ASPECTS OF THE BIOLOGY OF FISH POPULATIONS FROM THE MEDWAY ESTUARY, BASED ON POWER STATION INTAKE SAMPLING, WITH SPECIAL REFERENCE TO PARASITISM AND POLLUTION

A thesis submitted for the degree

of

Doctor of Philosophy

Faculty of Science, University of London

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ABSTRACT

Historical records suggest there has been a decline in the diversity of fish species in the Medway Estuary. The aims of the present study were to assess the type and composition of fish populations currently using the estuary, investigate aspects of their biology and gather information on the occurrence of specific pollutants in their tissues with a view to evaluating the influence of man's activities.

Quantitative sampling was carried out monthly between 1973 and 1975 from the intake screens of Kingsnorth Power Station. Trawl samples were also taken as a check for selectivity.

During the study over 46,000 fish, divided between 59 species, were collected. All individuals were weighed and measured, and selected species were aged. The annual cycle of species-occurrence, their relative abundance, population structure and growth of the most common species were investigated.

The diets of plaice, Pleuronectes platessa L., flounder, Platichthys flesus (L.), whiting, Merlangius merlangus (L.) and pouting, Trisopterus luscus (L.) were monitored. Seasonal and/or age variations in food intake and feeding behaviour were considered in conjunction with parasite and pollution studies.

The integumental tissues and branchial cavities of fish were inspected for parasites. Adults of the blood-feeding ectoparasitic copepod Lernaeocera branchialis (L.) infested whiting. Fish so infected showed a statistically significant reduction in body weight. Also, a brief study of their liver lipids revealed an approximately 50 percent loss in weight and this primarily reflected lower levels of phospholipid.

Selected fish, and some of their dietary constituents, were analysed for organochlorine pesticides, polychlorinated biphenyls and five heavy metals. Heavy metal levels were low in comparison with other

literature values. Chlorinated hydrocarbon values showed no marked seasonal variations connected with agricultural activities but their concentrations were correlated with the lipid content of most tissues.

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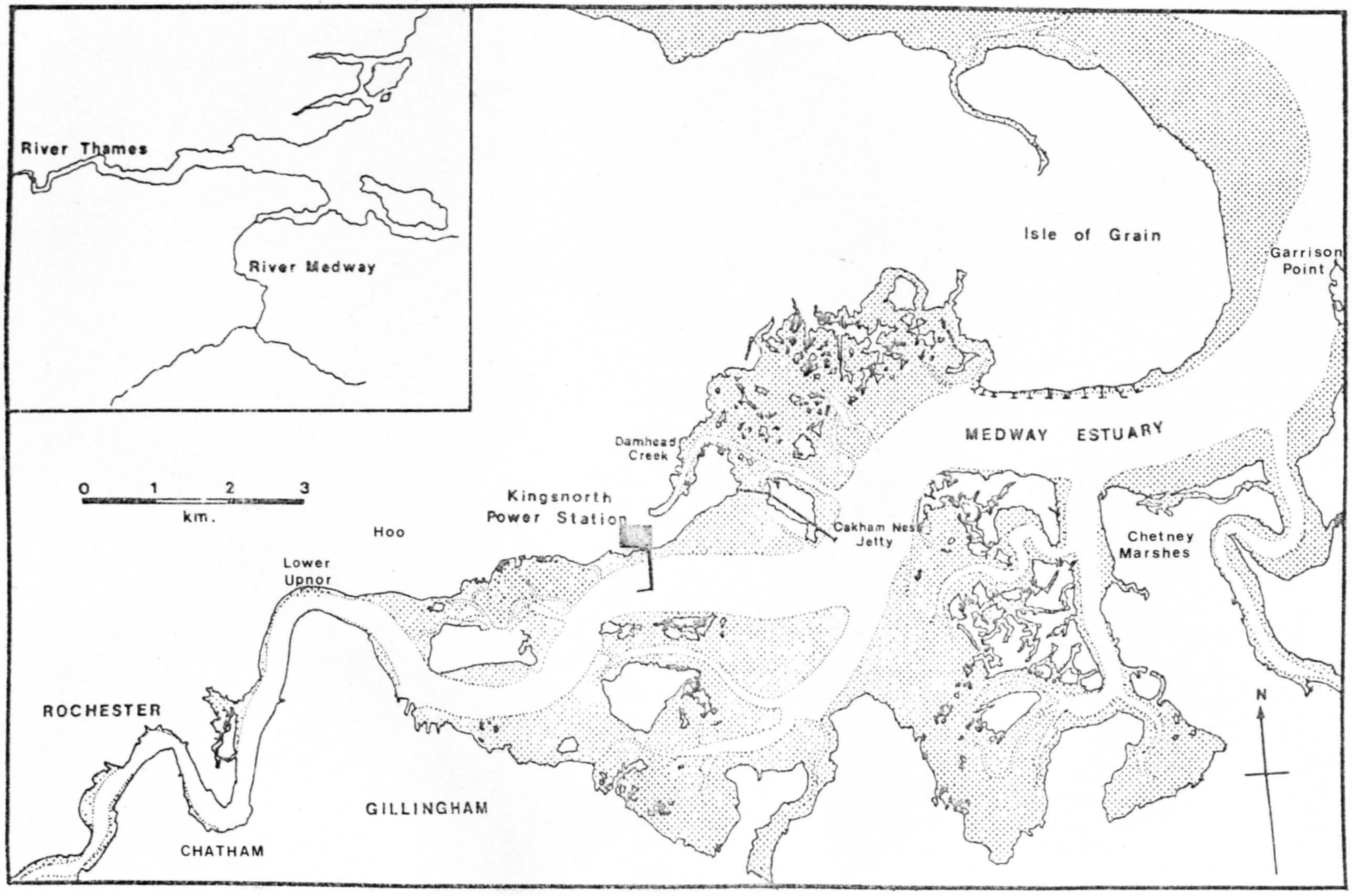

Fig. 1.1.1. The Lower Medway Estuary

SECTION 1

INTRODUCTION

Historical records suggest there has been a decline in fish species diversity in the Medway Estuary. Some species, including salmon (Salmo salar L.) and sturgeon (Acipensor sturio L.), are now never caught while smelts (Osmerus eperlanus L.), once plentiful, are taken only in small numbers (L. Wadhams, Rochester Oyster and Floating Fishery, pers. comm.). Two vessels still fish for brown shrimp (Crangon vulgaris L.) but Rochester (fig. 1.1.1) has long since lost its importance as a fishing port.

Because current information is lacking on fish in the area, the project, which is the subject of this thesis was undertaken to provide detailed information on the type and composition of fish populations in the estuary, and assess the influence of parasites and chemical pollutants so that future changes in the fishery can be more fully evaluated.

1.1 Physical Features of the Medway Estuary

The River Medway is formed by the confluence of a number of small streams which drain the sands and gravels of the Hastings Beds in East Sussex. After passing through poorly-drained Weald Clay, the river cuts through the chalk of the North Downs and London Clay before discharging into the seaward end of the Thames (inset fig. 1.1.1).

Its waters are tidal up to Allington (TQ 746 582), 43.8 kilometres from the mouth, where a system of locks and sluices regulate the river flow further upstream. Below this point, the estuary meanders through a narrow gorge, past Rochester and Chatham, before widening into a broad, flat-floored valley some 8 kilometres wide and 15.3 kilometres long (fig. 1.1.1). A winding main channel, 7.0 metres below Ordnance Datum Newlyn (ODN) at Lower Upnor (TQ 766 713) and 23.4 metres below ODN at its mouth, separates extensive saltings and mudflats from receding banks

of the Hoo Peninsula to the north and the area of Brickearth and Thanet Sands to the south. Some of these saltings, notably Chetney Marsh on the south side, have been reclaimed and are now used for sheep and cattle-grazing (Harrison, 1969) but most of the 60 square kilometres of river marshland remain uninhabited.

The sedimentary environments of the lower estuary are discussed in detail by Kirby (1969). Fine-grained deposits of silt and clay dominate the region; this sediment type extends along both sides of the main channel and includes the tidal flats and sublittoral slopes of all the major creeks. The channel itself is more variable, changing from fluid mud with a high organic content upstream at Gillingham via a zone of shelly muds to an area of flint gravels at Garrison Point.

Currents are particularly strong at the mouth of the estuary where the narrow channel gives rise to a maximum tidal range of 7.0 metres. The tidal curve is symmetrical in the lower estuary with periods of ebb and flood of equal duration but varying in velocity with both the volume of fresh-water discharge and wind strength.

1.2 Environmental parameters

Meteorological data indicate that prevailing winds in the Medway area are south-westerly; wind velocity at the Isle of Grain fluctuates around an annual mean of 10 knots although velocities reaching a maximum 36 knots were recorded during the sampling period.

The mean annual rainfall at Gillingham, 61.1 centimetres, was exceeded during both 1974 and the following year while 1973 was drier than average. Only slightly more rain falls in winter, when evaporation is minimal, than in summer when evaporation and transpiration are at a peak. These factors may then, together, exceed precipitation and possibly affect salinities in the estuary.

Salinity, pH, dissolved oxygen and biochemical oxygen demand (BOD) readings, taken at station in surface waters off Kingsnorth Power Station,

Table 1.2.1 Environmental parameters recorded during the survey

(spot readings taken at low tide)

Date	Salinity ($^{o}/oo$)	pH	Dissolved O_2 (% saturation)	B.O.D. in 5 days at 20°C
1973				
March	29.5	7.9	93	1.1
April	25.7	7.9	85	1.8
May	27.6	7.9	>100	3.1
June	28.0	8.0	86	2.6
August	30.0	7.7	76	1.9
October	29.5	7.8	87	1.4
November	30.4	7.8	90	2.1
1974				
January	27.6	7.7	88	1.1
July	30.9	7.9	93	3.2
August	30.4	8.0	84	2.0
September	27.6	7.7	69	1.1
November	24.6	7.6	80	1.1
1975				
February	19.9	7.5	79	2.1
April	18.8	7.8	89	1.5
May	22.9	7.9	>100	2.7
June	23.5	7.9	>100	1.8
July	28.4	7.8	83	1.8
August	28.9	8.0	>100	3.0
October	26.4	8.4	80	0.9

were supplied by the Southern Regional Water Authority (table 1.2.1). Salinity ranged between 18.8 and 30.9‰, with lowest readings recorded in February and April 1975. Under conditions of high freshwater discharge the overall salinity may be affected but this does not result in a vertical salinity stratification in the lower reaches (M.E. Thorne, Medway Ports Authority, pers. comm.).

The pH readings showed little fluctuation although results indicated a slight summer increase.

Gascoine and Wildish (1971) investigated the distribution of oxygen in the estuary; lowest dissolved oxygen (DO) concentrations, often zero, were found in the upper reaches, well outside the present sampling area. Under conditions of high evaporation and low flow existing for most of the summer, they observed that the deoxygenated plug of water was pushed further up the estuary resulting in higher DO values in the lower reaches than at other times of the year. These results were not supported by readings taken during the present investigations; DO levels were generally high and only fell below 80 percent saturation on three separate occasions, in August 1973, September 1974 and February 1975. BOD, which measures the aerobic bacterial activity related to the organic content of the water, also showed little seasonal fluctuation.

Daily water temperatures, supplied by Kingsnorth Power Station, were converted to mean weekly temperatures (fig. 1.2.1). Maximum water

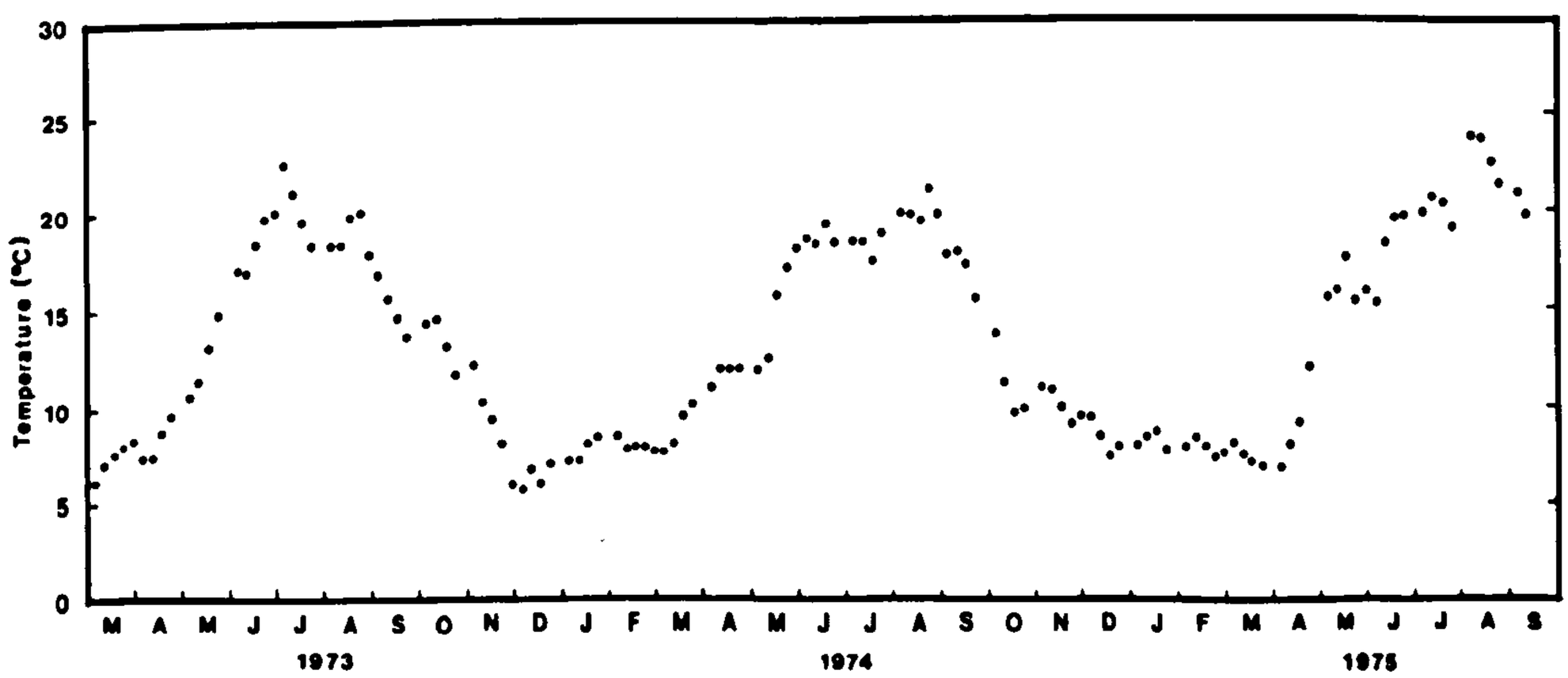

Fig. 1.2.1 Seasonal water temperatures (Kingsnorth power-station intakes)

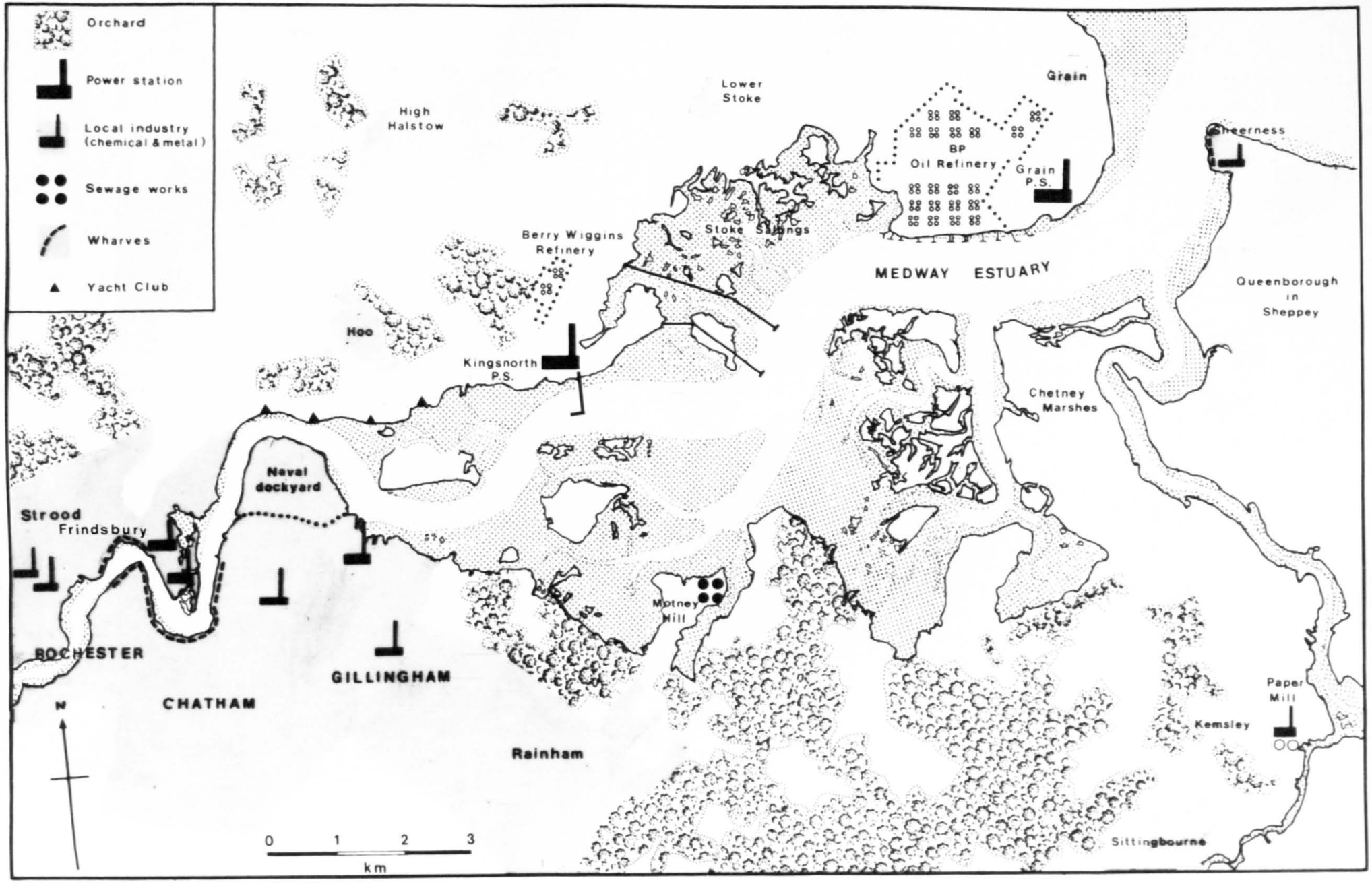

Fig.1.3.1 Location of agriculture and industry around the study area

temperatures were recorded during August 1975 but in all three summers (1973-1975) temperatures rose above 20 degrees Centigrade. Winters were mild throughout the sampling period and the mean minimum weekly temperature never fell below 5 degrees Centigrade.

1.3 Regional Developments and their Effects on the Environment

The transformation of the lower Medway area from Roman times until the Second World War was slow and largely a consequence of moderate population growth and increasing urbanization. Heavy industrial developments, use of new agricultural practices and increased leisure activities over the last twenty-five years have, therefore, had a disproportionate impact.

The first major industrial complex to be developed was the British Petroleum oil refinery (Plate 1); built on 1200 acres of reclaimed marshland on the Isle of Grain (fig. 1.3.1), it was commissioned in 1952. Original development resulted in the displacement of wildlife but the greater threat to the environment has been oil pollution. BP handles 11 million tons of crude oil per annum at Grain. A number of small spills have occurred but these have had a seemingly insignificant effect compared with the 1966 'Seestern' disaster when 1700 tons of oil were accidentally discharged into the estuary (Harrison and Buck, 1967). Some 8000 acres of saltmarsh were polluted and at least 5000 birds were estimated to have died. Aquatic life was also badly affected, although recovery was fairly rapid; soles (Solea solea (L.)) disappeared completely but had returned by early 1977.

Berry Wiggins refinery have major development plans for their 480 acres at Kingsnorth (fig. 1.3.1). They aim to devote the present site to a new oil refinery while diverting their tar plant to the BP site at Grain. This move would inevitably lead to an increased threat of further oil pollution.

The two power stations in the area, at Grain and Kingsnorth, have

Plate 1 BP oil refinery, on reclaimed marshland, as seen from Kingsnorth Power Station

Plate 2 Agricultural land in the immediate vicinity of the power station

also encroached upon marshland. Disruption of this habitat cannot be completely compensated for, but construction of two large settling lagoons at Kingsnorth have at least proved attractive to wildfowl (Harrison, 1972). The station discharges warm water effluent but its effects, at least on the invertebrate fauna, appear to have been minimal (G.J. Walters, City of London Polytechnic, pers. comm.).

Further upstream Frindsbury peninsula is developing as a light industrial area and the Royal Naval Dockyard occupies much of the opposite shore. Below Rochester Bridge wharves, boatyards and small factories line the river, facilities used by regular coastal and continental shipping. The effects on the environment of these diverse industries are difficult to determine because little is known about the types and quantities of effluents they produce.

On the south side of the lower estuary there has been little industrial development. Extensive areas of drained marshland are here used for grazing beef cattle and sheep and, although the habitat is changed, it has remained attractive to many species of wildfowl. The climate and soil are also ideal for fruit-growing (Plate 2) and orchards border much of the southern shore. Land subjected to such intensive methods of agriculture is out of balance with the rest of the environment and considerable quantities of fertilizers, herbicides and insecticides must be applied to maintain or increase production.

Recreational pressures in the lower estuary will continue to grow as both population and leisure time increase. There are several yacht clubs between Upnor and Hoo (fig. 1.3.1) and many more mooring facilities on both banks. It was estimated that in 1969, 3718 small craft were in use and that 17,500 persons were involved. With on-shore facilities largely undeveloped, the main threat to the environment is from organic pollution.

The discharge of increasing amounts of raw sewage from growing urban centres is considered to have been a major factor in changing the

aquatic life of the estuary. Attempts have recently been made to revive the oyster industry which was still flourishing in the 1860s (Smith, 1928). With no sewage treatment until the opening of the Motney Hill works in 1928 and several outbreaks of typhoid resulting from the consumption of shellfish, the industry's decline must be at least partially attributed to an increase in organic pollution.

Today all sewage from the Medway towns is directed to the Motney Hill works for treatment. Local industry has also been encouraged to direct its trade effluents into the system. Unfortunately, treatment at Motney Hill does not include removal of chemical pollutants such as heavy metals and chlorinated hydrocarbons which, when present, are inevitably transferred to the environment.

Ecologically, the future of the lower estuary is brighter today than in 1968 when the area was one of three sites in the United Kingdom considered suitable for grouping heavy industries in a Maritime Industrial Development Area (MIDA). By 1991 the MIDA would have taken up 6000 acres of reclaimed marshlands on the south bank (Kent County Council, 1970), most of which are of international scientific importance (Nature Conservancy, 1971). Since then, central government's attitudes have changed to such large-scale developments. As a result, future expansion in the region will most likely involve existing concerns (Economist Intelligence Unit Ltd., 1973).

In an attempt to trace local area effects on fish populations in the estuary, the present survey followed three main lines of investigation (described in sections 2, 3 and 4). A wide preliminary approach was necessitated by lack of previous work on fish in the area, but this also presented certain difficulties. One of the initial problems was to establish a satisfactory method of sampling; exploitation of the C.E.G.B. station at Kingsnorth as a reliable source for the bulk of material for this study, although basically satisfactory, provided results which still had to be interpreted with some caution (see p. 53).

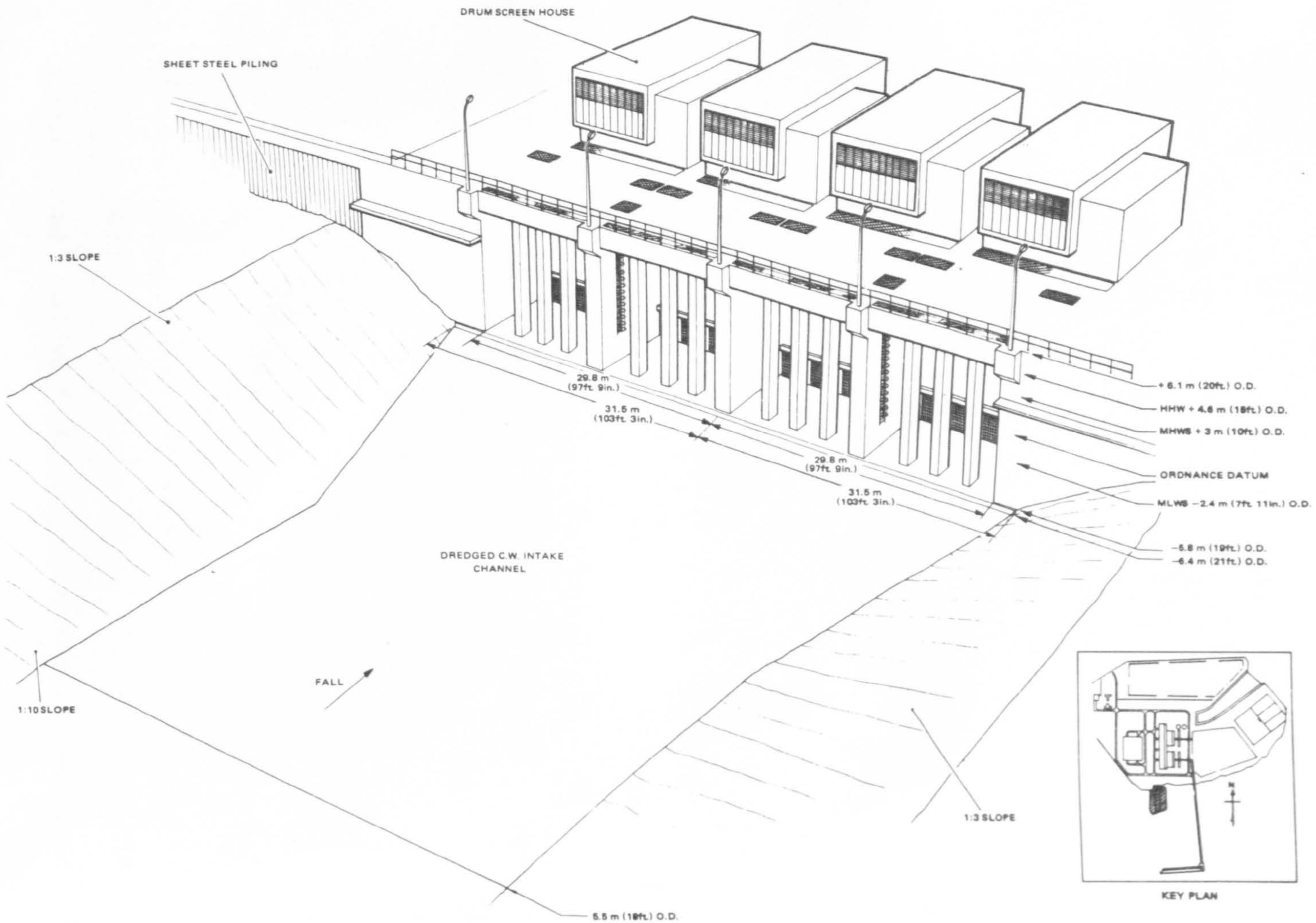

Fig. 1.4.1 Cooling-water intakes (diagram courtesy of C.E.G.B. Kingsnorth)

1.4 Power Station Sampling

Cooling-water intake screens at power stations can yield large quantities of biological material suitable for faunal studies.

Kingsnorth Power Station, on the main channel of the Medway Estuary (TQ 810 720), is a dual system (coal and oil) electricity-generating station of 2000 megawatts capacity. Electricity is produced, in each of its four generating sets, by superheated steam being fed into a series of three steam turbines which drive an electricity generator. At the end of the operation spent steam is condensed and the water recycled to the boilers.

Large quantities of cooling water are utilized to effect this latter process efficiently. River water is taken from a dredged channel (Plate 3, p.19 and fig. 1.4.1) about 140 metres long, 63 metres wide at its head and 5.7 metres below ODN in depth. The channel terminates in four inlet chambers (Plate 4, p.19 and fig. 1.4.1) through which water passes at a maximum rate of 64,100 litres per second. Each inlet is covered by eight coarse-pitch bar screens (partially shown in figures 1.4.1 and 1.4.2), in two rows of four, placed just above the bottom of the channel. A screen measures 2.03 by 2.79 metres and is divided by longitudinal bars into 20-centimetre gaps. Their function is to prevent entry of larger items of trash.

The inlet culverts lead to the pumphouse (fig. 1.4.2) where remaining extraneous matter, including fish, is filtered out by four double-entry revolving drum screens. Each drum is 14.6 metres in diameter and 3.2 metres in width, and covered by a fine metal mesh (less than 10 millimetres). On the inside it is equipped with metal strips which extend inwardly and catch the debris as the drum rotates. It is washed clean by powerful water jets and the waste is carried along culverts and deposited in two trash baskets of similar fine mesh (fig. 1.4.2).

