprising.

From a visual inspection of the diets however, there was a tendency for freshwater invertebrates, especially chironomids, to be more important in the diet of fish at Site 3 than at the other sites, discounting the small number of fish collected at Site 6. This probably reflected a greater occurrence of these organisms at Site 3, freshwater invertebrates drifting through the estuary from upstream will presumably have tended to collect in this region of the channelised section as did other allochthonous material (Chapter 1).

Seasonal variation in diet

The composition of the flounder diet in each of the monthly samples is shown in Figure 4.3. The data are presented as the monthly diet of each flounder year class as it progressed through the

FIGURE 4.3

Seasonal variation in diet composition of juvenile flounder from the channel:

FIG. 4.3a by percentage frequency of occurrence

FIG. 4.3b by average percentage volume

Figures show composition of the monthly diet of each flounder year class as it progressed through the study period.

The number of stomachs examined containing food is shown.

No data are presented where less than four stomachs containing food were available. ● indicates average percentage volume less than 2%.

FIG. 4.3a

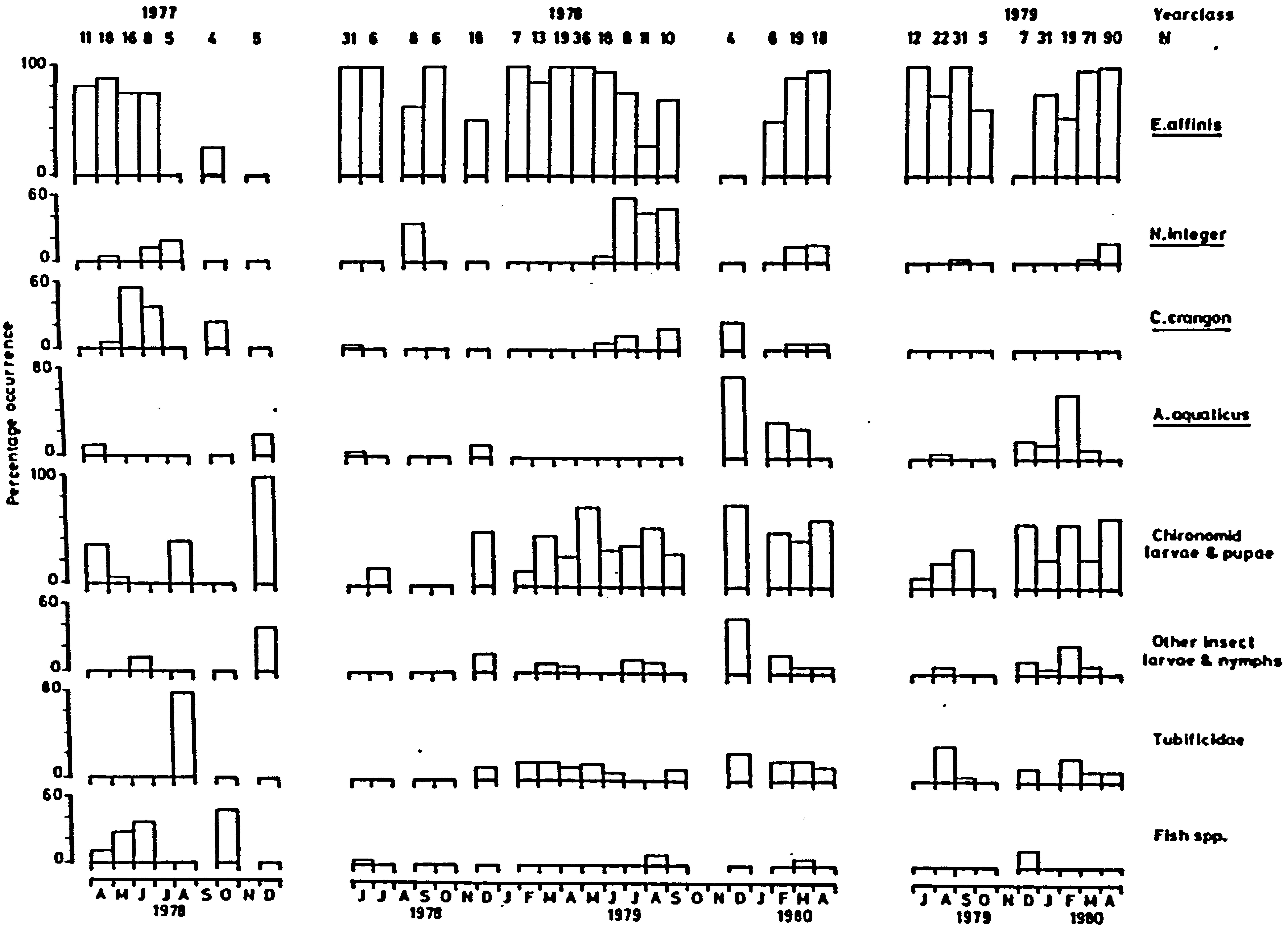
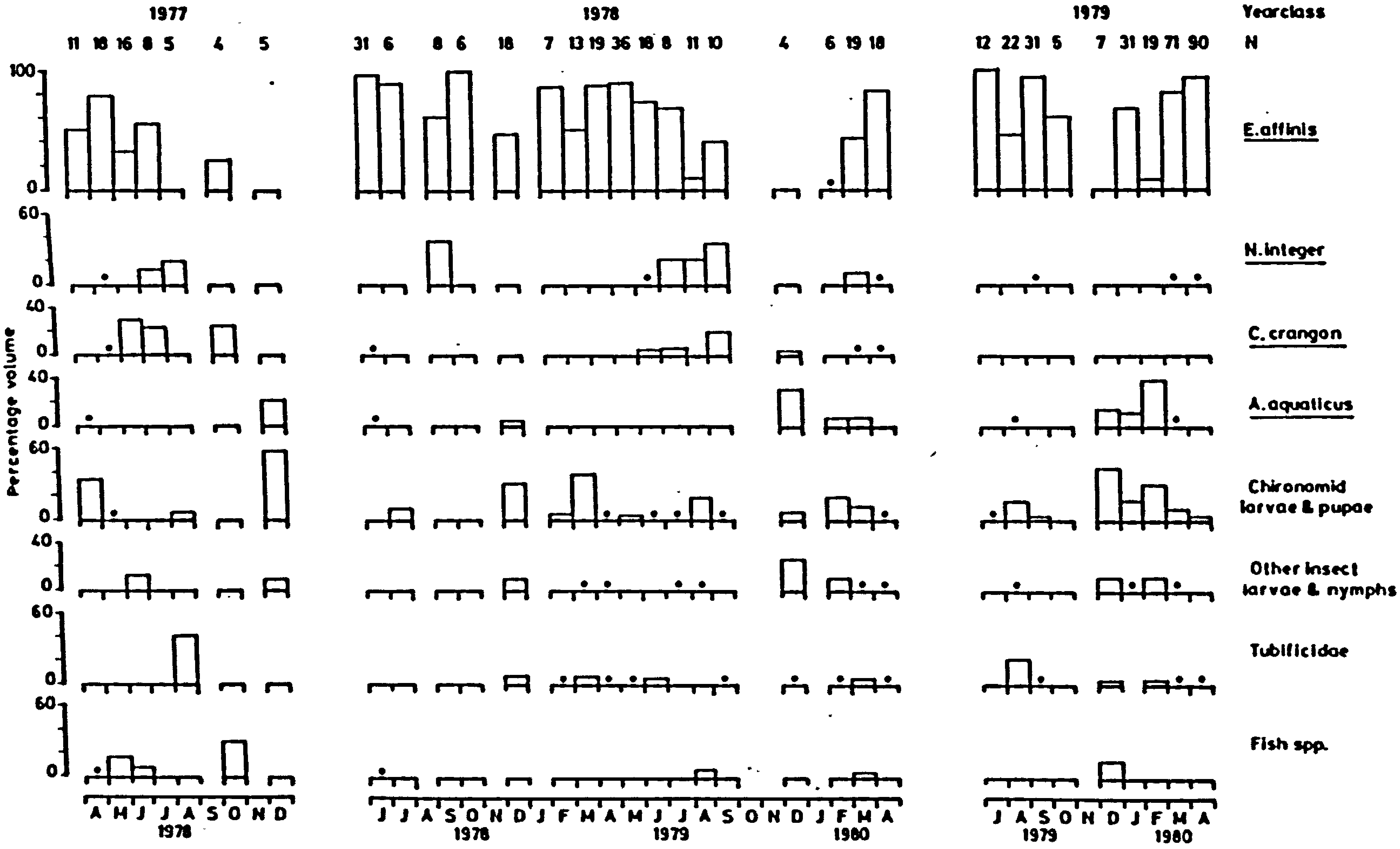

1977
11 18 16 8 5 4 5
1978
31 6 8 6 18 7 13 19 36 18 8 11 10 4 6 19 18
1979
12 22 31 5 7 31 19 71 90
Yearclass
N
E.affinis
N.integer
C.crangon
A.aquaticus
Chironomid larvae & pupae
Other insect larvae & nymphs
Tubificidae
Fish spp.
Percentage occurrence
100
60
80
0
A M J J A S O N D
1978
J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
J A S O N D J F M A
1979
1980

FIG. 4.3b

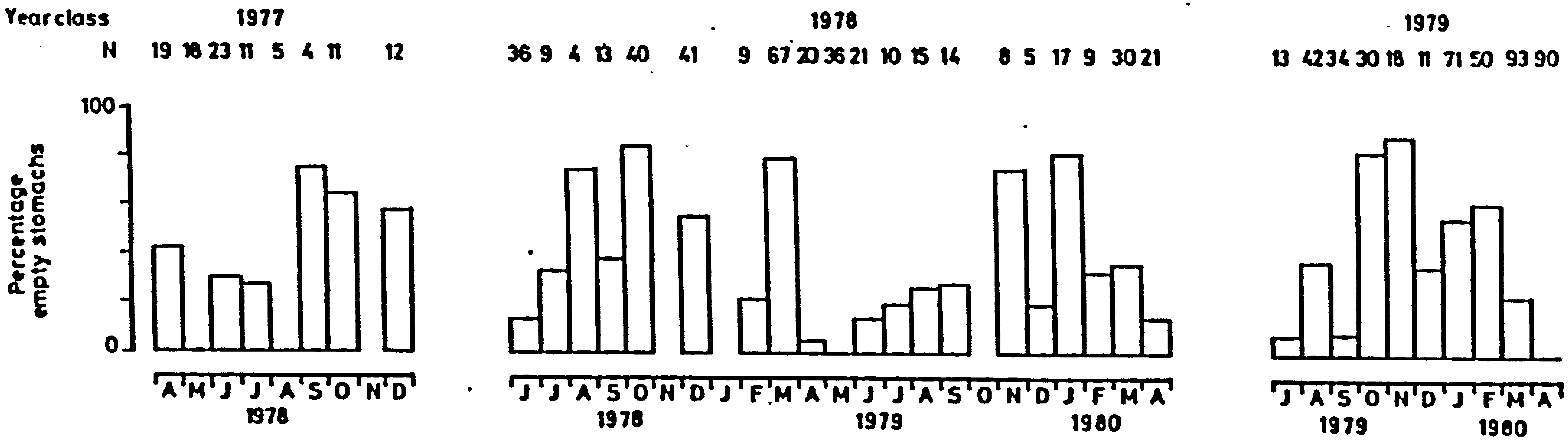


1977
1978
1979
Yearclass
11 18 16 8 5 4 5
31 6 8 6 18 7 13 19 36 18 8 11 10 4 6 19 18
12 22 31 5 7 31 19 71 90
N
Percentage volume
100
0
60
0
40
0
40
0
60
0
40
0
60
0
60
0
E.affinis
N.integer
C.crangon
A.aquaticus
Chironomid larvae & pupae
Other insect larvae & nymphs
Tubificidae
Fish spp.
A M J J A S O N D
1978
J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
J A S O N D J F M A
1979
1980

FIGURE 4.4

Percentage of empty stomachs in each monthly sample of juvenile flounder from the channel. The number of fish examined is shown. No data are presented where less than four fish were available.

FIG. 4.4


Yearclass
1977
1978
1979
N
19 18 23 11 5 4 11 12
36 9 4 13 40 41 9 67 20 36 21 10 15 14 8 5 17 9 30 21
13 42 34 30 18 11 71 50 93 90
100
0
Percentage empty stomachs
A M J J A S O N D
1978
J J A S O N D J F M A M J J A S O N D J F M A
1978
1979
1980
J A S O N D J F M A
1979
1980

study period. This permits changes in diet with increase in size, which will be considered in more detail in the following section, to be separated from purely seasonal effects. Only variations in the principal items are shown. Since there were no major differences in the types of food organisms consumed with location, samples from each site were combined for this investigation. Full details of monthly diet composition of flounder and all the other species examined are given in Appendix C.

E. affinis was the most important constituent of the stomach contents for much of the year. When examining the stomachs E. affinis was found to occur in particularly large numbers in April and May, and a large proportion of the flounder stomachs in these months were distended with copepods. The stomach of one flounder of 110mm standard length captured in April 1980 was estimated to contain over 8500 copepods.

Chironomid larvae and pupae were frequently found in the stomachs throughout the year, but formed a large part of the diet by volume mainly in the winter months. Asellus aquaticus and other minor freshwater food organisms followed a similar seasonal pattern of importance, presumably related to the higher freshwater flows during these months carrying them into the channelised section from upstream. A prolonged period of high freshwater flows occurred during August 1979 and the freshwater items were again prominent in the diet. In the summer and autumn months N. integer and C. crangon were important, but principally in the I-group diet. In the early summer months of May and June 1978 several of the I-group fish had cannabalised on postlarval flounder.

A large proportion of the flounder stomachs examined were in fact often empty of food (Figure 4.4). The highest percentages of empty stomachs in the samples were usually found in the autumn and winter, and this was probably the result of the low temperatures depressing feeding activity (Mulicki, 1947). However, even in the summer months many of the stomachs were empty. In April and May nearly all of the I-group flounder stomachs examined contained food and as noted above this was the time when E. affinis was being most heavily consumed.

Diet in relation to fish size

The overall diets of 0- and I-group flounder shown in Table 4.1 were very similar. Similarity between the two diets was high : PS = 0.93 (insect larvae and nymphs other than chironomids were grouped into one category for this calculation). In addition, the total diet of II-group flounder resembled that of the two younger age groups with E. affinis the major constituent (Figure 4.5), although the increased contribution of larger prey items is apparent.

The importance of E. affinis in the diet of both the I- and II-group fish is however, overemphasised in the total diets as presented with the result that the diets of all three age groups, the 0-, I- and II-groups, appear more similar than they actually were. This overemphasis was produced by the uneven distribution of sample sizes through the year with the largest catches of I- and II-group flounder taken during the spring when E. affinis was the dominant prey. Furthermore, in the spring the fish were newly promoted from the previous age group and showed little increase in size from the end of the preceding summer's growth; they were therefore small members of the age groups. Although flounder of the I-group age class continued to feed on E. affinis through the summer (Fig. 4.3), the copepod was never recorded in the stomachs of the II-group flounder examined after May. As these fish increased in size they appeared to feed entirely on larger prey.

FIGURE 4.5

Composition of the diet of II-group and $\geqslant$ III-group flounder from the channel. Histograms show percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume.

FIG. 4.5

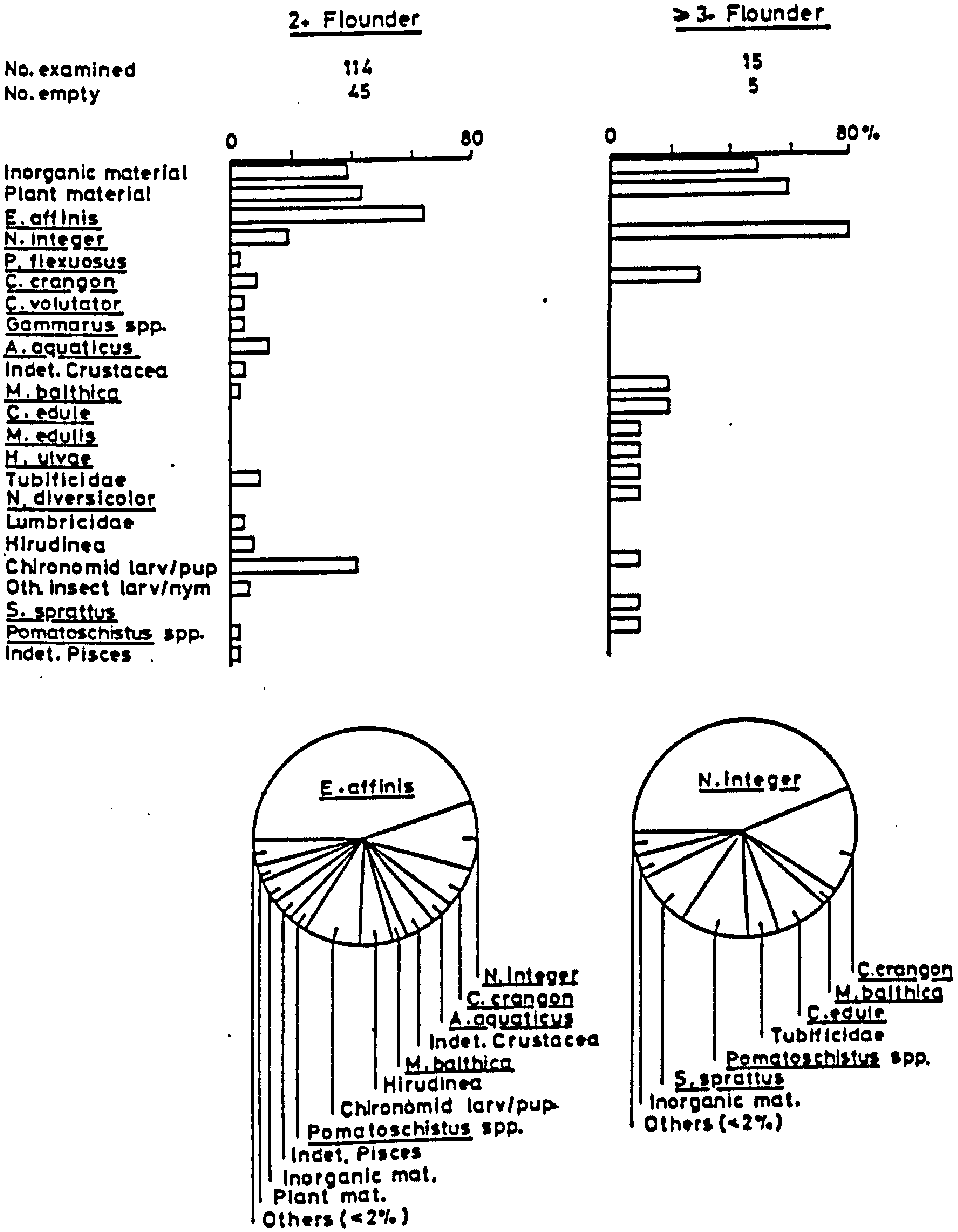
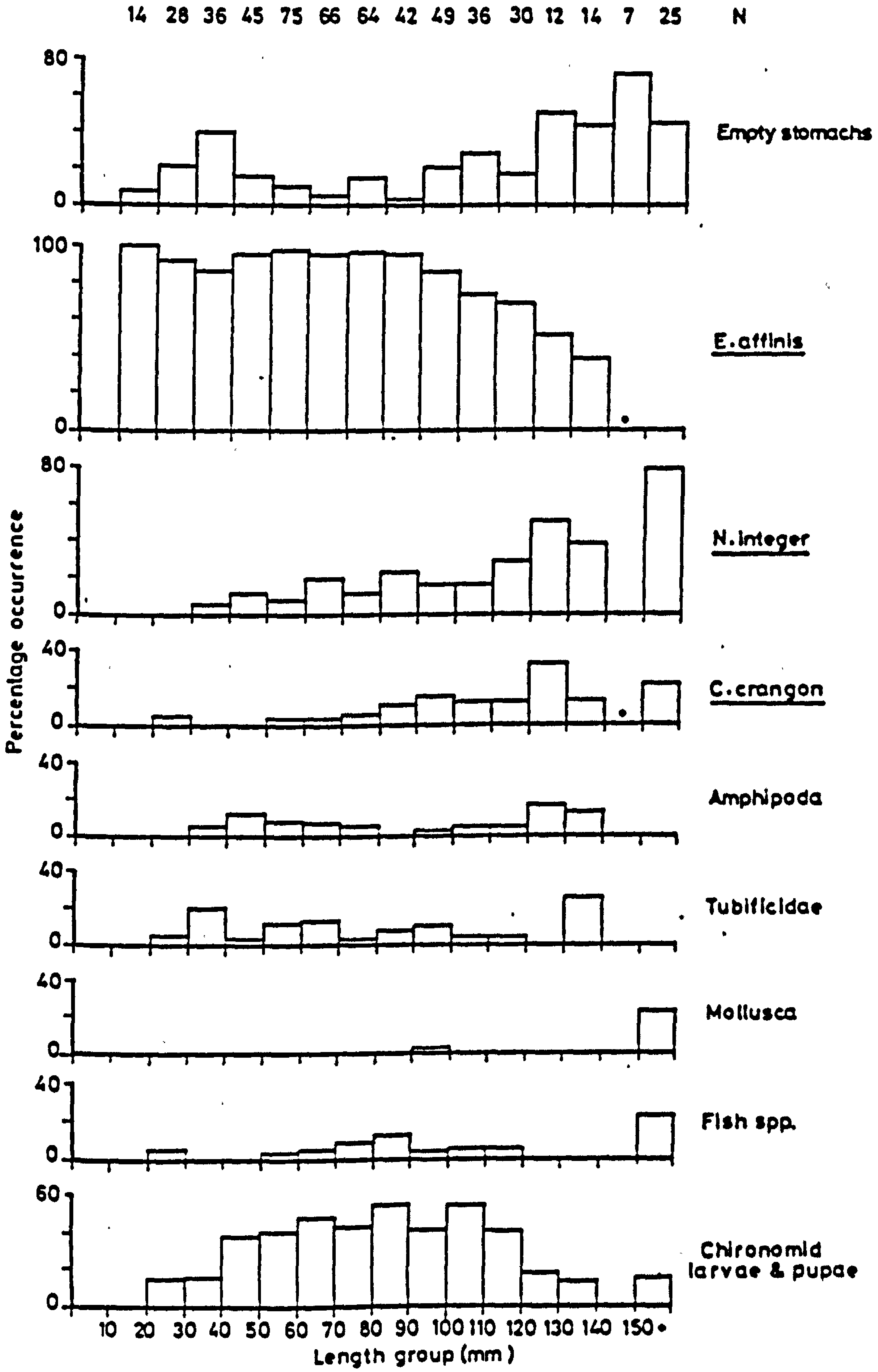

2. Flounder
≥3. Flounder
No. examined
No. empty
114
45
15
5
0
80
0
80%
Inorganic material
Plant material
E. affinis
N. integer
P. flexuosus
C. crangon
C. volutator
Gammarus spp.
A. aquaticus
Indet. Crustacea
M. balthica
C. edule
M. edulis
H. ulvae
Tubificidae
N. diversicolor
Lumbricidae
Hirudinea
Chironomid larv/pup
Oth. insect larv/nym
S. sprattus
Pomatoschistus spp.
Indet. Pisces
E. affinis
N. integer
C. crangon
A. aquaticus
Indet. Crustacea
M. balthica
Hirudinea
Chironomid larv/pup
Pomatoschistus spp.
Indet. Pisces
Inorganic mat.
Plant mat.
Others (<2%)
N. integer
C. crangon
M. balthica
C. edule
Tubificidae
Pomatoschistus spp.
S. sprattus
Inorganic mat.
Others (<2%)

FIGURE 4.6

Changes in the diet of flounder with size, shown as the percentage frequency of occurrence of food items in those stomachs containing food from each 10mm size class of fish. All fish from the channel during April to September. ● indicates less than four stomachs examined containing food and only the presence of the food item is shown.

FIG. 4.6


14 28 36 45 75 66 64 42 49 36 30 12 14 7 25 N
Empty stomachs
E.affinis
N.integer
C.crangon
Amphipoda
Tubificidae
Mollusca
Fish spp.
Chironomid larvae & pupae
Percentage occurrence
80
0
100
0
80
0
40
0
40
0
40
0
40
0
40
0
60
0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150+
Length group (mm)

A more accurate picture of the changes in diet which occurred with increase in size is provided in Figure 4.6 which shows the percentage occurrence of the various food items in the stomachs of each 10mm size group of fish. The data used for this figure were drawn from samples taken during April to September when the flounder, in terms of the proportion of stomachs containing food (Fig. 4.4), were feeding most actively. From the 90-100mm length group upwards the occurrence of E. affinis in the diet decreased and there was a corresponding increase in the occurrence of N. integer and C. crangon in the diet. Amphipods (Corophium volutator Pallas and Gammarus spp.), tubificids and chironomids were present in the stomachs of a wide size range of fish.

Flounder larger than 150mm had fed mainly on N. integer, C. crangon, molluscs and fish species. These were predominantly III-group and older fish the diet of which is shown separately in Figure 4.5. The molluscs Macoma balthica (L.), Cardium edule L., Mytilus edulis L. and Hydrobia ulvae (Pennant) were present in only a few of the stomachs of these fish, but were in addition frequently found in the intestinal tracts of the larger II-group fish, the stomachs of which were empty. These molluscs are only found in the outer areas of the estuary past Lytham (Popham, 1966a, b; personal observations) where they have been shown to be an important food of flounder, plaice and dab (Hiscock, 1971). The presence of the molluscs in the alimentary tracts of large flounder suggests that the fish were feeding in the outer estuary and migrating into the inner estuary. From the 120-130mm length group upwards there was an increase in the percentage of empty stomachs in the samples, although the number of fish examined was small. This was probably also related to the larger flounder feeding in the outer estuary.

b) P. minutus and P. lozanoi

Composition of the O-group diet

O-group P. minutus and P. lozanoi from the channel had fed mainly on N. integer and E. affinis (Table 4.2). The remainder of the diet was also principally of crustacean species with minor numbers of tubificids, Nereis diversicolor (Muller), insect adults and larvae, and fish species included. The overall diets at each site were broadly similar (Figures 4.7 and 4.8).

Diet in relation to fish size

P. lozanoi has a smaller body size than P. minutus and I-group individuals were absent from the inner estuary after May (Chapter 2), size related changes in diet were therefore only examined in P. minutus. The bulk of the food of I-group P. minutus during July to October was made up of N. integer and C. crangon (Figure 4.9). E. affinis was eaten by a small number of fish in contrast to its importance in the O-group diet. This change in diet with size is further illustrated in Figure 4.10. A similar change in diet with size in P. minutus has been noted by Hesthagen (1971) and Lee (1974).