Plate 3 Relationship between the power station intake channel (IC) and the main river channel

Plate 4 Power station cooling-water intakes

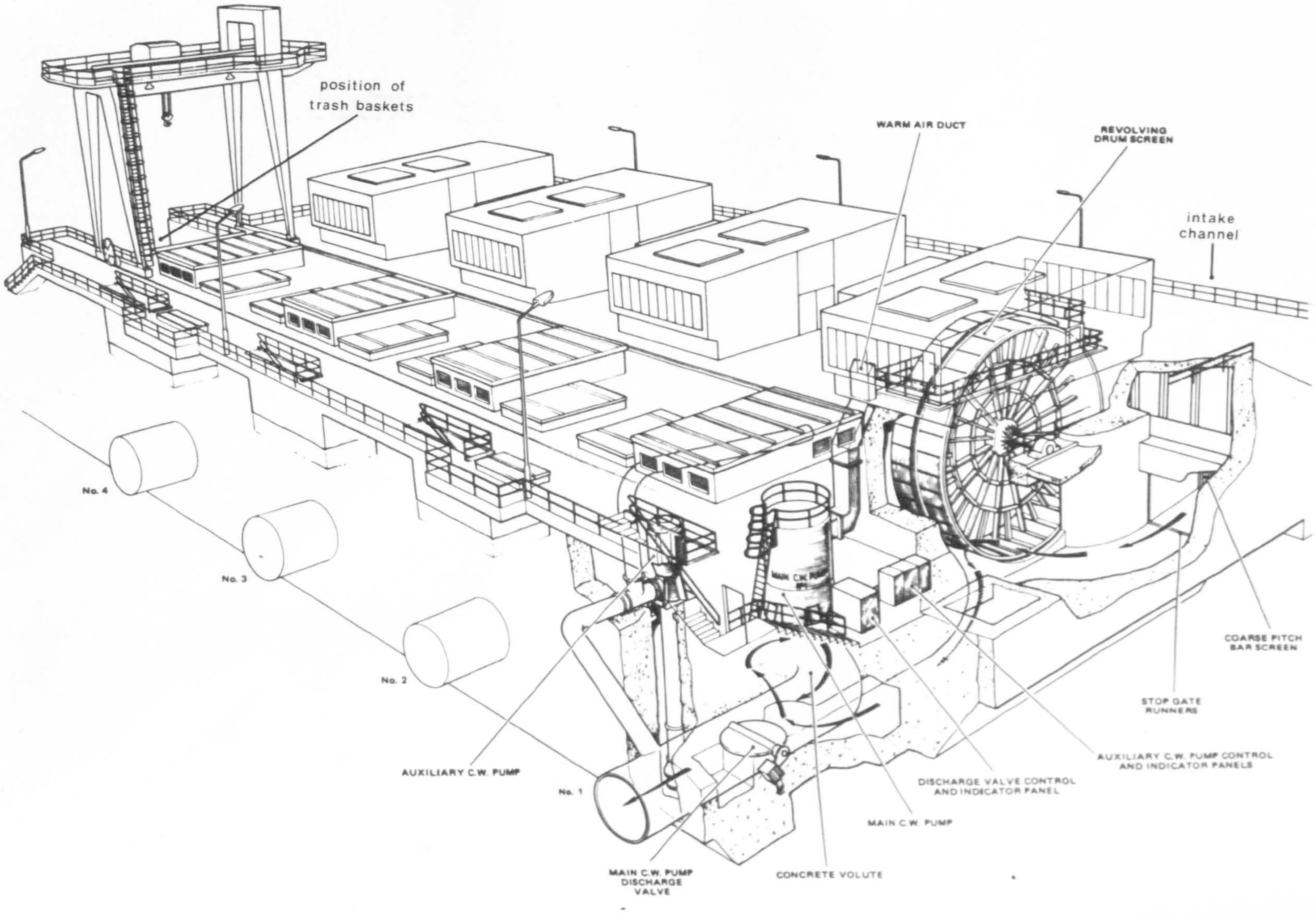

Fig. 1.4.2 Rear view of main pumphouse (diagram ourtesy of C.E.G.B. Kingsnorth)

The main cooling-water stream is drawn from the drum screens to the condensers and is finally discharged through an outfall at the head of Damhead Creek (fig. 1.1.1, p. 7). Not all power stations utilize the same screening procedures. Alternatives are described by Huddart (1971).

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SECTION 2

FISH POPULATION STUDIES

2.1 Introduction

Intake screens which filter out extraneous material from the cooling-water stream provide quantities of biological organisms suitable for faunal studies. Wood (1968) used the catch of whitebait herring from Kincardine Power Station in the Firth of Forth to investigate year-class fluctuations and to observe their geographical distribution along the east coast. Wheeler (1969b) has used the catch from five power stations on the Thames to monitor the re-establishment of fish fauna. More recently qualitative samples of fish have been obtained from the Medway Estuary for parasite and feeding studies (van den Broek, 1972) and from the North-East Coast (Wright, 1976) and Severn Estuary (Hardisty *et al*, 1974) to investigate pollutant levels.

The most comprehensive survey to date, undertaken by Huddart (1971) and Huddart and Arthur (1971a,b), quantifies the nekton from West Thurrock Power Station on the Thames during 1967 to 1970. Quantitative methods are currently also being employed by the University of Bath (M.W. Hardisty, pers. comm.), Thames Water Authority (M. Andrews, pers. comm.) and C.E.G.B. (N. Utting, pers. comm.).

2.2 Methods

2.2.1 The monitoring programme

(a) Field work

Fish were sampled monthly, from the trash baskets, between March 1973 and August 1975. The monitoring programme was established during the first two months and the first quantitative sample taken in May 1973.

(i) Day samples

Quantitative samples were collected between May 1973 and August 1975; each was taken over an eight-hour period, from 0800 to 1600 hours, and the

Addenda

Section 2.2.1 (a) Field work

Sampling dates were separated by roughly one month. Lengths of day and night samples, 8 and 16 hours respectively, were determined by the normal functioning of the power station; bins were emptied twice daily by station staff, at 0800 and 1600 hours.

dates were chosen so that times coincided with mid-tide level on a rising and falling tide respectively.

Prior to each sample a twenty-minute qualitative search was made of the 'trash' and as many different species as possible identified. Because of the greater numbers of species recovered in qualitative searches the quantitative programme was extended in March 1974.

(ii) Night samples

Separate quantitative samples were taken between March 1974 and May 1975. Each covered a sixteen-hour period, from 1600 to 0800 hours, and sampling began at low tide. Night and day samples were consecutive and were treated as separate entities.

(iii) Trawl samples

These were taken in August and November 1973, May and November 1974 and June 1975. The gear included a 2.5-metre beam trawl with shrimp net and a 7.5-centimetre-mesh otter trawl. Their use was dependent on availability which made quantitative sampling impossible but allowed simple, qualitative comparisons between trawl and screen samples.

The area trawled was that between the western approach of Kingsnorth jetty and Oakham Ness jetty (fig. 1.1.1, p. 7), a distance of about three kilometres. The trawl passed across the front of the intakes but some distance from them owing to the ship's draught and obstacles in the vicinity.

(b) Laboratory work

Fish were sorted into species and their numbers, standard lengths and weights recorded. On occasion numbers of sprats were so great that subsamples were taken. *Platichthys flesus* (L.) and *Pleuronectes platessa* L. were aged by their otoliths. The sagittal bones were dissected from the auditory capsules and read in xylol against a black background with reflected light (R.W. Blacker, Ministry of Agriculture, Fisheries and Food, Lowestoft, pers. comm.).

2.2.2 Review of techniques employed in the analysis of data

(a) Diversity indices

In most communities a relatively small proportion of species is abundant while a large proportion is rare. Diversity indices have been developed to express this distribution of individuals mathematically. In most expressions diversity is a maximum when each individual belongs to a different species and a minimum when all individuals belong to the same species. In most communities the distribution lies between these extremes.

Where strong limiting factors are operating - physical, chemical or man-induced - the number of species is usually reduced even though the total number of individuals remain unchanged. Consequently, species-diversity based on one or more trophic levels has been used by several workers to assess water-quality conditions (Wilhm and Dorris, 1966; Reisch and Winter, 1954). Benthic invertebrate communities, because of their habitat preference and low mobility, are particularly suitable for such studies (Wilhm, 1967) and this may account for the paucity of literature on the use of these indices in the interpretation of fish data.

Pielou (1966) and Wilhm (1967) have compared the measurement of diversity in different types of biological collections. In the present study three indices were calculated, all of which have been used previously in fish investigations (Dahlberg and Odum, 1970; McErlean et al, 1973; Allen and Horn, 1975; Haedrich and Haedrich, 1974; Bechtel and Copeland, 1970).

The species-richness index, D (Margalef, 1951), is defined as

$$D = \frac{(S - 1)}{\log_e N} \qquad (1)$$

where S is the number of species and N the total number of individuals. D is a measure of diversity which weights species number more than total abundance. It does not make provision for community structure and should, therefore, be used in conjunction with an index such as equation

(2) below, which includes the relative importance of each species in the community. D is further limited by the fact that it is not independent of sample size (Wilhm and Dorris, 1968) but it has been employed in the present study because it is sensitive to the seasonal influx of migratory species (Dahlberg and Odum, 1970).

Margalef (1956) proposed the analysis of natural communities by methods derived from information theory. In this context diversity means the uncertainty attached to the identity of any randomly selected individual (Pielou, 1966). The greater the number of species and the more nearly equal their proportions the greater the uncertainty and hence the diversity. This uncertainty was measured in the present study by the Shannon-Wiener function, H (Shannon and Weaver, 1949),

$$H = -\sum_{i=1}^{S} p_i \log_e p_i \qquad (2)$$

where p_i is the proportion of individuals in the i-th species. H increases with the number of species (S) and with the uniformity of species abundance.

Distribution of individuals can itself be measured by the uniformity or 'evenness' index of Pielou (1966).

$$J = \frac{H}{H_{max}} = \frac{H}{\log_e S} \qquad (3)$$

where H_{max} is the maximum value of H (equation 2), obtained when all species (S) are equally abundant.

Wilhm (1968) and Wilhm and Dorris (1968) suggested the substitution of numbers of individuals by weight units in the above equations. This was considered particularly useful in the present study where a single species, S. sprattus, dominated most samples by numbers but not necessarily by weight.

(b) Length-weight relationship

When lengths and weights of a fish species are plotted on double logarithmic graph paper, points for fish having the same relationship

between length and weight will lie on a straight line. This regression line represents the relationship

$$\log W = \log a + b \log L \qquad (4)$$

where W = weight, L = length, b = slope of the line and log a = its intercept on the y axis. If the fish sample is not first divided into groups according to sex or age, changes in slope may occur because the length-weight relationship is not usually constant throughout life. For an ideal theoretical fish which does not change its shape during its life history b = 3 (Le Cren, 1951) but for most fish species b lies between 2.5 and 4.0.

Equation (4) may be transformed to its more usual form

$$W = a\ L^b \qquad (5)$$

Where the difference between calculated b and 3 is not found to be statistically significant the constant, a, can be used as a measure of the condition of an individual fish and becomes the condition factor, CF (used in section 3.3.3, p.118).

$$CF = \frac{W}{L^3} \qquad (6)$$

2.2.3 Data analysis

(i) Correction of samples

The volume of water sampled varies directly with the number of cooling-water pumps in operation. A simple correction technique was employed to allow for different volumes sampled on separate occasions. Numbers and weights in each quantitative sample were divided by the number of cooling-water pumps in operation over the sampling period, giving values per pump. Similar adjustments were made to allow for slight discrepancies in sample times. Correction factors employed are shown in table 2.2.1.

Table 2.2.1 Correction factors employed

DAY SAMPLES

Month	Number of cooling-water pumps	Length of quantitative sample (hours and minutes)	Overall correction factor
1973			
May	3	7.30	0.36
June	1	8.00	1.00
July	1	7.30	1.07
August	2	8.00	0.50
September	1	7.30	1.07
October	2	8.00	0.50
November	3	7.00	0.38
December	2	6.30	0.62
1974			
January	3	8.00	0.33
March	2	7.45	0.52
April	3	7.35	0.35
May	1	7.30	1.07
June	1	7.45	1.03
July	1	8.00	1.00
August	1	7.30	1.07
September	2	7.00	0.57
October	2	7.30	0.53
November	2	8.00	0.50
December	3	3.00	0.89
1975			
January	4	4.30	0.44
February	3	7.30	0.36
April	3	7.15	0.37
May	3	6.45	0.40
July	2	7.00	0.57
August	3	4.00	0.67

NIGHT SAMPLES

Month	Number of cooling-water pumps	Length of quantitative sample (hours and minutes)	Overall correction factor
1974			
February	3	16.00	0.33
March	2	16.10	0.49
April	3	16.30	0.32
May	1	16.30	0.97
June	1	16.45	0.96
July	1	16.30	0.97
August	1	16.30	0.97
September	2	16.45	0.48
October	2	16.45	0.48
November	2	16.00	0.50
1975			
February	3	16.45	0.32
March	2	16.30	0.48
April	3	16.45	0.32
May	3	17.00	0.31

(ii) Comparisons between numbers of individuals in day and night samples

The two sets of data were tested for correlation and analysed by regression analysis. To stabilise the variance, square roots of sample numbers were plotted; day catch on the ordinate axis and night catch along the abscissa. By this method the expected regression line, which assumes numbers caught at night are double those taken during the day, is $y = 0.71x$.

(iii) Diversity of samples

For each sample the three diversity indices discussed above (section 2.2.2, p.25) were calculated. Diversity indices were also determined with weights substituted for numbers in these equations.

2.3 Results

2.3.1 Catch statistics

A total of 46,228 fish, 49 species and weighing 325.0 kilograms, were taken in 39 quantitative samples from the cooling-water intake screens. Trawling produced 526 specimens, 18 species and weighing 24.2 kilograms. Full details of these samples are given in Appendix I, p.202. In all, 59 fish species were recorded during the sampling period (table 2.3.1), 30 of which had not been recorded previously from the Medway Estuary (Wildish, 1969; Wharfe, 1975).

2.3.2 Comparison of sampling methods

Comparisons between night and day samples showed that numbers of fish taken at night varied between 1.71 and 7.08 times the day catch. Correlation between the square roots of these two sets of values ($r = 0.670$) was significant at the two percent level. The regression relationship between them was calculated to be $y = 0.41x + 4.42$ which is significantly different, at the five percent level, from the expected ($y = 0.71x$) and indicates that night samples are unexpectedly large.

Table 2.3.1 Species list of fish recorded during the study
* denotes species not recorded previously

Species	Common name
*Abramis brama (L.)	bream
Agonus cataphractus (L.)	hook-nose
*Alosa alosa (L.)	Allis shad
*Ammodytes tobianus L.	sand eel
Anguilla anguilla (L.)	eel
Aphia minuta (Risso)	transparent goby
*Aspitrigla cuculus (L.)	red gurnard
Atherina presbyter Valenciennes	sand-smelt
*Belone bellone (L.)	garfish
*Blennius pholis L.	shanny
*Callionymus lyra L.	dragonet
*Callionymus reticulatus Valenciennes	
*Carassius carassius (L.)	Crucian carp
Ciliata mustela (L.)	five-bearded rockling
Clupea harengus L.	herring
Crenimugil labrosus (Risso)	thick-lipped mullet
Dicentrarchus labrax (L.)	bass
*Esox lucius L.	pike
Gadus morhua L.	cod, codling
Gasterosteus aculeatus L.	three-spined stickleback
*Gobius niger L.	black goby
*Gymnocephalus cernua (L.)	ruffe
*Lampetra fluviatilis (L.)	lampern
Limanda limanda (L.)	dab
Liparis liparis (L.)	sea snail
Liparis montagui (Donovan)	Montagu's sea snail
Lophius piscatorius L.	angler fish
Merlangius merlangus (L.)	whiting
*Myoxocephalus scorpius	short-spined sea scorpion
Osmerus eperlanus (L.)	smelt
*Perca fluviatilis L.	perch
Platichthys flesus (L.)	flounder
Pleuronectes platessa L.	plaice
Pollachius pollachius (L.)	pollack
Pomatoschistus microps (Krøyer)	common goby
Pomatoschistus minutus (Pallas)	sand goby
*Pungitius pungitius (L.)	ten-spined stickleback
Raja clavata L.	roker
*Rhinonemus cimbrius (L.)	four-bearded rockling
*Rutilus rutilus (L.)	roach
*Salmo trutta L.	sea trout
*Scardinius erythrophthalmus (L.)	rudd
*Scomber scombrus L.	mackerel
*Scophthalmus maximus (L.)	turbot
*Scophthalmus rhombus (L.)	brill
*Scyliorhinus caniculus (L.)	lesser-spotted dogfish
Solea solea (L.)	Dover sole
Sprattus sprattus (L.)	sprat
Syngnathus acus L.	great pipefish
Syngnathus rostellatus Nilsson	lesser pipefish
*Syngnathus typhle L.	deep-snouted pipefish
Taurulus bubalis (Euphrasen)	sea scorpion
*Torpedo marmorata Risso	marbled electric ray
*Trachinus vipera Cuvier	lesser weever
*Trachurus trachurus (L.)	horse mackerel
*Trigla lucerna L.	tub gurnard
Trisopterus luscus (L.)	pouting
Trisopterus minutus (L.)	poor-cod
Zoarces viviparus (L.)	eelpout

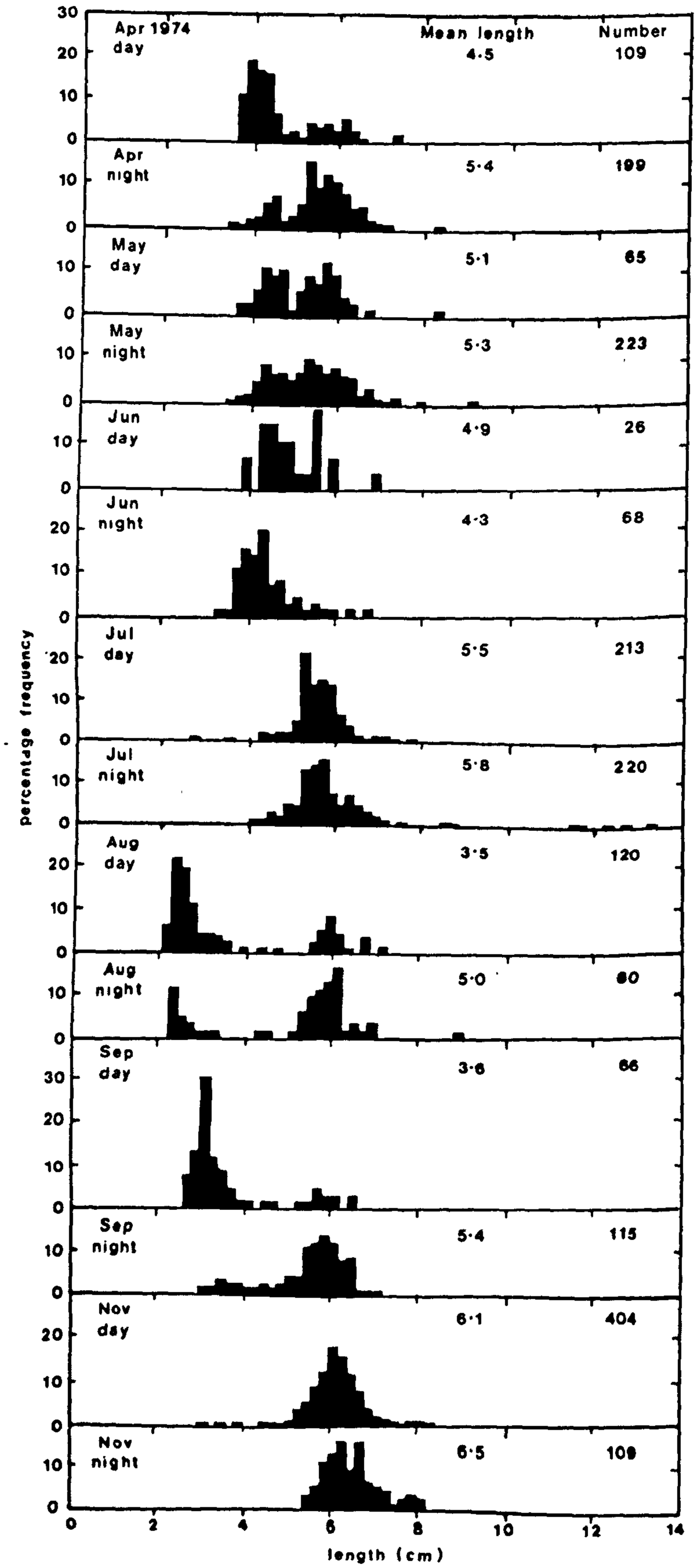


Fig.2.3.1 Length-frequencies of S.sprattus: comparison of day and night samples

Numbers of individuals within species were similarly tested for correlation (table 2.3.2 below). Numbers in day and night samples were strongly correlated in all cases with the exception of P. platessa, Dicentrarchus labrax (L.) and Gasterosteus aculeatus L.; sizes of their catch fluctuated considerably between the two sampling periods.

In the sprat population qualitative differences between night and day samples taken during 1974 (fig. 2.3.1) were also evident. With the exception of June, mean lengths of fish taken at night were greater than those caught during the day, especially in April, August and September.

Table 2.3.2 Correlations between fish numbers in day and night samples

Species	Correlation coefficient (r)	Probability (P)	Regression line characteristics	
			Slope	Intercept
(Total catch)	0.670	0.02>P>0.01	0.41	4.42
A. anguilla	0.650	0.02>P>0.01	0.40	0.44
A. presbyter	0.840	<0.001	0.31	0.29
C. harengus	0.763	0.01>P>0.001	0.54	-0.14
D. labrax	0.452	>0.1	0.50	0.52
G. aculeatus	0.565	0.05>P>0.02	0.19	0.54
L. limanda	0.801	0.001	0.66	-0.05
M. merlangus	0.952	<0.001	0.47	-1.04
P. flesus	0.931	<0.001	0.71	0.28
P. minutus	0.757	0.01>P>0.001	0.28	1.20
P. platessa	0.339	>0.1	0.24	1.45
S. rostellatus	0.834	0.01>P>0.001	0.60	0.34
S. solea	0.757	0.01>P>0.001	0.40	0.75
S. sprattus	0.728	0.01>P>0.001	0.42	6.09
T. luscus	0.974	<0.001	0.28	-0.10

Comparisons between trawl and screen samples (table 2.3.3) showed that only two species, Scyliorhinus caniculus (L.) and Trigla lucerna L. were exclusive to the former method. All other species taken in trawls

Table 2.3.3 Comparisons between trawll and screen samples

Date/Species	Trawl			Power station intakes		
	No. of Fish	Mean length (cm) (range)	Mean weight (g) (range)	No. of Fish	Mean length (cm) (range)	Mean weight (g) (range)
August 1973						
C. lyra	34	8.7 (6.6-10.9)	10.32 (4.26-18.66)	1	9.7	8.38
G. niger	4	7.6 (7.2-8.1)	11.52 (9.36-14.49)	1	9.7	17.46
P. platessa	153	5.2 (3.4-17.0)	3.52 (0.70-103.48)	7	4.2 (3.6-4.7)	1.04 (0.52-1.48)
P. microps	1	3.4	0.54	absent		
P. minutus	52	4.9 (3.1-6.8)	1.77 (0.33-4.92)	1	4.8	1.36
S. solea	22	9.8 (5.0-13.6)	16.65 (1.54-36.71)	1	14.3	36.43
S. sprattus	5	4.4 (3.4-6.5)	1.02 (0.28)-3.21)	2	4.0 (2.6-5.3)	0.84 (0.14-1.54)
Number of species	7			8		
November 1973						
A. cataphractus	1	4.6	1.05	1	9.2	9.29
G. niger	7	7.4 (5.7-8.5)	10.12 (4.24-15.46)	absent		
L. liparis	3	5.8 (5.2-6.2)	4.83 (3.82-6.31)	absent		
M. merlangus	29	15.8 (10.9-24.5)	43.89 (12.81-148.94)	161	11.8 (6.0-17.3)	17.43 (2.20-52.09)
P. flesus	1	18.0	120.12	9	7.6 (5.5-9.5)	7.92 (1.65-12.50)
P. platessa	9	15.4 (11.6-17.2)	42.75 (22.00-63.50)	34	5.8 (4.3-13.3)	3.25 (1.92-30.00)
P. minutus	1	6.5	3.88	137	6.1 (4.3-7.5)	2.61 (0.80-5.00)
T. luscus	40	16.8 (9.2-26.3)	71.54 (12.45-325.00)	5	13.8 (9.7-27.8)	39.99 (11.30-304.73)
Z. viviparus	1	16.0	19.43	absent		
Number of species	9			21		
May 1974						
A. cataphractus	7	8.8 (6.8-10.5)	9.27 (3.66-14.42)	absent		
L. limanda	3	13.4 (10.6-14.8)	44.56 (18.81-59.83)	5	6.8 (5.0-7.5)	4.13 (1.80-5.96)
P. flesus	23	17.6 (11.4-23.1)	111.06 (33.10-236.98)	21	14.9 (9.5-26.5)	66.24 (17.32-285.75)
P. platessa	8	12.3 (8.6-15.8)	42.23 (12.83-73.07)	4	10.6 (8.3-13.8)	20.74 (9.15-42.00)
S. caniculus	3	58.3 (53.2-62.5)	779.35 (657.89-1020.25)	absent		
S. solea	11	25.4 (19.3-34.1)	278.91 (102.52-599.23)	6	11.6 (6.3-17.1)	22.76 (2.35-59.47)
Number of species	6			19		
November 1974						
A. cataphractus	7	10.5 (9.8-11.8)	17.60 (13.47-24.36)	13	8.1 (7.6-8.3)	6.80 (4.00-7.34)
L. limanda	7	14.7 (12.5-15.8)	58.98 (33.36-72.45)	61	9.7 (3.7-16.3)	21.69 (0.68-81.21)
P. flesus	2	19.9 (18.0-21.7)	172.83 (125.62-220.03)	20	12.7 (7.0-23.6)	60.19 (6.40-282.00)
P. platessa	6	16.8 (13.3-20.4)	106.61 (47.24-171.16)	21	8.0 (5.4-20.8)	21.42 (2.45-170.00)
S. solea	1	21.4	159.21	8	15.0 (7.2-33.0)	57.25 (4.00-560.00)
T. luscus	3	17.5 (14.6-21.9)	107.52 (49.75-203.58)	229	13.6 (6.5-21.5)	41.84 (4.50-204.00)
Number of species	7			27		
June 1975						
L. limanda	6	15.0 (10.2-18.4)	62.25 (19.57-120.49)	absent		
M. merlangus	1	10.7	13.03	7	6.5 (6.1-6.9)	2.30 (2.20-3.00)
P. flesus	8	16.0 (13.2-22.0)	92.06 (51.55-201.09)	2	15.00 (12.50-17.50)	62.92 (35.75-90.09)
P. platessa	34	13.4 (9.9-19.1)	53.61 (17.82-108.32)	12	6.4 (3.4-11.6)	7.36 (0.66-24.78)
R. clavata	4	23.2 (19.1-27.0)	69.88 (31.79-104.51)	absent		
S. solea	20	20.4 (8.5-37.5)	186.00 (8.00-795.23)	14	16.2 (10.1-34.5)	51.46 (11.64-625.00)
T. vipera	1	8.2	8.80	absent		
	2	13.6 (13.2-14.0)	52.85 (49.41-56.29)	1	14.9	62.05
T. luscus	4	17.5 (15.3-20.0)	94.69 (64.02-147.59)	absent		
Number of species	9			10		

were common to both sampling techniques. The overall number of species taken by trawl was always less but this was at least partly due to small fish avoiding capture by passing through the mesh. However, trawl samples invariably contained one or more species not taken from the screens in the same month.

Generally, the sizes of fish taken by the two different techniques were comparable although there were some indications that larger fish may, on occasion, actively avoid the power station intakes. For example, in November 1973 flatfish taken by trawl were larger than those on the screens but flatfish of this size do occur at Kingsnorth as the November 1974 results for P. platessa and Solea solea (L.) verify.

2.3.3 Seasonal distributions

Successive monthly samples exhibited considerable fluctuations in the numbers of species, total numbers and total weights of individuals.

(a) Numbers of species in monthly samples

Figure 2.3.2 shows the seasonal variation in the number of species in each quantitative day sample and includes, for comparison, the total numbers of species recovered by all screen-sampling methods.

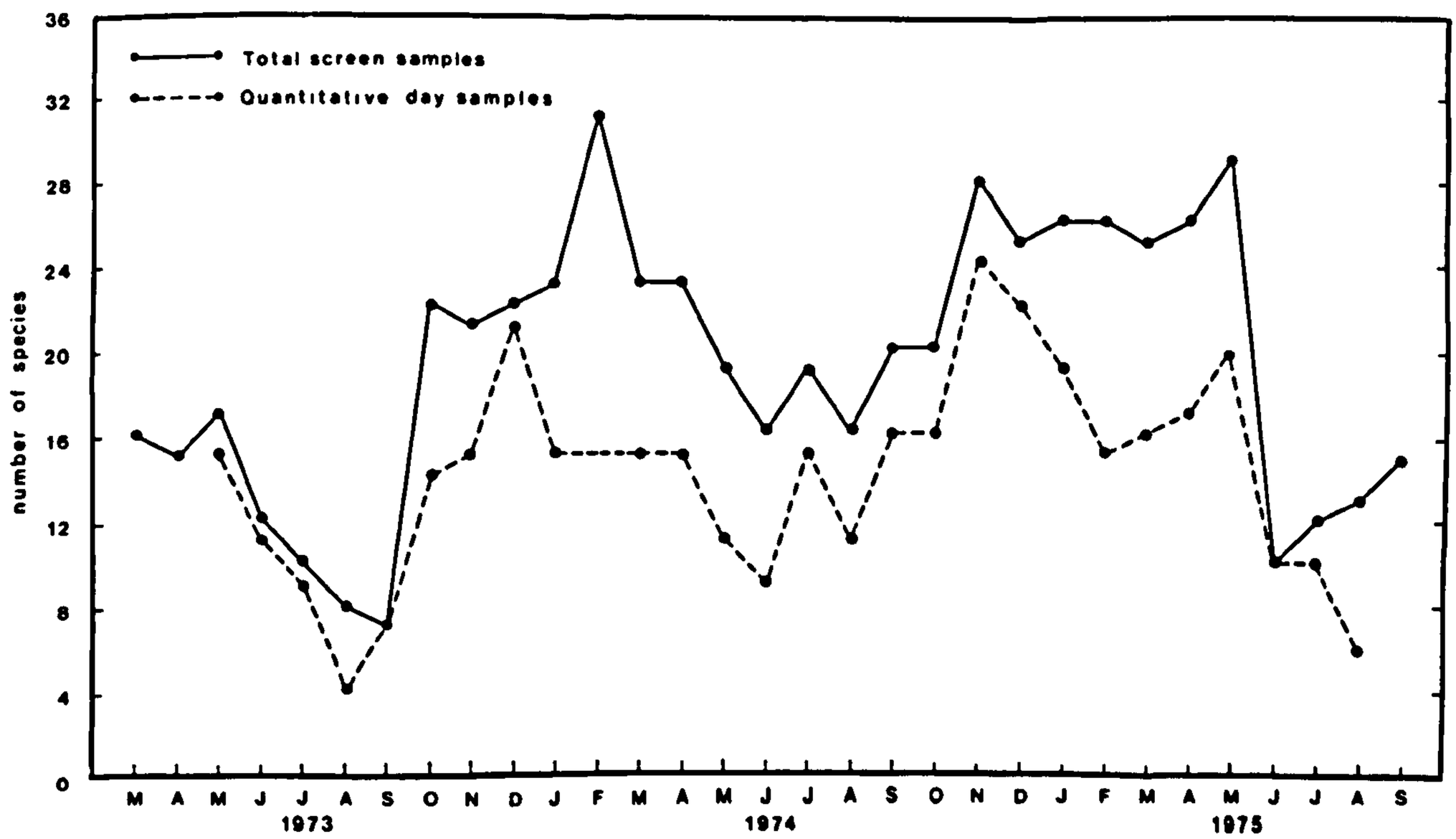
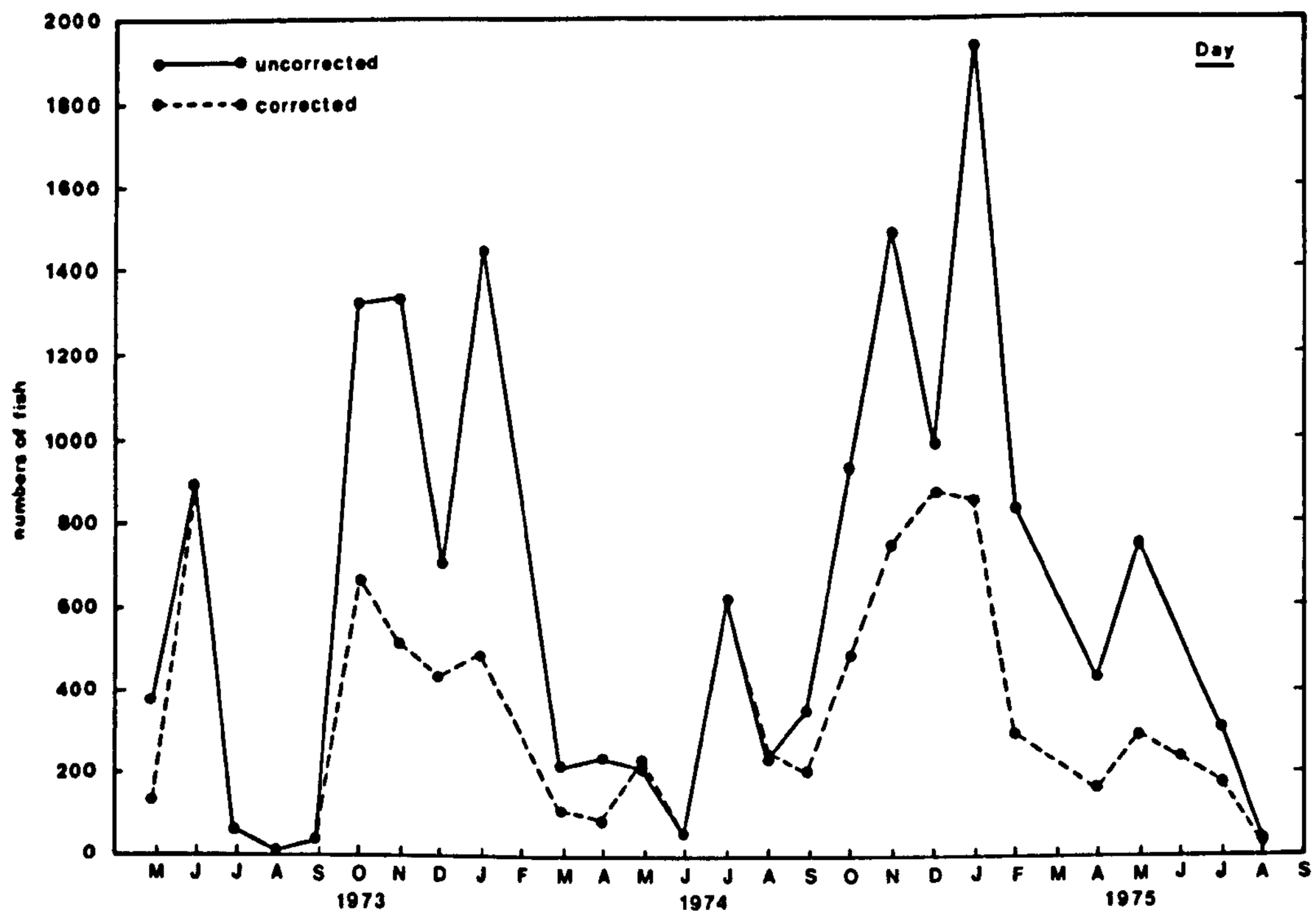


Fig.2.3.2 Number of species; seasonal variation



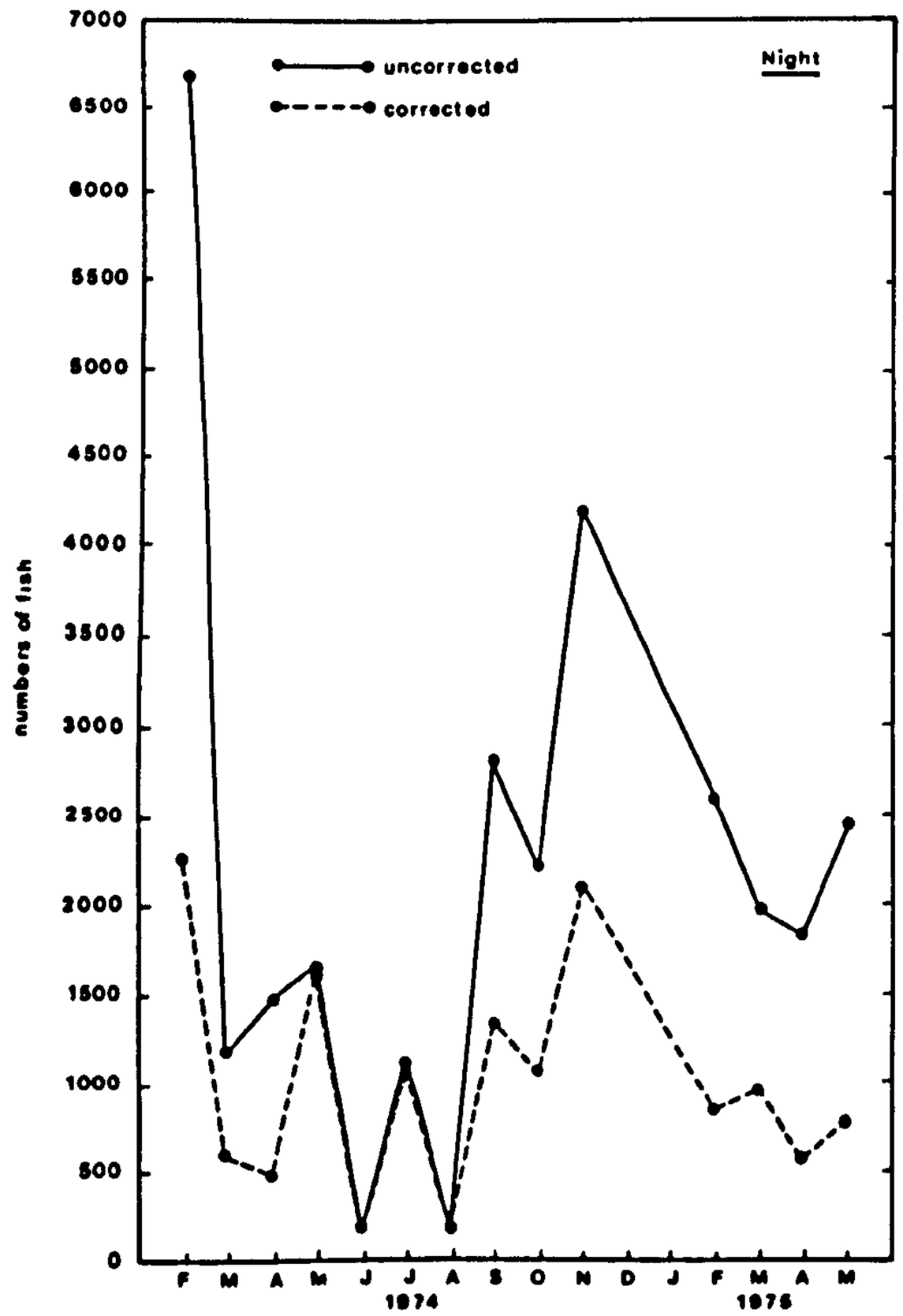


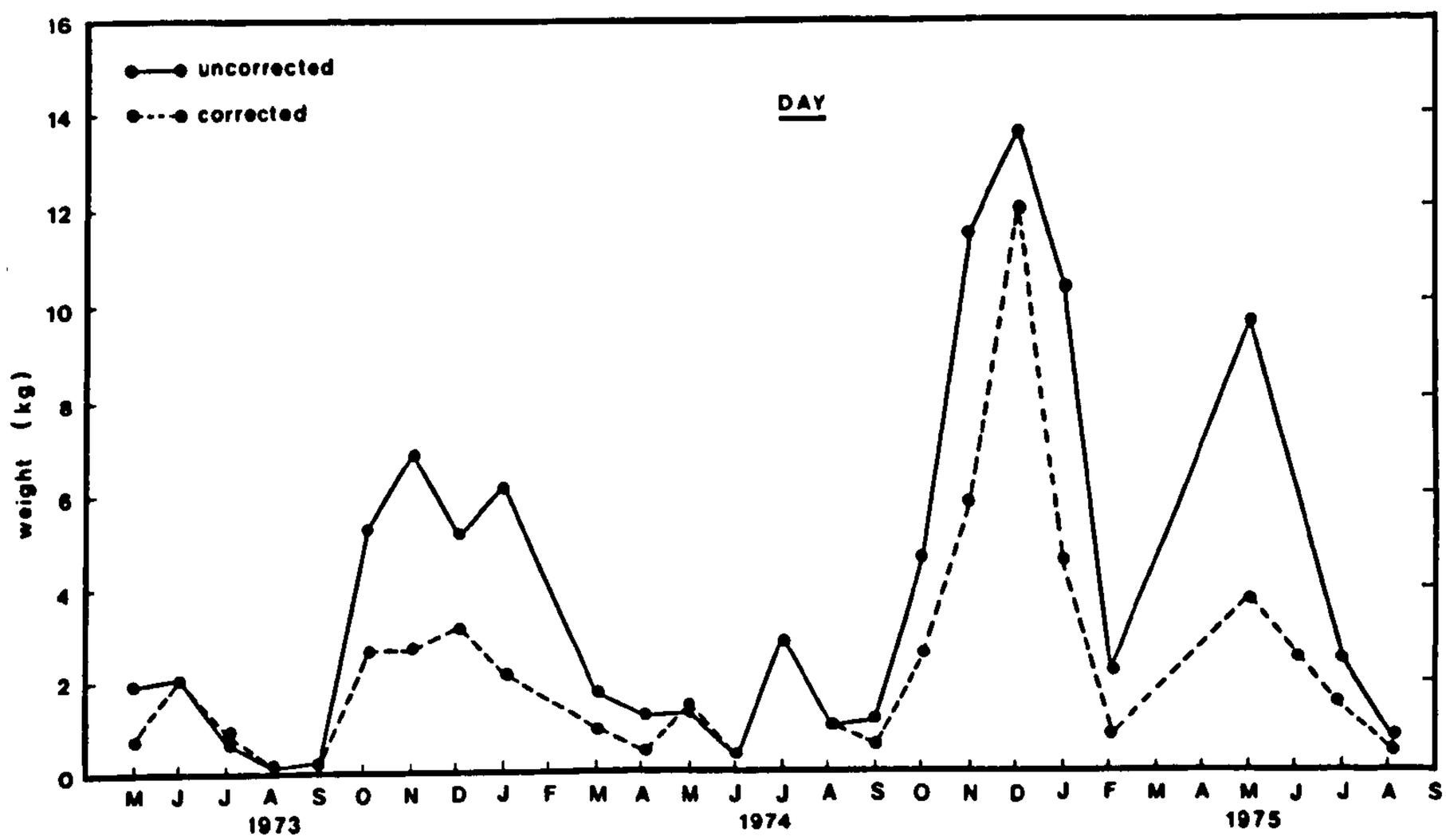
Fig.2.3.3 Numbers of fish in monthly samples

The day sample contained a maximum 24 species in November 1974 and comparable numbers were taken in December the previous year. Numbers of species reached a minimum in August 1973 and this figure (4) was below that in June 1974 (9) but similar to August 1975 (6). A considerably greater number of species was recovered by a combination of qualitative, and day and night samples, especially between January and May 1974 when 31 were recorded in February.

(b) Total numbers and weights in monthly samples

Total numbers of individuals and total weights of catch exhibited similar seasonal fluctuations (figs. 2.3.3 and 2.3.4). These did not coincide exactly with those of the number of species although any disparity was considerably reduced when the data were corrected for the variable number of cooling-water pumps operating on different sampling dates. Both corrected and uncorrected data are, nevertheless, included since the validity of the correction technique is still open to question (see section 2.4.1, p.53, for an assessment of the sampling method).

In day samples greatest numbers of fish, 1440 and 1860, were taken in January 1974 and 1975 respectively. However, when corrected, maxima occurred earlier, in June 1973 and December 1974. High numbers in June (893) were due to an influx of large numbers of sprats while a combination of sprats, sand gobies and sand smelts produced a similar peak in July the following year. On a weight basis (fig. 2.3.4) these species made less impact but, conversely, in May 1975 a relatively small number of flounders greatly affected the biomass curve. Greatest weight of catch in an eight-hour period, 13.6 kilograms, was taken in December 1974, almost double the November 1973 figure of 6.8 kilograms, the highest that year.



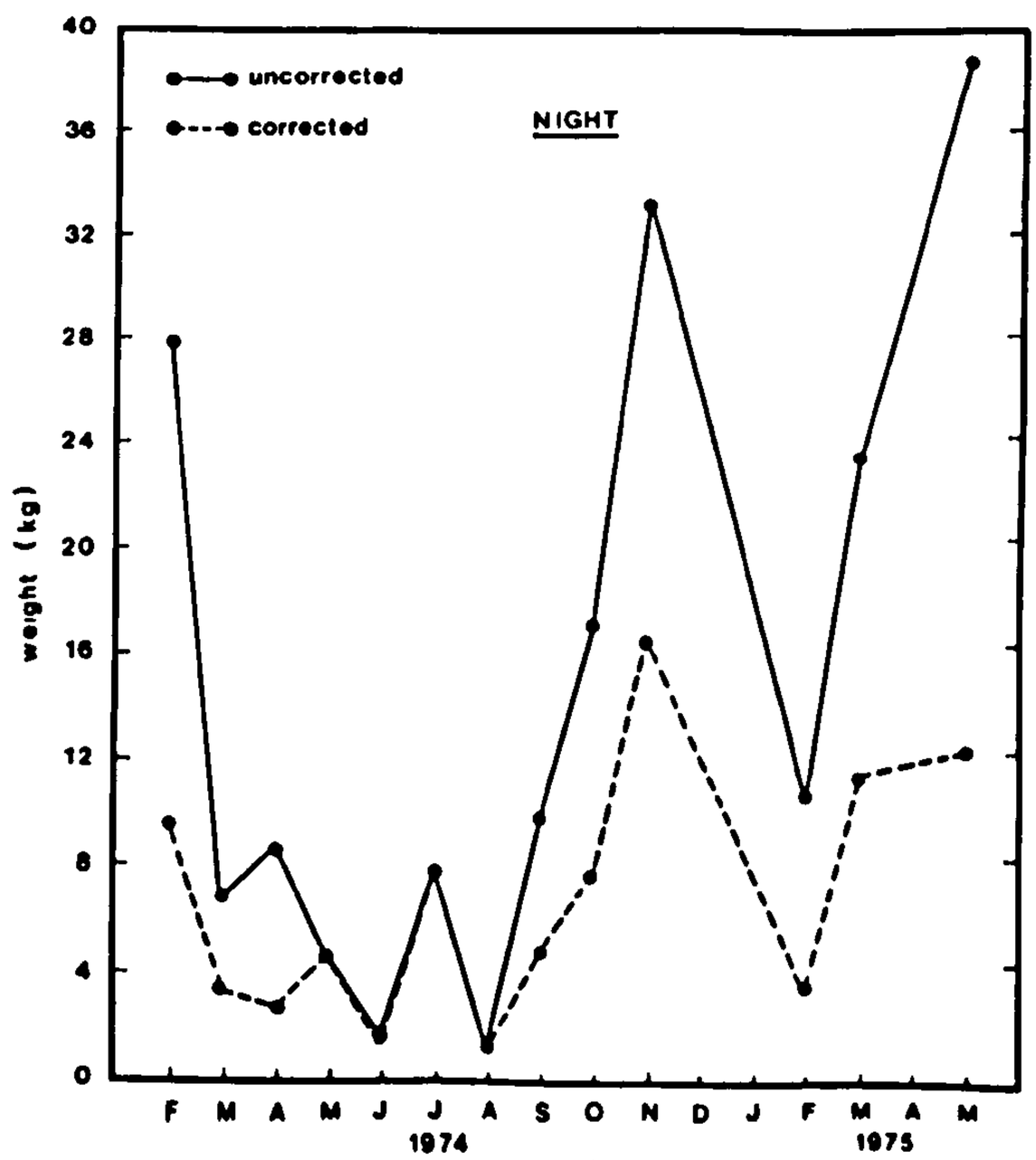


Fig. 2.3.4 Seasonal variations in the total weights of day and night samples

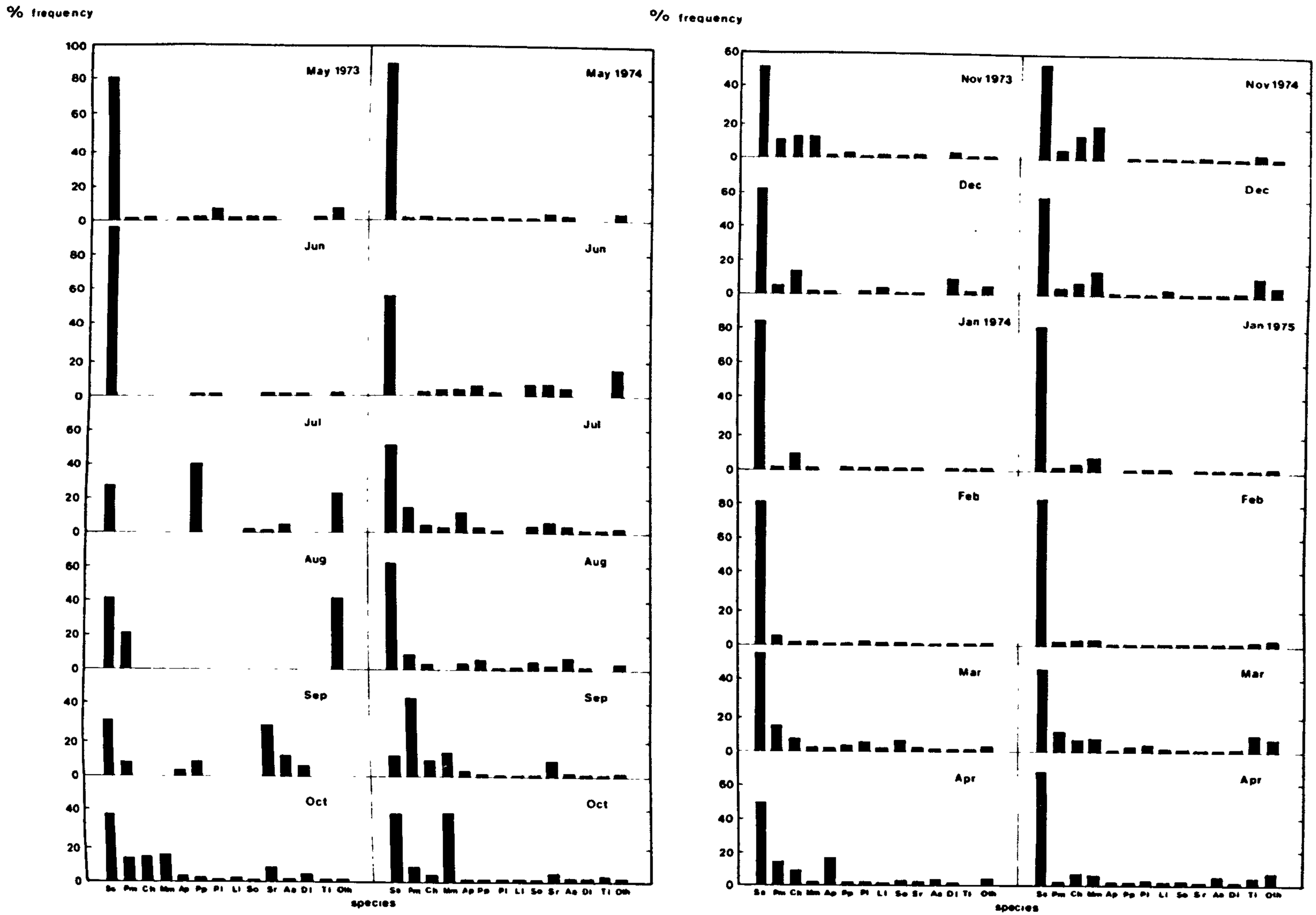


Fig.2.3.5 Proportional composition of monthly day samples (key opposite)

(c) Percentage composition of monthly samples

Numerically the monthly samples were dominated by sprats which, with twelve other species, formed more than ninety percent of the catch in all months except July and August 1973 and June 1974 (fig. 2.3.5). In these months, one or two individuals of rarer species were able to have a marked effect on a small catch.

(d) Seasonal distributions of individual species

Figure 2.3.6 shows seasonal distributions of the thirteen most abundant species in day samples. Within this group Anguilla anguilla (L.), P. flesus, P. platessa, Syngnathus rostellatus Nilsson, S. solea and S. sprattus were present on every, or nearly every, sampling date. S. sprattus and P. flesus were fairly evenly distributed while S. rostellatus, although occurring in all seasons, was most abundant in winter. On the other hand, S. solea and A. anguilla occurred in greater numbers in summer while P. platessa had an irregular distribution with peaks of abundance during both summer and winter months. The remaining species, Atherina presbyter Valenciennes, Clupea harengus L., D. labrax, Limanda limanda (L.), Merlangius merlangus (L.), Pomatoschistus minutus (Pallas) and Trisopterus luscus (L.), were more seasonal, being entirely absent during part of the year and usually occurring in greatest numbers in winter.

Fig. 2.3.5 Key

Ss	S. sprattus
Pm	P. minutus
Ch	C. harengus
Mm	M. merlangus
Ap	A. presbyter
Pp	P. platessa
Pf	P. flesus
Ll	L. limanda
So	S. solea
Sr	S. rostellatus
Aa	A. anguilla
Dl	D. labrax
Tl	T. luscus
Oth	Other species