Large P. minutus (> 50mm) did feed on E. affinis in the spring months (Figure 4.9) and it was the main constituent of the stomach contents. Unlike flounder in the same catches however, the sand goby did not consume the copepods in large numbers. N. integer and C. crangon may have been scarce in the inner estuary during these months, and P. minutus may therefore have been restricted to feeding on E. affinis.

Table 4.2 Composition of the diet of O-group *P. minutus* and *P. lozanoi* from the channel in the period July to October 1978. Number of stomachs examined with food: *P. minutus* = 365; *P. lozanoi* = 270.

	P. minutus		*P. lozanoi*	
Food item	% Occ.	% Vol.	% Occ.	% Vol.
Eurytemora affinis	59.3	39.8	53.0	37.9
Cyclopoid copepoda	0.3	0.2		
Harpacticoid copepoda	4.1	0.8	1.5	0.8
Neomysis integer	44.0	39.1	53.0	50.7
Corophium volutator	6.3	4.5	4.1	2.4
Gammarus spp.	1.9	1.7	1.5	0.7
Eurydice pulchra	2.2	1.8	1.5	1.0
Indeterminate Crustacea	8.2	6.9	5.6	4.6
Tubificidae	4.6	2.7	0.4	0.1
Nereis diversicolor	0.3	0.1		
Chironomidae larvae/pupae	2.5	1.4	0.7	0.1
Indet. Diptera larvae			0.4	0.1
Aerial insects			1.1	0.9
Pomatoschistus sp.	0.8	0.8		
Sprat			0.7	0.7
Inorganic material	0.3	0.1	0.7	+
Plant material	0.3	0.1	0.4	+

+ = Food items < 0.1%

FIGURE 4.7

Diet of O-group P. minutus from the channel by site.

FIGURE 4.8

Diet of O-group P. lozanoi from the channel by site.

Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.7


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
135
32
120
33
140
16
76
24
0
80
80%
Inorganic material
Plant material
E. affinis
Cyclopoid cop.
Harpacticoid cop.
N. integer
C. volutator
Gammarus spp.
E. pulchra
Indet. Crustacea
Tubificidae
N. diversicolor
Chironomid larv/pup
Pomatoschistus spp.
E. affinis
N. integer
Tubificidae
C. volutator
Indet. Crustacea
Chironomid larv/pup
Others (<2%)
Indet. Crustacea
E. pulchra
C. volutator
Others (<2%)
Gammarus spp.

FIG. 4.8


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
110
27
82
22
81
13
85
26
0
80
80%
Inorganic material
Plant material
E. affinis
Harpacticoid cop.
N. integer
C. volutator
Gammarus spp.
E. pulchra
Indet. Crustacea
Tubificidae
Chironomid larv/pup
Oth. insect larv/nym
Adult Diptera
S. sprattus
E. affinis
N. integer
C. volutator
Adult Diptera
Others (<2%)
E. affinis
N. integer
Indet. Crustacea
S. sprattus
Others (<2%)
E. affinis
N. integer
C. volutator
Others (<2%)
E. affinis
N. integer
C. volutator
Gammarus spp.
E. pulchra
Harpacticoid cop.
Indet. Crustacea

FIGURE 4.9

Diet of I-group P. minutus from the channel during July to October 1978, and January to April 1980. Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume.

FIG. 4.9

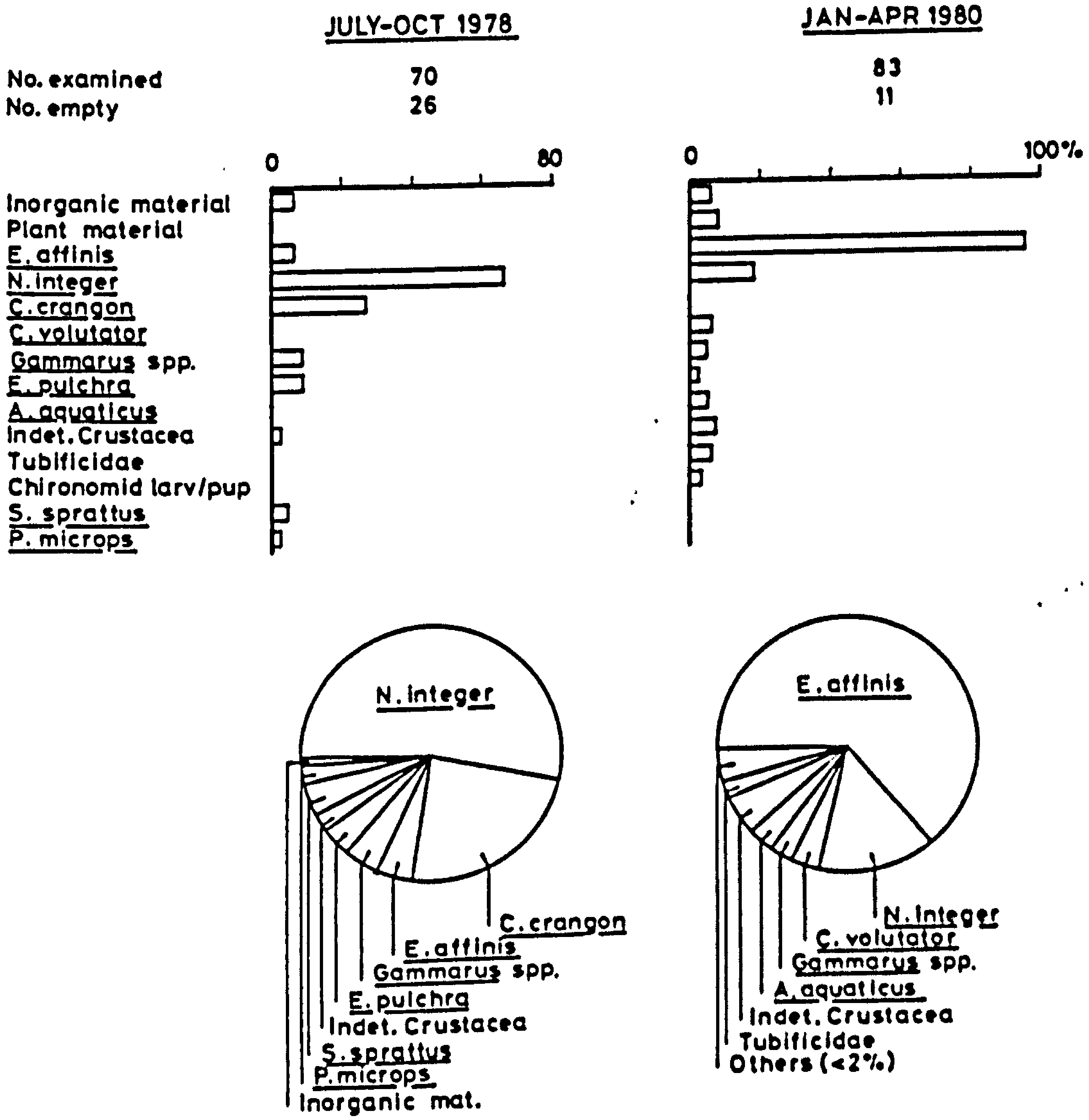

JULY-OCT 1978
JAN-APR 1980
No. examined
70
83
No. empty
26
11
0
80
0
100%
Inorganic material
Plant material
E. affinis
N. integer
C. crangon
C. volutator
Gammarus spp.
E. pulchra
A. aquaticus
Indet. Crustacea
Tubificidae
Chironomid larv/pup
S. sprattus
P. microps
N. integer
C. crangon
E. affinis
Gammarus spp.
E. pulchra
Indet. Crustacea
S. sprattus
P. microps
Inorganic mat.
E. affinis
N. integer
C. volutator
Gammarus spp.
A. aquaticus
Indet. Crustacea
Tubificidae
Others (<2%)

FIGURE 4.10

Changes in the diet of P. minutus with size. The number of stomachs in which a given food item occurred is expressed as a percentage of the total number of stomachs examined containing food in each 10mm length group of fish. All fish from the channel in the period July to October 1978.

FIG. 4.10

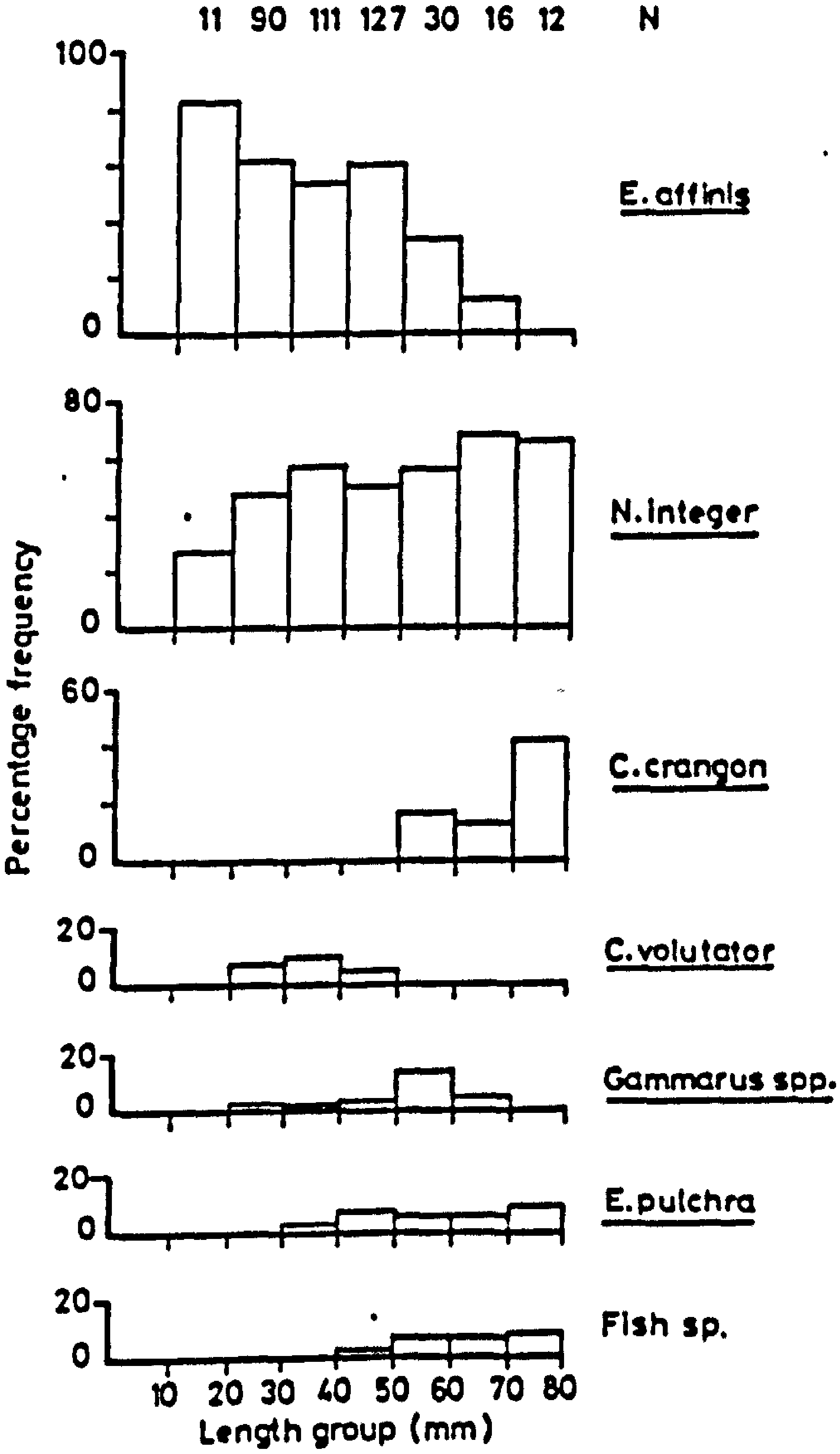

11 90 111 127 30 16 12
N
100
0
E.affinis
80
0
N.integer
60
0
C.crangon
20
0
C.volutator
20
0
Gammarus spp.
20
0
E.pulchra
20
0
Fish sp.
10 20 30 40 50 60 70 80
Length group (mm)
Percentage frequency

Table 4.3 Diet of O- and I-group sprat from the channel trawl, July to October 1978. Number of stomachs examined with food: O-group = 138; I-group = 25.

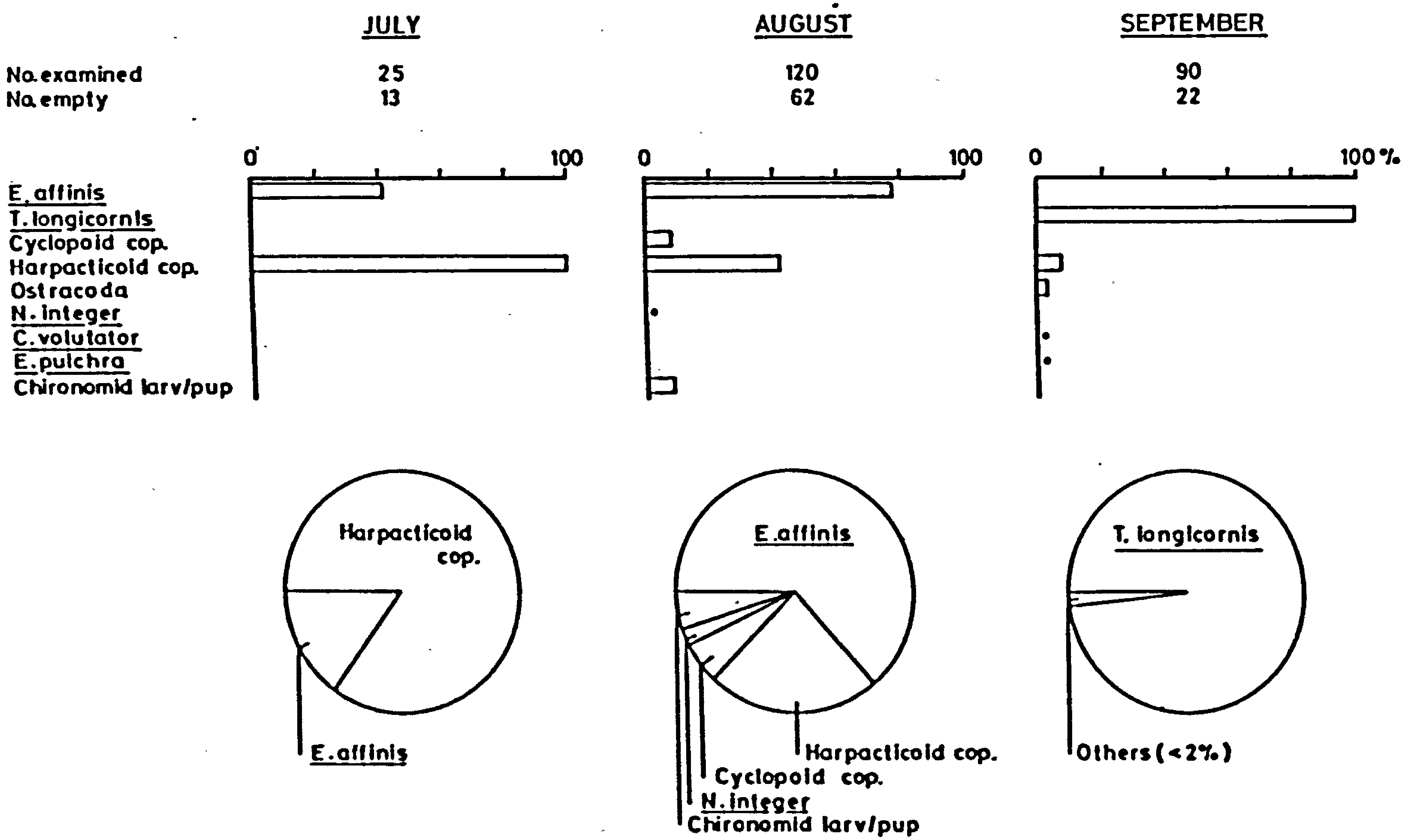
Food item	O-GROUP		I-GROUP	
	% Occ.	% Vol.	% Occ.	% Vol.
Eurytemora affinis	35.5	28.3	44.0	38.5
Temora longicornis	49.3	48.4	4.0	4.0
Cyclopoid copepoda	3.6	2.5		
Harpacticoid copepoda	30.4	18.0	8.0	0.3
Indeterminate copepoda			32.0	32.0
Ostracoda	1.4	+	8.0	+
Neomysis integer	0.7	0.7	32.0	25.2
Corophium volutator	0.7	+		
Eurydice pulchra	0.7	0.1		
Chironomidae larvae/pupae	3.6	2.0	4.0	+

+ = Food items < 0.1%

FIGURE 4.11

Diet of 0-group sprat from the channel by month, July to September 1978. Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.11


JULY
AUGUST
SEPTEMBER
No. examined
No. empty
25
13
120
62
90
22
0
100
0
100
0
100 %
E. affinis
T. longicornis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
N. integer
C. volutator
E. pulchra
Chironomid larv/pup
Harpacticoid cop.
E. affinis
E. affinis
Harpacticoid cop.
Cyclopoid cop.
N. integer
Chironomid larv/pup
T. longicornis
Others (<2%)

c) Sprat

Whereas E. affinis was the only species of calanoid copepod recorded in the stomachs of flounder, P. minutus and P. lozanoi, sprat had also fed on Temora longicornis (Muller) (Table 4.3). It dominated the stomach contents of the O-group fish in the September samples (Figure 4.11), but was absent from the stomachs of fish in July and August when harpacticoid copepods and E. affinis were respectively the most important items; no sample of sprats was collected in October.

Copepods were also the dominant food of the small number of I-group sprat examined (Table 4.3), and in addition several of the fish had consumed N. integer.

Diet of fish in the channelised section: fish on the intertidal banks

a) Flounder

Composition of the O-group diet

Table 4.4 shows the overall composition of the stomach contents of O-group flounder taken in the seine on the intertidal banks of the channelised section. The diet at each site is shown in Figure 4.12.

E. affinis was important in the diet at all sites, but was the foremost food item by volume only at Site 4 and among the small number of fish collected at Site 3. In the total diet and the diets at each site the greater importance of tubificids as a food item compared to in the channel was a major feature. In addition, harpacticoid copepods, while of lesser importance compared to tubificids and E. affinis, were eaten in large numbers by flounder on the intertidal banks whereas they were insignificant in the diet of fish from the channel. Harpacticoids were important in terms of percentage volume mainly at Sites 5 and 6, but their frequency of

Table 4.4 Composition of the diet of O- and I-group flounder from the intertidal banks, fish from all sites combined. Number of stomachs examined with food: O-group = 279; I-group = 62.

	O-GROUP		I-GROUP	
Food item	% Occ.	% Vol.	% Occ.	% Vol.
Eurytemora affinis	48.7	36.7	48.4	30.8
Cyclopoid copepoda	2.9	+	4.8	0.1
Harpacticoid copepoda	44.4	7.9	27.4	1.0
Ostracoda	0.4	+	1.6	+
Cladocera	0.7	0.2	1.6	0.8
Neomysis integer	5.4	3.4	9.7	4.5
Crangon crangon	0.7	0.3	11.3	4.9
Carcinus maenas	0.4	0.1	1.6	1.6
Corophium volutator	10.8	4.2	12.9	6.1
Gammarus spp.	0.7	+		
Indeterminate Crustacea	0.4	+		
Tubificidae	54.5	35.4	48.4	27.6
Nereis diversicolor	4.3	1.6	11.3	4.1
Lumbricidae			1.6	1.6
Chironomidae larvae/pupae	9.3	3.4	6.5	2.1
Dolichopodidae larvae	1.1	0.4		
Indet. Diptera larvae	1.4	0.4		
Ephemeroptera nymphs	0.4	+		
Flounder postlarvae	0.4	0.1	9.7	2.8
Sprat			1.6	1.6
Inorganic material	39.1	3.4	69.4	4.1
Plant material	39.8	2.5	45.2	6.3

+ = Food items < 0.1%

FIGURE 4.12

Diet of 0-group flounder from the intertidal banks by site. Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.12


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
16
0
146
12
124
33
46
8
0
100
80
80 %
Inorganic material
Plant material
E. affinis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
Cladocera
N. integer
C. crangon
C. maenas
C. volutator
Gammarus spp.
Indet. Crustacea
Tubificidae
N. diverscolor
Chironomid larv/pup
Oth. insect larv/nym
P. flesus postlarvae
E. affinis
N. integer
Tubificidae
Chironomid larv/pup
Others (<2%)
E. affinis
Tubificidae
Harpacticoid cop.
Others (<2%)
Tubificidae
E. affinis
Harpact. cop.
N. integer
C. volutator
Chironomid larv/pup
Inorganic mat.
Plant mat.
Others (<2%)
Tubificidae
C. volutator
E. affinis
Harpacticoid cop.
N. integer
N. diversicolor
Inorganic mat.
Plant mat.
Others (<2%)

occurrence in the stomachs was high at all sites. At Site 6 C. volutator and N. diversicolor were important in the diet of the flounder examined and the former was the principal crustacean prey at this site.

Composition of the I-group diet

The main components of the I-group flounder diet on the intertidal banks were E. affinis and tubificids (Table 4.4). The number of fish examined was too small for data on seasonal variations to be presented, but generally E. affinis was the principal food in the spring replaced by tubificids and the occasional larger crustacean in the summer. Harpacticoids appeared to be of little consequence in the I-group diet.

Numbers of fish feeding

The number of flounder examined from the intertidal banks with empty stomachs was usually low. Table 4.5a compares the proportion of empty stomachs in the monthly samples of O-group flounder from the channel and on the intertidal banks. In several of the samples a significantly lower proportion of the flounder on the intertidal banks had empty stomachs compared to fish in the channel ($P < 0.05$).

The data are not strictly comparable as samples from all sites were combined and the numbers were insufficient for a comparison of the percentage of fish feeding at each site along the channelised section for either seine or trawl catches. On four occasions it was possible to directly compare the numbers of fish feeding on the intertidal banks and in the channel at one location (Table 4.5b), on two of these occasions fish were collected separately to the normal sampling programme by beam trawling in the channel and in 1-2m depth on the banks. In the three samples taken during the

		1978			1979		
Sample		n	% empty	Significance	n	% empty	Significance
June	B	33	15.2	$\chi^2 = 0.04$; $P > 0.05$	32	18.7	-
	CH	36	13.9		NS	-	
July	B	29	0.0	$P = 0.01$	31	19.4	$P > 0.05$
	CH	9	33.3		13	7.7	
August	B	37	0.0	-	33	0.0	$\chi^2 = 19.06$; $P < 0.001$
	CH	NS	-		42	47.6	
September	B	40	5.0	$P = 0.007$	14	0.0	$P > 0.05$
	CH	13	38.5		34	8.9	
October	B	68	45.6	$\chi^2 = 27.45$; $P < 0.001$	NS	-	-
	CH	40	85.0		30	83.4	
December	B	NS	-	-	12	16.7	$P > 0.05$
	CH	9	56.1		11	36.4	

Table 4.5a Percentage of empty stomachs in monthly samples of 0-group flounder taken in the seine on the intertidal banks (B) and in the trawl from the channel (CH), fish from all sites combined. Statistical comparisons carried out using the Chi-square (χ^2) test or the Fisher exact test where expected values in the constructed 2 x 2 contingency tables were less than 5. The number of fish in the samples is shown. NS indicates no flounder collected.

Sample		n	% empty	Significance
Sept. 1978	B	30	0.0	$P < 0.001$
	CH	10	50.0	
Oct. 1978	B	11	18.2	$P < 0.001$
	CH	24	95.8	
Aug. 1980	B	27	0.0	$\chi^2 = 19.08$; $P < 0.001$
	CH	28	53.5	
Jan. 1981	B	12	66.7	$P > 0.05$
	CH	16	93.7	

Table 4.5b Percentage of empty stomachs in samples of 0-/I-group flounder from the intertidal banks (B) and from the channel (CH) at one location in the inner estuary. Statistical analysis as in Table 4.5a. The number of fish in the samples is shown.

summer and autumn differences in the proportion of empty stomachs were significant ($P < 0.05$). However, in the January sample neither the flounder on the intertidal banks nor in the channel were feeding to any extent and the difference in the proportion of empty stomachs was not statistically significant.

The results may suggest that flounder which were in the channel at high water had a lower food intake than those on the intertidal banks. However, it is emphasised that the differences observed only apply to the fish at the particular time at which the samples were taken. The feeding periodicity of flounder on the intertidal banks was known through the 24 hour feeding study (see later) and it was evident that on the banks the fish were feeding actively when the samples were taken. The pattern of feeding of flounder in the channel was not studied and these fish may have started feeding later than those intertidally. It should be remembered that in April and May when E. affinis was being heavily consumed hardly any of the stomachs of I-group flounder from the channel were empty (Fig. 4.4).

b) P. minutus and P. microps

As in flounder there was a large variation between the sites in the diets of O-group P. minutus and P. microps on the intertidal banks (Figures 4.13 and 4.14). Harpacticoid copepods, E. affinis, N. integer (for P. minutus) and tubificids were all major constituents of the diets. The importance of N. integer in the P. minutus diet compared to in the diet of O- and I-group flounder both on the banks and in the channel (see Table 4.1 and Fig. 4.3, and Table 4.2) indicates that this crustacean was a far more important dietary constituent for the sand goby species. N. integer was also only a

FIGURE 4.13

Diet of 0-group P. minutus from the intertidal banks by site.

FIGURE 4.14

Diet of 0-group P. microps from the intertidal banks by site.

Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.13


SITE 3
SITE 4
SITE 5
SITE 6
No. examined
No. empty
80
12
85
9
47
0
15
3
0
100
0
80
0
100
0
80 %
Inorganic material
Plant material
E.affinis
Cyclopoid cop.
Harpacticoid cop.
N.integer
C.volutator
Gammarus spp.
E.pulchra
Indet. Crustacea
Tubificidae
Chironomid larv/pup
Oth.insect larv/nym
Adult Diptera
Arachnidae
E.affinis
N.integer
Adult Diptera
Harpacticoid cop.
Others (<2%)
N.integer
Harpact. cop.
E.affinis
Tubificidae
Oth.insect larv/nym
E.pulchra
Others (<2%)
Harpacticoid cop.
N.integer
C.volutator
Tubificidae
Inorganic mat.
Plant mat.
Others (<2%)
Harpacticoid cop.
N.integer
E.pulchra
Indet. Crustacea
E affinis

FIG. 4.14

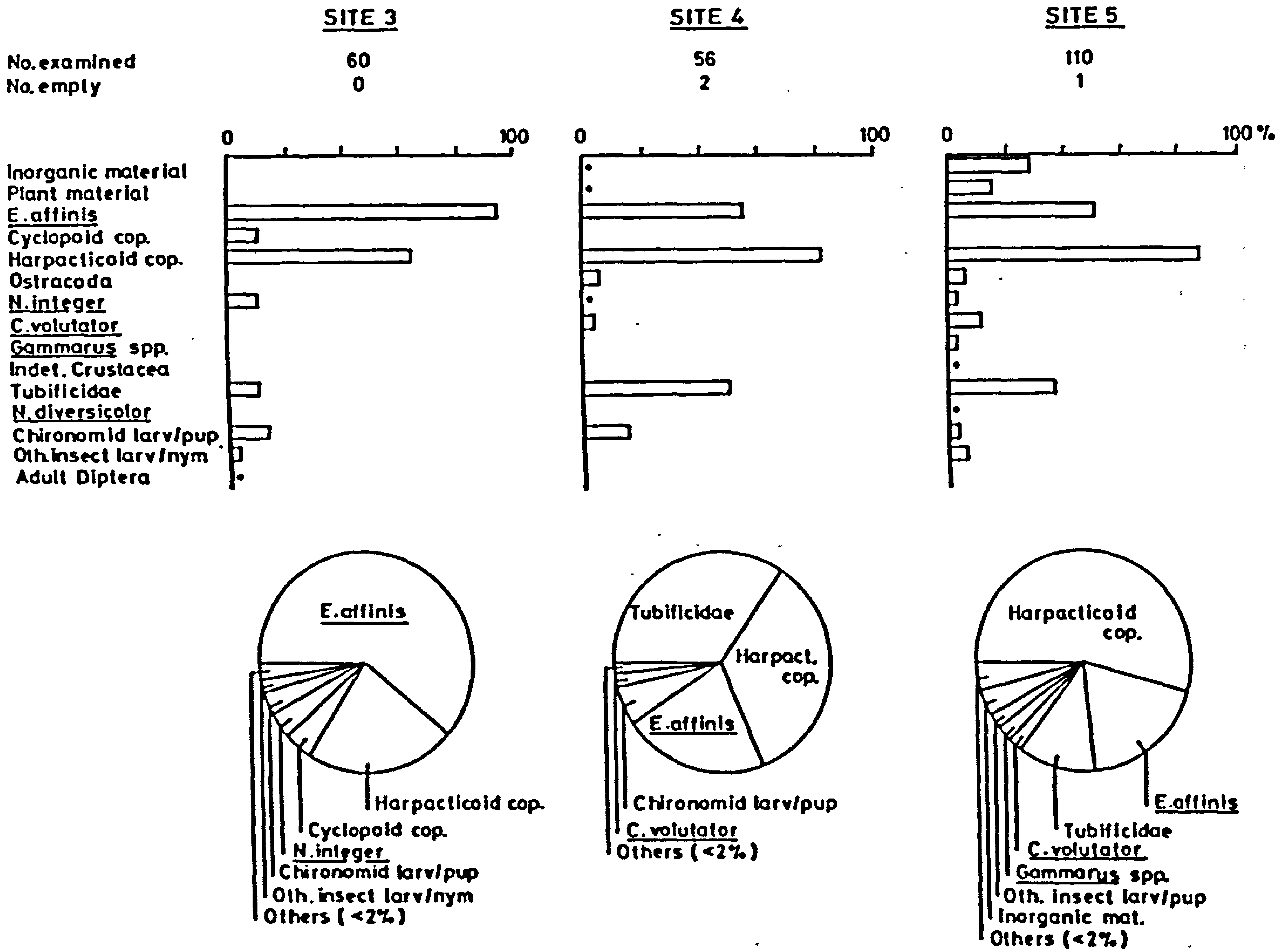

SITE 3
SITE 4
SITE 5
No. examined
No. empty
60
0
56
2
110
1
0
100
0
100
0
100 %
Inorganic material
Plant material
E. affinis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
N. integer
C. volutator
Gammarus spp.
Indet. Crustacea
Tubificidae
N. diversicolor
Chironomid larv/pup
Oth. insect larv/nym
Adult Diptera
E. affinis
Harpacticoid cop.
Cyclopoid cop.
N. integer
Chironomid larv/pup
Oth. insect larv/nym
Others (<2%)
Tubificidae
Harpact. cop.
E. affinis
Chironomid larv/pup
C. volutator
Others (<2%)
Harpacticoid cop.
E. affinis
Tubificidae
C. volutator
Gammarus spp.
Oth. insect larv/pup
Inorganic mat.
Others (<2%)

Table 4.6 Percentage of empty stomachs in samples of 0-group P. minutus taken in the seine on the intertidal banks (B) and in the trawl in the channel (CH). Statistical comparisons carried out using the Chi-square (χ^2) test or the Fisher exact test where expected values in the constructed 2 x 2 contingency table were less than 5.

Sample			n	% empty	Significance
July	Site 5	B	40	0.0	$P = 0.03$
		CH	30	13.4	
August	Site 3	B	30	6.7	$\chi^2 = 4.00$; $P < 0.05$
		CH	30	30.0	
"	Site 4	B	30	10.0	$\chi^2 = 5.69$; $P < 0.05$
		CH	30	40.0	
September	Site 3	B	10	40.0	$P > 0.05$
		CH	40	17.5	
"	Site 4	B	25	24.0	$\chi^2 = 0.002$; $P > 0.05$
		CH	45	26.7	
October	Site 3	B	40	15.0	$\chi^2 = 3.27$; $P > 0.05$
		CH	40	35.0	
"	Site 4	B	30	0.0	$P = 0.019$
		CH	30	30.0	
"	Site 6	B	13	23.1	$P > 0.05$
		CH	16	31.3	

minor food of P. microps compared to in P. minutus. This may have been related to the smaller body size of P. microps, although mysids were eaten by gobies as small as 15 mm in length.

The proportion of empty stomachs in P. minutus on the intertidal banks and in the channel are compared in Table 4.6. In some of the samples a significantly higher proportion of stomachs of P. minutus from the channel were empty ($P < 0.05$). However, on an equal number of occasions there was no significant difference. Virtually all the P. microps examined from the banks had food in their stomachs (Fig. 4.14).

c) Sprat

The diet of O-group sprat on the intertidal banks is shown in Table 4.7. There were few differences in the diet at each site (Figure 4.15) with E. affinis the principal food item followed by harpacticoids. As in sprat from the channel T. longicornis copepods were only present in the stomachs of fish in the September samples (Appendix C Table 12). Several of the sprat had consumed N. integer, but it was of little importance by volume. Tubificids occurred in a small number of the stomachs and they had probably been dislodged from the sediment into the water column by turbulence (Hunter and Arthur, 1978).

The I-group sprat had fed almost entirely on E. affinis (Table 4.7). Harpacticoids were a minor item in the diet of these larger fish and this may have reflected a more selective feeding on E. affinis. Several studies have shown clupeids feed on the largest zooplankton available (Hardy, 1924; Huddart and Arthur, 1971; Sandstrom, 1980).

Comparison of the proportion of empty stomachs in sprat from the intertidal banks and the channel, all sites combined, showed a significantly higher proportion of sprat from the channel to have empty

Table 4.7 Diet of O- and I-group sprat from seine catches in the channelised section, July to October 1978. Number of stomachs examined with food: O-group = 227; I-group = 95

Food item	O-GROUP % Occ.	O-GROUP % Vol.	I-GROUP % Occ.	I-GROUP % Vol.
Eurytemora affinis	93.0	64.7	89.5	95.3
Temora longicornis	19.8	7.8	2.1	+
Cyclopoid copepods	7.0	0.5		
Harpacticoid copepods	86.8	21.2	28.4	1.8
Ostracoda	7.9	0.1	14.7	0.5
Neomysis integer	15.4	1.7	5.3	2.4
Corophium volutator	4.4	0.2	1.0	+
Gammarus sp.	1.8	+		
Eurydice pulchra	0.5	+		
Tubificidae	3.1	2.3		
Chironomidae larvae/pupae	8.8	1.5	1.0	+

+ = Food items < 0.1%

FIGURE 4.15

Diet of 0-group sprat from the intertidal banks by site. Histograms show the percentage frequency of occurrence of prey organisms in the stomachs, and the areas in the pie-diagrams represent their average percentage contribution to the diet by volume. ● indicates percentage frequency of occurrence less than 2%.

FIG. 4.15

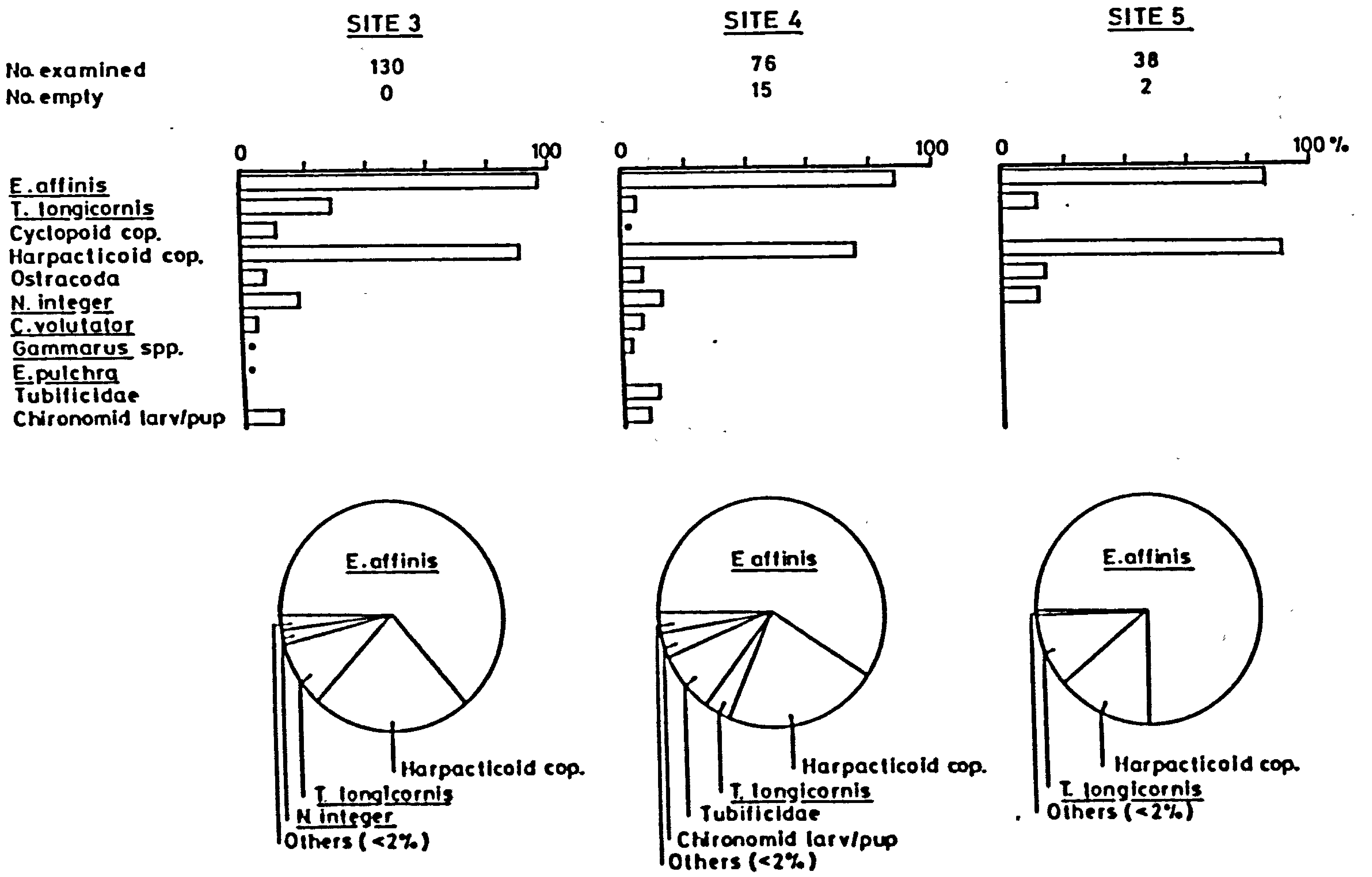

SITE 3
SITE 4
SITE 5
No. examined
No. empty
130
0
76
15
38
2
0
100
0
100
0
100 %
E. affinis
T. longicornis
Cyclopoid cop.
Harpacticoid cop.
Ostracoda
N. integer
C. volutator
Gammarus spp.
E. pulchra
Tubificidae
Chironomid larv/pup
E. affinis
Harpacticoid cop.
T. longicornis
N. integer
Others (<2%)
E affinis
Harpacticoid cop.
T. longicornis
Tubificidae
Chironomid larv/pup
Others (<2%)
E. affinis
Harpacticoid cop.
T. longicornis
Others (<2%)

Table 4.8 Percentage of empty stomachs in samples of 0-group sprat taken in the seine on the intertidal banks (B) and in the trawl in the channel (CH); a, samples from all sites combined; b, samples from one site. Statistical comparisons carried out using the Chi-square (χ^2) test or the Fisher exact test where expected values in the constructed 2 x 2 contingency table were less than 5. The number of fish in the samples is shown. NS indicates no sprat collected.

a)

Sample		n	% empty	Significance
July	B	90	5.5	χ^2 = 28.55; P < 0.001
	CH	25	52.0	
August	B	64	19.0	χ^2 = 15.11; P < 0.001
	CH	120	62.0	
September	B	47	0.0	χ^2 = 13.69; P < 0.001
	CH	90	24.4	
October	B	43	0.0	-
	CH	NS	-	

b)

Sample			n	% empty	Significance
July	Site 3	B	30	0.0	χ^2 = 26.17; P < 0.001
		CH	18	72.2	
August	Site 3	B	30	0.0	P > 0.05
		CH	30	16.7	
"	Site 4	B	30	33.4	χ^2 = 1.70; P > 0.05
		CH	30	53.4	

stomachs ($P < 0.05$) (Table 4.8a). However, except on one occasion the differences were not statistically significant in the comparisons at individual sites (Table 4.8b).

Feeding periodicity of flounder and P. microps on the intertidal banks

It was evident that the feeding activity of O-group flounder and *P. microps* was influenced by both the tidal state and the light-dark period (Figures 4.16 and 4.17). When high water occurred in the hours of daylight there was a readily discernible peak in fullness at or just after high tide, however, at night fullness values declined or remained at a low level irrespective of the tidal state. On the daytime tides the period of most intensive feeding appeared to be from LW + 2h on the flood tide to HW + 2-3h on the ebb tide. In flounder maximum fullness was always recorded a few hours after high water whereas in *P. microps* the maximum was at or just after high water. On 9-10th and 16-17th August there was only one high water during the hours of daylight and therefore one peak of feeding in the 24 hours. On 2nd-3rd August high water was at dawn and in the late afternoon and two peaks were recorded. A slight rise in the stomach contents of flounder was observed in the morning on 16-17th August when dawn was two hours after high water, but a similar rise was not found in *P. microps*. Even a few hours after high water a large proportion of the intertidal banks were uncovered by the tide and no longer available to the fish for feeding (Chapter 3).

Although a detailed examination of food organisms in the stomachs was not made there appeared to be little change in the types of food eaten over the tidal cycle. Tubificids and harpacticoid copepods were the principal foods consumed by flounder on all three of the 24 hour sample series and by *P. microps* on 2nd-3rd August. However,

FIGURE 4.16

Feeding periodicity of 0-group flounder on the intertidal banks.

FIGURE 4.17

Feeding periodicity of 0-group *P. microps* on the intertidal banks.

Mean stomach fullness with 95% confidence limits are shown. Stomach fullness is expressed as (dry weight of food/dry weight of fish) X 100. The times of high and low water are indicated and the hatched bars show the hours of darkness.

FIG. 4.16 Flounder

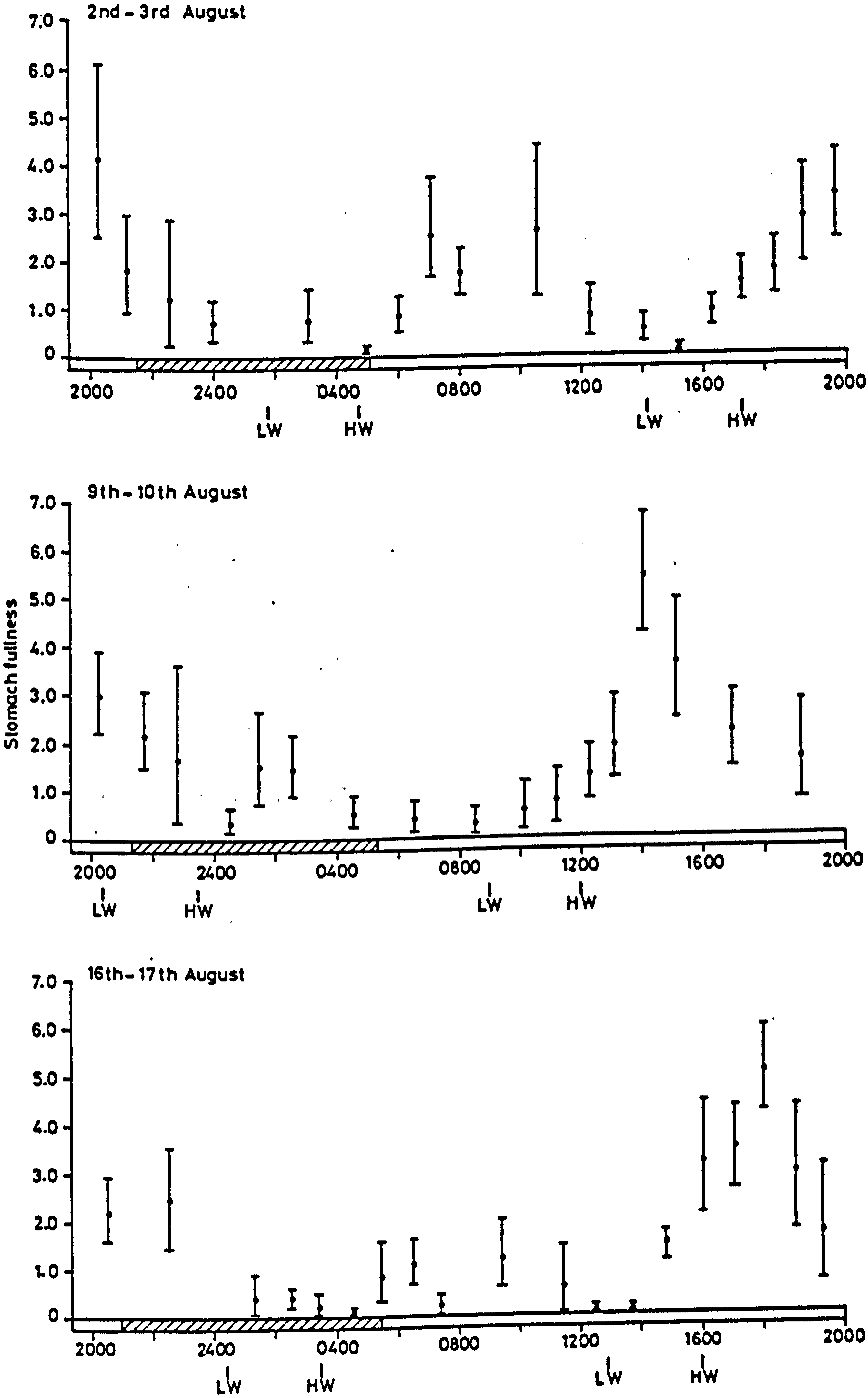
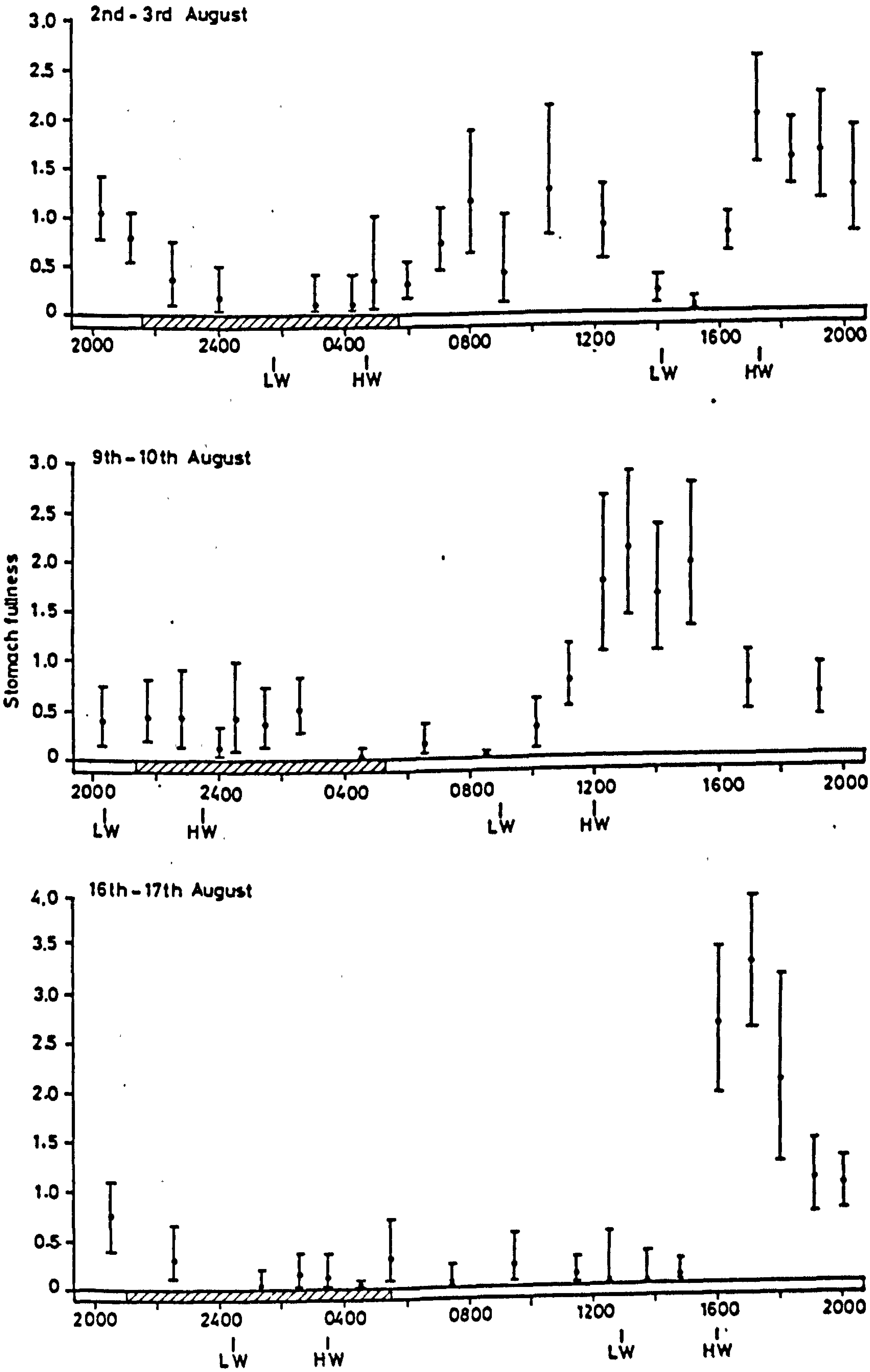


FIG. 4.17 <u>P.microps</u>



2nd - 3rd August

9th - 10th August

16th - 17th August

on 9-10th and 16-17th August P. microps had fed predominantly on E. affinis.

Diet of flounder upstream of Preston Dock

The major food items consumed by O-group flounder at the two sites upstream of Preston Dock were tubificids, chironomid larvae and pupae, E. affinis and cyclopoid copepods (Table 4.9). Tubificids and chironomids were important in the diet at both sites with chironomids the principal food item at Site 1, and tubificids the principal food at Site 2. Tubificids and chironomids were consistently important in the diet through the year (Figure 4.18).

E. affinis was important in the overall diet, but only at Site 2 and was mainly found in the stomachs of flounder examined in the early summer months of 1978. At Site 1 E. affinis was recorded in the stomachs on only one occasion in June 1978, and was replaced in the diet by freshwater zooplankton: cyclopoid copepods, cladocera and rotifers, items also consumed at Site 2. Cyclopoid copepods were mainly important for the smaller flounder but regularly occurred in the diet in all months. Rotifers were only important in the diet of metamorphosing and newly metamorphosed flounder taken in the early summer months.

The number of empty stomachs in the O-group samples was small even during the autumn when temperatures were decreasing (Figure 4.19). A large proportion were empty in December 1978 and this may have been the result of a low temperature of 4°C. All the fish were from Site 1 with no sample collected at Site 2.

In the small number of I-group flounder stomachs examined the main food items were chironomids and various other taxa of insect larvae and nymphs (Table 4.10). Tubificids were important in the

Table 4.9 Composition of the diet of O-group flounder at the two sites upstream of Preston Dock. Number of stomachs examined with food: Site 1 = 236; Site 2 = 218

	SITE 1		SITE 2	
Food item	% Occ.	% Vol.	% Occ.	% Vol.
Rotifera	22.5	3.2	11.9	1.4
Eurytemora affinis	3.0	1.4	33.9	16.0
Cyclopoid copepoda	50.0	15.8	34.9	7.6
Harpacticoid copepoda	4.2	0.2	1.8	0.1
Ostracoda	0.8	+		
Cladocera	27.5	6.7	3.2	0.8
Asellus aquaticus			5.0	1.5
Planorbis sp.			0.5	+
Tubificidae	47.0	22.3	72.9	45.6
Lumbricidae			1.4	0.2
Hirudinea			2.3	0.3
Chironomidae larvae/pupae	67.8	42.8	40.8	16.5
Psychodidae larvae			1.8	0.1
Simulidae larvae			0.9	+
Ceratopogonidae larvae	1.3	0.2	1.4	+
Tipulidae larvae	0.4	0.1	1.8	0.4
Dolichopodidae larvae	0.8	+		
Ephydridae larvae	7.2	3.0	0.5	0.1
Indet. Diptera larvae	4.2	1.0	1.8	0.2
Trichoptera larvae	0.4	0.1	0.5	+
Plecoptera nymphs	0.4	0.3		
Ephemeroptera nymphs	0.4	0.1	4.1	0.5
Hydrophilidae larvae	0.4	0.1		
Collembola	0.4	0.3		
Inorganic material	43.3	1.7	70.2	4.5
Plant material	27.5	0.7	65.6	4.2

+ = Food items $< 0.1\%$

FIGURE 4.18

Seasonal variation in diet composition of O-group flounder at Sites 1 and 2 upstream of Preston Dock:

FIG. 4.18a by percentage frequency of occurrence

FIG. 4.18b by average percentage volume

The number of stomachs examined containing food is shown. No data are presented where less than four stomachs containing food were available. ● indicates average percentage volume less than 2%.

FIG. 4.18a


SITE 1
SITE 2
N 29 49 26 30 4 9
39 24 13
4 7
24 42 28 9 8
29 10 22 6 26 5 9
Rotifera
80
0
E.affinis
100
0
Cyclopoid copepoda
100
0
Cladocera
80
0
Chironomid larvae & pupae
100
0
Other insect larvae & nymphs
100
0
Tubificidae
100
0
Percentage occurrence
M J J A S O N D
1978
J J A S O N D
1979
M J J A S O N D
1978
J J A S O N D
1979

FIG. 4.18b

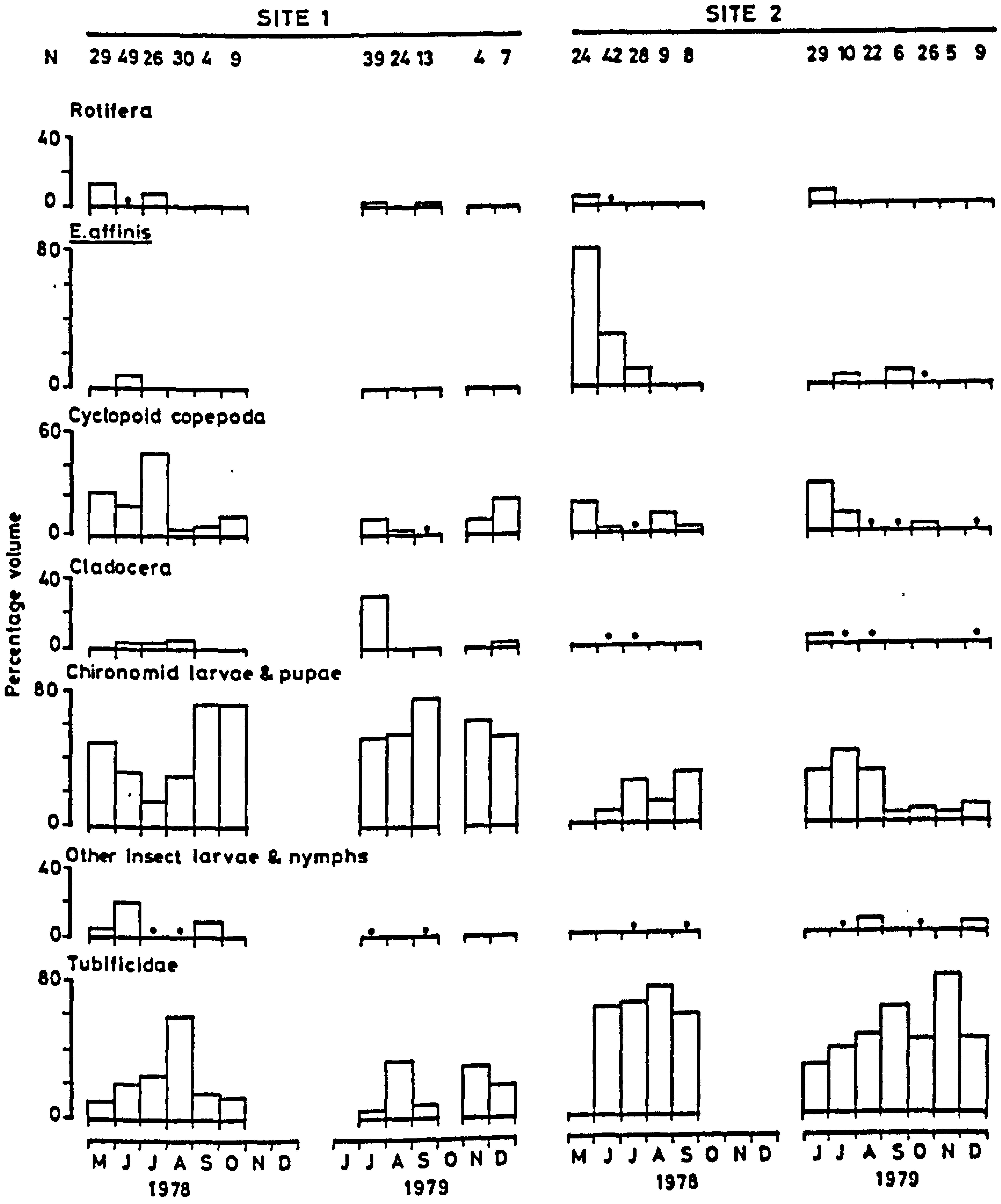

SITE 1
SITE 2
N
29 49 26 30 4 9
39 24 13 4 7
24 42 28 9 8
29 10 22 6 26 5 9
Rotifera
E.affinis
Cyclopoid copepoda
Cladocera
Chironomid larvae & pupae
Other insect larvae & nymphs
Tubificidae
Percentage volume
40
80
60
0
M J J A S O N D
1978
J J A S O N D
1979

FIGURE 4.19

Percentage of empty stomachs in each monthly sample of 0-group flounder from Sites 1 and 2 upstream of Preston Dock. The number of fish examined is shown. No data are presented where less than four fish were available.

FIG. 4.19

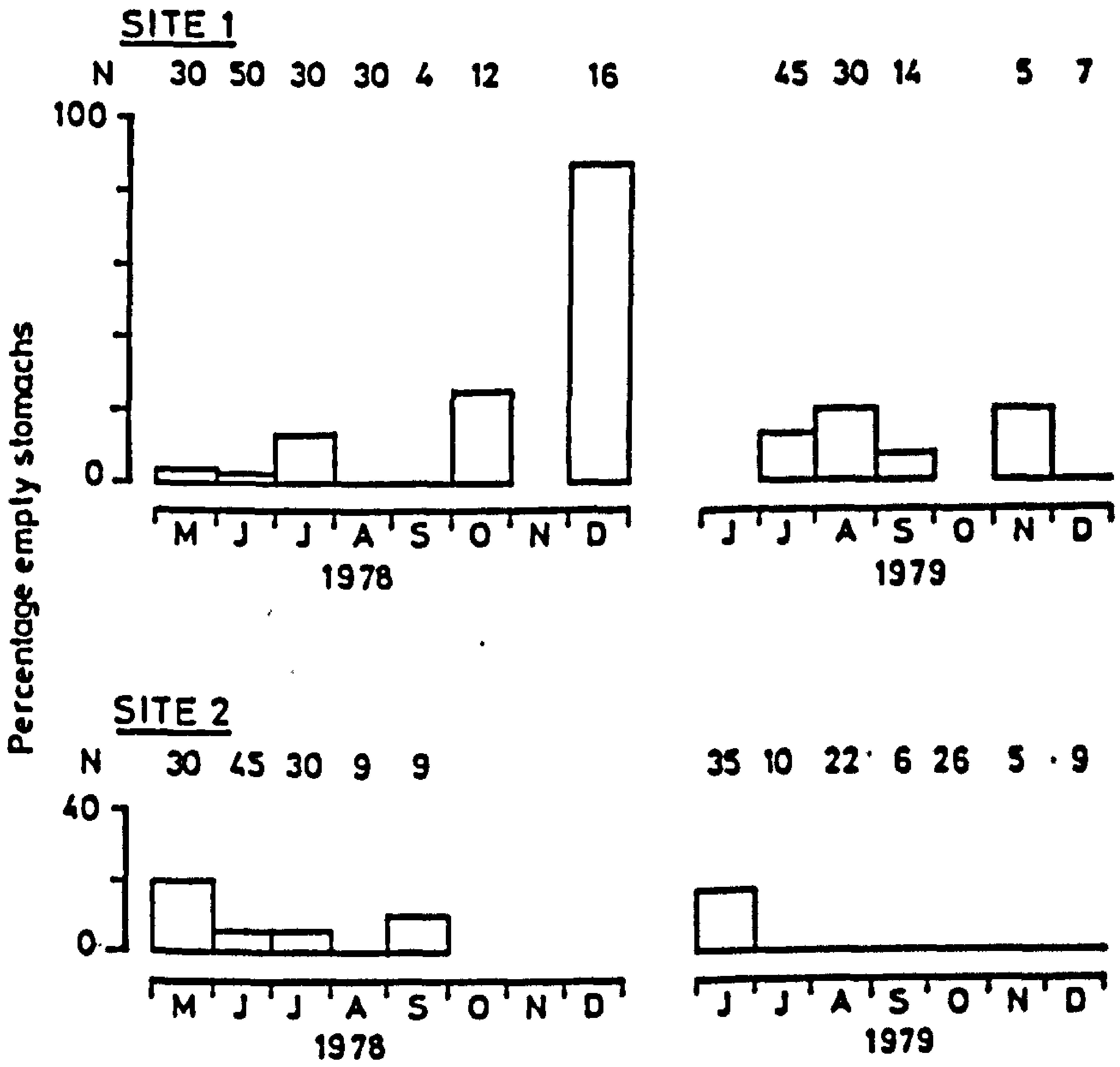

SITE 1
N 30 50 30 30 4 12 16
45 30 14 5 7
100
0
M J J A S O N D
1978
J J A S O N D
1979
Percentage empty stomachs
SITE 2
N 30 45 30 9 9
35 10 22 6 26 5 9
40
0
M J J A S O N D
1978
J J A S O N D
1979

Table 4.10 Composition of the diet of I-group flounder at the two sites upstream of Preston Dock. Number of stomachs examined with food: Site 1 = 38; Site 2 = 20.

	SITE 1		SITE 2	
Food item	% Occ.	% Vol.	% Occ.	% Vol.
Eurytemora affinis			5.0	4.6
Cyclopoid copepoda	18.4	7.7	10.0	0.2
Harpacticoid copepoda	2.6	+		
Neomysis integer			5.0	0.1
Asellus aquaticus			20.0	13.6
Tubificidae	23.7	6.4	60.0	22.0
Lumbricidae	2.6	2.0	20.0	5.9
Hirudinea	2.6	1.1	25.0	5.0
Chironomidae larvae/pupae	81.6	51.4	75.0	26.5
Psychodidae larvae	2.6	0.2	5.0	3.3
Ceratopogonidae larvae	5.3	1.5		
Indet. Diptera larvae			25.0	15.2
Ephemeroptera nymphs	26.3	5.6		
Gyrinidae			5.0	0.5
Chilopoda	2.6	2.6		
Flounder postlarvae	23.7	16.4		
Inorganic material	36.8	2.6	60.0	2.9
Plant material	39.5	2.5	65.0	0.2

+ = Food item < 0.1%

diet, particularly at Site 2, but to a lesser extent than in the 0-group fish. The number of stomachs examined was too small to suggest whether this represented a change in diet with size.

DISCUSSION

The food web in a shallow turbid estuary such as the Ribble is based predominantly on detritus (McLusky, 1981). Primary production by benthic microalgae may also play a part, but a food web based on the production of phytoplankton is only important in large estuaries where the water is deep and less turbid (Odum and Heald, 1975). In European estuaries the detritus is derived from sources outside the estuary and is carried in by the sea and by rivers (McLusky, 1981). A further source of detritus comes from the discharge of sewage effluent and several workers have suggested a degree of sewage enrichment may enhance the production of food for fishes provided it does not lead to anoxic conditions (Mansueti, 1961; Saila, 1975; Soule and Soule, 1981). The only fish which directly utilise detritus in British estuaries are the species of grey mullet (Hartley, 1940), it does however form an important source of food for the invertebrates which fish feed on (McLusky, 1981).

An examination of diet may present several problems. For example, there is often a large variation in the composition of stomach contents between fish, and therefore sample size effects may be important. In a strong tidal area where fish may be moving large distances with the currents any study of diet must recognise that the food organisms occurring in the stomachs may not have been consumed by the fish in the same area as they were caught. In the present study this was illustrated by the presence of molluscs in the alimentary tracts of large flounders. Also, it is unlikely that sprat had consumed the copepod T. longicornis in the study area. This copepod species is characteristic of the more seaward reaches of estuaries and coastal waters (Perkins, 1974). Nevertheless, from the differences in dietary constituents of fish in the channel and on the intertidal banks, and the results of the 24 hour feeding study, it is evident that the inner estuary was an important feeding area for the fish species examined.

The diets of P. minutus, P. lozanoi, P. microps and sprat in the inner estuary were broadly similar to those described in studies conducted in many other estuarine and inshore localities. P. minutus has been shown to feed mainly on small crustaceans such as copepods, amphipods and mysids (Hartley, 1940; Smidt, 1951; Healey, 1971; Fonds, 1973; Williams, 1977) with polychaetes and bivalve molluscs also important in some areas (Hesthagen, 1971, 1977; Lee, 1974). The diet of P. lozanoi has rarely been studied though always in conjunction with that of P. minutus and few differences have been found (Fonds, 1973; Williams, 1977). P. microps in the inner estuary fed mainly on copepods and tubificids. Copepods, especially harpacticoids, have also been reported as a major food for this species by Green (1968), Casabianca and Kiener (1969) and Miller (1975b). Hennig and Zander (1981) found harpacticoids were the main food of P. microps in the Elbe Estuary with tubificids rarely eaten despite their dominance in benthic samples. In the present study area it was clear that tubificids did form an important food for P. microps. Other studies have shown P. microps to feed more on larger crustaceans with polychaetes also occasionally eaten (Hesthagen, 1971; Healey, 1972; Zander, 1979). The food of young sprat and other juvenile clupeids has been shown to consist predominantly of copepods (Hardy, 1924; Jesperson, 1928; Marshall et al., 1939; Huddart and Arthur, 1971; De Silva, 1973) including harpacticoids in estuarine areas (Lebour, 1921; Hartley, 1940). Larger crustaceans may be included in the diet, and in the Severn Estuary where copepods were scarce in the environment Moore and Moore (1976a) found sprat fed entirely on N. integer and other similar sized crustaceans. Although the diet of juvenile herring was not studied in the inner estuary it is unlikely to have been different to that of sprat.

The feeding habits of juvenile flounder in the channelised section did, however, differ from the results of previous studies on the diet of this species in marine and estuarine areas (Hessle, 1930; Blegvad, 1932; Smidt, 1951; Williams et al., 1965; Muus, 1967; Moore and Moore, 1976b; Badsha, 1977; van den Broek, 1978; Summers, 1980; Wirjoatmodjo, 1980) in the importance of E. affinis in the diet. The diet contrasted with that described by Hiscock (1971) for flounder from the channel in the middle and outer estuary of the Ribble which had fed on amphipods, molluscs and tubiculous polychaetes; copepods were not mentioned as a food item. The feeding of flounder on E. affinis is perhaps surprising since flounder are generally regarded as demersal feeders. However, E. affinis can reach high densities in the plankton (Haertel and Osterberg, 1967; Heinle and Flemer, 1975) and the greatest numbers are usually found at the bottom of the water column (Alexander et al., 1935; Bousfield et al., 1975). E. affinis was most heavily consumed by the I- and II-group flounder in the spring and early summer and this is when the copepods reach maximum densities in the plankton (Heinle and Flemer, 1975; Collins and Williams, 1981). In the II-group fish examined E. affinis never featured in the diet after the spring. As discussed in the Results this seasonal pattern of feeding on E. affinis was also linked with changes in diet which occurred as the fish increased in size. An additional factor which may have been responsible for the very large numbers of copepods recovered from the stomachs in the spring was that temperatures were probably high enough for active feeding but too low for rapid digestion (Tyler, 1971b; Moore and Moore, 1976b). Kiorbe (1978) estimated that 13% of the stomach content of 0-group flounder is digested every hour at 10°C, whereas at 15°C this increases to 19%.

Planktonic copepods have been reported as a major constituent of the diet of juveniles of American flatfish species which reside in estuaries (Pearcy, 1962; Haertel and Osterberg, 1967; Frame, 1974) occurring in the diet of both 0- and I-group fish. However, in the latter age group they are only utilised in the spring when the copepods are abundant in the plankton. Pearcy (1962) reported Eurytemora spp. as forming 73% of the total volume of stomach contents of I-group winter flounder (Pseudopleuronectes americanus). This was in March and in future months the fish fed almost entirely on larger prey. It is suggested that the absence of E. affinis in the diet of flounder in other areas as shown in previous studies is probably the result of these studies mainly being carried out in the seaward reaches of estuaries or on the coast. E. affinis reaches highest densities at the lower end of the salinity range (Collins and Williams, 1981) and in more marine areas other prey organisms will be readily available to the fish.

Upstream of Preston Dock the juvenile flounder fed on freshwater organisms with chironomids the principal constituent in the 0-group diet at Site 1 and tubificids the principal constituent at Site 2.

The differences in diet above and below the Dock reflect the differences in the geomorphological characteristics and the prevailing salinity regime of the two regions, and their effect on the invertebrate prey fauna. The few accounts of the diet of flounder in freshwater which are available have also shown tubificids and chironomids to be dominant components (Stadel, 1936; Radforth, 1940; Green, 1968; Edwardson, 1974). Preliminary results on the food of small O-group flounder in tidal freshwater of the River Dee, North Wales, have indicated a diet very similar to that of small fish in the present study (Weatherley, pers. comm.). Chironomids, tubificids and cyclopoid copepods are all major components with cladocera and rotifers supplementary food items. As shown, chironomids and other freshwater invertebrates also featured in the diet of flounder and the other species below the Dock. Considerable numbers of freshwater invertebrates drift downstream into estuaries (Elliott and Corlett, 1972) and in the present study it was apparent that at times of high river discharge when quantities of drift are increased (Anderson and Lehmkuhl, 1968; Brooker and Hemsworth, 1978), this input may provide a significant additional source of food for fish in the channelised section.

Sufficient time was not available to carry out an examination of the feeding habits of freshwater fishes in the inner estuary. It would have been interesting, however, to investigate whether freshwater fish occurring downstream of the Dock were feeding in the raised salinities and what types of prey were consumed. Morin _et al._ (1980) stated that freshwater fish inhabiting brackish water in estuaries on the coast of Canada fed on marine organisms, but gave no details of the prey consumed.

In the channelised section there were clear differences in the diet composition of fish in the channel at high water and fish on the intertidal banks. Tubificids and harpacticoid copepods were a major component of the diet of fish taken on the latter area, but with the exception of harpacticoids in sprat were an insignificant or minor constituent of the stomach contents of fish in the channel. It seems likely that the sprat in the channel which had consumed harpacticoids had previously been feeding on the banks. From the differences in the proportion of empty stomachs in the samples there was also the suggestion that feeding conditions were more favourable on the banks than in the channel. Certainly, the feeding periodicity study showed a rise in the stomach fullness of flounder and *P. microps* as they moved over the intertidal banks on the day tides. As described in Chapter 3 nearly all of the flounder, *P. microps*, *P. minutus* and *P. lozanoi* in the inner estuary at high water were found intertidally. Although the relative densities of the prey organisms in the intertidal and channel habitats were not quantitatively assessed, a small number of grab samples which were taken indicated that tubificids were far more abundant in the fine sediments on the banks than in the sandy bottom of the channel. In fact except at Site 3 where there were large areas of mud on the channel floor (Chapter 1), tubificids rarely occurred in channel grab samples. Harpacticoid copepods will have been present in both regions. However, it is likely that in the channel the small forms adapted for interstitial life among the sand grains will, because of their size and position, not have been as readily available or as profitable to the fish, compared to the larger, broader forms that live epibenthically on soft sediments (Mann, 1982).

The large variation between the sites in the overall diets of fish on the intertidal banks was the result of the small numbers of fish examined and the concentration of the samples into a few occasions when a particular prey was heavily consumed. The detailed tables on diet composition presented in Appendix C show that considerable changes in diet occurred both between sites and between months. These changes presumably reflected spatial or temporal variations in the relative abundance or availability of the different prey organisms. It is recognised that it would have been useful in this study to examine prey abundance and to compare this with the results of the stomach analyses. However, even if this data is known measured or apparent availability of the prey items may have little relationship to their realised availability as far as the fish species are concerned (Wallace, 1981). Magnhagen and Wiederholm (1982a) found P. microps in the field fed mainly on C. volutator despite a greater abundance of chironomid larvae in the benthos. Laboratory experiments suggested however, that this was not evidence of selective predation, but rather a result of the greater activity of the amphipods making them more available to the fish. In the inner estuary given that the fish were feeding variously on benthic, tychopelagic and holopelagic prey organisms, obtaining data on the relative availability of the different prey to determine whether they were feeding selectively would have proved impracticable.

Flounder and P. microps fed on the intertidal banks during the daytime tides with little or no feeding as they moved intertidally at night. For flounder a similar pattern of feeding was indicated in the Solway by Williams et al. (1965) but although Summers (1980) and Wirjoatmodjo (1980) also found a tidal periodicity in food intake, feeding occurred on both day and night tides. In non-tidal waters Muus (1967) found crepuscular feeding. The absence of feeding in flounder at night fits in with the conclusions of Groot (1971) that they are primarily visual feeders, although their olfactory sense is well developed. In his study Summers (1980) observed flounder in the Ythan Estuary were feeding by biting into the substrate and then sifting the material through the gill rakers to obtain the infauna, and were therefore not searching for their prey visually. I have no knowledge of any previous studies on daily feeding activity of P. microps but Healey (1971), also working in the Ythan, found P. minutus fed during the rising tide and the beginning of the ebb, irrespective of whether high water was at night or in the day. All the nights on which samples were taken in the present study were moonless or the sky covered by clouds and it is therefore not known whether flounder and P. microps may have fed intertidally at night when there was bright moonlight, as has been observed in juvenile plaice on the coast (Lockwood, 1981).

The tidal periodicity of feeding in the inner estuary was to be expected if, as suggested, the main benthic food sources were located intertidally. It is less evident why it should occur when the fish were feeding on E. affinis. This may perhaps have been related to the overall increased activity of the fish as they moved over the intertidal banks. Considering the highly turbid water conditions in the inner estuary it is perhaps also surprising that the fish were apparently feeding purely using visual cues. It might have been expected that the fish would have at least been able to detect tubificid prey using chemical or mechanical stimuli, and therefore fed on the banks both at night and in the day. As noted earlier flounder have been shown to have a well developed olfactory sense

(Groot, 1971). It is possible that the activity of the invertebrate prey varies with the light-dark period but there is little information available on this aspect, although a diel rhythm of emergence has been shown for some demersal copepod species in subtidal habitats (Alldredge and King, 1980; Tranter et al., 1981). The results indicated that on the daytime tides feeding on the banks did not commence until the latter stages of the flood tide. However, because of the shallow depth of sampling the fish which were captured on the flood tide were still moving up the banks and fish distributed at deeper depths and moving less actively may have started feeding earlier.

The diurnal feeding chronology superimposed on the tidal rhythm means that flounder and P. microps in the inner estuary have only a short period in each 24 hours to satisfy their food requirements. In August when the 24 hour sample series were taken the fish were able to rapidly fill their stomachs when they were on the banks, but at other times of the year when food abundance may have been lower, this may not have been the case. The length of time the intertidal banks are covered by the tide, and the area of the banks immersed, will vary according to periods of neap and spring tides. As observed in the present study on some days in the summer months both high tides coincide with the hours of daylight whereas on others, and more usually, there will be only one high water in daylight and therefore one opportunity for the fish to feed. It is interesting to speculate on whether the tidal-diurnal feeding pattern may restrict the food intake of the fish. For a large part of each 24 hours the stomachs of flounder and P. microps were empty or nearly so, and the fish would presumably have fed if food was available. Experimental studies have shown that in fish appetite returns and feeding commences before the stomach is empty (Brett, 1971; Godin, 1981; Gwyther and Grove, 1981).

However, when the intertidal banks were immersed the fish may have filled their stomachs to a greater extent than if food was constantly accessible (Tyler and Dunn, 1976; Godin, 1981). In addition, during feeding gastric evacuation rate may have increased enabling the intestine to act essentially as a complementary stomach and allowing even greater food intake (Kuipers, 1975b).

In the literature the feeding ecology of animals is being increasingly examined with respect to models of optimal foraging theory (for reviews see Pyke _et al._, 1977; Krebs, 1978; Townsend and Hughes, 1981). The theory specifies for a given animal that complex of behaviour best suited to gather food in a given environment (Schoener, 1971). Under simple laboratory conditions it has been shown that fish do tend to feed in a manner predicted on the premise of maximisation of energy intake (Werner and Hall, 1974; Ringler, 1979). However, as noted these demonstrations were in simple and artificial environments. Obviously, from this study it is not possible to suggest whether or not fish in the inner estuary did optimise their diet, although intuitively predictable broad changes in diet with size were apparent. The clearest analogy to the feeding of fish intertidally may be the example of shore birds which are similarly restricted in their time for foraging by the tidal cycle, but in the opposite mode. Goss-Custard (1977) has shown that redshank (_Tringa totanus_ L.) feeding intertidally selected their prey in a manner predicted by optimal foraging models. It would be much more difficult to analyse the feeding behaviour of fishes in the field since they cannot be directly observed in the same way as birds, though it does seem a profitable area for further research.

Without information on the numbers of fish on the intertidal banks during the time they were submerged and their food intake it is not possible to assess the predation pressure exerted on the intertidal prey populations. Fish and invertebrate predators have been shown to have a substantial effect on subtidal (Blegvad, 1928; Virnstein, 1979) and intertidal (Reise, 1977a, b, 1978) soft bottom macrofauna communities. In areas where predation is very intense the regeneration of parts of invertebrates cropped by fish plays a major role in secondary production (Vlas, 1979a, b). Several studies are also now being conducted on predation effects on meiofaunal communities (Bell and Coull, 1978; Nichols and Robertson, 1979; Bell, 1980; Fleeger _et al._, 1982). Warwick (1981) reports that the seasonal abundance cycles of harpacticoid copepods in the Lynher Estuary are inversely correlated with the abundance of gobies which feed on the copepods. Similarly, on the mudflats of Puget Sound Feller and Kaczynski (1975) observed a reduction in harpacticoid abundance which they considered may have been the result of predation by large numbers of juvenile salmon. Other studies however, have considered feeding pressure exerted by fish has a negligible effect on harpacticoid populations (Bregnballe, 1961; Sibert _et al._, 1977; Alheit and Scheibel, 1982).

Dietary overlap on the intertidal banks was variable but often high (Table 4.11), even between the benthic species and sprat when _E. affinis_ and harpacticoid copepods were the main food (see Appendix C). The fish predators were of a comparable size and behaviour (for the benthic species) and the resources were limited to a small number of prey types. Unless each of the species had consistently specialised on one particular prey then low overlap could not have been achieved. Some separation of feeding habits was apparent in that _N. integer_ was

Sample		Comparison					
		P. minutus vs *P. microps*	*P. minutus* vs flounder	*P. minutus* vs sprat	*P. microps* vs flounder	*P. microps* vs sprat	Flounder vs sprat
July	Site 5	0.87	0.67	0.11	0.72	0.16	0.29
August	Site 3	0.47	-	0.40	-	0.83	-
	Site 4	0.49	0.30	0.45	0.66	0.49	0.16
September	Site 3	-	-	-	-	0.63	-
	Site 5	-	-	-	0.55	-	-
October	Site 3	-	-	0.94	-	-	-
	Site 4	0.76	0.82	0.82	0.73	0.72	0.77
	Site 5	-	-	-	0.58	-	-

Table 4.11 Dietary overlap of fishes on the intertidal banks. Overlap calculated using the Proportional Similarity Index and the average of percentage volume data. Values are given where at least ten stomachs of each species were examined containing food, except on two occasions when the stomachs of only nine flounder were available.

usually a far more important food for P. minutus, and presumably P. lozanoi also, on the banks compared to flounder and P. microps. This could be suggested as a consequence of competition, experimental data by Edlund and Magnhagen (1981) and Magnhagen and Wiederholm (1982b) have shown that where P. minutus and P. microps occur together the former species may be socially dominant. Caution should however, be exercised in directly transfering the results of experiments carried out in small aquaria to the natural habitat. The relative unimportance of N. integer in the flounder and P. microps diet may have been more an effect of the ease of capture of other prey compared to mysids for these two species.