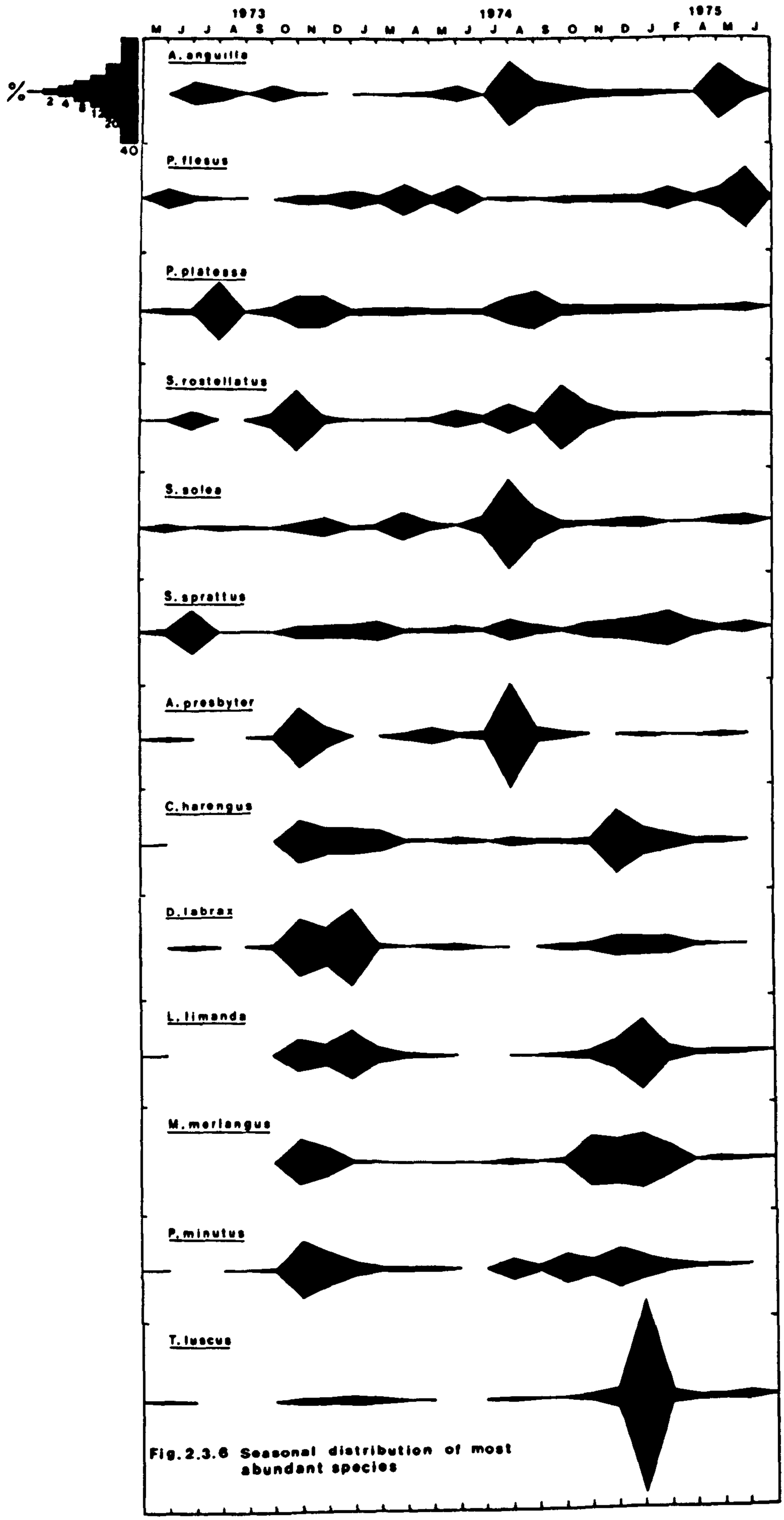


Fig. 2.3.6 Seasonal distribution of most abundant species

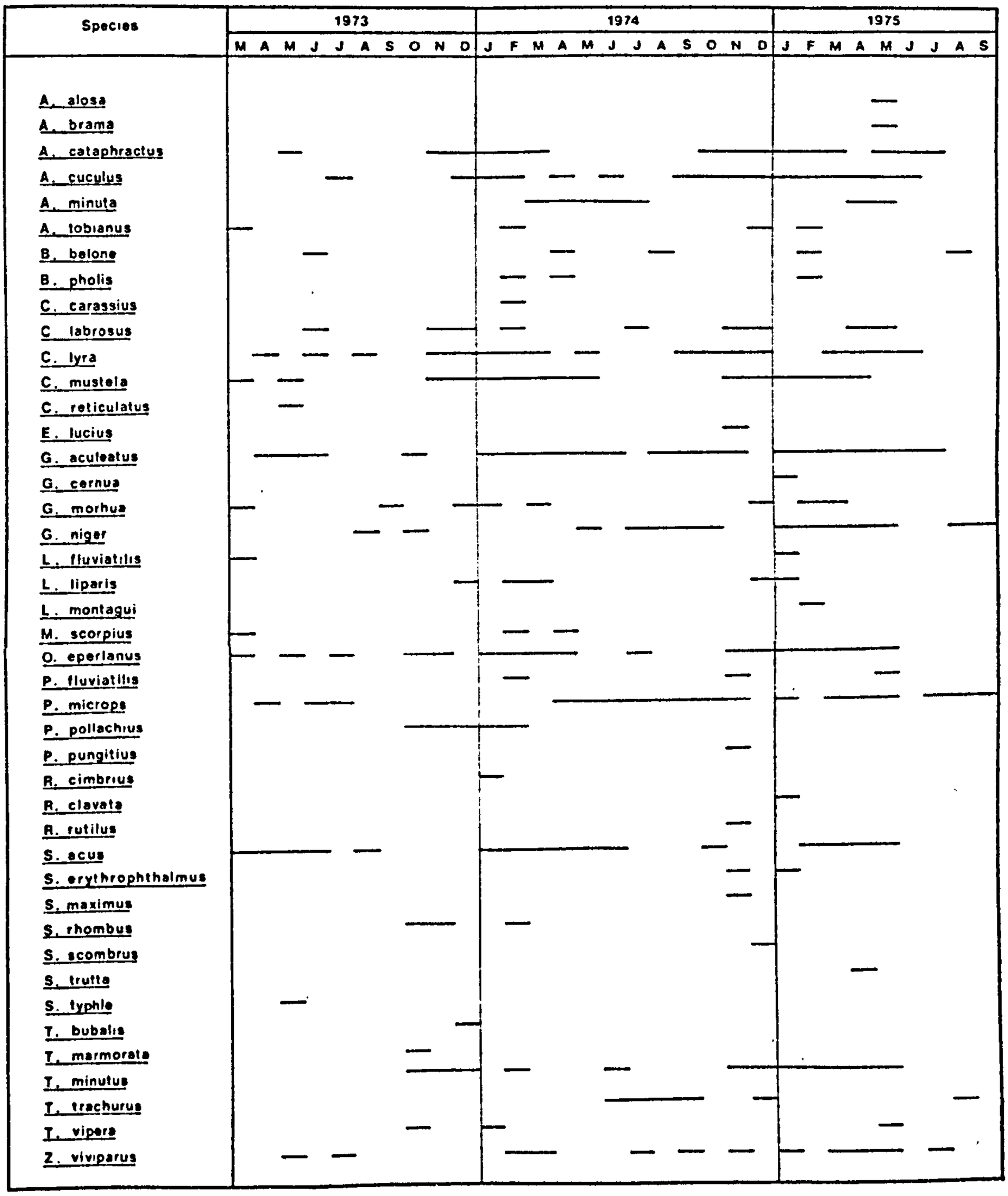


Fig. 2.3.7 Incidence of less-common species in screen samples during 1973-75

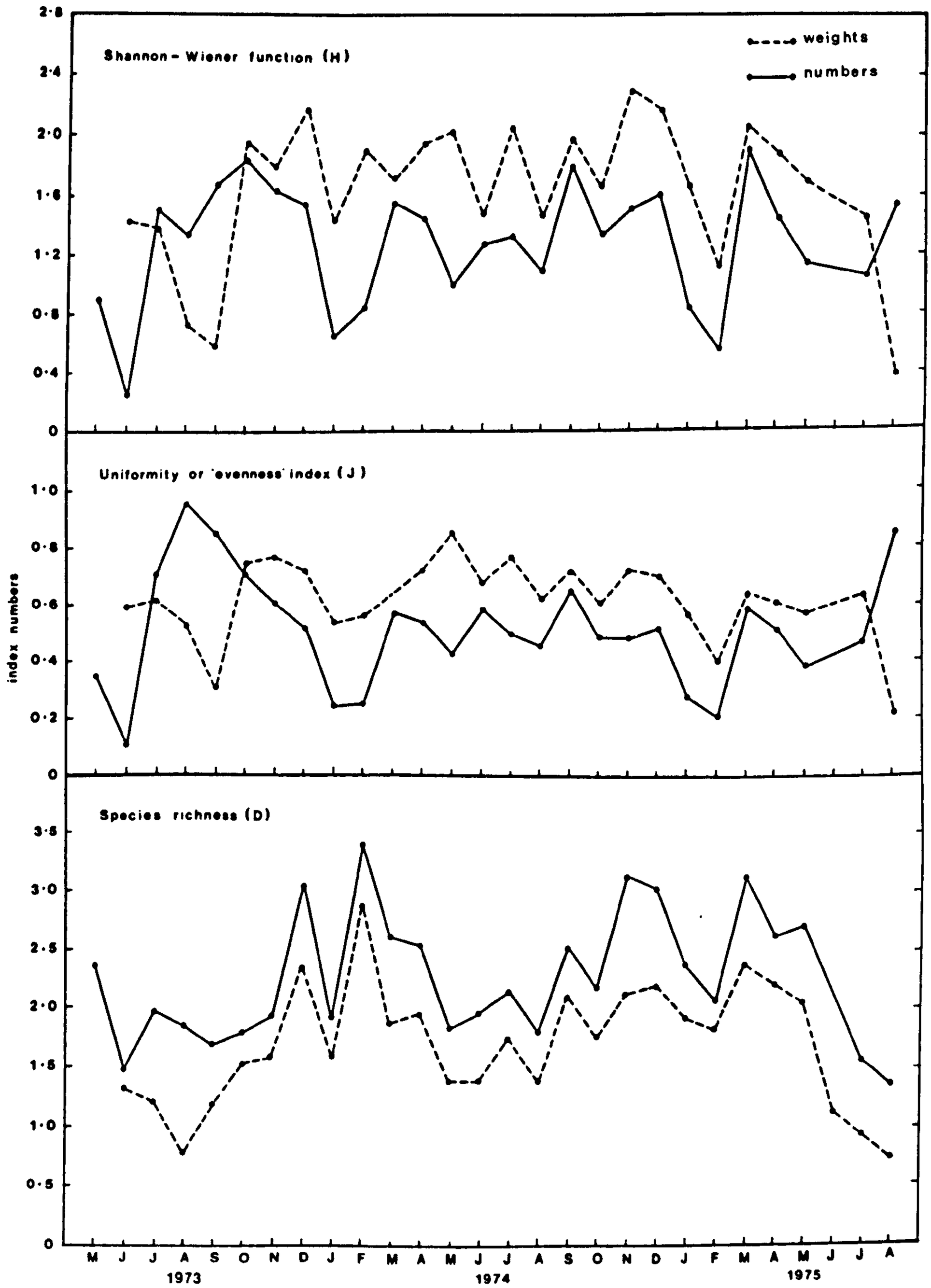


Fig. 2.3.8 Diversity indices: seasonal variations

Figure 2.3.7 shows the seasonal incidence of all remaining species collected and includes those fish, in quantitative and qualitative samples, which were present irregularly and in low numbers (fewer than 50 individuals). A complete species list, with catch statistics, is given in Appendix II, p208.

(e) Diversity indices (fig. 2.3.8)

The value of diversity, measured by the Shannon-Wiener information function (H), ranged for fish numbers from 0.25 (June 1973) to 1.89 (March 1975) and for fish weights from 0.39 (August 1975) to 2.29 (November 1974). H had a higher value on a weight basis at all times (except August and September 1973 and August 1975, because these samples were small in numbers of individuals). The large numbers of sprats reduced diversity while their comparatively low weights had less impact.

The seasonal trend of the uniformity or 'evenness' index (J) was comparable with H. J varied from 0.10 in June 1973 to 0.96 in August 1973 by numbers and by weights from 0.22 in August 1975 to 0.85 in May 1974.

Species richness (D) has a specific dimension which is different for numbers and weights so direct comparisons between these are not valid. However, seasonal trends were the same, the only divergence occurring between July and September 1973. In both numbers and weights, D reached a maximum in February 1974 and a minimum in August 1975.

2.3.4 Length-frequencies and length-weight relationships

Monthly length-frequency distributions of A. anguilla, A. presbyter, C. harengus, D. labrax, L. limanda, M. merlangus, P. flesus, P. minutus, P. platessa, S. rostellatus, S. solea, S. sprattus and T. luscus are presented in figures 2.3.9 - 2.3.11. Based on the changing lengths of these species in consecutive months, a model was constructed of the seasonal migrations of fish populations in and out of the estuary (fig. 2.3.12, p.48).

Four species, A. anguilla, A. presbyter, S. rostellatus and S. solea, exhibited irregular fluctuations in length and no seasonal migrations were evident. On the other hand, shifts in modal position between spring and autumn (figs. 2.3.9 - 2.3.11) in populations of D. labrax, L. limanda, M. merlangus, P. flesus, P. minutus, P. platessa and T. luscus may be attributed to the emigration of older fish and the subsequent immigration of newly-hatched individuals, as shown in fig. 2.3.12. In these species emigration and immigration were separated by one or more months while in C. harengus and S. sprattus they appeared to occur coincidentally during spring and summer. Sprat recruitment is discussed further in section 2.4.3, p.58.

In winter, individuals of D. labrax, L. limanda, M. merlangus, P. platessa and P. flesus were much larger than in preceding months. Their occurrence may be the result of an inshore migration, during adverse conditions, in search of shelter and/or food. Further direct and indirect evidence for such movements is provided by the nature of parasitic infection given in section 3.4, p130.

Length-weight relationships of the above, and seventeen other species, are presented in Appendix III, p212. No seasonal patterns were evident, which is partly explained by the reduced numbers of maturing or mature individuals in most populations; their presence would be expected to increase regression coefficients.

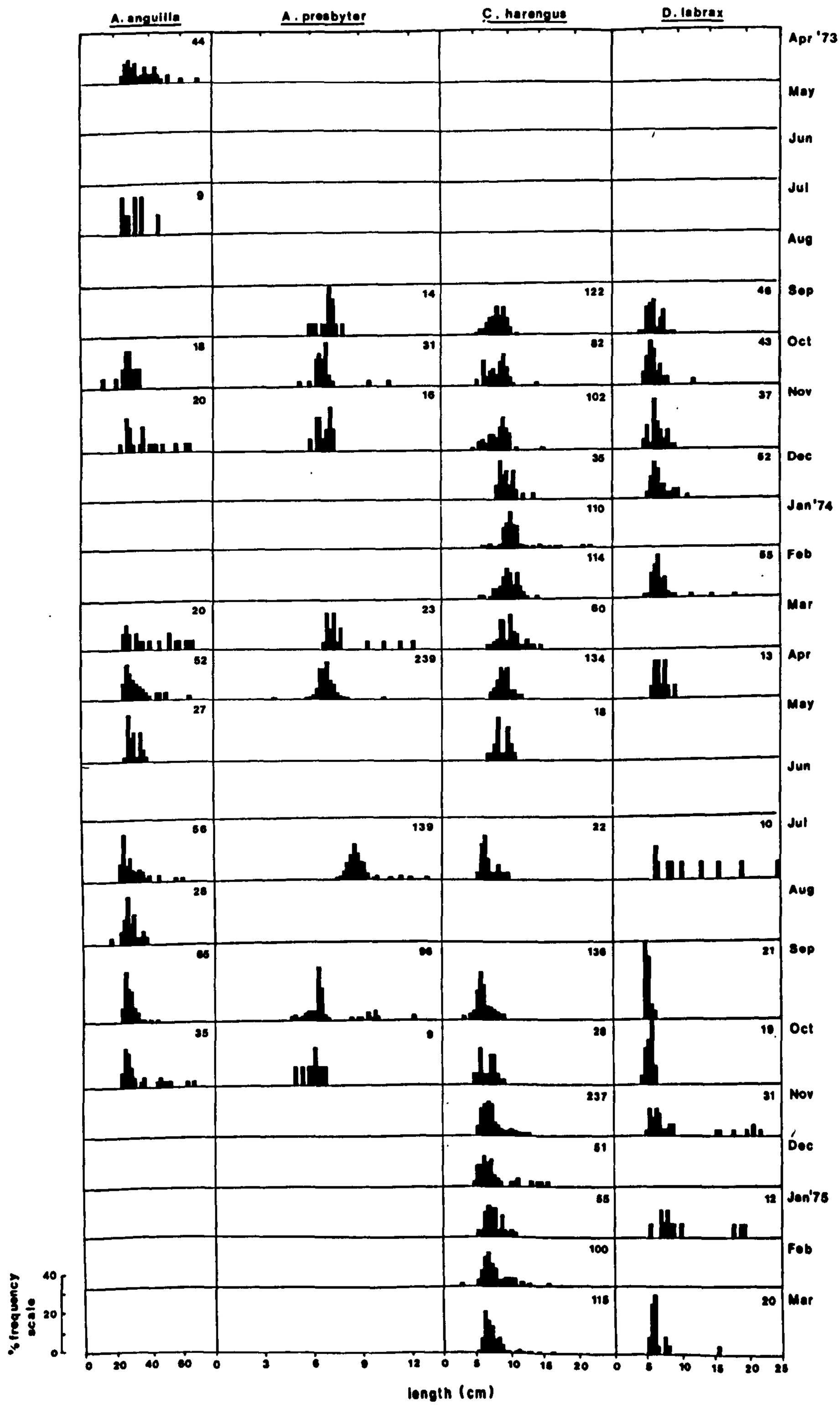


Fig. 2.3.9 Length-frequency distributions of individual fish species

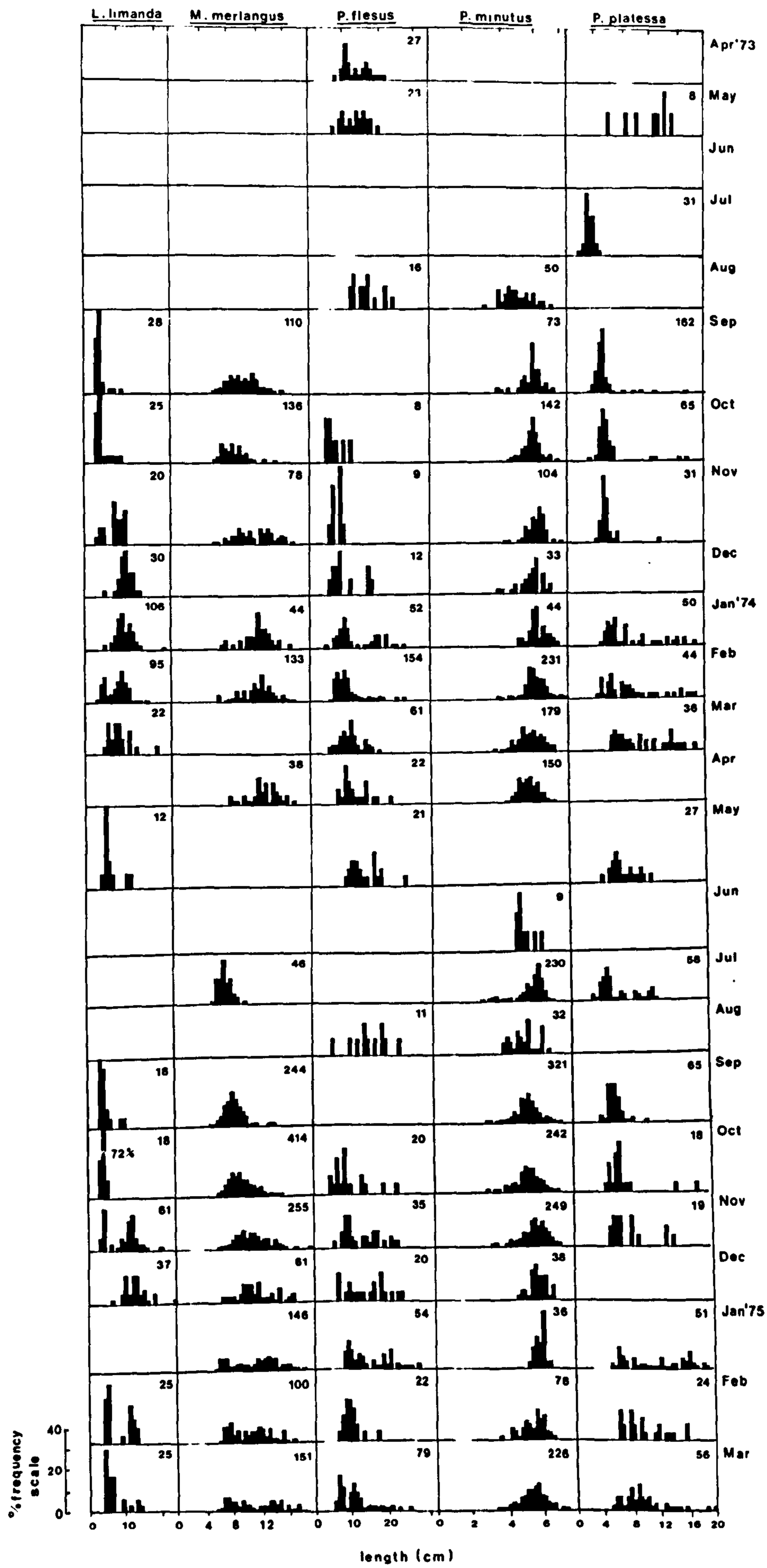


Fig. 2.3.10 Length-frequency distributions of individual fish species

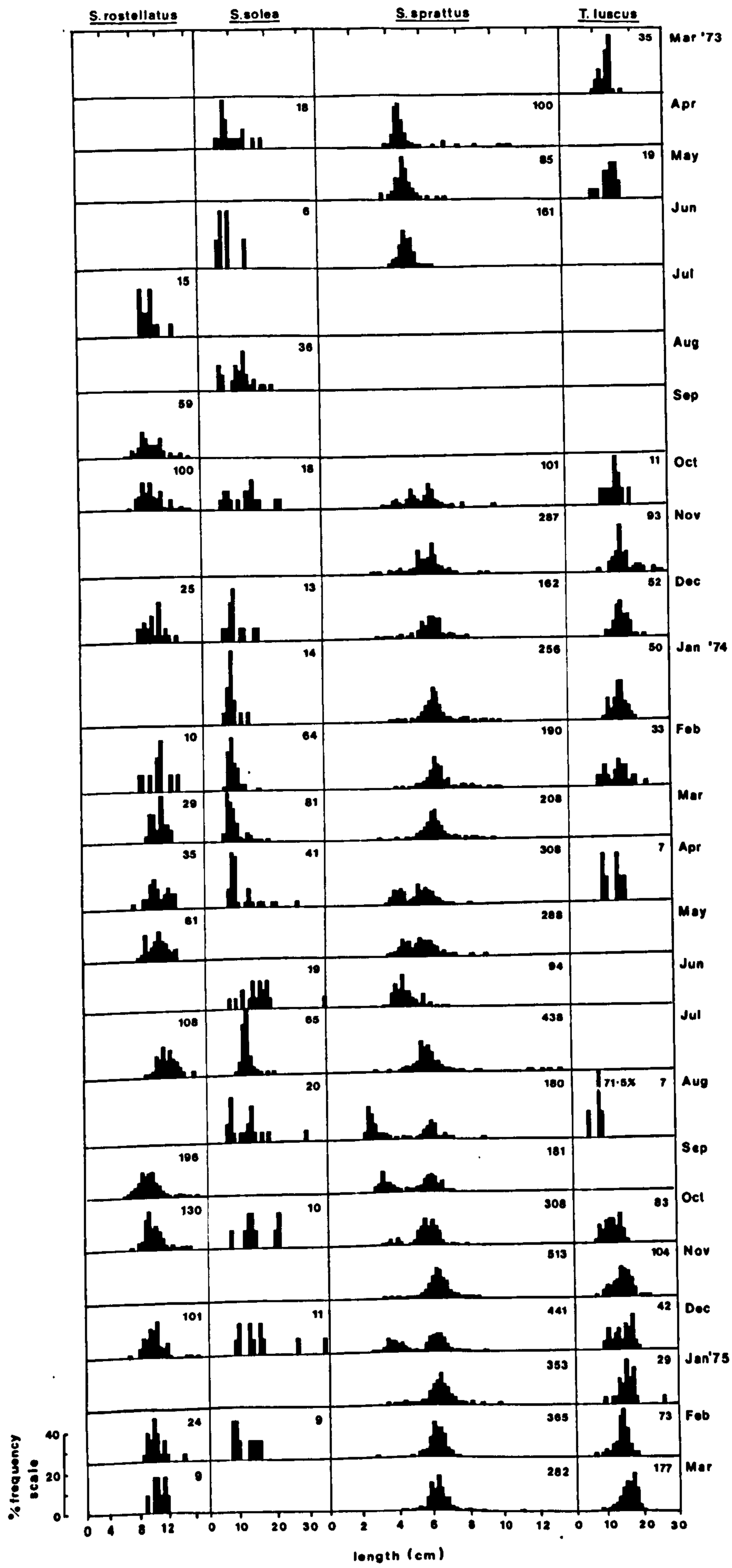


Fig. 2.3.11 Length-frequency distributions of individual fish species

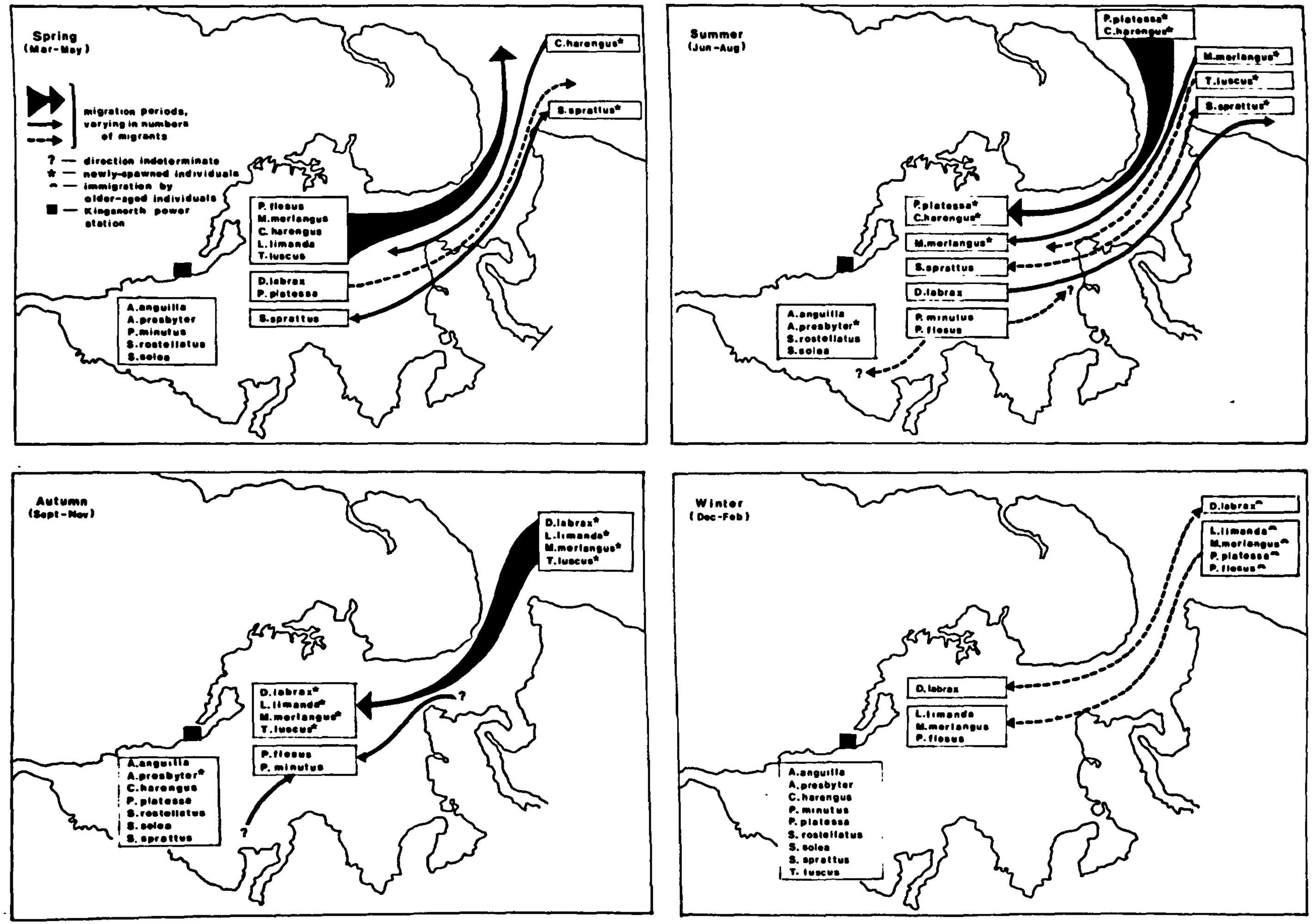


Fig. 2.3.12 Suggested seasonal migration patterns of Medway fish populations

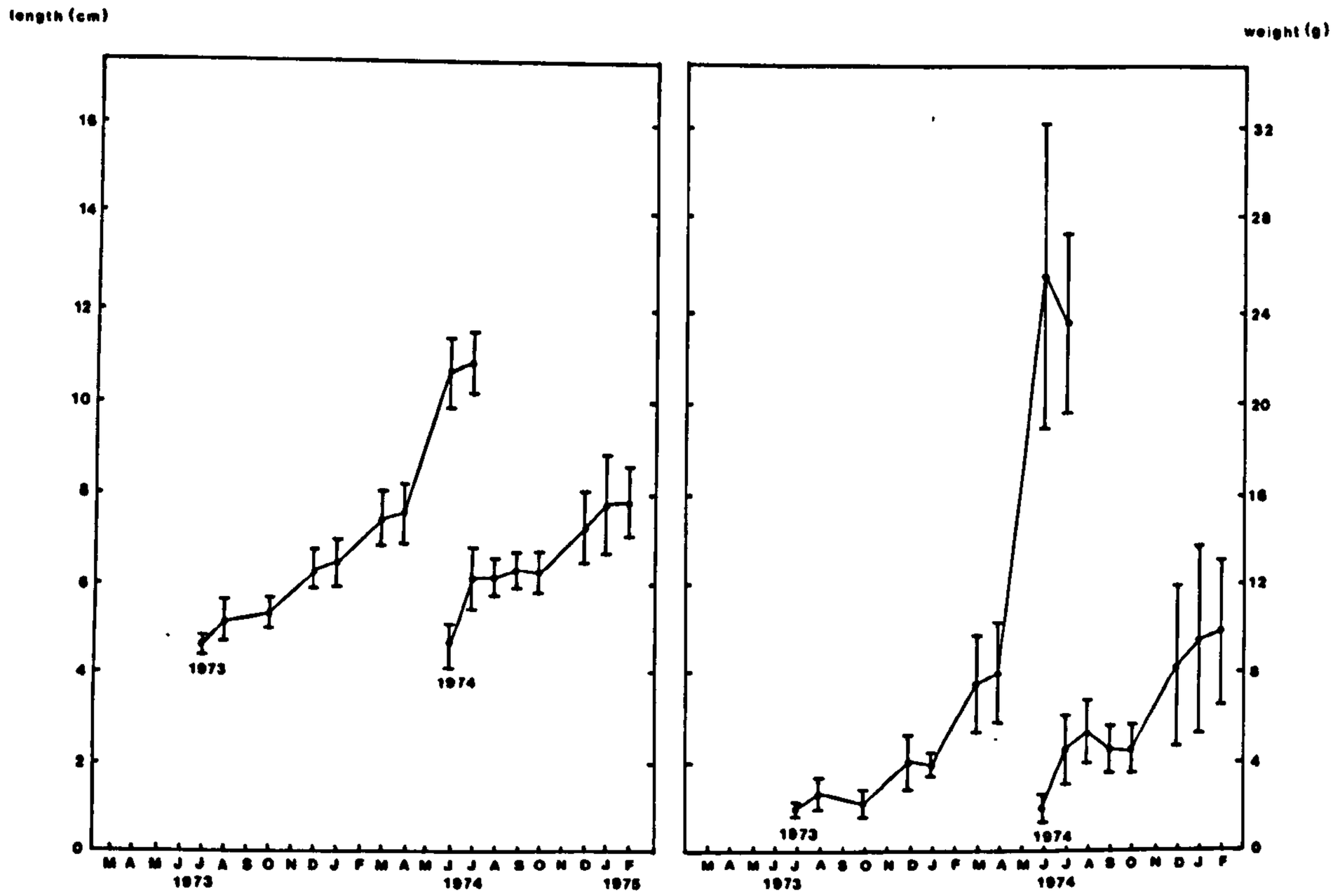


Fig. 2.3.13 Seasonal increases in length and weight of P.platessa (means and 95% confidence limits)