In the absence of data on prey availability the high overlap values cannot be taken as evidence for competition (Colwell and Futuyama, 1971; Hurlbert, 1978). If prey availability is also high complete overlap may occur without competition, whereas if prey availability is low then competition may be present. Low overlap values may also indicate competition since as a result the species may have segregated into separate food niches. In any study it is almost impossible to clearly establish competition, even when data on changes in resource partitioning with temporal changes in prey availability or changes in community composition are collected, the existence of competition can merely be inferred.

Studies on other fish communities in more coastal and offshore habitats have generally shown low dietary overlap with the resources partitioned among the community members (Tyler, 1972; Kislalioglu and Gibson, 1977), although as discussed by Hacunda (1981) the partitioning may often be less than is suggested. In these studies a wide range of prey was available to the fish species and food segregation was possible. Studies on resource overlap in fish communities in shallow estuarine areas have been carried out by Kislalioglu and Gibson (1977) and Thorman (1982). Among the broad assemblage of fishes in a Scottish sea loch Kislalioglu and Gibson (1977) found a tendency for the food resources to be segregated. However, within individual habitats trophic similarity was evident, especially in the open sand-mud environment where four of the five species (flounder, plaice, P. minutus and P. microps) had amphipods and polychaetes as the principal prey. Thorman (1982) considered competition occurred at least temporarily in a community of small fishes in a shallow estuary on the coast of Sweden. The four dominant species were P. microps, G. aculeatus, A. anguilla and Pungitius pungitius (L.), and as a result of competition Thorman suggested species were excluded from the estuary or were depressed in abundance. Several studies on freshwater fishes and salmonids have shown competitive exclusion and habitat segregation when competition for food is very intense (Zaret and Rand, 1971; Svardson, 1976; Werner and Hall, 1977, 1979).

In intertidal and shallow subtidal areas several workers have suggested that competition between species with similar diets is reduced by spatial separation with depth (Williams et al., 1965; Macer, 1967; Edwards and Steele, 1968; Wolff et al., 1981). As observed in Chapter 3 there was some separation of the species by depth on the intertidal banks, but this was slight and during the latter stages of the flood tide and at high water there was often little difference in the depth distributions.

Although the small prey organisms which were abundant on the intertidal banks formed an important source of food for small fishes, they will have been unsuitable to meet the energy requirements of larger fish. Paloheimo and Dickie (1966) and Kerr (1971a, b) have discussed how growth efficiency in fishes varies with relative prey size. Cost-benefit relationships for fish predators feeding on different sizes of prey have been produced by Werner (1974) and Kislalioglu and Gibson (1976); as fish size increases the size of prey which gives the maximum return for the minimum expenditure of effort also increases. It was apparent that II-group and older flounder turned to foraging in the outer areas of the estuary where large prey were more readily available. A similar change in foraging area with increase in size was observed by Toole (1980), juvenile English sole (Parophrys vetulus Girard) feeding intertidally on harpacticoid copepods and infaunal polychaetes changing to foraging subtidally on reaching a length of 80-100mm. The question arises as to why large flounder continued to migrate into the inner estuary even though they were no longer using the area for feeding. Johnston (1981) suggested that adult flounder found in the upper reaches of the River Dee Estuary represented part of a more comprehensive onshore migration which had over-run the feeding grounds in the outer regions of the estuary. However, whether this is the case in either the Dee or in the present study area remains speculation.

CHAPTER 5

IMPACT OF DREDGING OPERATIONS

INTRODUCTION

Until the closure of the Port of Preston, a navigable channel for shipping was maintained by constant dredging. In the years leading up to the closure two dredgers operated in the estuary, a hopper suction dredger working in the middle and outer reaches and a pipeline cutter suction dredger which maintained the channel from the Dock entrance to 3.2 km seaward where the main siltation problems occurred.

The cutter suction dredger in the inner estuary utilised a 2m diameter rotating cutterhead to physically excavate material from the bed of the estuary, the cutterhead being traversed from side to side across the channel between the training walls. Mixed with water, the loosened material was then drawn up through a suction pipe and pumped hydraulically through a pontoon supported pipeline for discharge into settling lagoons at the side of the estuary, the discharge consisting of 90% water and 10% solids. Approximately 210 - 250m^3 of solids were removed per hour and the dredger worked in the estuary for alternate periods of 14 days, during which usually 300 - 400m of channel were dredged, the distance varying according to the type of bottom material.

There is an extensive literature on the environmental impact of navigational dredging in estuaries (for reviews see Morton, 1977; Allen and Hardy, 1980). Studies have been directed towards assessing changes in water chemistry as substances are released from dredged sediments; changes in turbidity; destruction of benthic communities; smothering of organisms by settling silts; alteration of water circulation patterns; damage to adjacent areas by spoil disposal.

Most previous studies have concentrated on monitoring benthic invertebrates to assess the disruption to fauna associated with dredging operations. This is mainly because benthic invertebrates, particularly infaunal populations, are strongly dependent upon the biological, physical and chemical characteristics of the sediments which are excavated, and their low mobility means they are unlikely to avoid or escape disturbed areas (McCauley _et al._, 1977; Morton, 1977).

Studies on the impact of dredging on fishes have principally concerned experimental investigations of the lethal and sublethal effects of raised suspended solids concentrations (Rogers, 1969; Neumann _et al._, 1975, 1982; Sherk _et al._, 1975; Johnston and Wildish, 1982) and the toxicity to fish of seawater extracts of contaminated dredged sediments (LeGore and DesVoigne, 1973; Hoss _et al._, 1974). There are, however, few field data available on the impact of dredging operations on fish populations.

In this chapter the effects of the cutter suction dredger on the fish populations of the inner estuary are examined. The impact of the dredging on fish distribution is described and in addition a study is discussed in which the effects of entrainment on the fish populations were assessed. Brief consideration is also given to the possible effects of the cessation of dredging.

METHODS

To examine the effects of dredging on the distribution of fish, transverse trawls across the channel were made at varying distances to the front and to the rear of the working dredger. All samples were taken at low water when the currents in the estuary were slight and the trawls could be accurately positioned. The gear used was the beam trawl described in Chapter 3.

The locations in front of and behind the dredger at which samples were taken depended to a large extent on where the rocks of the training walls were sufficiently unobtrusive to allow the trawl to be used, the trawl being pulled completely across the channel from shore to shore. The position in the inner estuary at which dredging had started on the first day of each period of operations in which the trawls were taken had been previously marked, and trawls to the rear of the dredger were made both in and out of the dredged cut. The dredger worked along the channel in the direction sea to Dock, and therefore the dredge cut and trawls behind the dredger were located seaward, and at low water downstream of the cutterhead.

Although the cutter suction dredger operated from the Dock entrance to 3.2 km seaward, the soft sediments at the side of the channel and on the intertidal banks near the Dock entrance (see Chapter 1) made trawling difficult, and therefore all samples were taken when the dredger was operating beyond 2 km from the Dock. Most of the samples were taken when the dredger was working, but obviously trawls near the dredger (± 50m from the cutterhead) were made when dredging had stopped. Investigations of fish distribution around the dredger were made on seven occasions during the summer and early autumn months of 1979 and 1980.

In the settling lagoons at the side of the estuary the sediments sloped away from the location of the discharge pipe. As the discharge flowed over the floor of the lagoons channels were cut into the sediment. To examine whether fish were entrained during the dredging operations, the beam trawl was positioned in these channels and the sample collected examined for fish. From estimates of the proportion of the discharge passing through the trawl, and the time the trawl was in the flow, estimates were made of the number of fish entrained for each hourly period of the ebb tide. No samples were taken on the flood tide since during the flood the dredger had to be firmly anchored against the strong currents and no dredging was carried out. For this investigation the codend of the beam trawl was detached and the samples were collected in the main body of the net with a 10mm mesh, since otherwise the fine mesh of the codend rapidly became filled with sediment.

RESULTS

Effects of dredging on fish distribution

The catches taken in the trawls around the dredger were mainly of flounder and P. microps with only a few individuals of other species present (Table 5.1). Since samples were collected at distances up to 700m from the dredger it is not considered that the small numbers of the other species were a result of the dredging activities. The dominance of flounder and P. microps in low water catches has been discussed earlier in Chapter 3.

The numbers of flounder captured in the trawls are shown in Figure 5.1. To reduce the variation in catch sizes, numbers are presented as log(N+1). There was a decrease in flounder numbers for a short distance to the rear of the dredger but at 100-150m from the cutterhead catches were in most instances similar to those taken at greater distances. In front of the dredger the dredging operations appeared to have little effect on flounder distribution. Numbers present at 50m from the cutterhead showed no evidence of a reduction from normal, and on 2 September 1980 flounder were found to be abundant 25m in front of the dredger. On most occasions, apart from numbers in the initial 50 - 100m, catches in the dredge

Table 5.1 Species composition of trawl catches in low water dredging survey.

Species	Total numbers
Pomatoschistus microps	3394
Platichthys flesus	2907
Anguilla anguilla	49
Pomatoschistus minutus	16
Sprattus sprattus	10
Clupea harengus	9
Pomatoschistus lozanoi	6
Pleuronectes platessa	5
Gasterosteus aculeatus	5
Rutilus rutilus	4
Leuciscus cephalus	3
Solea solea	3
Leuciscus leuciscus	2
Dicentrarchus labrax	1
Gobio gobio	1
Gymnocephalus cernua	1
Scophthalmus maximus	1

FIGURE 5.1

Numbers of flounder captured in trawls to the front and to the rear of the cutter suction dredger. The hatched area above each graph represents the dredge cut.

FIG. 5.1

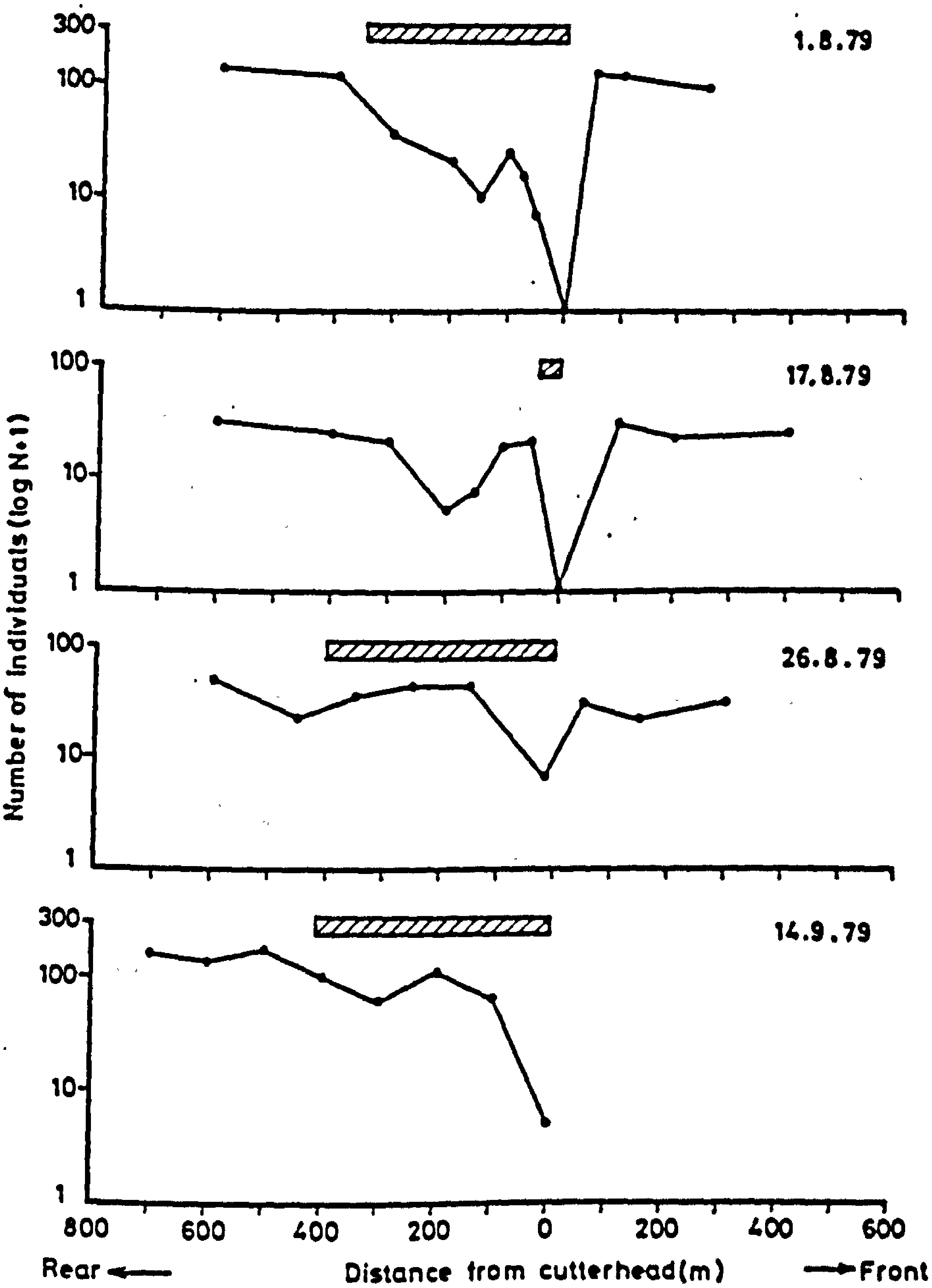

1.8.79
17.8.79
26.8.79
14.9.79
300
100
10
1
Number of Individuals (log N+1)
800
600
400
200
0
200
400
600
Rear ←
Distance from cutterhead (m)
→ Front

FIG. 5.1 contd.

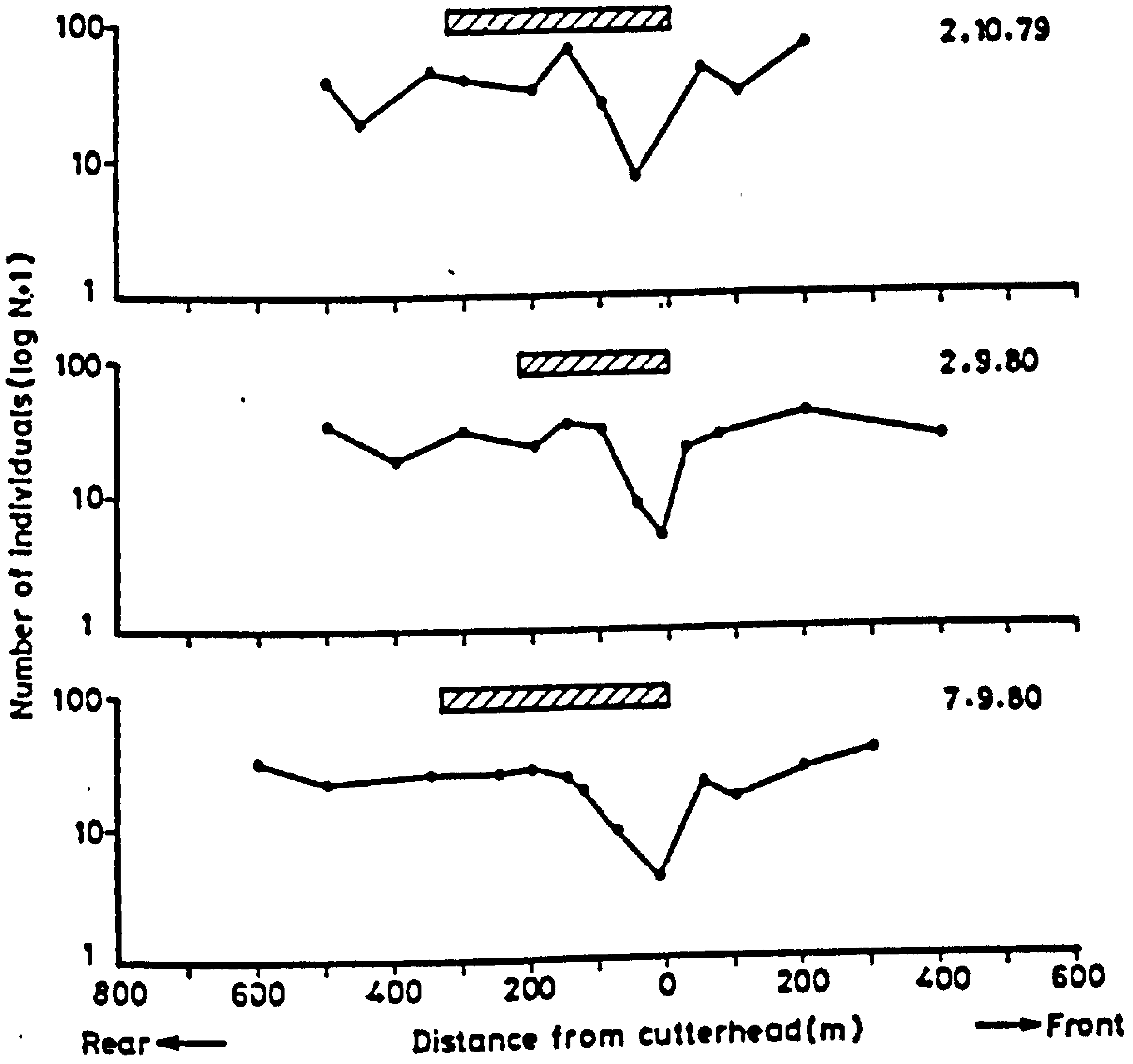

2.10.79
2.9.80
7.9.80
100
10
1
Number of Individuals (log N+1)
800
600
400
200
0
200
400
600
Rear
Distance from cutterhead (m)
Front

FIGURE 5.2

Numbers of P. microps captured in trawls to the front and to the rear of the cutter suction dredger. The hatched area above each graph represents the dredge cut.

FIG. 5.2

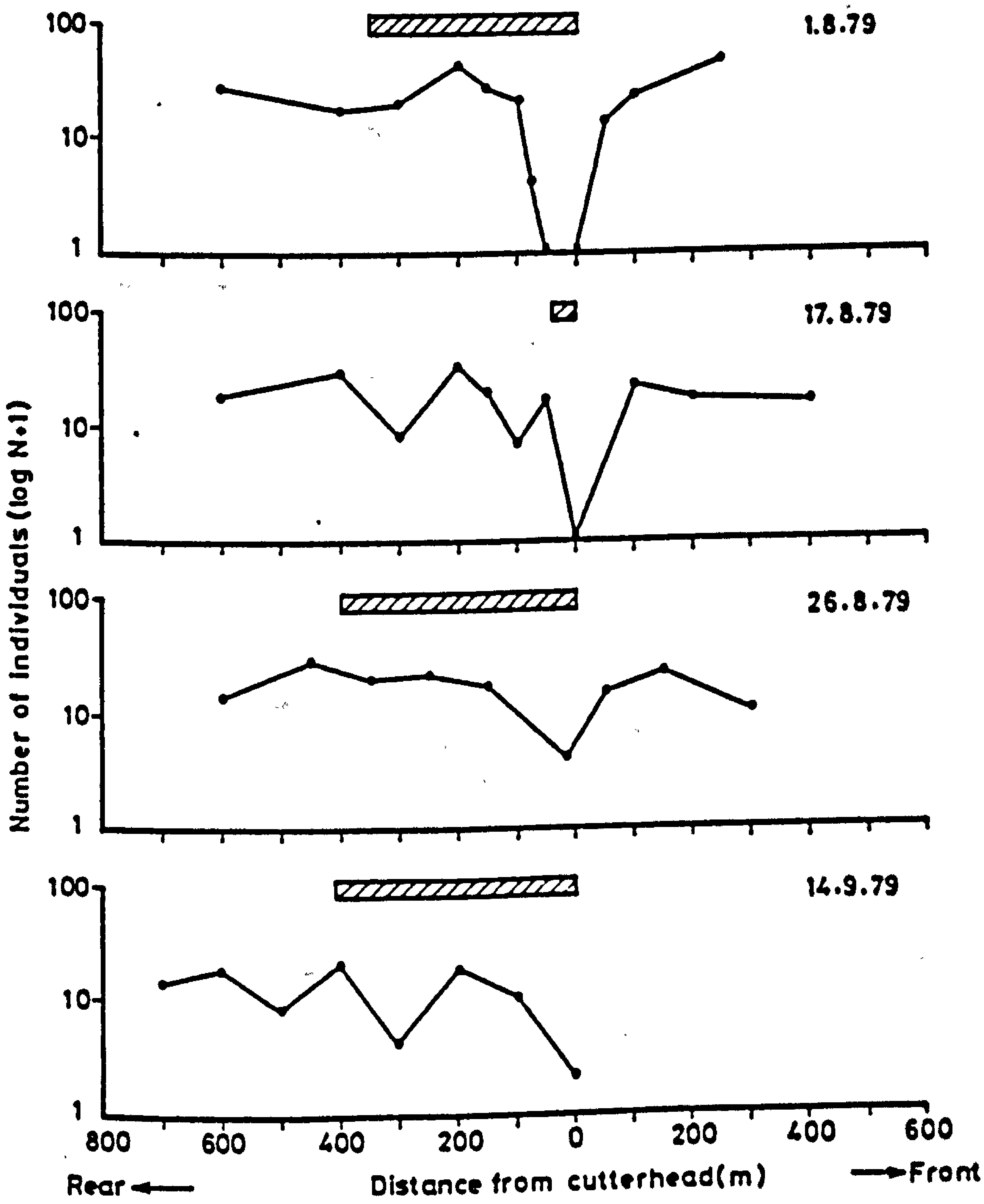
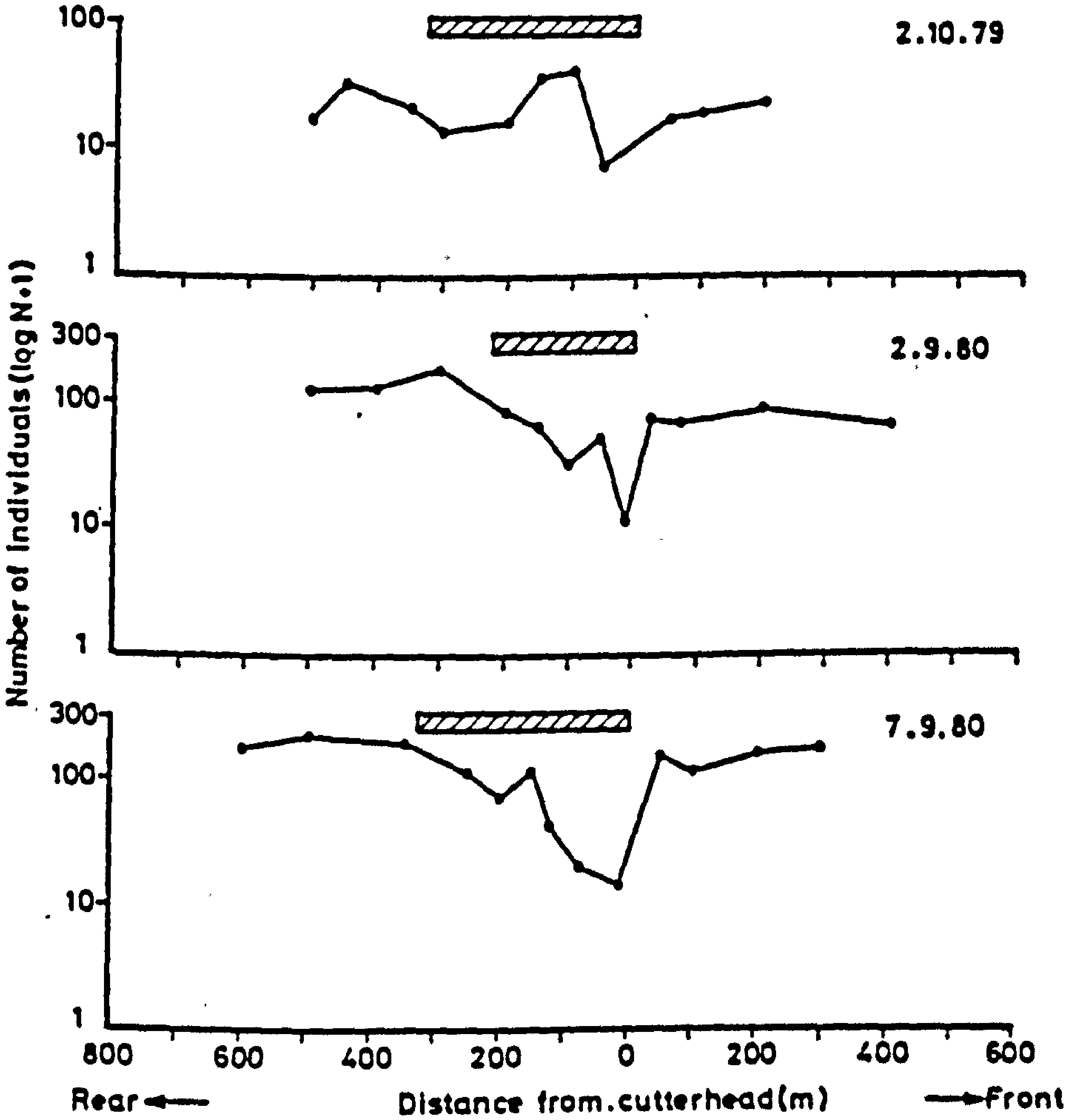

1.8.79
17.8.79
26.8.79
14.9.79
100
10
1
Number of Individuals (log N+1)
800
600
400
200
0
200
400
600
Rear
Distance from cutterhead(m)
Front

FIG. 5.2 contd.


100
10
1
2.10.79
300
100
10
1
2.9.80
300
100
10
1
7.9.80
Number of Individuals (log N+1)
800
600
400
200
0
200
400
600
Rear
Distance from cutterhead (m)
Front

cut as a whole did not differ markedly from collections made out of the cut. However, on 1 August 1979 numbers captured in front of and behind the cut were considerably higher. There was also evidence of this effect in September 1979, although trawls were only made to the rear of the dredge cut.

The numbers of P. microps captured showed a similar pattern to flounder (Figure 5.2), although even after log transformation it is apparent that there was often a wide variation in the catches between trawls. As with flounder there was a reduction in numbers for 50 - 100m behind the cutterhead but usually little observable effect beyond this distance. On 7 September 1980 overall catches in the dredge cut tended to be lower than catches outside the cut.