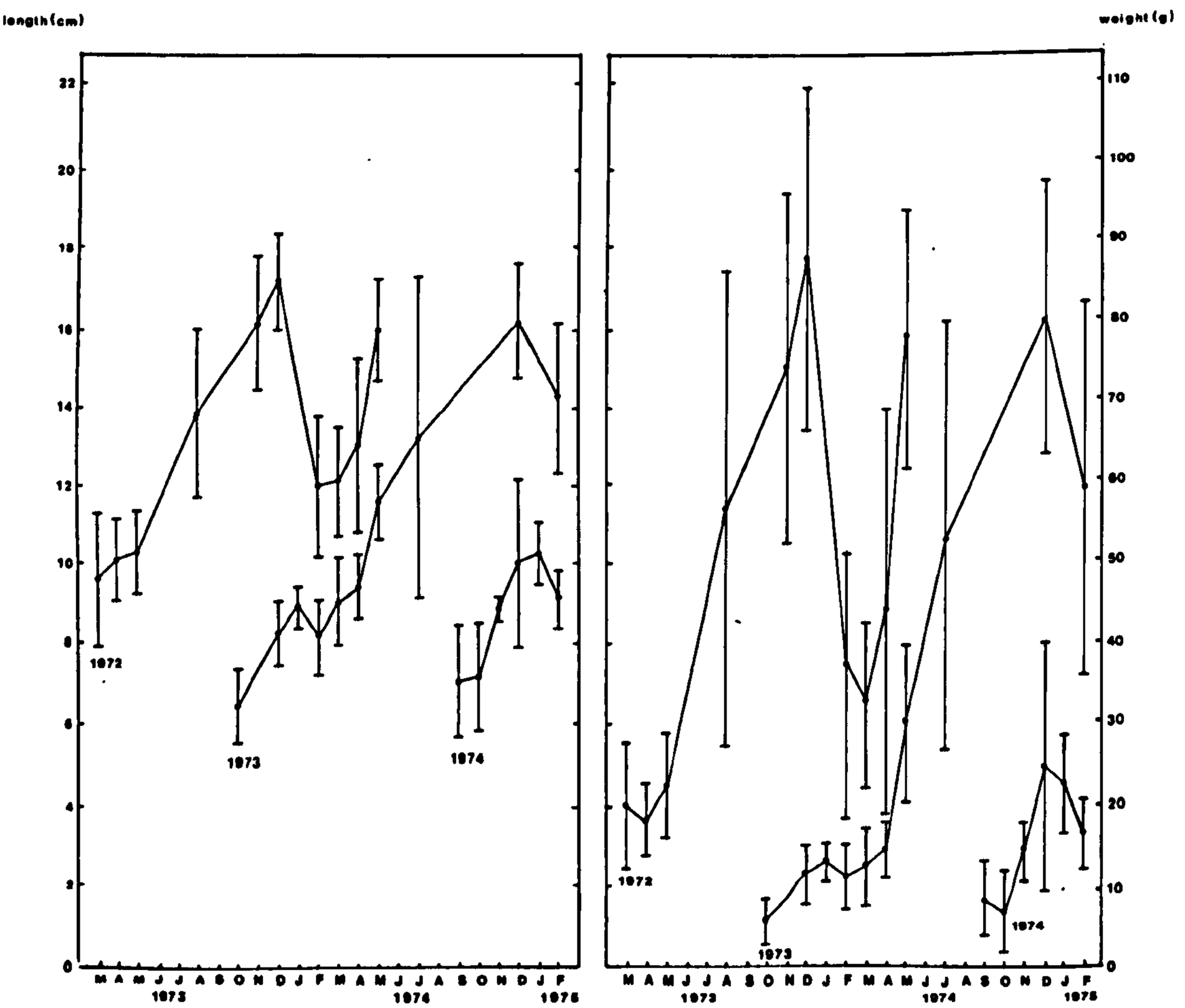


Fig. 2.3.14 Seasonal increases in length and weight of P flesus (means and 95% confidence limits)

2.3.5 Growth of young flatfish

Figure 2.3.13 shows the seasonal growth in length and weight of first-year plaice (P. platessa). Fish spawned in 1973 grew by an average 1.9 centimetres and 2.00 grams between July 1973 and January 1974. The following July, 1974 year-class plaice were longer and heavier than fish the previous year and in the succeeding six months their weights increased more rapidly.

In the three flounder (P. flesus) year-classes studied (fig. 2.3.14) monthly fluctuations were quite pronounced and annual growth was difficult to determine owing to the steep growth 'reductions' observed after December of 1973 and 1974. These are discussed in section 2.4.3, p.61. Flounders spawned in 1972 grew by a mean 7.6 centimetres and gained 68.48 grams between March and December 1973. In 1974 fish of the same age were shorter and lighter than 1972 year-class flounders had been although their growth-rates were similar. However, over a comparable period, October to February, growth-rates of first-year fish spawned in 1974 were faster than those spawned in 1973.

First-year flounders grew more quickly than plaice of the same age. Between October 1973 and July 1974 plaice and flounders grew by a mean 5.5 and 6.7 centimetres respectively, a monthly rate of 0.6 and 0.7 centimetres. However, the rate was slower for the five-month winter period, between September 1974 and the following February; 0.3 and 0.4 centimetres for plaice and flounder respectively.

Length-weight regression lines were calculated for three plaice and four flounder age-groups. The lines, together with the points from which they were computed, are shown in figures 2.3.15 and 2.3.16. Included also are the positions of individual 3/4 year-old plaice and 4/5 year-old flounders but these groups were too small in numbers for regression equations to be meaningful. Rising coefficients with age of plaice indicate that, proportionally, weight increases faster than length due possibly to increasing numbers of mature specimens in these older

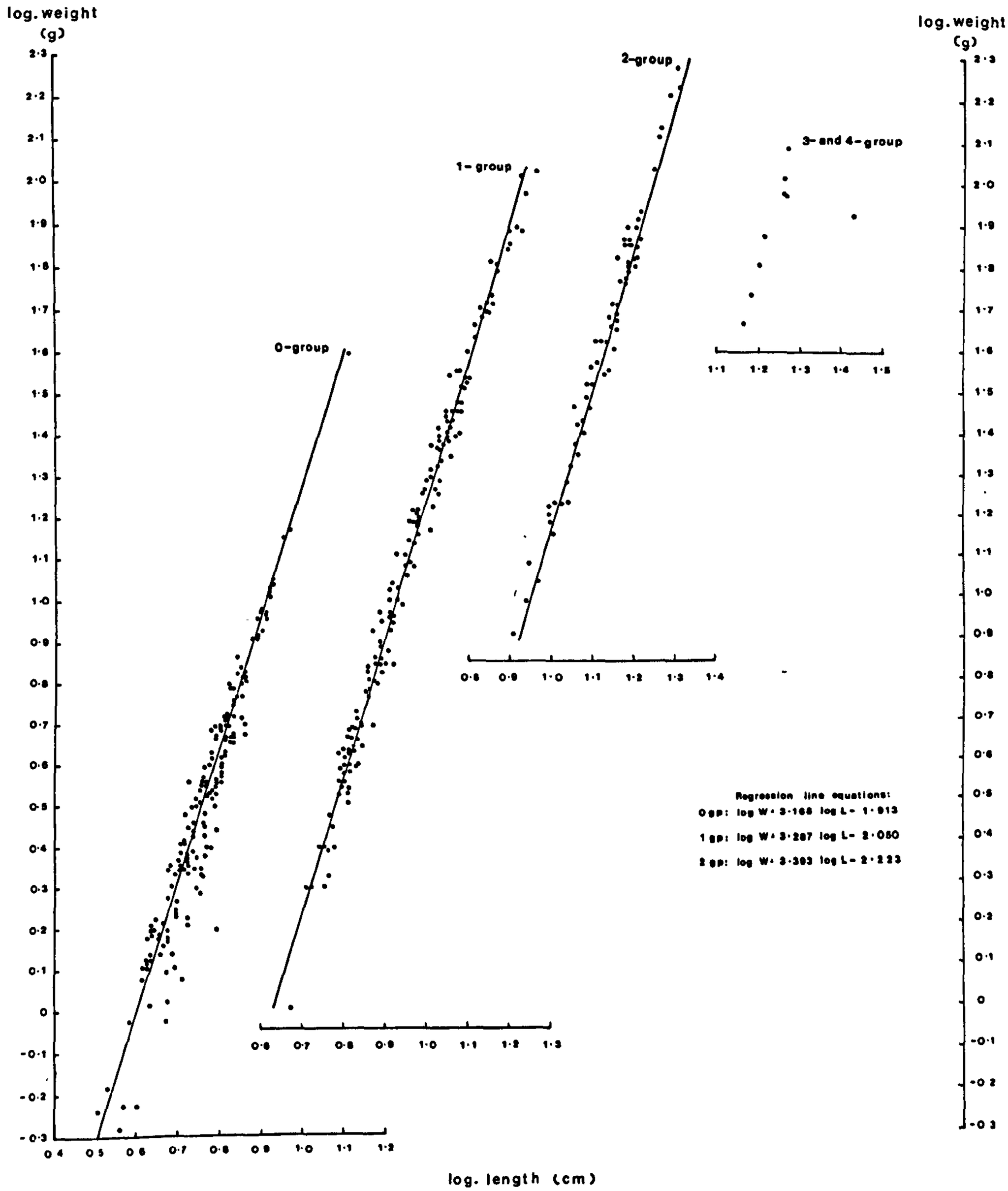


Fig. 2.3.15 Length-weight regressions for plaice age-groups

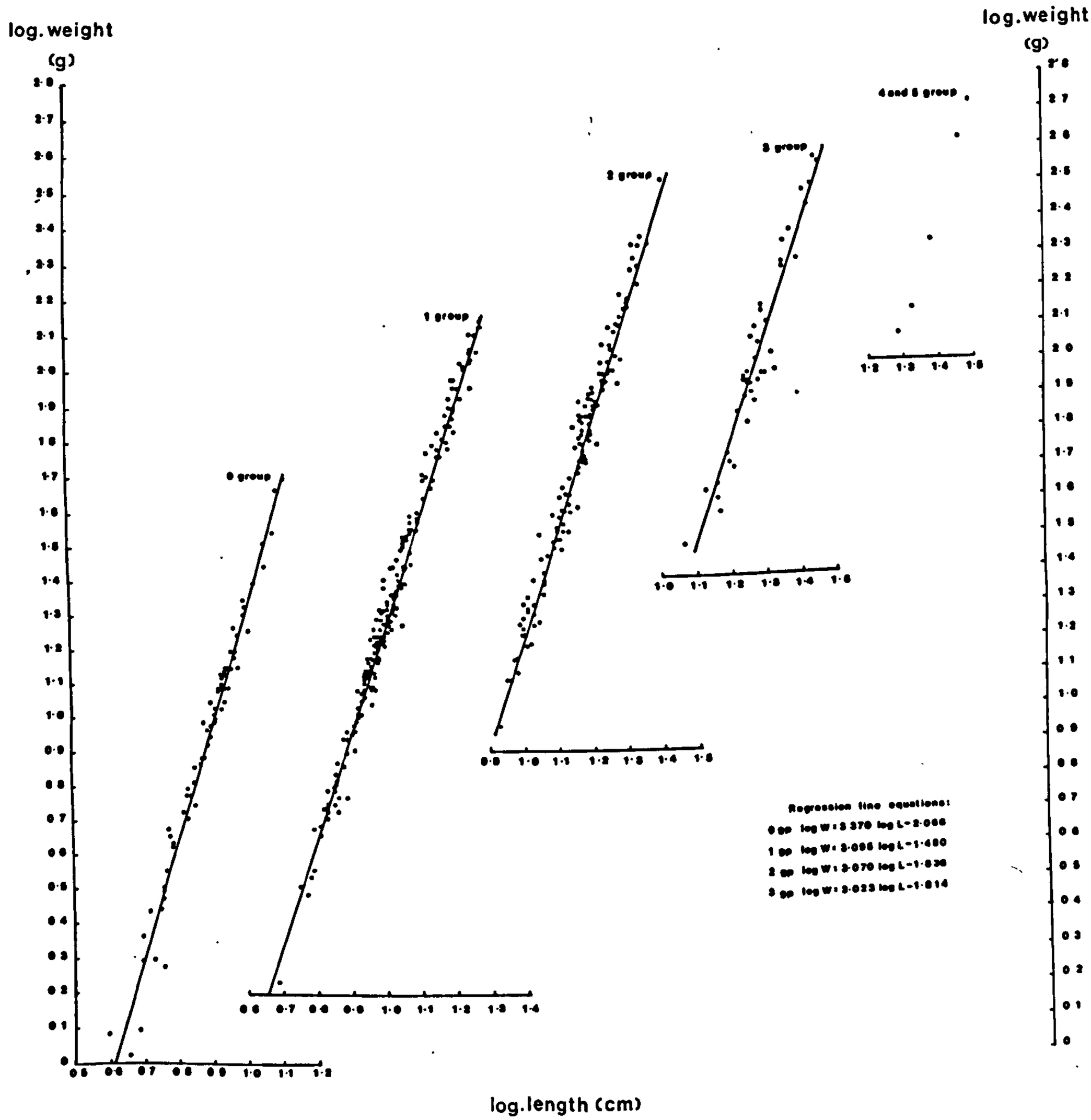


Fig. 2.3.16 Length-weight regressions for flounder age-groups

age-groups. However, this pattern was not repeated in flounder where, for no immediately obvious reason, the largest coefficient occurred in the lowest age-class.

2.4 Discussion

2.4.1 Evaluation of the sampling techniques

Sampling from power station intake screens can be used to follow seasonal changes in the relative abundance of fish species provided its limitations are realized. The main problem with the technique is that factors associated with the normal functioning of the station make standardization difficult, and some assumptions must be made.

Variation in the number of operative cooling-water pumps during a survey affects directly the volume of water sampled. Several workers (Huddart, 1971; I.C. Potter, pers. comm.) have used simple correction techniques to allow for this variable but these correction factors must be used with some caution.

At West Thurrock Power Station (Huddart, 1971) the cooling-water stream passes through a single intake culvert into a large open well from which lead six band screens each connected to a pump. The input velocity in the culvert was measured at 3.2 metres per second with all pumps in operation and 2.1 metres per second with four pumps working. Huddart corrected for different volumes of water but did not allow for the accompanying change in velocity as his investigations on *S. sprattus* and *Crangon vulgaris* L. (brown shrimp) had shown that numbers of small animals and numbers of operative pumps were negatively correlated. He concluded that even a small number of working pumps would prevent the escape of young sprats so that an increase in the number of the former would have no additional effect. Larger fish, however, may be affected quite differently by being able to withstand the water velocity when few pumps are operating but not when their number is increased.

Simple correlation analysis which does not take into account the

Table 2.4.1 Comparison of day and night samples by indices of diversity

Date	Shannon-Wiener function (H)				Uniformity index (J)			
	Numbers		Weight		Numbers		Weight	
	Day	Night	Day	Night	Day	Night	Day	Night
1974								
March	1.55	1.69	1.72	2.31	0.57	0.56	0.64	0.76
April	1.44	1.82	1.95	2.15	0.53	0.59	0.72	0.70
May	1.01	0.59	2.03	1.61	0.42	0.20	0.85	0.55
June	1.28	1.85	1.48	1.81	0.58	0.68	0.67	0.67
July	1.33	1.92	2.06	1.97	0.49	0.66	0.76	0.68
August	1.08	1.85	1.47	1.69	0.45	0.70	0.61	0.64
September	1.80	1.67	1.97	1.82	0.65	0.56	0.71	0.61
October	1.34	1.51	1.67	1.43	0.48	0.51	0.60	0.48
November	1.52	1.42	2.29	1.64	0.48	0.46	0.72	0.53
1975								
February	0.56	0.88	1.09	1.90	0.21	0.27	0.40	0.59
April	1.45	1.52	nd	nd	0.51	0.48	nd	nd
May	1.13	1.97	1.70	2.01	0.38	0.60	0.57	0.61

nd = not determined

seasonal factor may give a biased result. At Kingsnorth, a station supplying peak-demand electricity, only a single pump was in operation during the summers of 1973 and 1974. Any increase in a particular species during this period, due to an environmental change, would appear to be negatively correlated with the number of pumps even though the latter may be an irrelevant factor.

The use of a simple correction factor was probably more justified in the present study because the intakes at Kingsnorth are four separate structures (section 1.4, p.18). Nevertheless, it had to be assumed that each acted independently and sampled randomly from a common water body. This needs to be tested before further quantitative studies develop.

Night samples contained, on average, three times as many individuals as day samples, even though they were only twice as long. Roessler (1965) sampled three bottom habitats in Biscayne Bay, Florida, during both periods and found that, in two of the sampling areas, greater numbers were caught at night. However, Huddart (1971) compared three consecutive screen samples, including one taken at night, and showed that the 'night' factor was of little consequence.

From the evidence (section 2.3.2, p.29) it can be deduced that a 'night' factor (or, in some species, a 'day' factor) affects the size of catch. Many species, including plaice and flounder, are more active at night (Bregnballe, 1961) and it seems likely that active fish would more easily be drawn into the intakes than individuals buried in the benthos.

Roessler (1965) also compared the diversity of day and night samples and noticed a significantly richer variety of species at night. Similar comparisons were made in the present survey but results were not so conclusive (table 2.4.1). Night samples were more diverse, measured by the Shannon-Wiener function (H) in 75 percent of cases but uniformity (J) exhibited no consistent variation. Similarly, there was little difference between the diversity of samples on a weight basis.

Screen and trawl samples exhibited considerable similarities in composition but the latter were too few in numbers for statistical analyses to be attempted. Enough data were collected, however (table 2.3.3, p.33), to indicate that, although large fish can be drawn into the intakes, they may be proportionally under-represented in screen samples.

2.4.2 Sample diversity

Increased awareness of the importance of estuaries as feeding and nursery grounds for a wide variety of fish species has stimulated research into these communities. The majority of this work has concentrated on assessing man's influence on the environment by estimating the relative abundance of organisms rather than by less reliable methods using indicator species. Diversity indices have now been used by several workers (Allen and Horn, 1975; Dahlberg and Odum, 1970; Haedrich and Haedrich, 1974) in attempts to establish the seasonal patterns of fish in estuarine habitats. These studies were carried out over one annual cycle and their results compared with others from 'badly-stressed' areas, which receive the greatest amounts of effluent and exhibit the lowest mean annual diversities. This may appear to be a useful approach but interpretation of results is difficult because of annual fish migrations and site variability.

A more comprehensive survey, over a four-year period, was carried out by McErlean et al (1973) on fish populations in the Patuxent Estuary, Maryland. They observed a characteristic seasonal pattern for all parameters including species richness and uniformity indices (section 2.2.2, p.25). However, annual mean values decreased over the study period. The reductions could not be attributed to deterioration in environmental quality and appeared to be due to natural instability. Variability between consecutive years was one of the more important facts arising from the present survey and was also observed by Huddart (1971) in the Thames Estuary. Consequently, if man's influence is to be

assessed realistically, sampling must continue at least until one is able to predict future events with some certainty.

Diversity values (H) ranged from 0.25 to 1.89 and are comparable with, or higher than, literature values (table 2.4.2). Direct comparisons are of little use because diversity appears to be greatly affected by physiography and this, more than any other factor, man-induced or otherwise, probably accounts for the differences in the sets of values.

Table 2.4.2 Diversity values (H) from the literature

Authors	Habitat	Shannon-Wiener function (H) (range of values)
Bechtel and Copeland (1970)	Upper Galveston Bay, Texas	0.13 - 0.91
Dahlberg and Odum (1970)	Georgian Sounds	0.70 - 1.60
Haedrich and Haedrich (1974)	Mystic River Estuary, Mass	0.33 - 1.03
Stephens et al (1974)	Los Angeles Harbour	0.65 - 2.08
Allen and Horn (1975)	Colorado Lagoon, California	0.03 - 1.11
van den Broek (present study)	Medway Estuary, Kent	0.25 - 1.89

In the present survey, domination of many of the samples by sprats tended to depress the index values and great fluctuations in sprat numbers, for no immediately apparent reasons, led to variability and the absence of a clear seasonal pattern. Weight indices were generally higher because the total weight of sprats in the samples was proportionately less than their numbers. Similar observations have been made by Bechtel and Copeland (1970) and Wilhm (1968).

2.4.3 Changes in estuarine fish populations

The advantage of using a static sampling technique compared with moveable gear is that, provided the tidal state is the same, it is easier to sample a similar body of water on different occasions. In this way one would expect to minimize the differences in catch. Practice has shown, however, that short-term fluctuations in the catch of estuarine fish are very marked under natural conditions as experienced by other workers (Herald and Simpson, 1955; Carlisle, 1969; Huddart, 1971). In the Medway, superimposed on this variation was a clear seasonal cycle, numbers of species, numbers of individuals and total weights of catch reaching maxima in winter and minima in summer.

Temporal variations are difficult to explain. Several studies (Allen and Horn, 1975; Recksiek and McCleave, 1973) have shown distinct correlations between temperature and numbers of individuals. Although this may account for seasonal variations it does not explain day-to-day fluctuations which are probably controlled by more subtle factors. In the Thames Estuary, Huddart (1971) found considerable fluctuations in oxygen tension which often occurred weekly and mean values for this parameter, e.g. quarterly, had little significance. Numbers of sprats and oxygen tension showed a distinct synchrony which was statistically significant.

In Medway samples sprats occurred more consistently than in those from the Thames. However, the overall seasonal patterns were the same in the two estuaries; high, but irregular numbers of sprats in all months except between June and September (Appendix I, p202). In the present study, the sprat population formed 61.1 percent of the total catch and on several occasions, especially between January and May, formed more than 80 percent of the monthly sample. Consequently, a change in this population affected the total monthly catch considerably.

Table 2.4.3 Plaice; age structure (by percentage) of samples taken during 1974 (based on otolith examinations)

Month	Age (years)				
	0	1	2	3	4/5
January		65.4	34.6		
February		45.8	33.3	16.7	4.2
March		44.0	44.0	12.0	
April	3.7	81.5	14.8		
May		58.3	41.7		
June	36.0	56.0	8.0		
July	53.8	46.2			
August	95.7	4.3			
September	96.0	4.0			
October	89.5	5.3	5.3		
November	40.0	40.0	20.0		
December	45.8	50.0	4.2		

Table 2.4.4 Flounder; age structure (by percentage) of samples taken during 1974 (based on otolith examinations)

Month	Age (years)				
	0	1	2	3	4/5
January		92.0	8.0		
February		64.0	36.0		
March		50.0	50.0		
April		38.5	42.3	19.2	
May		20.9	44.2	34.9	
June		57.1	28.6	16.7	
July/August	14.3	28.6	28.6	14.3	14.3
September	71.4	21.4	7.1		
October	83.3			16.7	
November	60.0	28.0	12.0		
December	43.8	50.0	6.3		

Sprat reductions in summer are not a response to environmental deterioration but appear to be largely due to a seaward migration of older fish (Robertson, 1936). Huddart (1971) detected this movement in 1968 when 2 year-old sprats were absent from his June samples. A similar decline was observed in the Medway population during 1973 but not the following year. In 1974, monthly length-frequency distributions of sprat (fig. 2.3.11, p47) suggest there were two spawning periods, in spring and late summer, and that the spring spawners were responsible for maintaining numbers over the summer period. Double spawning in sprats has been observed previously (Wheeler, 1969a) and in the present case may have been a consequence of an extremely mild winter.

Seasonal fluctuations in total catch were not solely a consequence of changes in the sprat population. There were also considerable increases in the numbers of species during winter, many of which were rare with fewer than ten individuals recorded for each of thirty species. Some rare species were taken during, or directly after, a storm and it was noticeable that the catch was considerably increased at these times. The two rarest species, Torpedo marmorata Risso, now in the British Museum (Natural History) and Scophthalmus maximus (L.) were taken under such conditions.

Seasonal patterns displayed by other species abundant in screen samples were similar to sprat (fig. 2.3.12, p48); a spring migration of larger (and older) fish away from the study area (and, presumably, out of the estuary) followed by an influx of newly-spawned individuals during summer and autumn. The main influx of young plaice and flounder was between June and September when both populations consisted largely of 0-group individuals (tables 2.4.3 and 2.4.4). Fish at Kingsnorth appear to be representative of those in the estuary because during this period a total 153 plaice of mean length 5.2 centimetres were taken by trawl.

Movements of young flatfish in inshore waters have been studied by several workers (Bregnballe, 1961; Edwards and Steele, 1968; Gibson, 1973).

Following inshore migrations the fish settle at depths according to species and size. Average growth is rapid initially but then appears to slow as larger fish migrate and late-spawners arrive (Bregnballe, 1961). Using the present sampling technique the depth or location from which individuals have been taken cannot be determined. This makes accurate calculation of growth rates difficult and, at best, they can only be rough approximations.

First-year flounders were calculated (p50) to have a faster mean growth-rate than plaice of the same age. In plaice, the slowing rate in summer (fig. 2.3.13, p49) was probably due to a change in population structure of the type described above. Also, apparent growth 'reductions' in flounder during winter (fig. 2.3.14, p49) were probably due to an influx of small fish from less-favourable areas outside the estuary. The 'reductions' were too large to be caused by a decrease in feeding over this period (see section 3.4, p127).

Population sampling described in this section provided broad information on the presence and absence of species, breeding seasons, migrations and growth rates. However, such results reveal little of the underlying causes for fish movement or the reasons for changes in growth rate. Factors such as feeding behaviour, availability of food, parasitic load and even the presence of environmental pollutants might all be expected to have some effect on growing and breeding fish. Therefore, to consider in detail the more subtle aspects of the Medway environment, these factors were investigated in the following sections - 3 (p 62) and 4 (p134).

SECTION 3

DIETARY AND PARASITOLOGICAL STUDIES

3.1 Introduction

3.2 Methods

3.2.1 Diet and ectoparasite analyses

3.2.2 Copepod ectoparasites; a detailed study

3.3 Results

3.3.1 Nature and variation of diets

(a) Gadoids: Merlangius merlangus and Trisopterus luscus (L.)

(b) Pleuronectids: Platichthys flesus (L.) and Pleuronectes platessa L.

3.3.2 Ectoparasites: species occurrence and host-parasite relations

(a) Cryptocotyle lingua (Creplin); a digenean parasite infecting gadoids and pleuronectids

(b) Crustacean parasites infecting gadoids and pleuronectids

3.3.3 Effects of copepod ectoparasites: a detailed study of Lernaeocera branchialis (L.) on whiting

(a) Effects on length-weight relationship and condition factor

(b) Effects on the liver

(c) Effects on diet

3.4 Discussion

SECTION 3

DIETARY AND PARASITOLOGICAL STUDIES

3.1 Introduction

The Medway Estuary is important as a nursery ground for young fish (section 2.4.3, p58). A large biomass of food organisms must be available to sustain these populations of rapidly-growing individuals. However, precise dietary constituents of even the most common fish species in this estuary have not previously been determined.

Whiting, pouting, plaice and flounder were selected for study; preliminary investigations had shown they were present consistently in screen samples. They are also of importance as potential food species and in replenishing stocks outside the area. Diets of whiting and plaice are documented from a number of inshore locations (Steven, 1930; Elkin, 1954; Nagabhushanam, 1964; Edwards and Steele, 1968) but pouting and flounder have been studied by comparatively few workers (Hartley, 1940; Bregnballe, 1961; Kühl, 1973).

In inshore areas fish are particularly vulnerable to parasitic infestation; some parasite species may exploit the host's feeding habits and enter the mouth with the food while others are transmitted more easily under crowded conditions. Experimental fish farming projects have confirmed that infestations, by ectoparasites in particular, may reach exceptionally high levels and reduce significantly the growth of the fish population (Mackenzie and Gibson, 1970).

With notable exceptions (Scott, 1929; Sproston and Hartley, 1941; Wickins and Macfarlane, 1973; Shotter, 1973a,b, 1976), there has been little comprehensive research into the ectoparasitic loads of fish; most studies have dealt with individual parasite species. The copepod Lernaeocera branchialis (L.) has received particular attention because of its size and prominent position in the gadoid branchial chamber. From this position it attacks the blood-system and it is usually located in

the bulbus arteriosus or heart. Claus (1868) outlined the parasite's life-history and the developmental stages have also been described (Sproston, 1942). Kabata (1970) reviewed the biochemical aspects of the infection. His investigation (Kabata, 1958) into the effects of L. branchialis on liver lipid content was extended in the present study and applied to Medway whiting.

3.2 Methods

3.2.1 Diet and ectoparasite analyses

(i) Sampling

Samples of whiting, pouting, plaice and flounder were collected and dealt with as previously described (section 2.2.1, p23). Whenever possible 25 specimens of each species were analysed per month. Fish were randomly selected from large collections or, where the monthly sample was small, all fish were investigated.

(ii) Sample treatment

The incidence, numbers and positions of all trematode and crustacean parasites in subcutaneous tissues and branchial cavities were noted. The pleuronectid body was divided into zones (fig. 3.2.1) and subcutaneous metacercariae of the trematode Cryptocotyle lingua (Creplin) accurately plotted.

The gut was removed from each fish and divided into two regions; stomach and buccal cavity, intestine and rectum. Contents of the former were weighed and the dietary components identified to species wherever possible. Relative abundance of each constituent was estimated by an arbitrary abundance scale of 1 - 5 as follows:

Abundance rating	Interpretation
5	abundant
4	very common
3	common
2	uncommon
1	rare

Food organisms in the intestine were also identified but, because of disintegration of their tissues, no estimates of abundance were made.

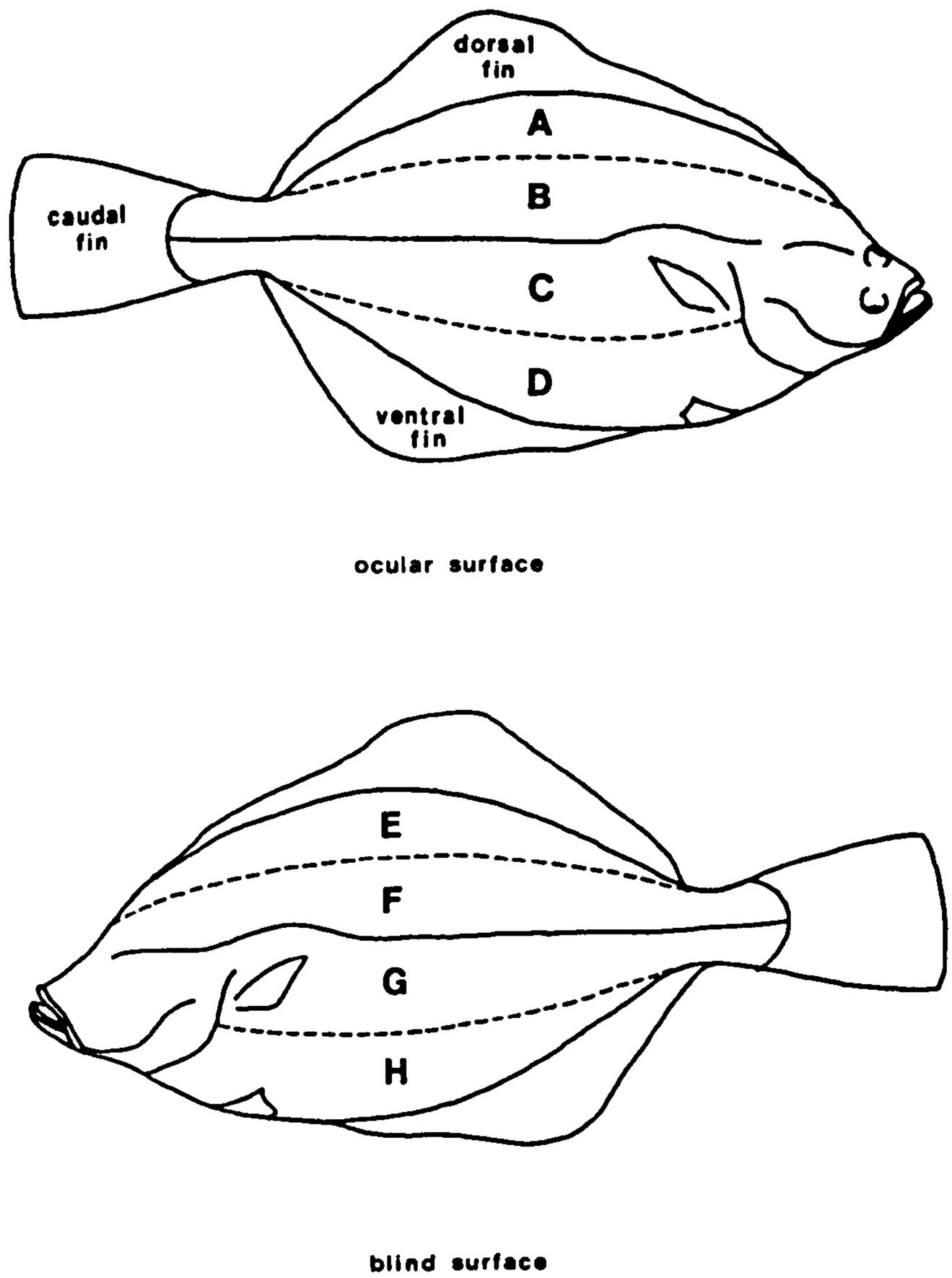


Fig.3.2.1 Infection of Cryptocotyle lingua on pleuronectids; division of body into zones

Cirratulid polychaetes in gut samples could not be identified to species. Sublittoral grab samples were taken around the cooling-water intakes without success. Two cirratulid species, Caulleriella zetlandica (McIntosh) and Audouinia tentaculata (Montagu), have been recorded from the littoral zone in the Medway (Wharfe, 1975) but not in the vicinity of the power station.

(iii) Analysis of results

Standard statistical methods for χ^2 and correlation were adopted in testing the significance of results.

3.2.2 Copepod ectoparasites: a detailed study

(i) Sampling and sample treatment

Whiting uninfected and infected with *L. branchialis* were selected during a one-week period in November 1974. Each fish was weighed and measured immediately after capture and the incidence, numbers and positions of all branchial crustacean parasites recorded. Following dissection the liver was blotted dry, weighed and deep-frozen, and from this point on treated individually at all times. The 'degree of fulness' of each stomach was estimated and points allocated as follows:

Visual estimation of 'fulness'	Points
Full	8
¾ full	6
½ full	4
¼ full	2
Trace	1
Empty	0

Stomach contents were weighed and items identified.

(ii) Extraction of liver lipids

Each liver was macerated in the presence of Analar chloroform: methanol (2:1 $^{v}/v$). Salts were removed from the extract by partitioning with 0.1 M potassium chloride solution (Folch *et al*, 1957). The recovered organic phase was dried and the amount of total lipid determined gravimetrically.

(iii) Resolution of extracts by thin-layer chromatography (TLC)

Approximately equal amounts of lipid extract from individual livers were applied to TLC plates (silica-gel G, 0.6 millimetre thickness) along with standard solutions of glycerol mono-, di- and tristearate, palmitic acid and cholesterol; each at a concentration of one milligram per millilitre chloroform. Plates were developed in 60:40:1 $^{v}/v$ petroleum ether, diethyl ether and acetic acid (all Analar grade) and constituent

Table 3.2.1 Summary of methods used in the biochemical analysis of liver lipids

Analysis	Weight of lipid used	Analytical Chemistry		Spectrophotometry		
		Pre-treatment	Treatment	λ (nm)	Blanks	Standard solutions
Phospholipid Fiske and Subbarow (1925)	5-10 mg	hot digestion: add 1.1 ml 60% perchloric acid	When cool add: 7.5 ml distilled water 1.0 ml 5% ammonium molybdate 0.5 ml 'reducing agent'* (leave 15 mins)	660	water	0-100 µgm phosphorus
Acyl ester Stern and Shapiro (1953)	0.2-0.5 mg	Add: 3 ml 3:1 v/v ethanol:diethyl ether 0.5 ml 2M hydroxylamine hydrochloride 0.5 ml 3.5 N NaOH	After 20 mins add 0.6 ml 3.3 N HCl 0.5 ml 0.37 M ferric chl. in 0.1 N HCl	520	ethanol: ether	triglyceride
Cholesterol Sackett (1925)	1 mg	None	Add 5 ml chloroform, 2 ml acetic anhydride/ sulphuric acid reagent (20:1 v/v) (Leave 15 mins in dark)	680	chlorof.	cholesterol 0-100 µg/ml

* 'reducing agent': 30 g sodium bisulphite, 6 g sodium sulphite, 0.5 g 1-amino 2 napthyl-4-sulphonic acid dissolved in distilled water and made up to 250 ml. Stand for 3 hours - filter into an amber bottle.

lipids detected by spraying the plates with 30 percent sulphuric acid and charring in an oven.

(iv) Spectrophotometric determination of phospholipid phosphorus, acyl ester and cholesterol

Analytical procedures used are summarized in table 3.2.1. The determination for phosphorus (Fiske and Subbarow, 1925) can only be performed on the inorganic element and, therefore, phospholipid had to be broken down to phosphate before spectrophotometry could be applied. Approximate values of phospholipid were calculated by multiplying measurements of inorganic phosphorus by 25. This factor is derived from the assumption that all fatty acids in a sample have an average composition corresponding to oleic acid (Owen et al, 1972).

The acyl ester test is a determination of ester bonds in a lipid and is indicative of triglyceride. The method (Stern and Shapiro, 1953) is based on the formation of coloured ferric hydroxamic acid derivatives using ferric chloride as a reagent. An acyl ester standard was prepared by dissolving 538.5 milligrams triglyceride in ethanol:ether (3:1 $^{v}/v$) and making up to 100 millilitres. Dilution of 5 millilitres to 100 resulted in a concentration of one micro-equivalent acyl ester per millilitre.

Cholesterol analysis involves dehydration of the steroid ring system with sulphuric acid (Sackett, 1925). Care must be taken with the acetic acid/sulphuric acid reagent which has to be freshly prepared (on ice at $0^{o}C$) shortly before use.

(v) Fatty acid analyses of lipid extracts

The method releases fatty acids from the lipid, converts them to methyl esters and analyses them by gas-liquid chromatography.

Known amounts of lipid material (about 20 milligrams) were refluxed with 3 millilitres boron trifluoride/methanol reagent in sealed boiling tubes (Morrison and Smith, 1964). When cool, 2 millilitres each of water and petroleum ether were added and the contents allowed to partition. The

organic phase was retained; solvent was evaporated and resulting methyl esters redissolved in 100 microlitres diethyl ether.

Esters were purified by TLC. Plates were developed in benzene then sprayed with 2', 7'-dichlorofluorescene (0.01% $^{w}/v$ in 80% ethanol) and examined under ultraviolet light. The methyl ester streak was scraped off the plate, transferred to a centrifuge tube and esters eluted with dry diethyl ether.

The samples and a range of standard solutions, for qualitative assessment only, were analysed by Hewlett-Packard 5750G research chromatograph with flame ionization detection. Instrumental conditions for the system are given in table 3.2.2.

On the GLC traces, the areas under the peaks are linearly proportional to the weight of material eluting from the column (Christie, 1973). In the quantitative interpretation of each chromatogram all peaks were measured and expressed individually as a percentage of the total fatty-acid composition.

3.3 Results

3.3.1 Nature and variation of diets

During the study 1542 fish guts were analysed, derived from 433 plaice, 417 flounders, 404 whiting and 288 pouting. Fish numbers were erratic in monthly samples and particularly low during summer months. Hence when seasonal results were analysed, it was in some cases necessary to pool data from two or more consecutive months.

(a) Gadoids: M. merlangus and T. luscus

(i) Composition of the total diets

Constituent food organisms in the alimentary canals of whiting and pouting are shown in table 3.3.1. 'Percentage occurrence' of a dietary component refers to its presence in that proportion of guts analysed while 'percentage abundance', based only on stomach analyses, is the ratio between total abundance ratings (p64) of a food organism and the

Table 3.3.1 Whiting and Pouting: frequency of occurrence and abundance of food organisms in the diets

Food organism	Whiting		Pouting	
	Occurrence (%)	Abundance (%)	Occurrence (%)	Abundance (%)
Indeterminate Coelenterata	0.3	+	0.7	+
Hydrobia ulvae (Pennant)	0.5	0.1	1.4	0.4
Mytilus edulis Linnaeus	-	-	0.4	+
Indeterminate Mollusca	-	-	1.0	+
Peloscolex benedeni (Udekem)	0.5	0.1	-	-
Arenicola marina Linnaeus	0.3	+	-	-
Nepthys caeca (Müller)	1.7	0.5	7.6	1.9
*Nereis diversicolor (Müller)	11.9	5.0	22.9	8.7
Indeterminate Polychaeta	0.5	0.1	4.5	+
Indeterminate Copepoda	2.7	1.1	2.4	+
*Carcinus maenas (Linnaeus)	4.0	0.9	22.9	7.2
*Crangon vulgaris Linnaeus	68.3	48.2	87.5	50.5
Leander serratus (Pennant)	-	-	0.4	0.6
Mesopodopsis slabberi (van Beneden)	0.3	0.5	-	-
Neomysis integer (Leach)	20.5	11.6	22.2	18.6
Praunus flexuosus (Müller)	1.5	0.1	2.8	1.0
Indeterminate Mysidacea	15.1	9.4	11.8	+
* Total Mysidacea	37.4	21.6	34.0	19.6
Caprella sp.	-	-	1.0	1.1
Corophium sp.	-	-	1.0	+
Gammarus sp.	5.9	3.4	7.3	3.0
Orchestia sp.	-	-	0.4	+
Indeterminate Amphipoda	3.5	0.9	7.6	1.3
* Total Amphipoda	9.4	4.3	17.3	5.4
Gnathia sp.	-	-	1.4	+
Idotea chelipes (Pallas)	1.0	0.5	0.7	+
Indeterminate Isopoda	0.3	+	1.7	+
Indeterminate Crustacea	2.2	+	0.4	+
Atherina presbyter Valenciennes	-	-	0.7	+
Callionymus lyra Linnaeus	-	-	0.4	+
Pomatoschistus minutus (Pallas)	2.7	1.6	1.7	1.0
Sprattus sprattus (Linnaeus)	4.0	3.7	0.4	+
Indeterminate Pisces	23.3	12.2	19.8	4.7
* Total Pisces	30.0	17.5	23.0	5.7

* major components

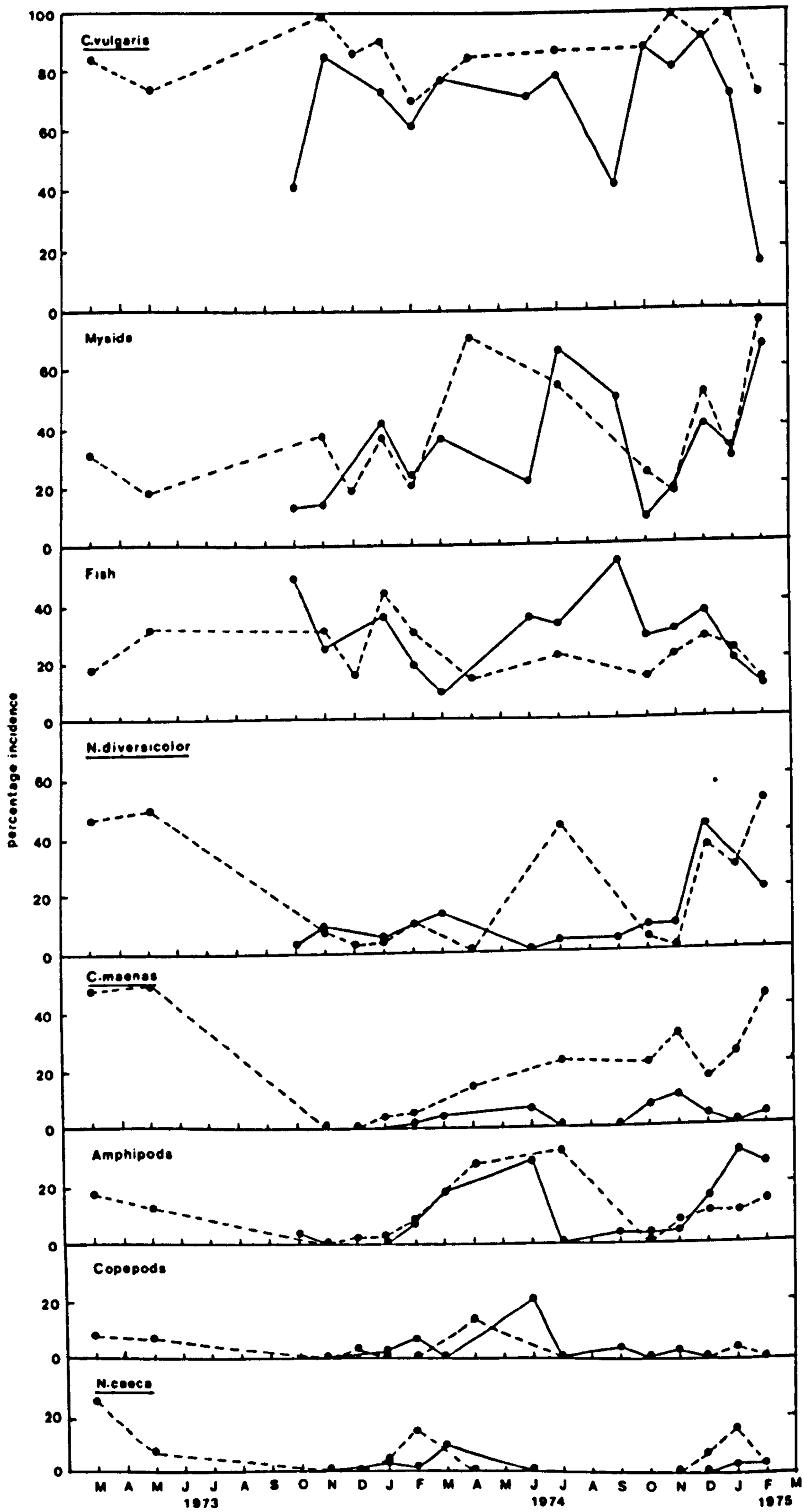


Fig.3.3.1 Seasonal variations of main dietary constituents of whiting (●——●) and pouting (●- - -●)

grand sum derived from dietary constituents in all stomachs.

Main components in the diets of both gadoids were the shrimp, Crangon vulgaris L., and mysids, especially Neomysis integer (Leach). Apparent discrepancy in the pouting mysid total (34.0%) is because Praunus flexuosus (Müller) and N. integer always occurred simultaneously. Supplementary food items showed some variation; Carcinus maenas (L.) occurred more often and in greater abundance in the guts of pouting than in whiting while fish as food organisms were much more abundant in the latter species.

(ii) Seasonal occurrence of food organisms

The incidence of dietary constituents fluctuated monthly and there were only occasional traces of recurring seasonal patterns (fig. 3.3.1). In whiting these patterns were most clearly illustrated by the intake of fish which reached a peak in autumn. It is interesting that October 1973 and September 1974 were not only periods of maximal fish intake but were also coincident with the reduced occurrence of C. vulgaris in the diet. Between these maxima fish were less frequent and reached a minimum 9.1 percent in March 1974 while the shrimp intake never fell below 60 percent throughout this time. The latter declined in February 1974 although not as much as the following year when, in the same month, they occurred in only 16 percent of guts analysed. However, this low did not coincide with a recurring increase of fish in the diet (see discussion, section 3.4, p128).

Mysids and amphipods were present erratically with maxima in both winter and summer months. For example, amphipods occurred in 32 percent whiting in January 1975 and yet were entirely absent from the diet the previous winter. N. diversicolor did not usually figure prominently in the diet and, although it reached a maximum 42 percent in December 1974, its incidence was usually less than half this value.

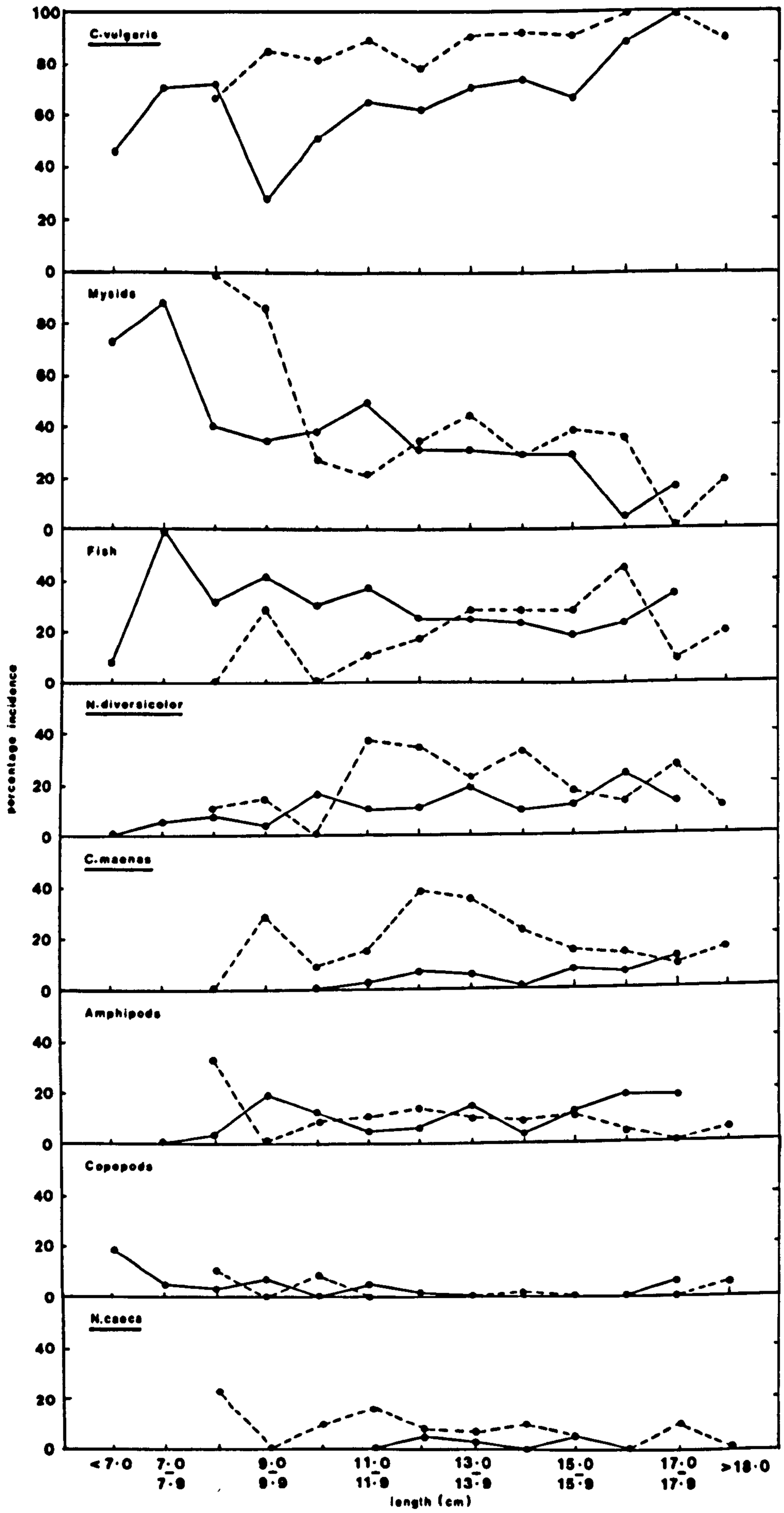


Fig. 3.3.2 Variation of whiting (●—●) and pouting (●--●) diets with fish length

In the pouting diet the occurrence of C. vulgaris was high throughout the survey period, contrasting with whiting's more erratic uptake, and in each monthly sample was present in over 70 percent of guts analysed. Fish were also of constant occurrence in pouting but mysids, N. diversicolor and C. maenas exhibited fluctuations which did not clearly relate to seasonal factors or food substitution.

(iii) Changes in diet with fish length

The majority of gadoids were in their first year so age comparisons proved impracticable. However, divided into one-centimetre size-classes some differences in feeding became apparent. Whiting smaller than 7.0 centimetres consumed a greater proportion of copepods than larger individuals although they were not exclusive to this group (fig. 3.3.2). These small fish, and those in the next size-class, also fed more frequently on mysids. On the other hand, fish occurred less often in the diet of whiting smaller than 7.0 centimetres and most frequently in guts of individuals from the next size-class.

In contrast with whiting, pouting in all size-classes (fig. 3.3.2) fed heavily on C. vulgaris while mysids, N. caeca, amphipods and copepods occurred more frequently in guts of individuals less than 9.0 centimetres than in others. The incidence of fish in the diet was erratic and there was little indication that they were eaten predominantly by larger pouting. Unfortunately the sample was too small for the significance of these results to be tested.

(b) Pleuronectids: P. flesus and P. platessa

(i) Composition of the total diets

Both flatfish fed most frequently on cirratulid polychaetes, the tubificid Peloscolex benedeni (Udekem) and N. diversicolor (table 3.3.2) but differed in their species dependency. P. benedeni occurred more often in flounder guts, and in greater numbers, than in plaice where cirratulids were more frequently encountered. The two species also

Table 3.3.2 Flounder and Plaice: frequency of occurrence and abundance of food organisms in the diets

Food Organism	Flounder		Plaice	
	Occurrence (%)	Abundance (%)	Occurrence (%)	Abundance (%)
Indeterminate Coelenterata	5.3	0.5	1.6	0.1
Cardium edule Linnaeus	1.7	+	3.7	1.8
*Hydrobia ulvae (Pennant)	7.2	0.5	12.0	1.1
Littorina littorea (Linnaeus)	-	-	0.5	+
*Macoma balthica (Linnaeus)	11.3	1.0	10.2	5.0
Mytilus edulis Linnaeus	-	-	0.5	+
Indeterminate Amphineura	-	-	0.2	0.1
Indeterminate Mollusca	1.4	+	1.4	+
*Peloscolex benedeni (Udekem)	40.5	41.9	31.0	21.3
Tubifex costatus Claparède	0.2	+	-	-
Capitellidae	3.4	0.5	1.9	0.1
*Cirratulidae	20.9	25.3	50.8	45.5
*Nepthys caeca (Müller)	4.1	1.5	13.2	3.6
*Nereis diversicolor Müller	21.1	10.2	24.9	10.5
Indeterminate Polychaeta	2.9	+	3.5	+
Indeterminate Copepoda	6.7	0.5	8.8	2.8
Carcinus maenas (Linnaeus)	6.0	1.8	1.9	+
*Crangon vulgaris Linnaeus	13.9	12.3	4.2	0.9
Neomysis integer (Leach)	-	-	0.7	0.4
Mesopodopsis slabberi (van Beneden)	0.5	+	-	-
Indeterminate Mysidacea	-	-	0.2	+
Caprella sp.	-	-	0.2	+
Corophium sp.	0.2	+	0.2	+
Gammarus sp.	1.0	0.3	0.5	0.3
Indeterminate Amphipoda	1.2	+	3.2	0.3
Gnathia sp.	1.2	+	0.5	+
Idotea chelipes (Pallas)	0.5	0.5	0.7	+
Indeterminate Isopoda	1.2	+	0.5	0.1
Indeterminate Crustacea	2.2	+	2.8	+
Pomatoschistus minutus (Pallas)	0.7	0.5	-	-
Sprattus sprattus (Linnaeus)	0.7	+	-	-
Trisopterus luscus (Linnaeus)	0.2	+	-	-
Indeterminate Pisces	2.6	2.6	-	-
Indeterminate plant material	1.7	+	0.9	0.1
Sand, debris	0.7	+	0.2	+

* major components

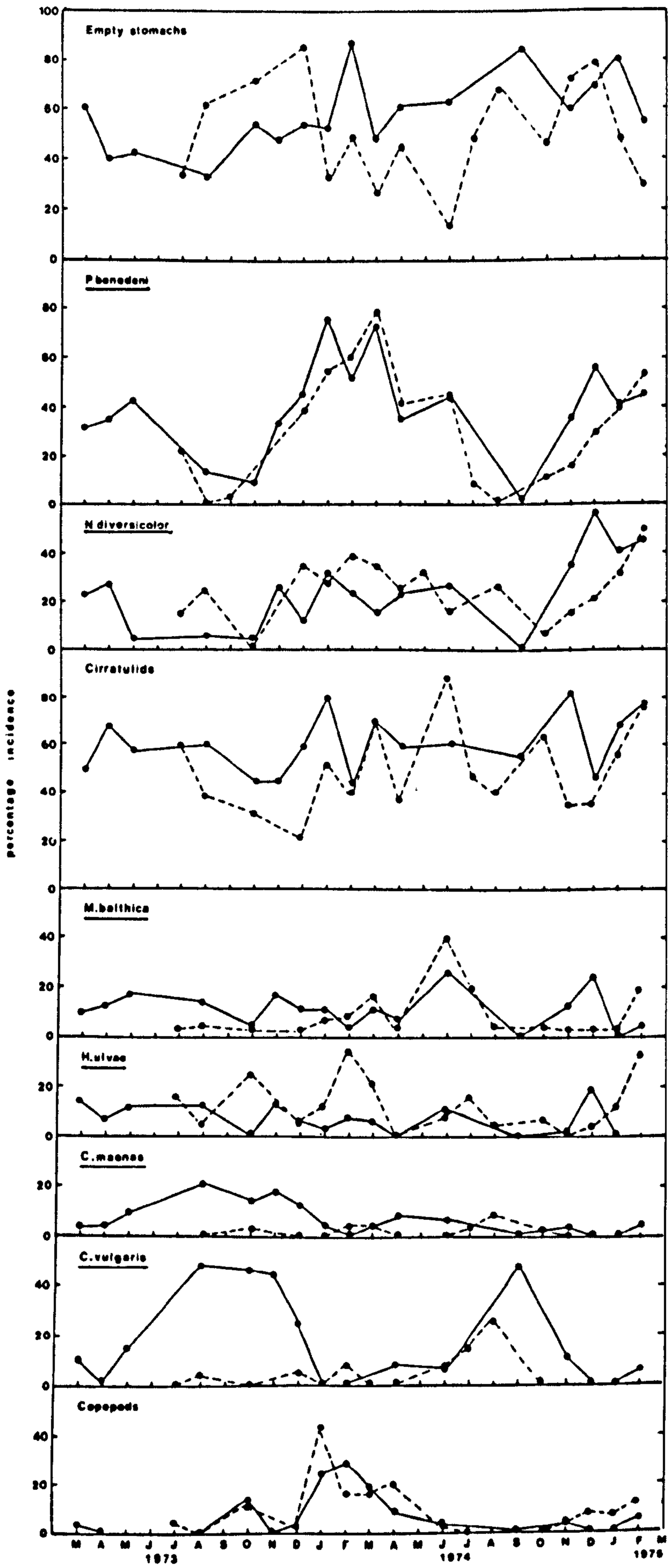


Fig.3.3.3 Seasonal variations of main dietary constituents of flounder (▸——◂) and plaice (▸- - -◂)

differed in their supplementary food items; Nepthys caeca (Müller) and molluscs Hydrobia ulvae (Pennant) and Macoma balthica (L.) were consumed more often by plaice than flounder. Copepods were the only crustaceans to appear regularly in the plaice diet while in flounder C. vulgaris, although occurring less frequently than N. diversicolor, was more abundant.