Entrainment

The numbers of fish collected from the discharge into the lagoons are shown in Table 5.2. Estimates of the total numbers entrained, based on estimated proportion of discharge sampled and length of sampling period, are presented in Table 5.3. From comparison of the two sets of values it will be evident that it was possible to sample only a small proportion of the discharge. The majority of the fish collected were in fact still alive in spite of the passage through the dredger and pipeline, but since they could not escape from the lagoons all fish entrained will have subsequently died.

Most of the fish taken in May were elvers immigrating into the estuary and similarly in June large numbers of metamorphosing and small juvenile flounder were entrained. The data (estimated numbers entrained) for 27 August are also presented in Figure 5.3 which shows that whereas P. minutus and P. lozanoi were most frequently taken 3 - 5 hours after high water, numbers of flounder and P. microps

Table 5.2 Numbers of fish collected from the discharge into the lagoons during each hourly period of the ebb tide.

Species	Hourly periods after high water								
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
18.5.80									
<u>A.anguilla</u>			27	18	10	9	6	11	44
<u>P.flesus</u>			0	1	2	2	2	2	3
<u>S.acus</u>			1	0	0	0	0	0	0
<u>S.solea</u>			0	0	0	1	0	0	0
25.6.80									
<u>P.flesus</u>			462	294	236	247			
24.7.80									
<u>P.flesus</u>			0	3	8	5			9
6.8.80									
<u>A.anguilla</u>		0	0	1	1				
<u>G.aculeatus</u>		0	0	0	1				
<u>P.flesus</u>		0	0	2	5				
27.8.80									
<u>P.flesus</u>			0	1	2		5	5	4
<u>P.lozanoi</u>			0	5	8		6	2	0
<u>P.microps</u>			0	3	6		44	58	116
<u>P.minutus</u>			3	16	11		6	0	0
<u>S.sprattus</u>			0	1	3		4	3	1
21.9.80									
<u>A.anguilla</u>			0	0		1	0		1
<u>G.aculeatus</u>			0	0		1	0		0
<u>P.flesus</u>			0	3		0	3		5
<u>P.microps</u>			1	1		4	0		13
<u>P.minutus</u>			6	3		4	0		0
24.9.80									
<u>P.flesus</u>		0		1	0				
<u>P.lozanoi</u>		0		3	5				
<u>P.microps</u>		0		4	2				
<u>P.minutus</u>		0		12	9				

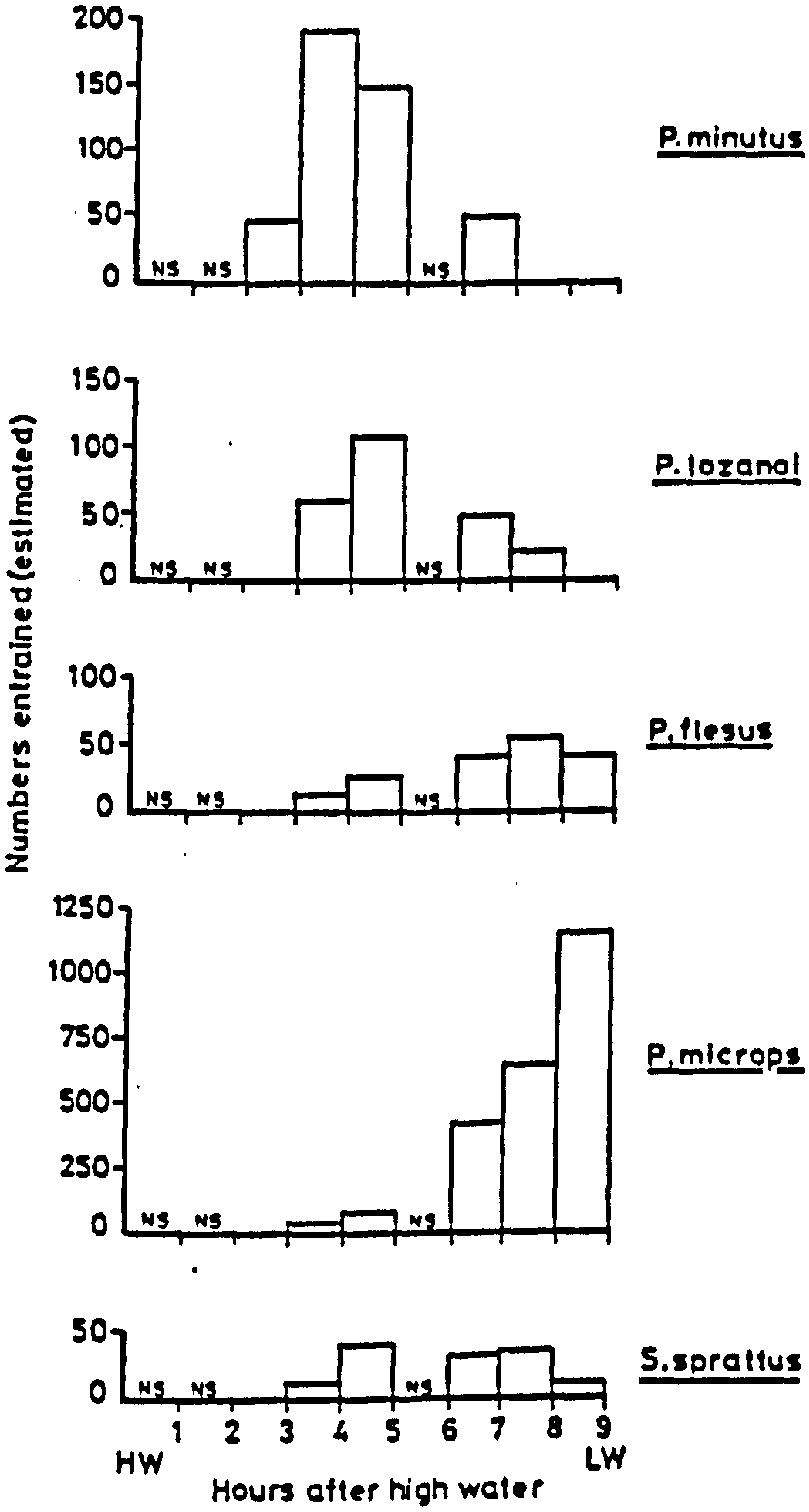
Table 5.3 Estimated numbers of fish entrained by the cutter suction dredger. Estimates are based on the data presented in Table 5.2, the estimated proportion of the discharge sampled, and length of sampling in each hourly period.

Species	Hourly periods after high water								
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
18.5.80									
A.anguilla			324	216	143	94	140	106	422
P.flesus			0	12	28	21	46	19	29
S.acus			12	0	0	0	0	0	0
S.solea			0	0	0	10	0	0	0
25.6.80									
P.flesus			3696	2940	2266	4940			
24.7.80									
P.flesus			0	45	87	75			120
6.8.80									
A.anguilla		0	0	13	9				
G.aculeatus		0	0	0	9				
P.flesus		0	0	26	46				
27.8.80									
P.flesus			0	12	26		40	55	40
P.lozanoi			0	60	107		48	22	0
P.microps			0	36	80		352	633	1160
P.minutus			45	192	147		48	0	0
S.sprattus			0	12	40		32	33	10
21.9.80									
A.anguilla			0	0		8	0		12
G.aculeatus			0	0		8	0		0
P.flesus			0	26		0	22		60
P.microps			7	8		24	0		156
P.minutus			45	26		24	0		0
24.9.80									
P.flesus		0		11	0				
P.lozanoi		0		33	46				
P.microps		0		44	18				
P.minutus		0		133	83				

FIGURE 5.3

Estimated numbers of fish entrained during each hourly period of the ebb tide on 27 August 1980. NS indicates no sample taken.

FIG. 5.3


200
150
100
50
0
NS
NS
NS
P. minutus
150
100
50
0
NS
NS
NS
P. lozanoi
100
50
0
NS
NS
NS
P. flesus
1250
1000
750
500
250
0
NS
NS
NS
P. microps
50
0
NS
NS
NS
S. sprattus
1
2
3
4
5
6
7
8
9
HW
LW
Hours after high water
Numbers entrained (estimated)

increased to maximum at low water. This pattern is explained by the differing movements of the species off the intertidal banks on the ebb tide described in Chapter 3.

DISCUSSION

The few studies which have examined the distribution of fish in relation to dredging operations have presented only limited data and are largely anecdotal. Ingle (1952) observed no evidence of decreased numbers of fish even within a short distance of a dredger whereas Stickney (1972, 1973) found the immediate vicinity of a hydraulic dredger was avoided, although fish did not evacuate the general area of dredging. The former author reported an increase in shrimp abundance attributed to an increase in benthic food supply, and Viosca (1958) also suggested that both fish and shrimp congregated near dredgers, again thought to be due to excavation of benthic organisms on which they could feed.

The results of this study showed that at low water there were decreased numbers of flounder and P. microps present for a distance of 50-100m behind the cutter suction dredger. However, in spite of the general disturbance and noise generated by the operations there appeared to be little effect on abundance at a corresponding distance in front of the dredger. The lower catches immediately behind the cutterhead may have been the result of entrainment of the fish, but only a short section of channel was dredged on each tide (see Introduction) and this would not account for the decreased catches at greater distances. Over the tidal cycle fish will have been moving past the dredger with the currents and it may have been expected that even in the most recently dredged sections fish would have moved in to replace those lost were there not some other, presumably deleterious, factor or factors operating.

The dredging will have clearly altered the physical habitat of the fish and they may have avoided the most recently excavated sections of the channel, whereas further behind the dredger consolidation of the substrate and continued accretion probably returned the habitat to that similar in undredged areas. The dredging will have considerably steepened the sides of the channel and this is where the fish were mainly concentrated at low water (Chapter 3). It is possible that the dredging may have led to changes in water chemistry (O'Neal and Sceva, 1971; May, 1973; Windom, 1975; Smith et al., 1976), however, this aspect was not monitored in the present study. Dredging inevitably leads to a rise in turbidity levels, but fish species inhabiting shallow muddy estuaries are presumably adapted or naturally tolerant of raised suspended solids concentrations, and demersal species are especially tolerant (Rogers, 1969; Sherk et al., 1975).

Generally, the numbers of flounder and P. microps captured in trawls outside of the dredged cut and in the cut were not markedly different, but on a few of the sampling dates larger numbers were taken out of the cut. The reason for the overall differences in numbers recorded on these occasions is also not known, especially since the results were somewhat equivocal in that the dates when higher numbers were taken out of the cut were not consistent for the two species.

Because fish are highly mobile and can avoid unsuitable areas they are normally considered to be less affected by dredging operations than sessile or slow moving benthos (Stickney, 1973; Morton, 1977; Allen and Hardy, 1980; Rees, 1980). Clearly however, at least some fish did not avoid the traversing cutterhead since they were collected from the discharge into the lagoons. Too much emphasis should not be given to the estimates of numbers killed and the data are presented principally to show that entrainment did take place. Given the large volume of the discharge which enabled only a small proportion to be sampled, and the force of the flow which made any sampling difficult, the numbers must be regarded with caution. The loss of small fish through the 10mm mesh used for sampling means they are most likely underestimates. However, it seems improbable that the dredging did have a significant effect, the numbers involved were almost certainly relatively small compared to the total marine and estuarine fish population in the inner estuary.

Clearly, the numbers entrained will have varied through the year according to the seasonal abundances of the species. In the present study this was illustrated by the large catches of eels and flounder in May and June respectively, when the young fish were immigrating into the estuary. As shown, numbers of the individual species entrained varied over the tidal cycle. At low water flounder and P. microps were concentrated in the channel and large numbers were discharged into the lagoons, however, it is likely that those fish in the upper parts of the training wall would not have been affected. It seems probable that entrainment may have been dependent on the mode of dredging. For example, it was notable that relatively few clupeids were recorded on the lagoons and only when the dredger was excavating a shallow depth of sediment may fish in the overlying water column have been drawn in. Although the fish collected from the discharge in the trawl were mainly small eels, O- and I-group flounder, and O-group gobies and sprat, large flounder including individuals of age groups V and VI, and eels up to 70cm in length, were seen on the lagoons. It is perhaps surprising that these large fish were entrained as it may have been expected they would have been easily capable of avoiding the cutterhead.

In some instances it is conceivable that dredgings operations may have a detrimental effect on fish populations. In recent papers Groot (1979a, b, 1980) has discussed the possible impacts of an increase in offshore dredging for sand and gravel extraction, particularly on herring populations. It has been suggested that the disturbance generated by dredging operations may cause disorientation to migrating salmonids (Allen and Hardy, 1980; Rees, 1980). The juvenile stages are probably most vulnerable to direct mortality by dredging since it has been shown that during their downstream migration to the sea they have a reduced swimming performance (Thorpe and Morgan, 1978). In the only other study on entrainment of which I have knowledge Dutta (1976) reported entrainment of many thousand juvenile salmon per day by a hydraulic dredge. Certainly, in the Ribble the numbers of salmon and sea trout smolts passing through the estuary can be considered far more limited than the numbers of marine and estuarine fishes moving in and out with the tide. On one occasion large numbers of smolts were collected from the discharge and found lying on the surface of the lagoons. However, this was during a period of heavy fish mortality in the freshwater reaches through pollution, and along with the smolts large numbers of cyprinids were also collected from the discharge. These samples were therefore discounted and juvenile salmonids were not recorded on any other occasion.

With a long history of dredging in the estuary the question arises as to the possible consequences of the cessation of dredging, particularly in the inner estuary where the main dredging effort was concentrated in the years leading up to closure of the Port.

Studies are usually undertaken to determine the deleterious impacts of dredging operations on the estuarine ecosystem, but in some instances dredging may be beneficial especially where there are problems in the dispersion of pollutants and dredging leads to an increase in tidal exchange (Herbich and Schiller, 1974; Allen and Hardy, 1980).

Before closure of the Port, the Hydraulics Research Station (1980) carried out a study to consider the bed levels which would result from the ending of dredging, and the effects of any changes on water levels in the estuary. The future bed conditions were derived from the rise in levels which tended to occur even while dredging was in progress, and from analysis using a mathematical model developed to predict water level changes. The projected bed levels are shown in Figure 5.4 along with the average longitudinal profile for 1977 which was taken to be representative of the estuary during maintenance dredging. In the inner estuary it was suggested that levels would rise from an average of 1.5m above Ribble Datum, to 3m above Datum at the Dock entrance. Consequent on the increases it was calculated that tidal volume in the inner estuary would be reduced by 7 - 9%, the maximum decrease occurring 5km below the Dock.

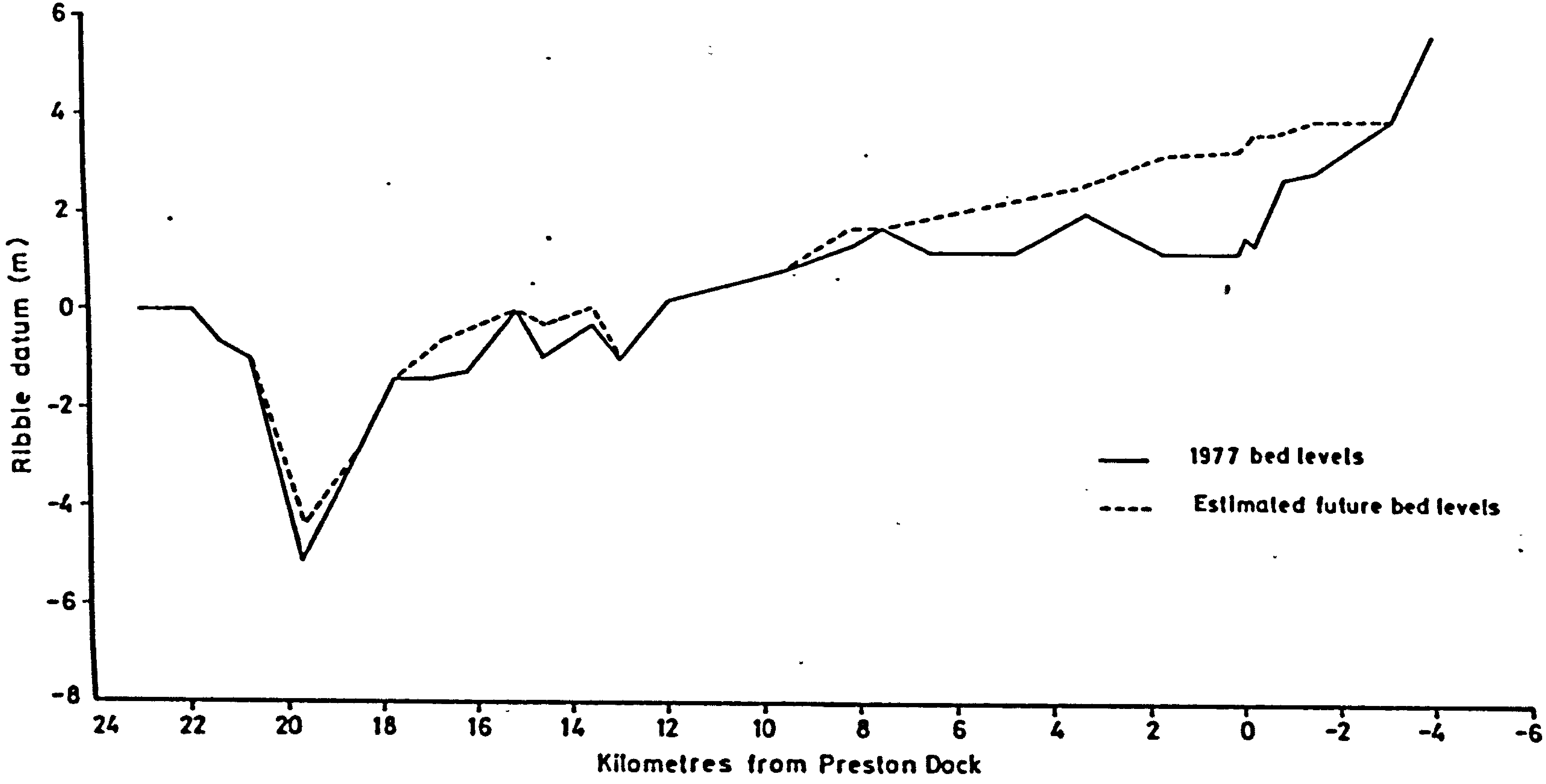
Since the cessation of dredging the bed of the estuary has risen to levels similar to those predicted (Mr. G. B. Hoare, Port of Preston Authority, pers. comm.), although the exact bed profile is not known as soundings are now only occasionally taken. Given the polluted conditions extant in the inner estuary (Chapter 1) it is suggested that any reduction in tidal volume and the rate at which water exchange occurs, must have a negative effect on the estuarine ecology. The bed levels will continue to fluctuate depending on variations in freshwater flow (Hydraulics Research Station, 1980) and accretion can

FIGURE 5.4

Longitudinal profiles of the bed of the Ribble Estuary.

(Data from Hydraulics Research Station, 1980).

FIG. 5.4


6
4
2
0
-2
-4
-6
-8
Ribble datum (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
Kilometres from Preston Dock
1977 bed levels
Estimated future bed levels

be expected to be greatest during the summer months when river discharge tends to be low. This is when pollution, in terms of oxygen debt, is also usually most severe (Chapter 1). It should be noted however, that it is not known whether the operations of the dredger had any effect on water quality in the estuary, particularly whether the resuspension of organic material in sediments may have increased the BOD load to the estuary.

A possible further effect of the rise in bed levels and reduction in tidal volume may be a change in the distribution of fish species along the inner estuary. A decreased salt water intrusion would lead to the overlap zone between freshwater and marine-estuarine species (Chapter 2) moving further down the estuary. Freshwater species could become resident in the estuary below the Dock entrance. An additional factor important in determining the distribution of the marine-estuarine species would be lower current velocities as a result of the raised bed levels (Chapter 3).

In the inner estuary major changes in hydrography similar to those suggested in the outer sections, with the estuary reverting to pre-training and dredging conditions, are highly improbable (Sir William Halcrow and Partners, 1980). However, estuaries are dynamic and constantly changing, and from an engineering point of view the final consequences of the cessation of dredging in the inner reaches are far from clear. Ecological effects are even more difficult to predict and whether any changes to the fish community and other biota do occur, must await the results of future studies.

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APPENDIX A

SEINE AND OTTER TRAWL CATCH DATA

TABLE A1. Site 1 Seine catches

Species	1978									1979												1980			
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
<u>A. anguilla</u>	20	3	22	4	6								3	5	5	8	2								
<u>G. aculeatus</u>		1			1							1								1					
<u>G. gobio</u>		1	1	3	34	3	1		1		2	2					8	2		1					1
<u>L. cephalus</u>			217	35	1290	47	1				1	1				143	13	6		134	3		1	4	
<u>L. leuciscus</u>	4	22	446	19	350						10	21				18	130	30		102					
<u>N. barbatulus</u>		1		5	1											1	2	1							
<u>P. phoxinus</u>					4	2						1					7	1		7	7		6	1	
<u>P. flesus</u>	2	412	102	196	33	3	16		7		2	7	1	10	50	533	27	11		5	7		2	2	3
<u>P. microps</u>					1		4											8							
<u>R. rutilus</u>				13	110	2	2									3	36	8		18				2	
Total species	3	6	5	7	10	5	5	NS	2	NS	4	6	2	2	2	6	8	8	0	7	3	0	3	4	2
<u>Total individuals</u>	26	440	788	275	1830	57	24	NS	8	NS	15	33	4	15	55	706	225	67	0	268	17	0	9	9	4
H	0.231	0.119	0.451	0.422	0.376	0.233	0.366		0.113		0.330	0.401	0.150	0.232	0.119	0.303	0.555	0.629	-	0.463	0.374	-	0.267	0.377	0.151
D	0.613	1.877	1.381	2.459	2.739	2.239	2.848		1.407		2.551	3.230	1.661	0.830	0.573	1.733	2.576	3.833	-	2.471	1.623	-	2.096	3.144	1.661
J	0.609	0.154	0.652	0.437	0.399	0.457	0.623		0.494		0.698	0.516	0.761	0.513	0.420	0.396	0.638	0.768	-	0.555	0.942	-	0.746	0.921	0.774

TABLE A2. Site 2 Seine catches

Species	1978									1979												1980			
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept.	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. abramis																			1						
A. anguilla	170	8	1	11									5	3					1					5	45
C. harengus		1														146		17	2						
G. aculeatus	1	4		1											1	1	1	1	1	3					1
G. gobio	1	1	2	3	20	6	5						1	1	4		25	3	2						1
L. cephalus	9	3	113	29	354	52	94				3	1		5	27	34	86		11	4	2			1	4
L. leuciscus	1	1		1	475	50	141		3		1	3		2	36	24	37	6	8	15	22		9	4	
L. ramada						1																			
P. phoxinus												3			7	1							3	2	2
P. flesus	5	122	1560	61	10	9			1				1	3	542	6	22	6	16	6	12		5	2	
P. lozanoi																			3						
P. microps				28	1	6	4										1	21	22						
P. minutus																		4	39						
R. rutilus		6			58	50	34							3	5		288	6	24	3	4				
S. sprattus	1			25												1		93							6
Total species	7	8	4	8	6	7	5	NS	2	NS	2	3	3	6	7	7	7	9	12	5	4	0	3	5	6
Total individuals	188	146	1676	159	918	174	278	NS	4	NS	4	7	7	17	622	213	460	157	130	31	40	0	17	14	59
[illegible]	0.373	0.290	0.152	0.664	0.438	0.639	0.462		0.572		0.570	0.516	0.252	0.573	0.232	0.493	0.491	0.362	0.731	0.376	0.412	-	0.361	0.491	0.350
[illegible]	2.438	1.229	0.559	1.590	1.087	2.251	1.637		1.661		1.661	2.366	2.362	4.051	2.148	2.577	2.251	3.643	4.293	2.682	1.872	-	1.623	1.492	2.821
[illegible]	0.295	0.332	0.497	0.772	0.369	0.748	0.680		0.759		0.760	0.992	0.649	0.951	0.277	0.496	0.359	0.625	0.770	0.831	0.760	-	0.979	0.913	0.466

TABLE A3. Site 3 Seine catches

Species	1978									1979												1980			
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. tobianus		154	52	447	1	1	3						1				6								
A. anguilla	3	46		1							3		40	31	23		3						11	2	6
C. harengus		166	196		3	1	9									297	404	7	2	8	·				
D. labrax					3												1								
G. aculeatus				1			1														3		1		2
G. gobio					3	2											1								
L. cephalus				1	24	3										1	1	1							
L. leuciscus	2				17	28	·		3		1	1				1		1	2	1	1	2	1	2	
P. phoxinus																					2			1	
P. flesus				4	3		1							1		2	2	3			1				
P. platessa				1																					
P. lozanoi		1																							
P. microps				3	2900	17	2		1									2	2						
P. minutus				3	40	11	34									3			1						
P. pungitius																	1								
R. rutilus	1				21	14	3		2			2			3		26	1	10		3	1			
S. sprattus		51	93		7949	102	191					3			3	126	377	149	127	2					
S. acus				33			2																	1	
Total species	3	3	3	9	11	9	9	NS	3	NS	2	3	2	2	3	6	10	7	6	3	3	2	3	4	2
Total individuals	8	418	341	494	7956	179	272	NS	6	NS	6	6	41	52	29	430	822	204	144	11	10	3	11	6	8
[illegible]	0.238	0.332	0.409	0.24[illegible]	0.292	0.366	0.398		0.296		0.130	0.236	0.077	0.067	0.241	0.277	0.391	0.145	0.270	0.243	0.670	0.199	0.360	0.375	0.481
[illegible]	2.233	1.535	0.791	2.5[illegible]	2.490	1.551	1.292		2.372		1.253	2.572	0.620	0.664	1.348	1.858	3.082	2.398	2.314	1.320	4.009	2.056	1.770	5.895	1.907
[illegible]	0.832	0.774	0.872	0.211	0.291	0.672	0.421		0.959		0.979	0.377	0.940	0.971	0.570	0.581	0.372	0.178	0.261	0.663	0.911	1.070	0.444	1.009	0.784