(ii) Seasonal occurrence of food organisms

In contrast to the gadoids a large proportion of flatfish had empty stomachs (fig. 3.3.3). Numbers in this condition reached a maximum in winter but they were also recorded at other times of the year when food in the intestines indicated feeding was continuing (see discussion, section 3.4, p 127).

In flounder, P. benedeni was most frequent between January and March 1974 and within this period occurred in a mean 67.4 percent of total guts analysed. The occurrence of P. benedeni in the plaice diet displayed a clear seasonal cycle with maximum incidence (78.3 percent) in March 1974 and reaching a minimum in August. As it declined cirratulids increased and their peak in June 1974 was coincident with maximum feeding activity, measured by the number of food-containing stomachs. No similar substitution relationship existed in flounder because cirratulids were relatively uncommon in their diet.

C. vulgaris was the only other dietary constituent of flounder to show a recurring seasonal pattern. The remaining food organisms were seasonally more variable.

(iii) Changes in diet with fish age

Plaice and flounders could be divided into five and six age-classes respectively. In each species numbers in the two oldest groups were too low for valid comparison with younger fish and are excluded from this discussion.

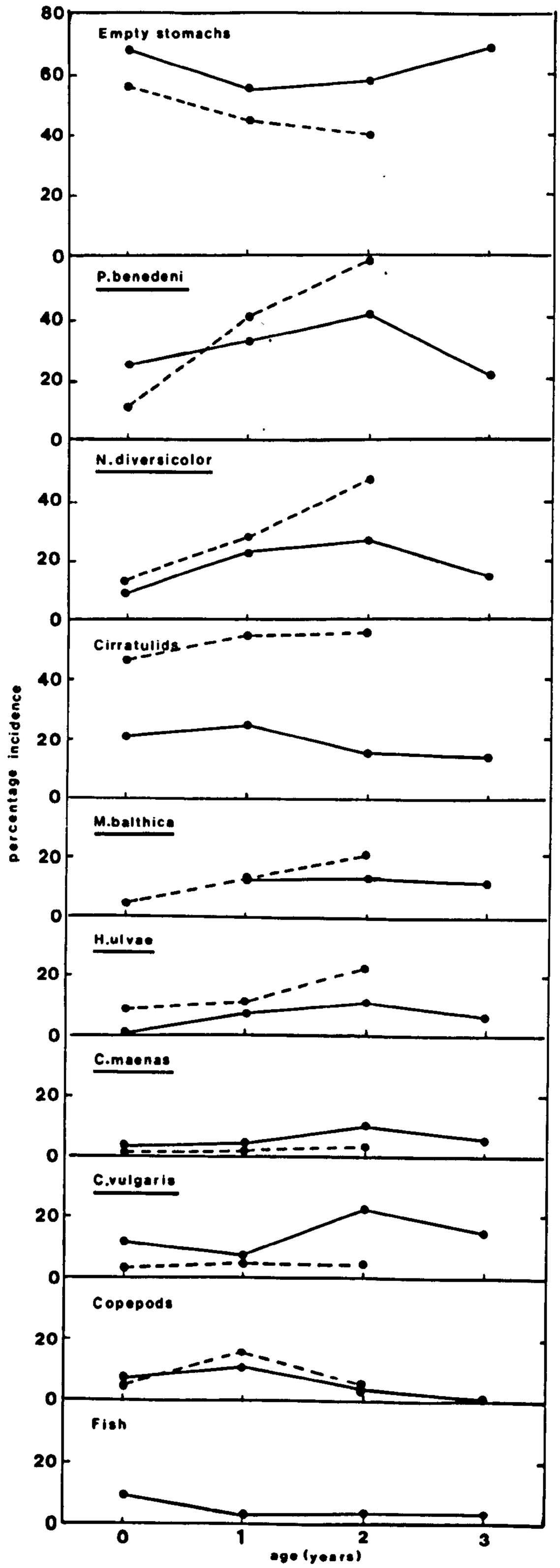


Fig.3.3.4 Variation of plaice (•---•) and flounder (•——•) diets with age

Table 3.3.3 Ectoparasitic and superficially encysted species recorded from fish in the Medway Estuary

Parasite	Infection site	Host	
		Plaice	Flounder
Digenea			
Cryptocotyle lingua metacercariae	subcutaneous tissues	+	+
Stephanostomum baccatum metacercariae	subcutaneous tissues	+	-
Crustacea			
Lepeophtheirus pectoralis	fins and body surface	-	+
Acanthochondria depressa	branchial cavity	-	+
Lernaeocera branchialis larvae	gill filaments	-	+
'Chalimus' larvae	fins and body surface	+	+
		Whiting	Pouting
Digenea			
Cryptocotyle lingua metacercariae	subcutaneous tissues	+	+
Crustacea			
Lernaeocera branchialis	branchial cavity	+	-
Lernaeocera lusci	branchial cavity	-	+
Clavella uncinata	branchial cavity	+	-

A greater proportion of empty stomachs was recorded in 0-group fish (fig. 3.3.4) but in neither pleuronectid was the difference between age-classes statistically significant (χ^2; $0.80>P>0.20$). First-year flounders (0-group) fed most frequently on P. benedeni and cirratulid polychaetes with C. vulgaris, fish and copepods also occurring regularly. Molluscs and the larger crustaceans, including C. maenas, were present less often and were more important in the diets of older fish.

The main dietary constituents of plaice in their first three years were cirratulids, P. benedeni and N. diversicolor. In the case of all three food organisms, their proportion steadily increased with age but only in the last two cases were the differences significant (χ^2; $P<0.001$). Molluscs were also taken more regularly by older plaice (χ^2; $P<0.01$) but copepods, as in flounder, occurred most often in one year-olds.

3.3.2 Ectoparasites: species occurrence and host-parasite relations

Ectoparasite species observed in plaice, flounder, whiting and pouting during the survey are listed in table 3.3.3. The digenean Cryptocotyle lingua (Creplin) was the only parasite common to all four fish types, the crustacean parasites displaying varying degrees of specificity. Lernaeocera branchialis (L.) occurred on both flounder and whiting but different stages of the life-cycle are specific and restricted to one or other of the hosts. 'Chalimus' larvae were more general in their distribution. However, because of the structural similarity between larvae of related species it is unlikely the term refers to a single species. On plaice these larvae, and Stephanostomum baccatum (Nicoll), were only rarely encountered and have been omitted from further study.

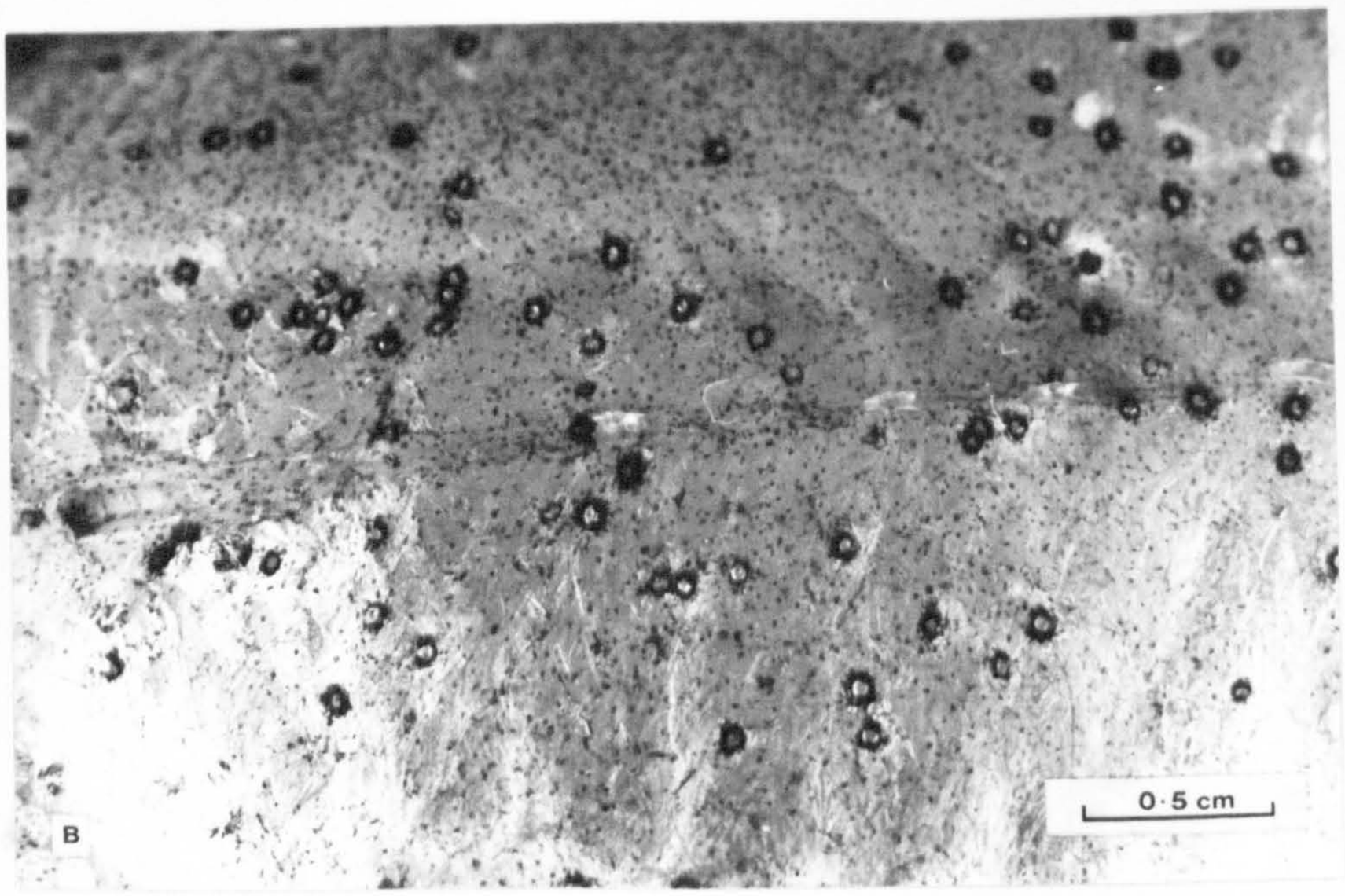


Plate 5 Cryptocotyle lingua (Creplin) infection

A. Infection on pouting

B. Close-up of encysted metacercariae in the pouting integument

(a) Cryptocotyle lingua (Creplin) (Trematoda: Heterophyidae); a digenean parasite infecting gadoids and pleuronectids

(i) Incidence and intensity of infection ('Percentage incidence' refers to the percentage of the fish population infected, 'intensity' to the number of parasites per infected host.)

Fish serve as intermediaries for many trematodes, particularly those, like C. lingua, whose definitive hosts are fish-eating birds. Metacercariae of such worms encyst beneath the skin or in the bodies of inshore fishes. Metacercariae of C. lingua were embedded in the body surface and gill filaments where, surrounded by melanin, they were easily seen as black spots (Plate 5).

From table 3.3.4 it should be noted that of 685 whiting examined, 46.0 percent were infected, 28.6 percent carrying fewer than 25 cysts each. In comparison, infection was heavier in pouting in two respects; firstly, a higher percentage (62.9 percent) was infected and secondly, although

Table 3.3.4 Incidence and intensity of C. lingua infection on whiting, pouting, plaice and flounder

	Whiting	Pouting
Number of fish examined	685	356
Number infected	315	224
% infected	46.0	62.9
Number of metacercariae	5671	13803
Number of parasites per infected fish	18.0	61.6
% fish with 0 metacercariae	54.0	37.2
<25 "	28.6	25.0
25-100 "	15.3	16.8
100-250 "	2.2	11.5
250-500 "	-	5.9
>500 "	-	3.6
	Plaice	**Flounder**
Number of fish examined	441	420
Number infected	244	299
% infected	55.3	71.2
Number of metacercariae	997	7150
Number of parasites per infected fish	4.1	23.9

only 25.0 percent carried fewer than 25 metacercariae, 3.6 percent had 500 or more cysts each on the body surface. This density was higher than for any of the other fish species investigated.

C. lingua occurred most frequently on flounder, 71.2 percent. Plaice were less heavily infected and with only 4.1 cysts per infected fish, parasite density was the lowest for the four hosts.

(ii) Seasonal changes in incidence and intensity of infection

In whiting (fig. 3.3.5), percentage incidence reached 96.2 percent in November 1973, with a comparable level of infection in January 1975. However, monthly samples were generally variable, infection fluctuating by 73 percent between September and October 1974. Intensity exhibited

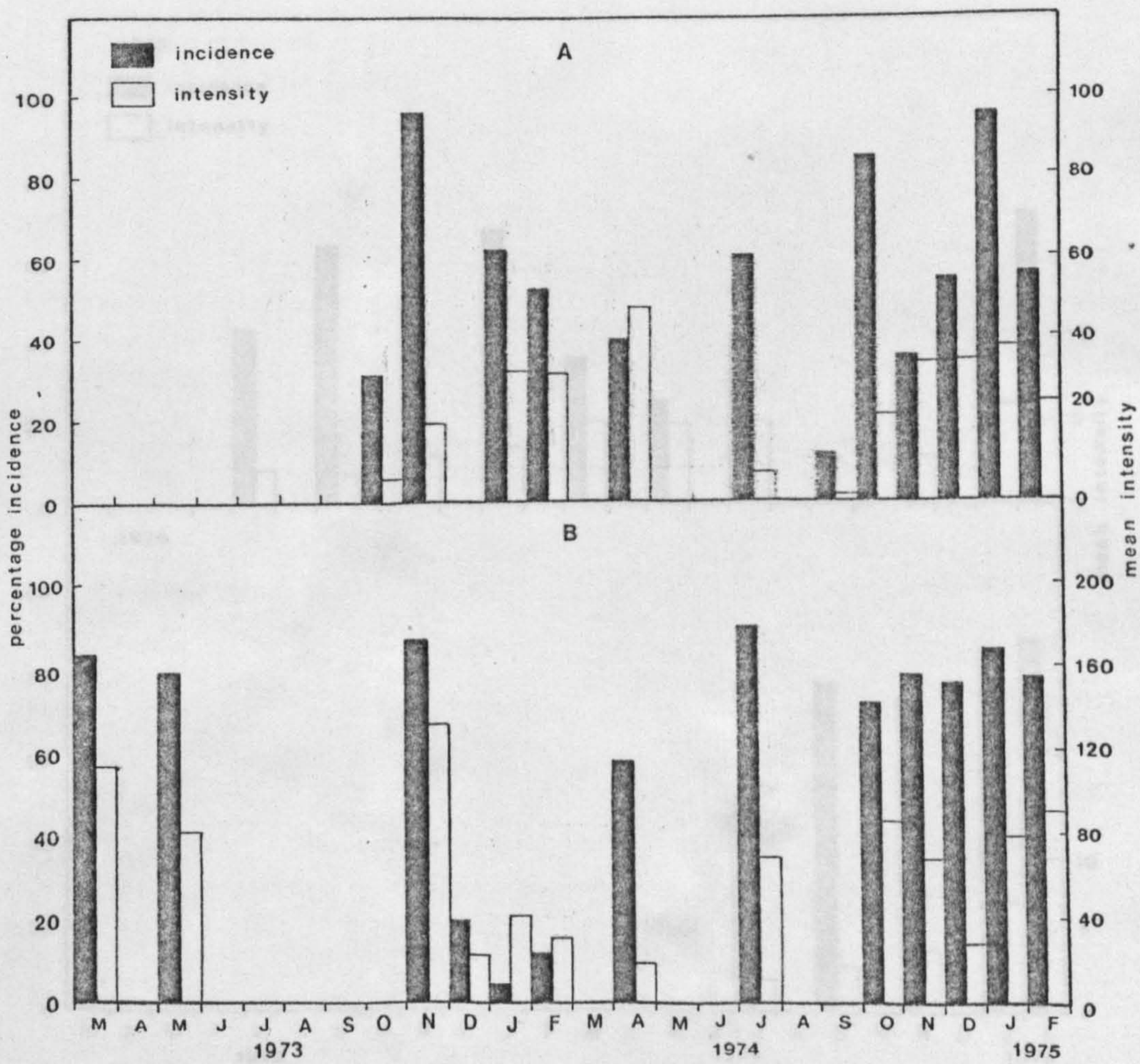


Fig. 3.3.5 Infection of Cryptocotyle lingua on A. whiting and B. pouting during 1973–75

no such short-term variation. Individuals with the highest parasite densities were recovered in April 1974 which contrasted sharply with a fall in frequency at this time.

Pouting results were more regular; greatest numbers of uninfected individuals were taken in January 1974, after which infection rose rapidly to reach a plateau of mean 79.0 percent in July. The rapid fall in December 1973 was not repeated the following year although there was a reduction in parasite density during this period.

The incidence of C. lingua on plaice also remained fairly constant over the annual cycle (fig. 3.3.6). Infection rose from 43.3 to 68.2 percent between July 1973 and January 1974 which, in both year-classes, was comparable with the following year.

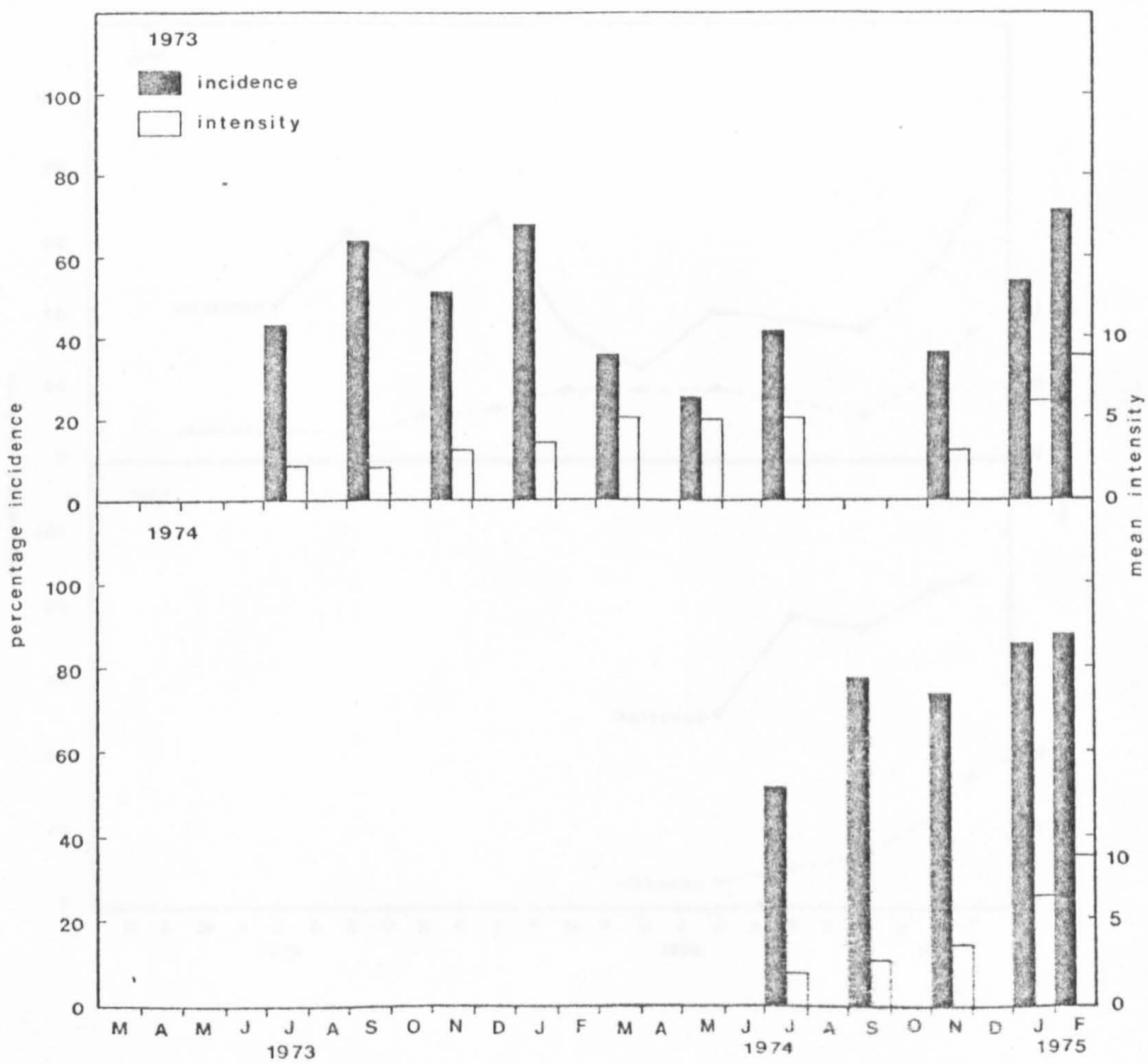


Fig. 3.3.6. Infection of Cryptocotyle lingua in 1973 and 1974 year-classes of Plaice

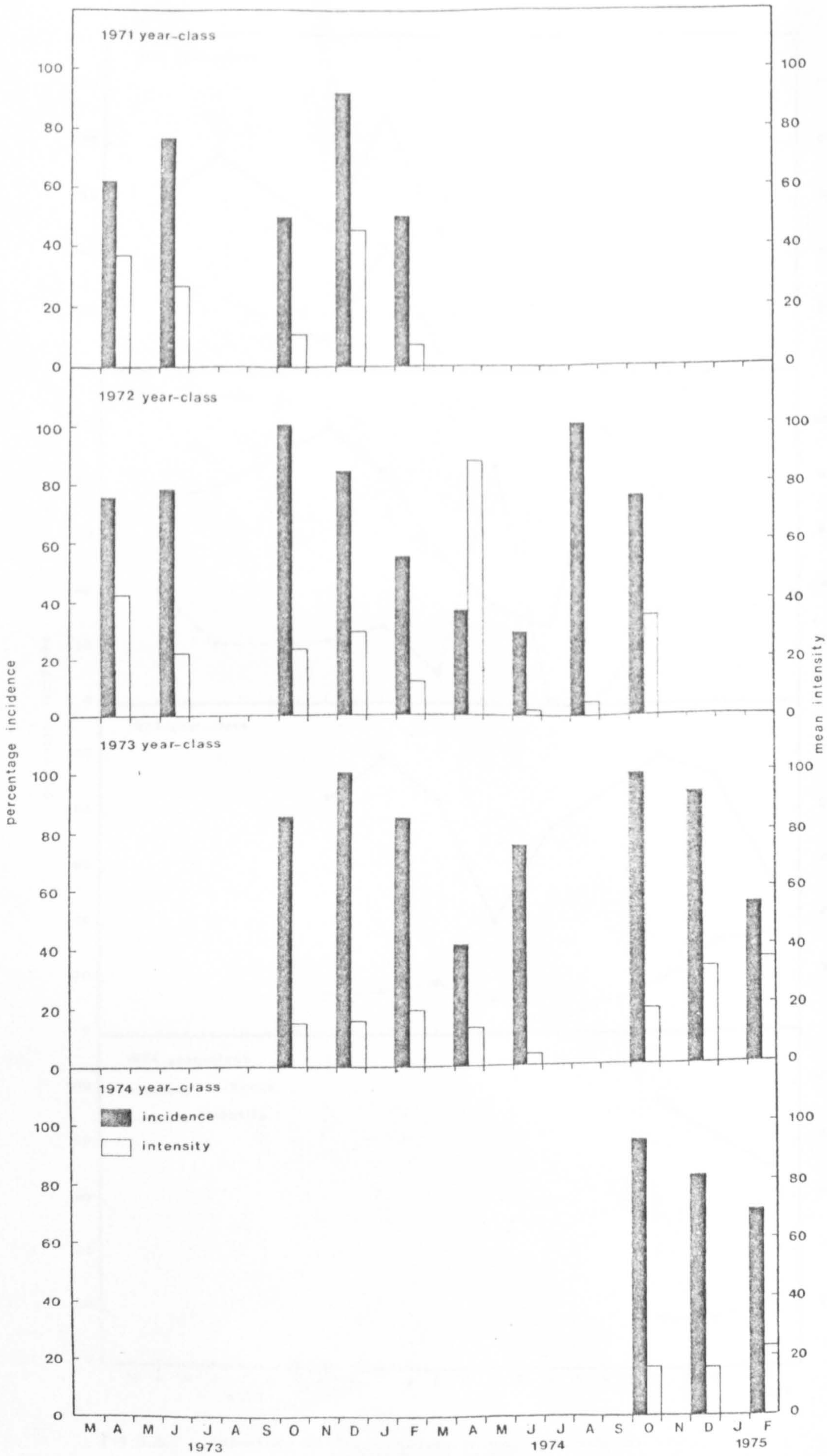


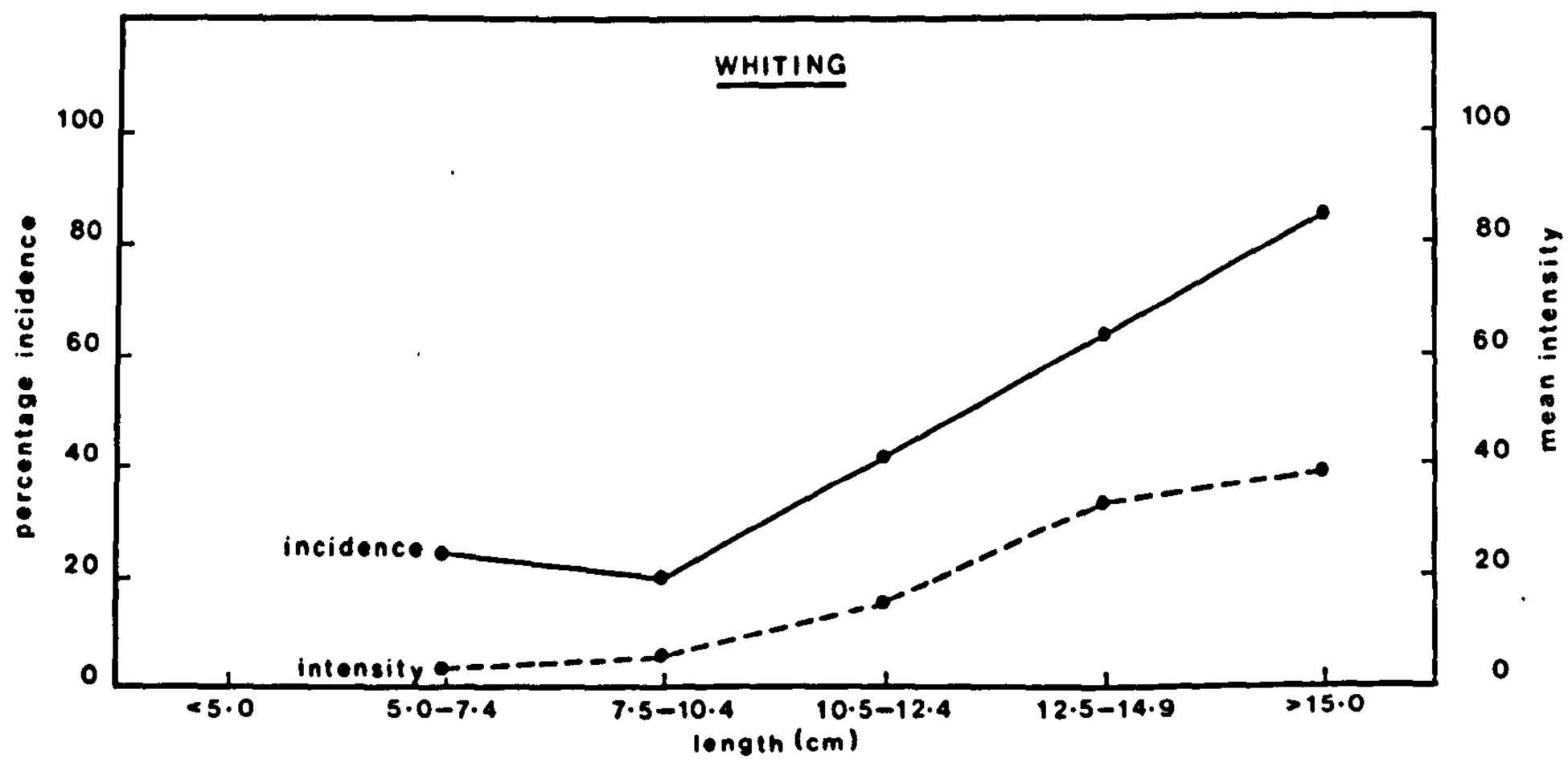
Fig.3.3.7 Infection of Cryptocotyle lingua on flounder during 1973-75

Flounders, on the other hand, exhibited greater seasonal fluctuations (fig. 3.3.7). Level of infection approached 100 percent between October and December and then fell to a minimum (28.6 percent in 1972 year-class fish) in spring or early summer. Intensity also followed this pattern with one deviation in the 1972 year-class showing how results can be distorted by a single heavily-infected individual.