TABLE A6. Site 3 trawl catches

Species	1978									1979												1980			
	Apr.	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. tobianus				6			2																		
A. anguilla			4		17	1						7		2			4	1	2				4	42	484
A. minuta																		1							
C. harengus		11			1						1			13	3	1	22							1	4
G. morhua						1																			
G. aculeatus																	2				1				
P. flesus	10	3	24	13	8	4	29		45		5	32	1	53	3	21	94	109	8	1	4	17	43	83	96
P. platessa	3	4	4	1			2									2			2						2
P. lozanoi	88	17	40	13	33	122	80										14	33	2	1			1	11	4
P. microps					45	8			6								82	3				3		1	
P. minutus	41	3	232	48	223	278	557		1			3	4	1		2	200	170	6	3		1	20	58	6
P. pictus																	4								
S. rhombus																1									
S. solea	3			1													2						1		20
S. sprattus	3	396	116	21	346	6	1					13		3	7		12	16					1		2
T. luscus				2																					
Total species	6	6	6	8	7	7	6	■	3	■	2	4	2	5	3	5	10	7	5	3	2	3	6	6	8
Total individuals	148	434	420	105	673	420	671	■	52	■	6	55	5	72	13	27	436	333	20	5	5	21	70	196	618
D	2.444	0.779	0.491	0.619	0.538	0.555	0.230		0.172		0.130	0.526	0.140	0.321	0.370	0.286	0.632	0.542	0.371	0.260	0.140	0.209	0.373	0.591	0.512
H	2.374	1.373	1.375	1.449	2.179	2.287	1.769		1.163		1.293	1.729	1.031	2.134	1.701	2.793	3.190	2.376	1.879	2.861	1.531	1.313	2.790	2.191	2.579
J	2.997	0.229	0.684	0.731	0.631	0.529	0.525		0.383		0.372	0.764	0.709	0.498	0.944	0.649	0.647	0.972	0.871	0.881	0.770	0.919	0.949	0.707	0.551

TABLE A5. Site 4 Seine catches

	1978									1979												1980			
Species	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. tobianus	2	348	26	90		6	9						4	1			4	2							
A. anguilla	12	2											26	76	9	2	8	1			1		6		
C. harengus			312	9		2							13	3	10	3	8	11	1	13	20	3			
D. labrax					2																				
G. aculeatus	1											1					1			1	1				
L. cephalus	1				8							1		2											
L. leuciscus					1				1			3													
P. flesus	2			2	86	1	11		2					4	137	13	27	6	1			1			
P. platessa							1																		
P. lozanoi						4	4												3						
P. microps				2	1305	8	18		4								41	23	8	6					
P. minutus				2	22	5	43										2	18	58		1				
R. rutilus					6		1													1	1				
S. maximus						1																			
S. sprattus	1		48	119	62	3	14					2				13	52	8	7	57	4		1		
S. acus				4																					
Total species	6	2	3	7	8	8	8	NS	3	NS	0	4	3	5	3	4	8	7	6	5	6	2	2	0	0
Total individuals	19	350	386	228	1492	30	101	NS	7	NS	0	7	43	86	156	31	143	69	78	78	28	4	7	0	0
H	1.411	0.074	0.250	0.527	0.230	0.621	0.652		0.299		-	0.573	0.349	0.174	0.194	0.527	0.658	0.692	0.551	0.311	0.547	0.150	0.121	-	-
D	1.979	0.300	0.873	2.384	2.205	1.729	1.542		2.366		-	3.550	1.224	2.058	0.992	2.012	1.248	3.263	2.643	2.114	3.553	1.661	1.193	-	-
J	2.662	0.097	0.531	0.521	0.237	0.395	0.773		0.872		-	0.538	0.729	0.236	0.452	0.897	0.293	0.837	0.541	0.539	0.539	0.773	0.547	-	-

TABLE A6. Site 4 trawl catches

										1979												1980			
Species	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. tobianus	5			8	1	2											1							1	1
A. anguilla	1	1													1				1					42	2
A. minuta						1																			
C. harengus	1	12									1				3		1			3			1		1
G. morhua				1															5			1		1	3
L. cephalus						1																			
M. merlangus																			6						
P. flesus	2	4		4	3	6	32		1		3	3	9		7	2	2	3	40	4	5	151	5	217	101
P. platessa	1	1		3		1	3									1								3	11
P. lozanoi	144	6		4	8	100	30						2				7	21	7			1	1	9	
P. microps					4	3	1		1										1		1	2			
P. minutus	30	5		14	25	189	100		6				3		1	2	12	111	68	6		8	4	18	
S. solea				7																					4
S. sprattus	2	1241		3	39	26	1				1	1			9	38		18							1
Total species	8	7	0	8	6	9	6	NS	3	NS	3	2	3	0	5	4	5	4	7	3	2	5	4	7	8
Total individuals	186	1270	0	44	80	329	167	NS	8	NS	5	4	14	0	21	43	23	153	128	13	6	163	11	291	124
H	0.949	0.099	-	0.709	0.507	0.452	0.440		0.219		0.250	0.150	0.377	-	0.460	0.174	0.423	0.349	0.489	0.358	0.130	0.132	0.377	0.340	0.297
D	1.023	1.931	-	3.239	2.627	1.379	2.249		2.219		2.861	1.661	1.743	-	3.023	1.837	2.937	1.373	2.847	1.779	1.283	1.809	2.881	2.433	3.944
J	0.452	0.078	-	0.249	0.732	0.498	0.389		0.637		0.881	0.761	0.795	-	0.799	0.319	0.726	0.374	0.611	0.946	0.977	0.136	0.836	0.438	0.552

TABLE A7. Site 5 Seine catches

Species	1978									1979												1980			
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. tobianus		4		186		1	1						8				2	1	1	2				1	1
A. anguilla	18												33	18		2	1						1	2	5
C. harengus		28	28	1	1				2				26	3	329	21	5	2	2	52	1				
D. labrax																		1							
G. aculeatus																								1	
L. cephalus																	1								
L. leuciscus																				1					
L. ramada																				1					
P. flesus			8	9	2	44	46								2	10	2	4			2		2		
P. lozanoi				79		2	20						9											1	
P. microps				289	2	38	33		3								1	31	1	9					
P. minutus		1	1	313		7	34						1			30		1	1				1		
R. rutilus																	1								
S. solea				1												1									
S. [illegible]	3	230	3	42	4	4			4				8		1	28	3		1	21			1		
S. [illegible]													1			1									
Total species	2	4	4	8	4	6	5	ND	3	ND	0	0	7	2	3	7	8	6	5	6	2	0	4	4	2
Total individuals	21	[illegible]	40	920	9	96	134	ND	9	ND	0	0	86	21	332	93	16	40	6	86	3	0	5	5	6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	[illegible]	[illegible]	[illegible]

TABLE A8. Site 5 trawl catches

Species	1978									1979												1980			
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec.	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
A. cataphractus				1																					
A. tobianus	1		1	2	1	3								1	1		1	1		1				1	2
A. anguilla	1											2		5		2						1		3	7
A. minuta														1			1								
C. mustela			1																						
C. harengus														16	4	1		1							
G. morhua																		1		1				1	
G. aculeatus																	1					1			
M. merlangus																		9							
N. barbatulus																					1				
P. flesus	3	2	16			10	1		3		1	30	8	2	19	2	6	10		20	4	27	3	113	21
P. platessa	1		4	2		10	2											1	2	1			1	6	14
P. lozanoi	110	2	4	10	39	113	13					2	3	14		2	44	71	1			1	1	6	
P. microps					2	2										1	4	8		8		1		1	
P. minutus	35	1	88	65	66	100	70		2				4	2	23	21	104	267	5	48		4	3	8	
P. pictus																		1							
S. solea			2			1																			1
S. sprattus			112	7	73	50					4	28			9	744	78	21		2		1			1
S. acus				1													1								
T. vipera																		2							
T. luscus				2																					
Total species	6	5	8	8	5	8	4	—	2	—	2	4	3	7	5	7	9	12	3	7	2	7	4	8	6
Total individuals	151	5	228	90	181	289	86	—	5	—	5	62	15	41	56	773	240	393	8	81	5	36	8	139	46
[illegible]	0.574	0.250	0.477	0.409	0.478	0.532	0.235		0.272		0.454	0.571	0.357	0.591	0.577	0.690	0.357	0.654	0.279	0.449	0.140	0.337	0.591	0.313	0.378
[illegible]	2.278	2.861	2.478	1.590	1.772	2.707	1.551		1.631		1.539	1.624	1.729	3.729	2.298	2.049	3.361	3.240	2.275	3.144	1.531	2.849	3.572	3.246	3.097
[illegible]	0.509	1.092	0.349	0.440	0.728	0.604	0.646		1.000		0.737	0.665	0.991	0.754	0.733	0.696	0.395	0.511	0.819	0.573	0.720	0.442	0.896	0.576	0.723

APPENDIX B

EFFECTS OF PRESERVATION ON BODY MEASUREMENTS

EFFECTS OF PRESERVATION ON BODY MEASUREMENTS

On capture all fish were preserved in a solution of 4% formaldehyde in fresh water neutralised by the addition of 3.5 g/l of sodium borax. Preservation in formaldehyde has been shown to cause significant changes in length and weight of fish (Shetter, 1936; Blaxter, 1971; Pearcy, 1962; Healey, 1971; Lockwood, 1973), the extent of the change depending on the composition of the solution (Parker, 1963; Lockwood and Daly, 1975). To assess the effects of the preservative used in this study on body measurements, samples of sprat (length range 30-89 mm), P. microps (15-42 mm) and flounder (10-120 mm) were measured live to the nearest 0.1 mm for fish below 55 mm standard length using a travelling microscope, and to the nearest 0.5 mm for fish above this using a measuring board. The fish were then placed in individual containers of preservative and remeasured after 24 hours, 7, 14, 28, 56, 84, 112, 140, 168 and 364 days. All measurements were made without reference to previous observations. A similar experiment was undertaken to determine the effects of preservation on the weight of flounder.

Table B.1 gives the changes in length and weight over time, expressed as a percentage of the original live length and weight. Over 364 days there was a mean shrinkage in length of 1.10% in P. microps, 1.80% in sprat, and 2.28% in flounder. In the latter species the reduction in length was similar to that observed in other flatfish species (Pearcy, 1962; Lockwood, 1973; Lockwood and Daly, 1975). The shrinkage of 0.90% in P. microps after 14 days was the same as that observed in P. minutus by Healey (1971) after a similar period. Over 80% of the shrinkage occurred within 24 hours in flounder and sprat, and 7 days in P. microps. The rapidity of

Table B.1 Changes in mean length of P. microps and sprat, and mean length and weight of flounder preserved in 4% neutral formalin, expressed as a percentage of the live length and weight. Figures in parentheses are 95% confidence limits of the mean.

Days after preservation	P. microps	Sprat	Flounder	
			length	weight
	n = 35	n = 73	n = 79	n = 79
1	-0.49 (± 0.22)	-1.50 (± 0.18)	-1.96 (± 0.20)	+10.72 (± 0.93)
7	-0.89 (± 0.25)	-1.54 (± 0.18)	-2.09 (± 0.22)	+7.47 (± 1.02)
14	-0.90 (± 0.25)	-1.60 (± 0.19)	-2.18 (± 0.22)	+5.92 (± 0.98)
28	-0.90 (± 0.25)	-1.66 (± 0.19)	-2.20 (± 0.22)	+5.14 (± 1.00)
56	-0.90 (± 0.25)	-1.68 (± 0.19)	-2.22 (± 0.22)	+4.60 (± 0.97)
84	-0.92 (± 0.25)	-1.73 (± 0.19)	-2.25 (± 0.22)	+4.36 (± 0.94)
112	-0.99 (± 0.29)	-1.75 (± 0.19)	-2.27 (± 0.22)	+4.20 (± 0.93)
140	-1.05 (± 0.29)	-1.78 (± 0.20)	-2.27 (± 0.22)	+4.02 (± 0.95)
168	-1.10 (± 0.29)	-1.78 (± 0.20)	-2.28 (± 0.22)	+3.95 (± 0.95)
364	-1.10 (± 0.29)	-1.80 (± 0.20)	-2.28 (± 0.22)	+3.42 (± 0.99)

the reduction is the result of at least part of the shrinkage being caused by physical changes brought about by death alone. Shetter (1936) estimated that rigor mortis caused a 2.6% decrease in the length of juvenile brook trout, <u>Salvelinus fontinalis</u> (Mitchill), and similar effects have been observed in plaice (Lockwood and Daly, 1975).

A review of the literature shows that while different strengths of formalin may have a slight effect on the degree of shrinkage in length, for any group of related species (e.g. flatfish species) the percentage change is usually similar. However, the composition of the preserving medium does affect changes in weight (Parker, 1963; Lockwood and Daly, 1975). In the present investigation an initial rapid increase in weight of flounder was followed by a gradual decline to a mean increase of 3.42% after one year.

In spite of the changes observed, all measurements in this thesis are based on preserved fish and no corrections have been applied. Measurements of length-weight in flounder (Chapter 2) were recorded after preservation for 3 months, when weight values had started to approach those of live fish. Otherwise, all measurements of length were made after a minimum of 24 hour's preservation. When large numbers of flounder are being individually weighed the accuracy of the measurements is probably little better than that of the observed increase after 3 months. Similarly for measurements of length, a shrinkage of 1 - 2% is hardly significant when the fish are measured to an accuracy of ± 1 mm. If as it appears, most of the shrinkage in length is a consequence of post-mortem changes, the measurements, though not representing live lengths, are comparable with those of other workers who at best take the lengths of recently killed fish.

APPENDIX C

DIET COMPOSITION

Table C.1 Organisms identified from the stomachs of fish captured in the inner estuary.

Rotifera		*Branchionus* sp.
Crustacea	Copepoda	*Eurytemora affinis* (Poppe)
		Temora longicornis (Muller)
		Cyclops sp.
		Tachidius discipes Giesbrecht
		Tigriopus brevicornis (Muller)
		Laophontidae
		Thalestridae
	Ostracoda	
	Cladocera	*Daphnia pulex* (De Geer)
		Chydoridae
	Mysidacea	*Neomysis integer* (Leach)
		Praunus flexuosus (Muller)
	Decapoda	*Crangon crangon* (Linnaeus)
		Carcinus maenas (Linnaeus)
	Amphipoda	*Corophium volutator* Pallas
		Gammarus zaddachi Sexton
		Gammarus pulex (Linnaeus)
	Isopoda	*Eurydice pulchra* Leach
		Asellus aquaticus (Linnaeus)
Annelida	Oligochaeta	*Tubifex costatus* Claparede
		Tubifex tubifex (Muller)
		Limnodrilus hoffmeisteri Claparede
		Lumbricidae
	Polychaeta	*Nereis diversicolor* Muller
	Hirudinea	*Erpobdella octoculata* (Linnaeus)
		Glossiphonia complanata (Linnaeus)
Mollusca	Gastropoda	*Hydrobia ulvae* (Pennant)
		Planorbis sp.

	Lamellibranchiata	*Macoma balthica* (Linnaeus)
		Cardium edule Linnaeus
		Mytilus edulis Linnaeus
Insecta	Diptera	Chironomidae larvae and pupae
		Ceratopogonidae larvae
		Simulidae larvae
		Psychodidae larvae
		Pericoma sp.
		Tipulidae larvae
		Dolichopodidae larvae
		Ephydridae larvae
	Coleoptera	Hydrophilidae larvae
		Gyrinidae larvae
	Ephemeroptera	Caenidae nymphs
		Ephemerellidae nymphs
		Ecdyonurus sp.
		Baetidae nymphs
	Plecoptera	
	Trichoptera	*Hydropsyche* sp. larvae
	Collembola	
Chilopoda		
Arachnida		
Pisces		*Platichthys flesus*
		Pomatoschistus microps
		Pomatoschistus minutus
		Sprattus sprattus

* *Eurytemora affinis* (Poppe) classified according to Gurney (1931)

Table C.2a Composition of the diet of flounder from the channel in each month, by percentage occurrence: 1977 year class, April 1978 to December 1978. NS indicates no sample collected. No data is presented where less than four stomachs examined contained food.

	1978								
Month :	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
No. stomachs examined	19	18	23	11	5	4	11	NS	12
No. empty	8	0	7	3	0	3	7		7
<u>Eurytemora affinis</u>	81.8	88.9	75.0	75.0			25.0		
Cyclopoid copepoda				12.5					60.0
Harpacticoid copepoda		16.7	12.5						
Cladocera	18.2								
<u>Neomysis integer</u>		5.6		12.5	20.0				
<u>Crangon crangon</u>		5.6	56.3	37.5			25.0		
<u>Corophium volutator</u>	36.4		12.5						20.0
<u>Asellus aquaticus</u>	9.1								20.0
<u>Macoma balthica</u>			12.5						
Tubificidae					80.0				
<u>Nereis diversicolor</u>	9.1	5.6							20.0
Chironomidae larvae/ pupae	36.4	5.6			40.0				100.0
Tipulidae larvae									20.0
Indet. Diptera larvae			12.5						20.0
Plecoptera nympha									20.0
Flounder postlarvae		16.7	37.5						
<u>Pomatoschistus</u> spp.							50.0		
Indet. Pisces	9.1	11.1							
Inorganic material	27.3	72.2	62.5	50.0	60.0		25.0		
Plant material	27.3	22.2		12.5	60.0		25.0		40.0

Table C.2b Composition of the diet of flounder from the channel in each month, by average percentage volume: 1977 year class, April 1978 to December 1978. NS indicates no sample collected. No data are presented where less than four stomachs examined contained food.

	1978								
Month :	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
No. stomachs examined	19	18	23	11	5	4	11	NS	12
No. empty	8	0	7	3	0	3	7		7
Eurytemora affinis	50.8	79.3	32.8	56.4			25.0		
Cyclopoid copepoda				+					+
Harpacticoid copepoda		+	+						
Cladocera	0.5								
Neomysis integer		0.1		12.5	20.0				
Crangon crangon		0.1	30.3	23.5			25.0		
Corophium volutator	3.3		3.3						0.5
Asellus aquaticus	0.1								21.7
Macoma balthica			5.0						
Tubificidae					41.8				
Nereis diversicolor	9.1	0.8							9.6
Chironomidae larvae/pupae	33.4	0.1			6.1				58.0
Tipulidae larvae									0.3
Indet. Diptera larvae			12.5						2.1
Plecoptera nymphs									7.8
Flounder postlarvae		5.8	7.4						
Pomatoschistus spp.							47.7		
Indet. Pisces	1.5	10.2							
Inorganic material	0.8	1.9	8.7	7.6	5.6		2.3		
Plant material	0.5	1.7		+	26.5		+		+

+ = Food items less than 0.1%

Table C.3a Composition of the diet of flounder from the channel in each month, by percentage occurrence: 1978 year class, June 1978 to April 1980. NS indicates no sample collected. No data are presented where less than four stomachs examined contained food.

	1978							1979												1980			
Month :	June	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
No. stomachs examined	36	9	4	13	40	NS	41	NS	9	67	20	36	21	10	15	14	NS	8	5	17	9	30	21
No. empty	5	3	3	5	34		23		2	54	1	0	3	2	4	4		6	1	14	3	11	3
<u>Eurytemora affinis</u>	100.0	100.0		62.5	100.0		50.0		100.0	84.6	100.0	100.0	94.5	75.0	27.3	70.0					50.0	89.5	94.5
Cyclopoid copepoda							11.1		14.3			2.8		37.5									
Harpacticoid copepoda	3.2								14.3		5.3	5.6											
Ostracoda											5.3	2.8											
Cladocera		16.7																					
<u>Neomysis integer</u>				37.5									5.6	62.5	45.3	50.0						15.8	16.7
<u>Praunus flexuosus</u>																					16.7		
<u>Crangon crangon</u>	3.2												5.6	12.5		20.0			25.0			5.3	5.6
<u>Corophium volutator</u>							11.1				5.3										16.7	10.5	
<u>Gammarus</u> spp.									14.3		5.3				18.2				25.0		16.7		5.6
<u>Asellus aquaticus</u>	3.2						11.1												75.0		33.4	26.3	
Indet. Crustacea							5.6				5.3				9.1								
<u>Macoma balthica</u>																					16.7		5.6
Tubificidae							11.1		14.3	15.4	10.5	13.9	5.6			10.0			25.0		16.7	15.8	11.1
Lumbricidae																			25.0		33.4		
Hirudinea																			25.0		16.7	15.8	
Chironomidae larvae/pupae		16.7					50.0		14.3	46.2	26.3	72.2	33.4	37.5	54.5	30.0			75.0		50.0	42.1	61.1
Psychodidae larvae							5.6																
Tipulidae larvae										7.7											16.7	5.3	
Dolichopodidae larvae															9.1								
Indet. Diptera larvae											5.3								50.0		16.7		5.6
Adult Diptera (aerial)																					16.7		
Trichoptera larvae																					16.7		
Ephemeroptera nymphs							11.1							12.5							16.7		
Flounder postlarvae	3.2														9.1								
<u>Pomatoschistus</u> spp.																						5.3	
Inorganic material		50.0		12.5	50.0		11.1			69.2	63.2	69.4	72.2	75.0	45.5	90.0			75.0		33.4	26.3	94.5
Plant material		33.4					50.0			76.9	52.6	80.6	50.0	62.5	72.7	90.0			75.0		33.4	42.1	88.9

Table C.3b Composition of the diet of flounder from the channel in each month, by average percentage volume: 1978 year class, June 1978 to April 1980. NS indicates no sample collected. No data are presented where less than four stomachs examined contained food.

	1978							1979												1980			
Month :	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
No. stomachs examined	36	9	4	13	40	NS	41	NS	9	67	20	36	21	10	15	14	NS	8	5	17	9	30	21
No. empty	5	3	3	5	34		23		2	54	1	0	3	2	4	4		6	1	14	3	11	3
Eurytemora affinis	97.4	88.8		62.5	100.0		37.0		87.8	51.2	88.7	90.4	73.8	68.1	9.1	40.5					1.3	43.8	81.2
Cyclopoid copepoda							+		+			+		+									
Harpacticoid copepoda	+								+		+	+											
Ostracoda											+	+											
Cladocera		1.9																					
Neomysis integer				37.5									1.3	21.2	22.0	34.8						9.1	0.1
Praunus flexuosus																					1.5		
Crangon crangon	1.5												5.6	5.9		19.1			3.4			1.1	0.1
Corophium volutator							1.3				2.0										0.3	0.4	
Gammarus spp.									6.0		3.5				8.4				1.5		0.2		0.1
Asellus aquaticus	0.1						4.3												31.4		6.6	6.6	
Indet. Pisces							0.1				+				4.5								
Macoma balthica																					9.1		5.6
Tubificidae							8.1		0.7	6.9	0.2	+	5.6			+			0.4		1.0	2.7	+
Lumbricidae																			17.3		2.5		
Hirudinea																			2.1		17.2	9.3	
Chironomidae larvae/pupae		9.3					31.3		5.5	38.3	0.5	2.0	0.7	0.3	18.8	0.4			6.1		20.7	11.9	0.3
Psychodidae larvae							1.2																
Tipulidae larvae										0.9											9.9	1.2	
Dolichopodidae larvae															+								
Indet. Diptera larvae											0.1								27.1		1.2		0.1
Adult Diptera (aerial)																					0.5		
Trichoptera larvae																					0.9		
Ephemeroptera nymphs							9.3							0.4							0.1		
Flounder postlarvae	1.0														8.4								
Pomatoschistus spp.																						4.8	
Inorganic material		+		+	+		0.5			0.3	4.3	2.4	10.5	2.6	2.5	2.8			2.1		8.4	0.6	7.9
Plant material		+					6.9			2.4	0.7	5.2	2.5	1.5	26.3	2.4			8.6		13.6	8.5	4.6

+ = Food items less than 0.1%

Table C.4a Composition of the diet of flounder from the channel in each month, by percentage occurrence: 1979 year class, July 1979 to April 1980. No data are presented where less than four stomachs examined contained food.

	1979						1980			
Month :	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
No. stomachs examined	13	42	34	30	18	11	71	50	93	90
No. empty	1	20	3	25	16	4	40	31	22	0
Eurytemora affinis	100.0	72.7	100.0	60.0			74.2	52.6	94.4	97.8
Cyclopoid copepoda	8.4	9.1								
Harpacticoid copepoda		40.9						5.3		2.2
Ostracoda		13.6	3.2							
Neomysis integer			3.2						1.4	17.8
Corophium volutator		4.5					6.5		5.6	
Gammarus spp.		9.1						5.3		6.7
Asellus aquaticus		4.5				14.3	12.9	57.9	8.5	
Indet. Crustacea				40.0						
Tubificidae		31.8	3.2			14.3		21.1	8.5	8.9
Nereis diversicolor		4.5								
Lumbricidae		4.5								
Hirudinea									1.4	
Chironomidae larvae/pupae	8.4	22.7	35.5			57.1	25.8	57.9	26.8	64.5
Simuliidae larvae								5.3		
Ceratopogonidae larvae									2.8	
Dolichopodidae larvae								5.3	1.4	
Indet. Diptera larvae		4.5				14.3				
Trichoptera larvae								10.5		
Plecoptera nymphs								5.3	2.8	
Ephemeroptera nymphs							3.2	15.8		
Indet. Pisces						14.3				
Inorganic material	58.4	31.8	71.0			71.4	25.8	26.3	57.8	100.0
Plant material		45.5	54.5	100.0		28.6	29.0	57.9	40.9	91.1

Table C.4b Composition of the diet of flounder from the channel in each month, by average percentage volume: 1979 year class, July 1979 to April 1980. No data are presented where less than four stomachs contained food.

	1979						1980			
Month :	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
No. stomachs examined	13	42	34	30	18	11	71	50	93	90
No. empty	1	20	3	25	16	4	40	31	22	0
Eurytemora affinis	100.0	45.8	94.5	60.0			67.5	8.3	77.3	92.3
Cyclopoid copepoda	+	+								
Harpacticoid copepoda		+	+					+		+
Ostracoda		+	+							
Neomysis integer			1.1						0.4	+
Corophium volutator		3.6					1.0		1.1	
Gammarus spp.		4.9						1.8		+
Asellus aquaticus		0.4				14.3	11.0	38.2	1.7	
Indet. Crustacea				40.0						
Tubificidae		21.2	0.1			3.1		2.9	1.6	+
Nereis diversicolor		0.8								
Lumbricidae		2.4								
Hirudinea									0.5	
Chironomidae larvae/pupae	+	16.6	2.9			45.9	16.5	31.2	9.7	3.0
Simuliidae larvae								0.4		
Ceratopogonidae larvae									1.5	
Dolichopodidae larvae								1.5	0.1	
Indet. Diptera larvae		0.2				11.5				
Trichoptera larvae								0.7		
Plecoptera nymphs								5.3	0.1	
Ephemeroptera nymphs							0.3	3.0		
Indet. Pisces						14.3				
Inorganic material		3.6	0.8			8.1	2.0	4.9	3.2	3.8
Plant material		0.5	0.6	+		2.8	1.7	1.8	2.8	0.9

+ = Food items less than 0.1%

Table C.5a Monthly diet at each site of O-group *P. minutus* from the channel trawl during July to October 1978, by percentage occurrence.

Month :	July			August				September				October			
Site :	3	4	5	3	4	5	6	3	4	5	6	3	4	5	6
No. stomachs examined	25	15	30	30	30	30	20	40	45	40	40	40	30	40	16
No. empty	2	0	4	9	12	5	5	7	12	6	14	14	9	1	5
Eurytemora affinis	82.6	86.7	69.2	9.5	44.5	12.0		33.4	27.3	88.2	73.1	96.2	66.7	97.4	72.7
Cyclopoid copepoda					5.6										
Harpacticoid copepoda	8.7	6.7	11.5		5.6		6.7	15.2	6.1						
Neomysis integer	17.4	60.0	42.3	47.6	44.5	80.0	66.7	72.7	51.5	29.4	30.8	23.1	33.4	35.9	27.3
Corophium volutator			23.1			12.0	20.0	12.1	12.1	2.9	7.7				
Gammarus spp.		6.7						3.0	3.0		11.5				9.1
Eurydice pulchra								3.0	12.1					2.6	18.2
Indet. Crustacea	4.4			19.1	33.4	8.0	20.0	3.0	24.2		7.7			7.7	
Tubifidae		6.7		61.9			6.7	3.0		2.9					
Nereis diversicolor							6.7								
Chironomidae larvae/pupae				28.6			6.7	3.0						2.6	
Pomatoschistus spp.										2.9		3.9	4.8		
Inorganic material												3.8			
Plant material												3.8			

Table C.5b Monthly diet at each site of O-group *P. minutus* from the channel trawl during July to October 1978, by average percentage volume.

Month :	July			August				September				October			
Site :	3	4	5	3	4	5	6	3	4	5	6	3	4	5	6
No. stomachs examined	25	15	30	30	30	30	20	40	45	40	40	40	30	40	16
No. empty	2	0	4	9	12	5	5	7	12	6	14	14	9	1	5
Eurytemora affinis	74.0	55.6	42.4	+	27.3	4.0		11.7	6.1	66.2	48.1	75.4	61.9	61.5	54.5
Cyclopoid copepoda					4.1										
Harpacticoid copepoda	6.4	+	1.8		+		+	1.6	1.5						
Neomysis integer	15.2	41.4	37.8	31.0	38.0	79.6	62.5	67.3	48.7	26.3	29.5	17.0	33.4	31.9	21.2
Corophium volutator			18.0			8.4	12.0	10.7	7.0	1.7	5.1				
Gammarus spp.		0.8						3.0	3.0		11.5				9.1
Eurydice pulchra								1.0	11.0					1.9	15.2
Indet. Crustacea	4.4			12.6	30.6	8.0	16.7	3.0	22.7		5.8			3.8	
Tubificidae		2.2		36.4			3.3	1.2		2.9					
Nereis diversicolor							2.2								
Chironomidae larvae/pupae				20.0			3.3	0.5						0.9	
Pomatoschistus spp.										2.9		3.8	4.7		
Inorganic material												1.9			
Plant material												1.9			

+ = Food items less than 0.1%

Table C.6a Monthly diet at each site of 0-group <u>P. lozanoi</u> from the channel trawl during July to October 1978, by percentage occurrence. Data are not included for those occasions when less than four stomachs were available.

Month :	July		August				September				October			
Site :	3	5	3	4	5	6	3	4	5	6	3	4	5	6
No. stomachs examined	10	9	30	10	30	10	40	40	30	40	30	30	12	35
No. empty	3	2	6	4	9	4	6	8	2	4	12	10	0	18
<u>Eurytemora affinis</u>	57.1	100.0	16.7	16.7	9.5		38.2	21.9	85.7	88.9	88.9	55.0	91.7	52.9
Harpacticoid copepoda					4.8	16.7	2.9							5.9
<u>Neomysis integer</u>	14.3		87.5	50.0	90.5	66.7	88.2	68.8	32.1	13.9	16.7	60.0	58.4	41.2
<u>Corophium volutator</u>	28.6				14.3		2.9	6.3	3.6	5.6				
<u>Gammarus</u> spp.							2.9			5.6				5.9
<u>Eurydice pulchra</u>								3.1					8.4	11.8
Indet. Crustacea	14.3			33.4		33.4		12.5	3.6	5.6		5.0		11.8
Tubificidae											5.6			
Chironomidae larvae/pupae			4.2						3.6					
Indet. Diptera larvae													8.4	
Adult Diptera (aerial)			8.4								5.6			
Sprat								6.3						

Table C.6b Monthly diet at each site of 0-group P. lozanoi from the channel trawl during July to October 1978, by average percentage volume. Data are not included for those occasions when less than four stomachs were available.

Month :	July		August				September				October			
Site :	3	5	3	4	5	6	3	4	5	6	3	4	5	6
No. stomachs examined	10	9	30	10	30	10	40	40	30	40	30	30	12	35
No. empty	3	2	6	4	9	4	6	8	2	4	12	10	0	18
Eurytemora affinis	42.8	100.0	4.2	16.7	4.8		12.5	15.8	64.4	75.3	83.3	40.0	42.6	27.9
Harpacticoid copepods					4.7	16.7	+							1.4
Neomysis integer	14.3		87.5	50.0	85.7	66.7	85.2	65.1	28.8	13.5	11.1	60.0	51.4	41.2
Corophium volutator	28.6				4.8		1.7	0.7	3.0	5.0				
Gammarus spp.							0.6			2.1				5.9
Eurydice pulchra								0.2					4.2	11.8
Indet. Crustacea	14.3			33.4		16.7		12.5	3.6	4.1		+		11.8
Tubificidae											1.4			
Chironomidae larvae/pupae			1.0						0.2					
Indet. Diptera larvae													1.8	
Adult Diptera (aerial)			7.3								4.2			
Sprat								5.7						

+ = Food items less than 0.1%

Table C.7a Monthly diet at each site of 0-group sprat from the channel trawl during July to October 1978, by percentage occurrence. Data are not included for those occasions when less than four stomachs were available.

Month :	July		August				September		
Site :	3	5	3	4	5	6	4	5	6
No. stomachs examined	18	7	30	30	30	30	26	30	30
No. empty	13	0	5	16	25	16	18	0	0
Eurytemora affinis	20.0	57.1	88.0	81.2	60.0	42.9			
Temora longicornis							100.0	100.0	100.0
Cyclopoid copepoda			20.0						
Harpacticoid copepoda	100.0	100.0	28.0	49.9	60.0	64.3	12.5	6.7	6.7
Ostracoda								6.7	
Neomysis integer					20.0				
Corophium volutator									3.4
Eurydice pulchra									3.4
Chironomidae larvae/pupae			8.0			21.4			

Table C.7b Monthly diet at each site of O-group sprat from the channel trawl during July to October 1978, by average percentage volume. Data are not included for those occasions when less than four stomachs were available.

Month :	July		August				September		
Site :	3	5	3	4	5	6	4	5	6
No. stomachs examined	18	7	30	30	30	30	26	30	30
No. empty	13	0	5	16	25	16	18	0	0
Eurytemora affinis	18.5	12.4	79.1	75.9	54.8	28.7			
Temora longicornis							96.7	97.9	99.3
Cyclopoid copepoda			13.7						
Harpacticoid copepoda	81.5	87.6	6.4	24.1	25.2	53.2	3.3	2.1	0.1
Ostracoda								*	
Neomysis interer					20.0				
Corophium volutator									0.1
Eurydice pulchra									0.5
Chironomidae larvae/pupae			0.8			18.1			

* = Food items less than 0.1%

Table C.8a Monthly diet at each site of O-group flounder from the intertidal banks in 1978, by percentage occurrence. Data are not included for those occasions when less than four stomachs were available.

Month :	June		July		August		September		October		
Site :	4	5	5	6	3	4	5	6	4	5	6
No. stomachs examined	25	8	9	17	5	30	30	9	11	45	11
No. empty	5	0	0	0	0	0	0	2	2	26	3
Eurytemora affinis	100.0	62.5	66.7	17.6	80.0	13.4	6.7		100.0	31.6	
Cyclopoid copepoda						6.7	3.4				
Harpacticoid copepoda	20.0	25.0	100.0	47.1	80.0	16.7	100.0	14.3	88.9	42.1	50.0
Neomysis integer				5.9	20.0	3.4	20.0		33.4		
Crangon crangon	5.0			5.9							
Carcinus maenas				5.9							
Corophium volutator			11.1	47.1			33.4	42.9			25.0
Indet. Crustacea											12.5
Tubificidae		37.5	66.7	47.1	60.0	100.0	100.0	85.7		52.6	100.0
Nereis diversicolor			22.2	47.1							
Chironomidae larvae/pupae		12.5	11.1		100.0	6.7	6.7			10.5	
Indet. Diptera larvae							6.7				
Ephemeroptera nymphs						3.4					
Flounder postlarvae	5.0										
Inorganic material			11.1	70.6		66.7	100.0	71.4	33.4	63.2	87.5
Plant material			11.1	29.4		70.0	93.4	14.3	11.1	57.9	87.5

Table C.8b Monthly diet at each site of 0-group flounder from the intertidal banks in 1978, by average percentage volume. Data are not included for those occasions when less than four stomachs were available.

Month :	June		July		August		September		October		
Site :	4	5	5	6	3	4	5	6	4	5	6
No. stomachs examined	25	8	9	17	5	30	30	9	11	45	11
No. empty	5	0	0	0	0	0	0	2	2	26	3
Eurytemora affinis	95.6	62.5	19.3	11.7	13.0	+	+		43.0	26.3	
Cyclopoid copepoda						+	+				
Harpacticoid copepoda	0.4	+	58.4	15.2	+	+	29.4	+	29.5	5.3	+
Neomysis integer				1.2	16.8	0.1	12.4		27.5		
Crangon crangon	2.3			2.2							
Carcinus maenas				1.7							
Corophium volutator			9.1	28.2			2.4	30.2			17.7
Indet. Crustacea											+
Tubificidae		31.3	11.5	15.3	5.1	94.8	40.6	65.9		44.0	69.8
Nereis diversicolor			1.7	17.2							
Chironomidae larvae/pupae		6.2	+		65.1	0.2	+			7.3	
Indet. Diptera larvae							2.2				
Ephemeroptera nymphs						0.4					
Flounder postlarvae	1.7										
Inorganic material			+	6.9		4.3	10.3	3.9	+	2.6	+
Plant material			+	0.4		0.2	2.7	+	+	14.5	12.5

+ = Food items less than 0.1%

Table C.9a Monthly diet at each site of O-group flounder from the intertidal banks in 1979, by percentage occurrence. Data are not included for those occasions when less than four stomachs were available.

Month :	Jun	July			Aug	September		Dec
Site :	4	4	5	6	4	4	5	5
No stomachs examined	30	13	10	6	27	6	4	12
No. empty	5	0	4	2	0	0	0	2
Eurytemora affinis	100.0	100.0	83.4	25.0	18.5	100.0	75.0	
Cyclopoid copepoda					3.7			
Harpacticoid copepoda	12.0	30.8	33.4		48.2	66.7	100.0	
Ostracoda						16.7		
Cladocera				25.0	3.7			
Neomysis integer				25.0	3.7			10.0
Corophium volutator					3.7			50.0
Gammarus spp.					3.7			
Tubificidae			16.7	25.0	100.0	16.7	100.0	60.0
Nereis diversicolor								10.0
Chironomidae larvae/pupae	4.0			25.0	11.1	16.7		10.0
Dolichopodidae larvae					11.1			
Indet. Diptera larvae					3.7			
Inorganic material	4.0	23.1	16.7	50.0	14.8	50.0	100.0	50.0
Plant material		7.7		25.0	51.8	66.7	75.0	60.0

Table C.9b Monthly diet at each site of 0-group flounder from the intertidal banks in 1979, by average percentage volume. Data are not included for those occasions when less than four stomachs were available.

Month :	Jun	July			Aug	September		Dec
Site :	4	4	5	6	4	4	5	5
No. stomachs examined	30	13	10	6	27	6	4	12
No. empty	5	0	4	2	0	0	0	2
Eurytemora affinis	98.2	100.0	83.4	25.0	0.3	100.0	+	
Cyclopoid copepoda					+			
Harpacticoid copepoda	0.1	+	8.3		1.1	+	7.2	
Ostracoda						+		
Cladocera				10.7	+			
Neomysis integer				22.9	1.6			8.4
Corophium volutator					0.7			17.6
Gammarus spp.					0.3			
Tubificidae			8.3	18.8	90.2	+	59.4	26.3
Nereis diversicolor								9.7
Chironomidae larvae/pupae	1.7			14.3	0.9	+		10.0
Dolichopodidae larvae					4.4			
Indet. Diptera larvae					0.3			
Inorganic material	+	+	+	8.3	+	+	33.4	11.0
Plant material		+		+	0.2	+	+	17.0

+ = Food items less than 0.1%

Table C.10a Monthly diet at each site of O-group P. minutus from the intertidal banks during July to October 1978, by percentage occurrence.

Month :	July	August		September			October		
Site :	5	3	4	3	4	5	3	4	6
No. stomachs examined	40	30	30	10	25	7	40	30	13
No. empty	0	2	3	4	6	0	6	0	3
Eurytemora affinis	15.0	78.6	22.2	16.7	5.3		100.0	90.0	10.0
Cyclopoid copepoda			3.7						
Harpacticoid copepoda	100.0	3.6	37.0	16.7	42.1	57.1	17.6	83.4	40.0
Neomysis integer	17.5	64.3	40.7	33.4	58.0	14.3	8.8	13.4	20.0
Corophium volutator	7.5		3.7		5.3	28.6			
Gammarus spp.	2.5		3.7						
Eurydice pulchra	2.5				5.3			3.4	20.0
Indet. Crustacea			3.7						20.0
Tubificidae	27.5		44.4		5.3	71.4	5.9	3.4	
Chironomidae larvae/pupae		3.6						6.7	
Indet. Diptera larvae			7.4			14.3		3.4	
Adult Diptera (aerial)		3.6		83.4	5.3	14.3			
Ephemeroptera nymphs					5.3				
Arachnida							2.9		
Inorganic material	42.5					42.9	5.9	3.4	
Plant material	22.5			33.4		57.1	2.9	10.0	

Table C.10b Monthly diet at each site of O-group P. minutus from the intertidal banks during July to October 1978, by average percentage volume.

Month :	July	August		September			October		
Site :	5	3	4	3	4	5	3	4	6
No. stomachs examined	40	30	30	10	25	7	40	30	13
No. empty	0	2	3	4	6	0	6	0	3
Eurytemora affinis	1.3	34.4	6.8	16.7	5.3		93.6	47.9	10.0
Cyclopoid copepoda			+						
Harpacticoid copepoda	70.9	3.6	24.8	+	21.5	7.2	1.0	26.6	30.0
Neomysis integer	9.3	55.9	30.5	31.0	57.2	2.4	4.3	11.5	20.0
Corophium volutator	2.1		1.2		+	25.0			
Gammarus spp.	1.9		1.3						
Eurydice pulchra	1.3				5.3			2.6	20.0
Indet. Crustacea			3.7						20.0
Tubificidae	4.7		28.1		0.3	22.6	0.1	3.3	
Chironomidae larvae/pupae		2.6						3.6	
Indet. Diptera larvae			3.6			9.5		3.3	
Adult Diptera (aerial)		3.5		52.3	5.1	7.1			
Ephemeroptera nymphs					5.3				
Arachnida							1.0		
Inorganic material	7.8					6.0	+	1.2	
Plant material	0.7			+		20.2	+	+	

+ = Food items less than 0.1%

Table C.11a Monthly diet at each site of O-group P. microps from the intertidal banks during July to October 1978, by percentage occurrence.

Month :	July		August		September			October	
Site :	3	5	3	4	3	4	5	4	5
No. stomachs examined	7	40	30	30	23	8	38	18	32
No. empty	0	0	0	2	0	0	0	0	1
Eurytemora affinis	100.0	15.0	90.0	35.7	100.0	25.0	73.7	100.0	71.0
Cyclopoid copepoda			20.0						
Harpacticoid copepoda	28.6	100.0	50.0	75.0	95.6	100.0	100.0	83.4	54.8
Ostracoda						37.5	10.5		6.5
Neomysis integer	42.9	7.5	10.0	3.6					
Corophium volutator		2.5					29.0	11.1	
Gammarus spp.							5.3		3.2
Indet. Crustacea							2.6		
Tubificidae	14.3	27.5	16.7	82.1	4.4	12.5	60.5	16.7	19.4
Nereis diversicolor							2.6		
Chironomidae larvae/pupae			20.0	21.4	8.7		2.6	11.1	6.5
Indet. Diptera larvae			3.4		4.4		15.8		
Adult Diptera (aerial)					4.4				
Inorganic material		10.0					65.8	5.6	9.7
Plant material		2.5					39.5	5.6	

Table C.11b Monthly diet at each site of O-group *P. microps* from the intertidal banks during July to October 1978, by average percentage volume.

Month :	July		August		September			October	
Site :	3	5	3	4	3	4	5	4	5
No. stomachs examined	7	40	30	30	23	8	38	18	32
No. empty	0	0	0	2	0	0	0	0	1
Eurytemora affinis	91.4	6.4	69.1	11.9	41.7	6.2	9.3	44.8	48.9
Cyclopoid copepoda			8.6						
Harpacticoid copepoda	6.4	82.1	5.6	11.8	51.6	88.9	45.6	44.6	29.0
Ostracoda						3.1	0.8		+
Neomysis integer	2.2	1.8	6.9	1.0					
Corophium volutator		0.8					5.6	6.5	
Gammarus spp.							4.8		2.2
Indet. Crustacea							0.7		
Tubificidae	+	6.4	1.8	65.4	0.6	1.8	14.2	2.4	15.7
Nereis diversicolor							2.5		
Chironomidae larvae/pupae			6.2	9.9	0.6		0.1	1.7	4.2
Indet. Diptera larvae			1.8		2.9		6.1		
Adult Diptera (aerial)					2.6				
Inorganic material		1.3					8.6	+	+
Plant material		1.2					1.7	+	

+ = Food items less than 0.1%

Table C.12a Monthly diet at each site of 0-group sprat on the intertidal banks during July to October 1978, by percentage occurrence. Data are not included for those occasions where less than four stomachs were available.

Month :	July			August		September		October	
Site :	3	4	5	3	4	3	5	3	4
No. stomachs examined	30	30	30	30	30	40	4	30	13
No. empty	0	5	0	0	10	0	0	0	0
Eurytemora affinis	100.0	88.0	100.0	100.0	95.0	90.0		100.0	100.0
Temora longicornis						95.0	100.0		
Cyclopoid copepoda				6.7	5.0	17.5		20.0	
Harpacticoid copepoda	100.0	72.0	93.4	63.4	65.0	100.0	75.0	96.7	92.3
Ostracoda		8.0	10.0			22.5	50.0		
Neomysis integer	6.7		6.7			42.5	50.0	13.4	53.9
Corophium volutator						7.5			15.4
Gammarus spp.						5.0		10.0	15.4
Eurydice pulchra						2.5			
Tubificidae		12.0			20.0				
Chironomidae larvae/pupae				6.7	25.0	25.0		10.0	

Table C.12b Monthly diet at each site of 0-group sprat on the intertidal banks during July to October 1978, by average percentage volume. Data are not included for those occasions when less than four stomachs were available.

Month :	July			August		September		October	
Site :	3	4	5	3	4	3	5	3	4
No. stomachs examined	30	30	30	30	30	40	4	30	13
No. empty	0	5	0	0	10	0	0	0	0
Eurytemora affinis	85.9	69.6	90.0	82.1	51.9	11.3		92.8	65.6
Temora longicornis						29.3	94.2		
Cyclopoid copepoda				3.7	0.5	0.5		+	
Harpacticoid copepoda	13.7	21.3	9.4	10.0	21.2	51.6	3.5	6.3	27.0
Ostracoda		0.9	0.2			0.2	0.6		
Neomysis integer	0.4		0.4			5.8	1.7	0.5	7.1
Corophium volutator						0.2		0.1	0.2
Gammarus spp.						0.1			0.1
Eurydice pulchra						0.2			
Tubificidae		8.2			15.7				
Chironomidae larvae/pupae				4.2	10.7	0.8		0.3	

+ = Food items less than 0.1%

Table C.13a Diet of O-group flounder each month at the two sites upstream of Preston Dock in 1978, by percentage occurrence. Where less than four stomachs with food were examined the data are not presented.

Month :	May		June		July		August		September		Oct	Dec
Site :	1	2	1	2	1	2	1	2	1	2	1	1
No. stomachs examined	30	30	50	45	30	30	30	9	4	9	12	16
No. empty	1	6	1	3	4	2	0	0	0	1	3	14
Rotifera	79.3	25.0	18.4	2.4	57.7							
<u>Eurytemora affinis</u>		83.4	14.3	69.1		39.3						
Cyclopoid copepoda	41.4	16.7	57.1	23.8	73.1	17.9	40.0	33.4	75.0	75.0	33.4	
Harpacticoid copepoda			4.1				3.4					
Ostracoda			2.0									
Cladocera			18.4	4.8	50.0	3.6	26.7					
Tubificidae	17.2		46.9	88.1	46.2	92.9	93.4	77.8	100.0	100.0	33.4	
Chironomidae larvae/pupae	44.8		67.4	19.1	34.6	57.1	56.7	22.2	100.0	75.0	88.9	
Ceratopogonidae larvae			6.1									
Tipulidae larvae			2.0									
Dolichopodidae larvae			2.0		3.9							
Ephydridae larvae			34.7									
Indet. Diptera larvae	6.9		8.2				6.7					
Plecoptera nymphs	3.5											
Ephemeroptera nymphs						3.6			25.0	37.5		
Hydrophilidae larvae			2.0									
Collembola			2.0									
Inorganic material			30.6	88.1	50.0	100.0	100.0	100.0	50.0	50.0	44.5	
Plant material		25.0	61.2	59.5	19.2	100.0	23.4	44.5	25.0	25.0	11.1	

Table C.13b Diet of O-group flounder each month at the two sites upstream of Preston Dock in 1978, by average percentage volume. Where less than four stomachs with food were examined the data are not presented.

Month :	May		June		July		August		September		Oct	Dec
Site :	1	2	1	2	1	2	1	2	1	2	1	1
No. stomachs examined	30	30	50	45	30	30	30	9	4	9	12	16
No. empty	1	6	1	3	4	2	0	0	0	1	3	14
Rotifera	12.1	4.2	1.6	+	8.1							
<u>Eurytemora affinis</u>		79.7	7.0	29.2		8.9						
Cyclopoid copepoda	24.6	17.1	17.0	2.0	47.8	1.5	3.8	13.3	5.5	2.9	11.5	
Harpacticoid copepoda			0.5				0.5					
Ostracoda			+									
Cladocera			3.1	0.2	3.7	0.1	4.8					
Tubificidae	10.4		20.3	61.4	25.1	64.0	58.9	73.7	14.5	57.6	12.8	
Chironomidae larvae/pupae	48.5		31.0	7.2	14.2	24.4	29.9	13.0	71.8	30.4	71.3	
Ceratopogonidae larvae			0.9									
Tipulidae larvae			0.7									
Dolichopodidae larvae			0.1		0.2							
Ephydridae larvae			14.3									
Indet. Diptera larvae	2.3		1.7				1.4					
Plecoptera nymphs	2.1											
Ephemeroptera nymphs						1.1			8.2	1.1		
Hydrophilidae larvae			0.3									
Collembola			1.3									
Inorganic material			+	+	0.9	+	+	+	+	8.0	2.2	
Plant material		+	0.2	+	+	+	0.7	+	+	+	2.2	

+ = Food items less than 0.1%

Table C.14a Diet of O-group flounder each month at the two sites upstream of Preston Dock in 1979, by percentage occurrence.

Month :	June	July		August		September		Oct	November		December	
Site :	2	1	2	1	2	1	2	2	1	2	1	2
No. stomachs examined	35	45	10	30	22	14	6	26	5	5	7	9
No. empty	6	6	0	6	0	1	0	0	1	0	0	0
Rotifera	65.5	17.2				7.7						
Eurytemora affinis			40.0				100.0	15.4				
Cyclopoid copepoda	44.8	64.1	80.0	16.7	36.4	15.4	50.0	53.9	50.0		100.0	22.2
Harpacticoid copepoda	6.9				4.6			3.9	25.0		85.7	
Ostracoda											14.3	
Cladocera	3.5	82.1	10.0		4.6						28.6	11.1
Asellus aquaticus					4.6			3.9				100.0
Planorbis sp.												11.1
Tubificidae	27.6	25.6	80.0	58.4	95.5	30.8	100.0	92.3	50.0	100.0	85.7	100.0
Lumbricidae					4.6							22.2
Hirudinea												55.6
Chironomidae larvae/pupae	27.6	82.1	80.0	83.4	81.2	100.0	16.7	42.3	75.0	40.0	100.0	100.0
Psychodidae larvae					4.6							33.4
Simuliidae larvae												22.2
Ceratopogonidae larvae												33.4
Tipulidae larvae					18.2							
Ephydridae larvae												11.1
Indet. Diptera larvae		5.1						7.7				22.2
Trichoptera larvae						7.7						11.1
Ephemeroptera nymphs			10.0		4.6			3.9				22.2
Inorganic material	10.3	5.1	60.0	83.4	90.9	69.2	100.0	100.0	25.0	100.0	100.0	100.0
Plant material	20.7	7.7	50.0	20.8	95.5	69.2	100.0	100.0	25.0	100.0	42.9	100.0

Table C.14b Diet of O-group flounder each month at the two sites upstream of Preston Dock in 1979, by average percentage volume.

Month :	June	July		August		September		Oct	November		December	
Site :	2	1	2	1	2	1	2	2	1	2	1	2
No. stomachs examined	35	45	10	30	22	14	6	26	5	5	7	9
No. empty	6	6	0	6	0	1	0	0	1	0	0	0
Rotifera	6.9	2.6				2.6						
Eurytemora affinis			4.5				7.6	0.1				
Cyclopoid copepoda	27.2	9.3	10.2	2.5	1.0	0.4	1.6	2.3	7.9		20.9	0.2
Harpacticoid copepoda	3.5				+			+	0.8		2.0	
Ostracoda											0.6	
Cladocera	3.5	30.3	1.0		0.2						1.9	0.3
Asellus aquaticus					0.5			0.1				34.2
Planorbis sp.												0.1
Tubificidae	28.7	4.8	37.6	33.1	45.2	7.4	61.2	41.1	29.7	79.2	18.5	42.0
Lumbricidae					1.5							0.6
Hirudinea												5.9
Chironomidae larvae/pupae	29.9	51.9	41.2	53.3	30.4	75.3	4.0	6.7	61.6	3.7	52.4	8.9
Psychodidae larvae					0.4							0.6
Simuliidae larvae												1.0
Ceratopogonidae larvae												0.4
Tipulidae larvae					4.2							
Ephydridae larvae												0.3
Indet. Diptera larvae		1.1						0.9				2.1
Trichoptera larvae						0.9						0.2
Ephemeroptera nymphs			0.5		2.3			0.1				0.3
Inorganic material	+	+	5.0	8.4	3.6	10.9	24.9	24.0	+	6.0	1.4	2.0
Plant material	0.3	+	+	2.7	10.7	2.5	0.7	24.7	+	11.1	2.3	0.9

+ = Food items less than 0.1%