(iii) Changes in infection with size and age of host

C. lingua parasitized all size-classes of whiting and pouting examined (fig. 3.3.8) and in both cases incidence of infection and length of host were highly correlated ($P<0.001$). In whiting, infection was low (less than 25 percent) in individuals under 10.5 centimetres but beyond this size incidence and intensity rose rapidly, the former reaching 85.3 percent in fish over 15.0 centimetres. Pouting were more variable and incidence of infection decreased in fish between 15.0 and 20.0 centimetres. However, intensity was high, especially in the largest individuals.

Flatfish, in contrast to gadoids, showed no relationship between occurrence of C. lingua and age of host (figs. 3.3.6 and 3.3.7, p.85 and 86,, table 3.3.5, p89). 0-group flounders had a high level of infection (90.1 percent) but only 21.1 percent of these carried more than 25 cysts each. Older fish were rather more variable with both incidence and intensity fluctuating.



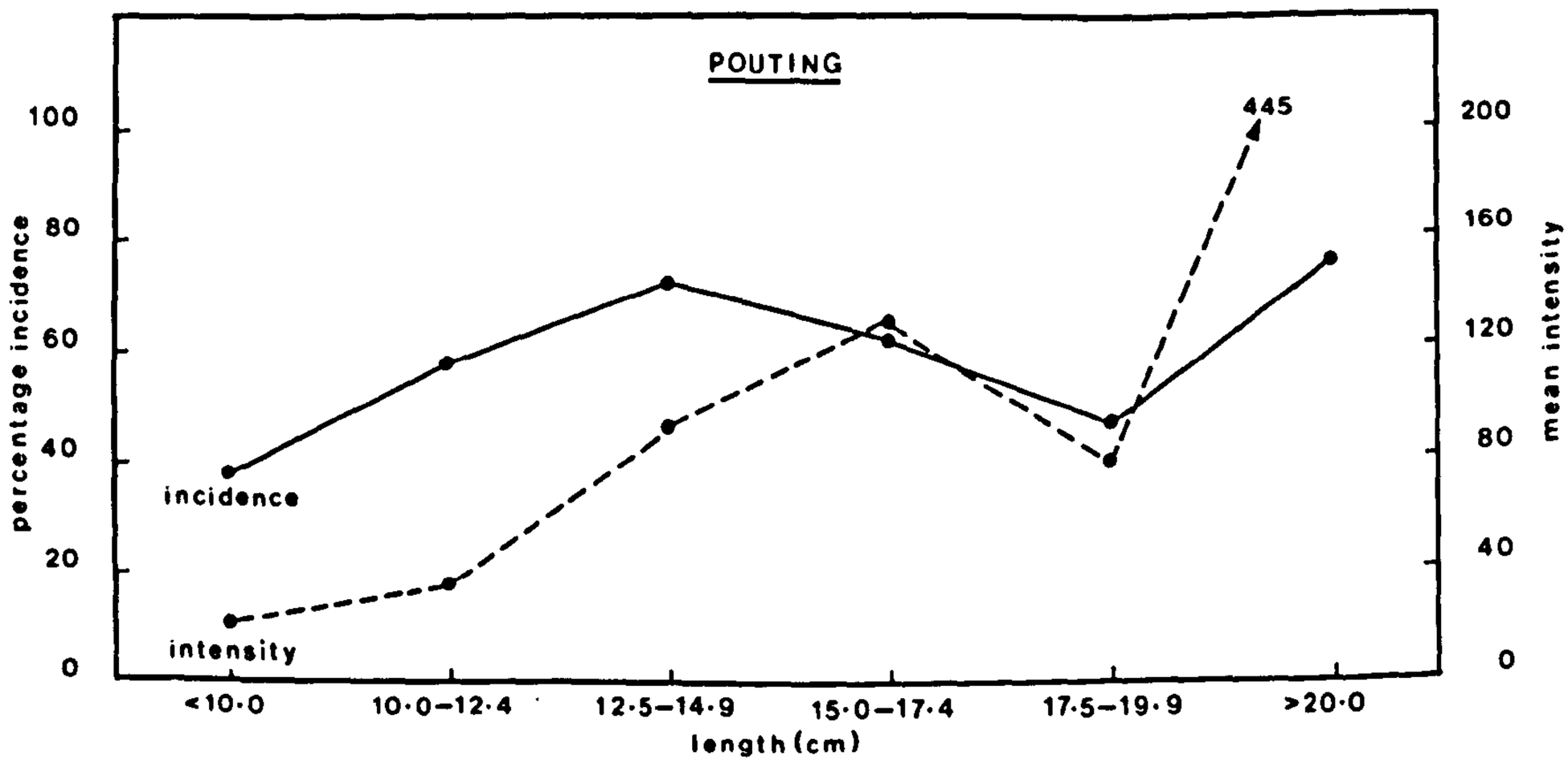


Fig.3.3.8 Cryptocotyle lingua on whiting and pouting; variation of infection with length of host

Table 3.3.5 Variation of Cryptocotyle lingua infection with age of flounder host

	Age class of fish (years)				
	0	1	2	3	4/5
No. of fish examined	71	184	129	31	5
No. infected	64	139	74	18	4
% frequency of infection	90.11	75.5	57.4	58.1	80.0
No. of metacercariae: ocular side	624	1,982	1,870	156	87
blind side	402	1,285	654	62	28
total	1,026	3,267	2,524	218	115
Percentage flounder with					
0 metacercariae	9.9	24.5	42.6	41.9	20.0
<25 "	69.0	56.9	37.2	45.7	40.0
25 - 100 "	21.1	15.9	14.6	12.4	40.0
100 - 250 "	-	2.7	4.9	-	-
250 - 500 "	-	-	-	-	-
>500	-	-	0.8	-	-

(iv) Distribution

In pleuronectids, metacercariae were not randomly distributed over the body surface (table 3.3.6). A significantly larger number occurred on the ocular side (χ^2; $P<0.001$) with parasites concentrated on either side of the lateral line canal (zones B and C, fig. 3.2.1, p65). However, infection was heaviest in the fins with numbers significantly greater than on the rest of the body surface (χ^2; $0.20>P>0.05$).

Table 3.3.6 Distributions of C. lingua metacercariae in the integuments of 0-group flounders and 0- and 1-group plaice

Location	Plaice		Flounders	
	Numbers of Parasites	% of Total	Numbers of Parasites	% of Total
Zone A	28	3.1	91	4.1
B	113	12.4	406	18.1
C	113	12.4	310	13.9
D	39	4.3	114	5.1
E	21	2.3	18	0.8
F	17	1.9	65	2.9
G	14	1.5	62	2.8
H	26	2.8	28	1.3
caudal fin	337	36.8	624	27.9
dorsal and ventral fins	207	22.6	521	23.3
ocular surface	293	32.0	921	41.1
blind surface	78	8.5	173	7.7
fins	544	59.5	1145	51.1

Gill filaments were more heavily infected than subcutaneous tissues of the body (fig. 3.3.9). The difference between numbers of cysts on the gills from ocular and blind surfaces was not significant in either plaice (χ^2; $0.95>P>0.90$) or flounder (χ^2; $0.80>P>0.50$). In both cases filaments on the fourth gill bar were the least likely infection sites (table 3.3.7).

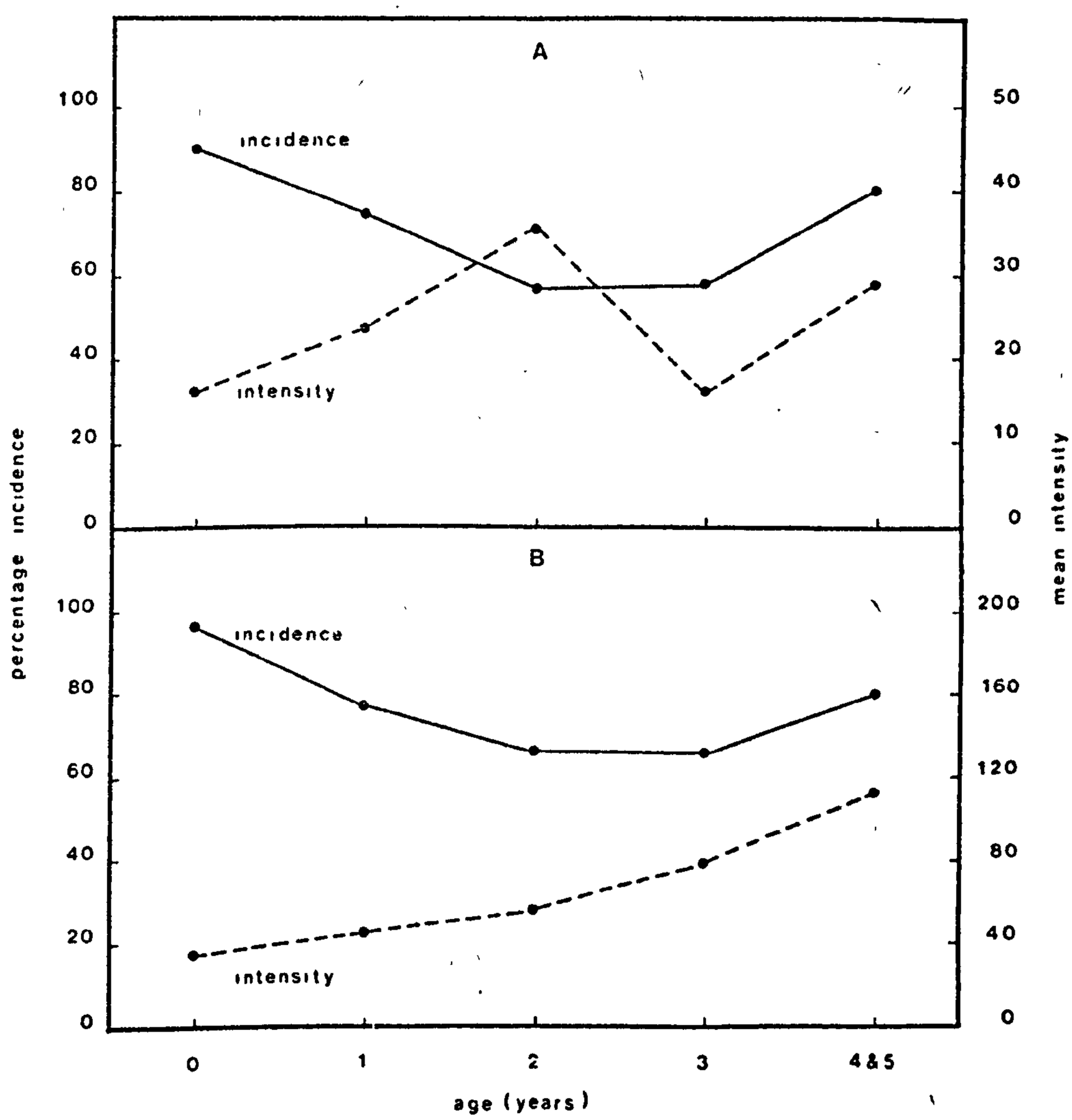


Fig.3.3.9 Infection of Cryptocotyle lingua on flounder; metacercariae within the integument of A. the body surface, B. the gill arches

Table 3.3.7 Distribution of C. lingua metacercariae on gill filaments of total plaice and flounders

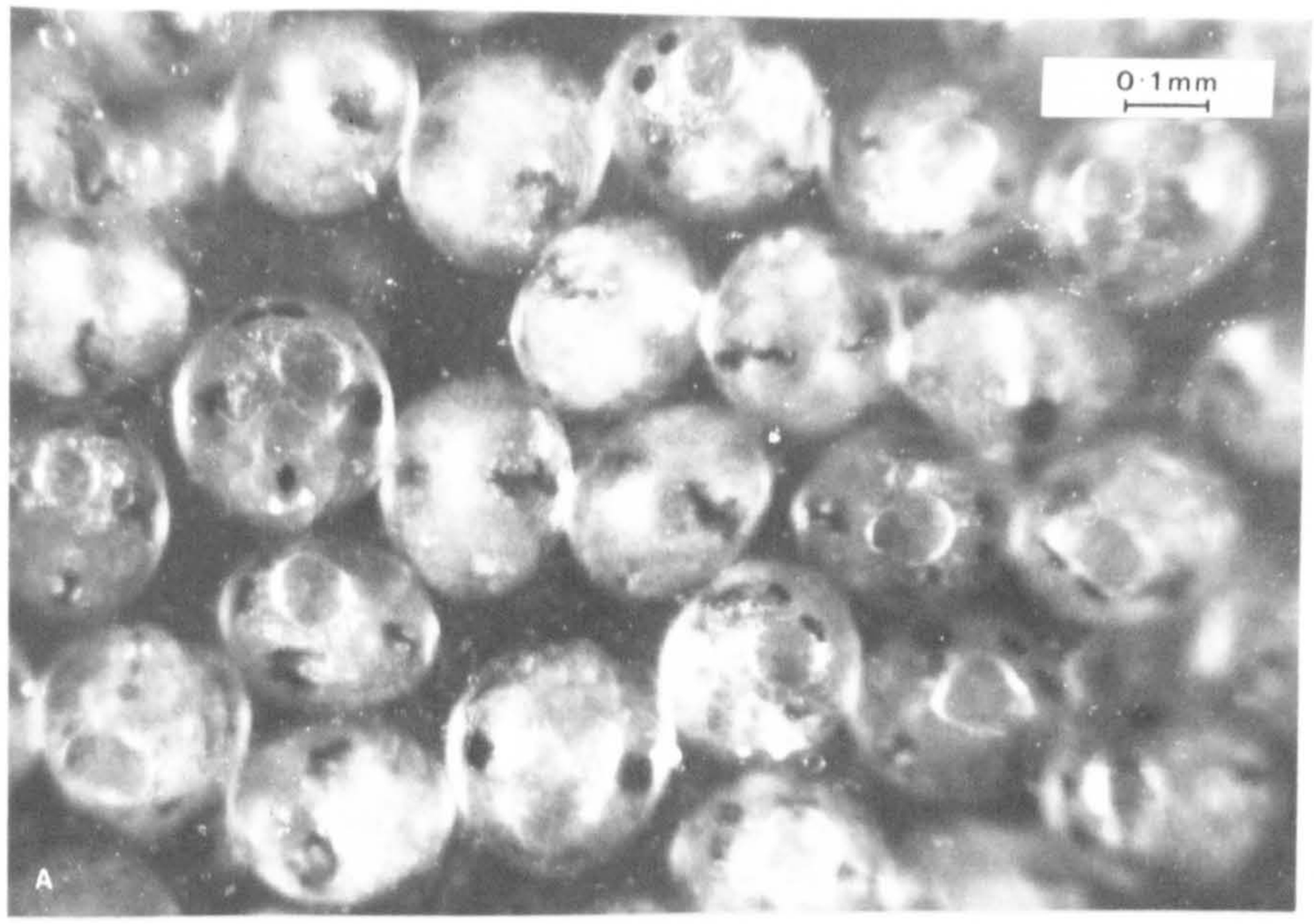
Location		Number of parasites		Percentage of total	
		Ocular	Blind	Ocular	Blind
Plaice					
Gill arch	1	133	160	12.0	14.4
	2	217	184	19.6	16.6
	3	152	137	13.7	12.3
	4	59	67	5.3	6.0
	Total	561	548	50.5	49.4
Flounder					
Gill arch	1	1858	1802	12.2	11.9
	2	2638	2431	17.4	16.0
	3	2276	2034	15.0	13.4
	4	1119	1012	7.4	6.7
	Total	7891	7279	51.0	48.0

(b) Crustacean parasites infecting gadoids and pleuronectids

Lernaeocera branchialis (L.) (Copepoda: Lernaeoceridae)

Plates 6-8 show various stages of the parasite's complex life-cycle and which is unusual in that an intermediate, as well as a definitive vertebrate host, is required for its completion. Hatching eggs (Plate 6A) yield nauplii which develop into male and female copepodids (Plate 6B). Copulation (Plate 6C) on the intermediate host (flounder) is followed by infection of the definitive host (whiting) where metamorphosis (Plate 7) produces the distinctive gravid adult (Plate 8).

In the following discussion the terms larva, immature and mature adults were adopted for various life-cycle stages. 'Larva' includes all stages on flounder while the term 'immature adult' refers to post-copulation females which infect whiting (Plate 7). 'Mature adults' are those individuals, parasitic solely on gadoids, that have undergone



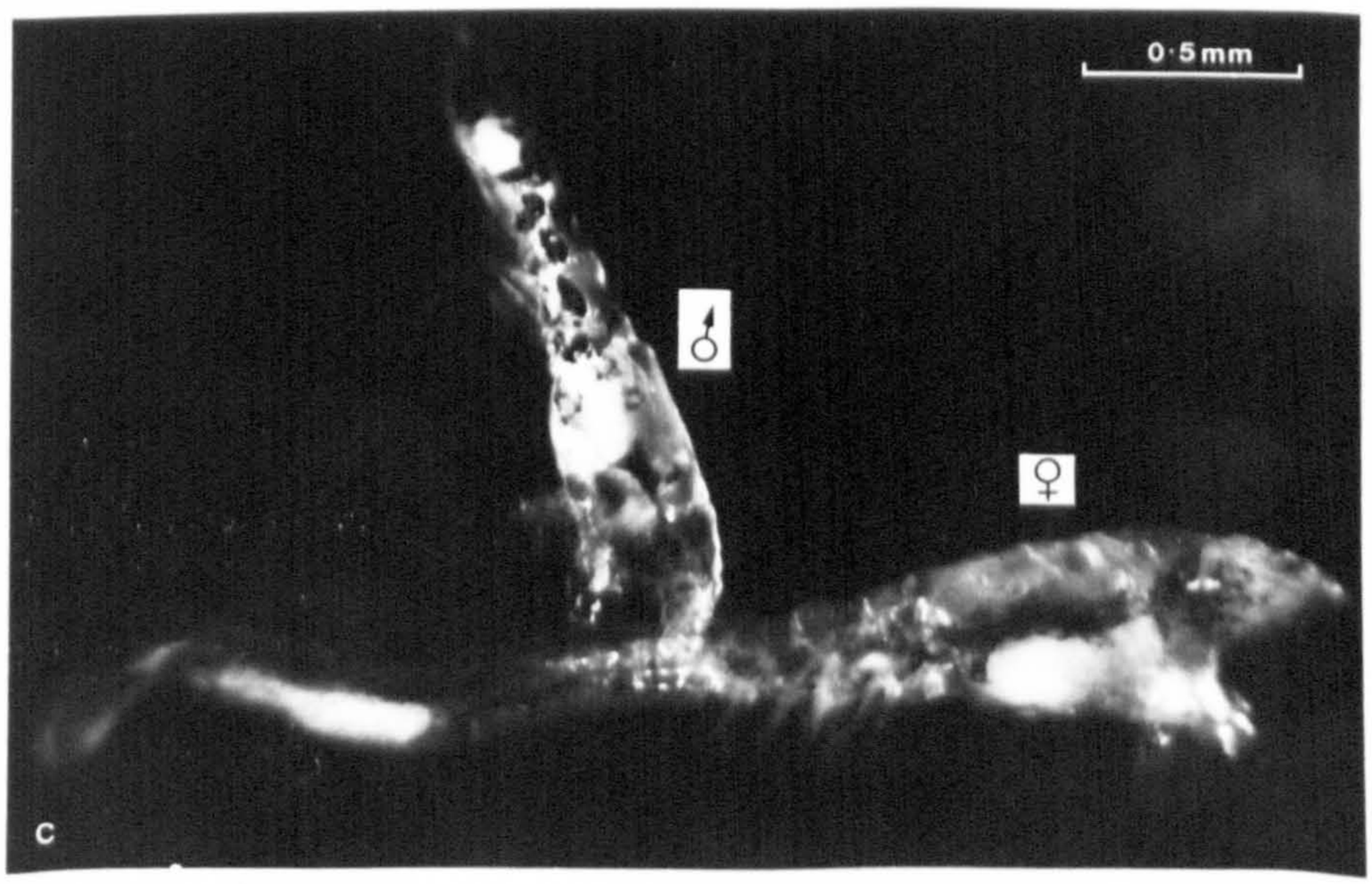
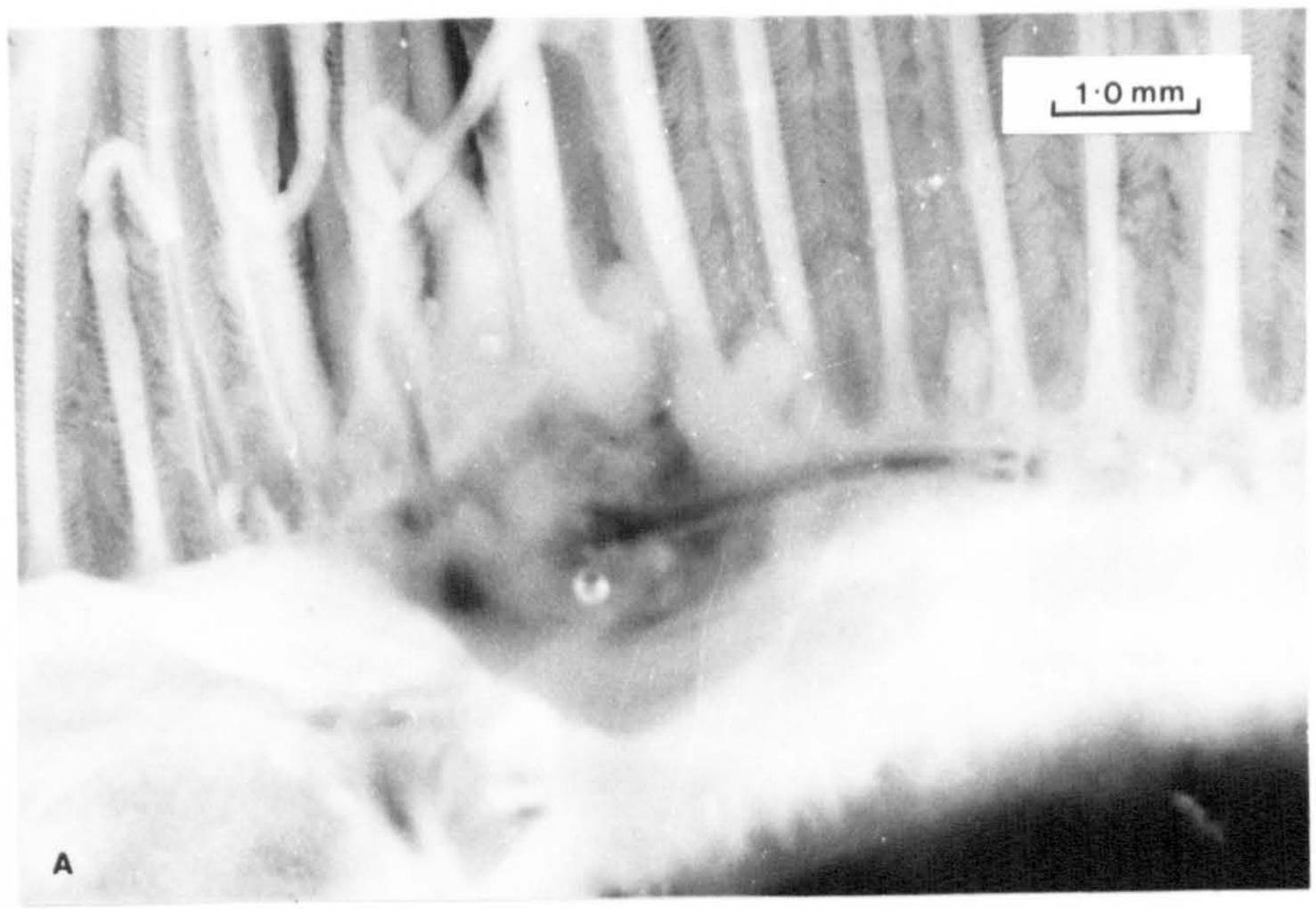


Plate 6 Lernaeocera branchialis; life-cycle stages

A. eggs containing nauplius larvae

B. male and female copepodids attached to gill filaments of flounder

C. copulating copepodids removed from a flounder gill



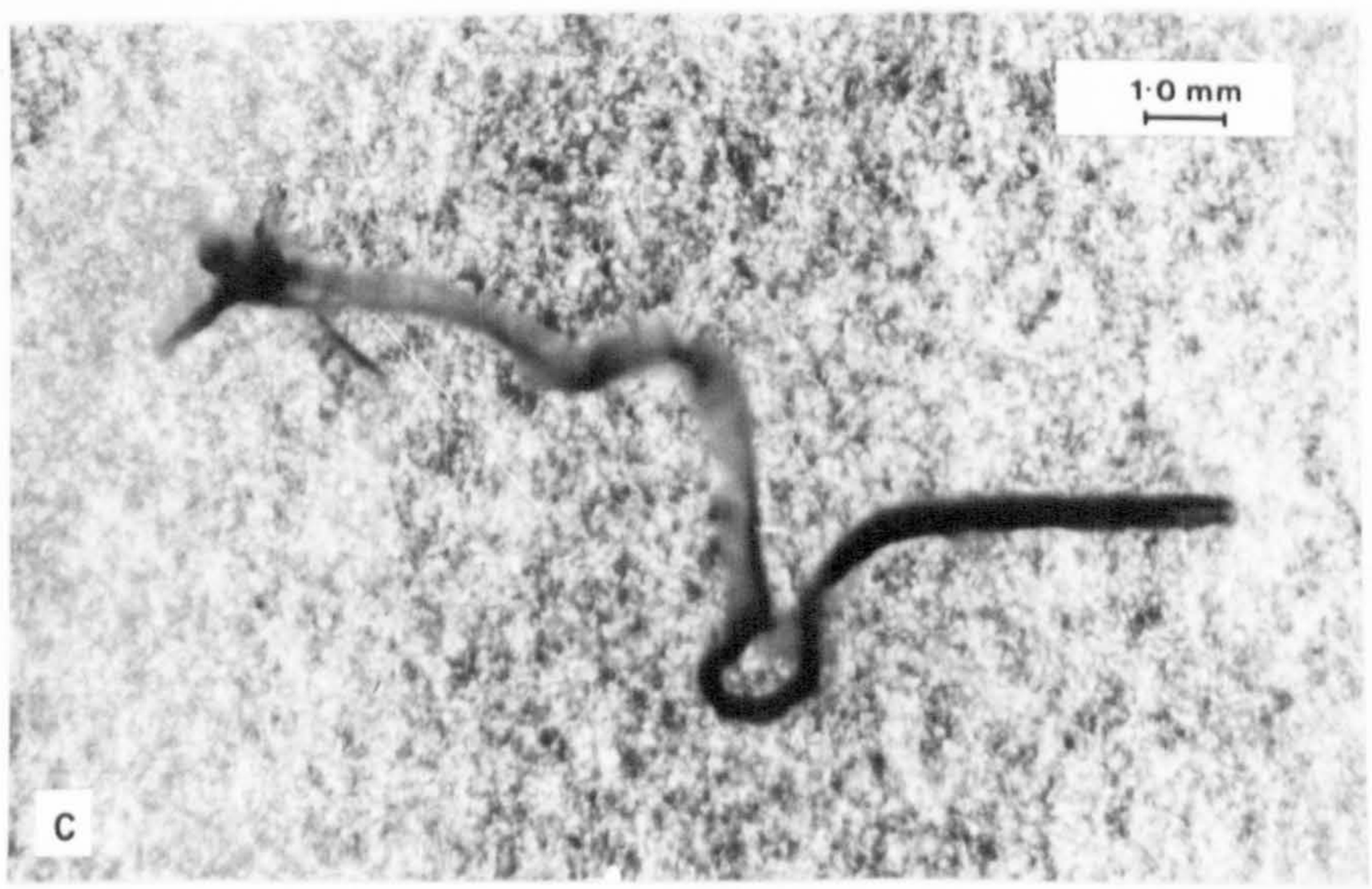


Plate 7 L. branchialis; life-cycle stages

A. post-copulation female undergoing metamorphosis within a gill-arch of whiting

B.&C. more advanced stages of development from whiting

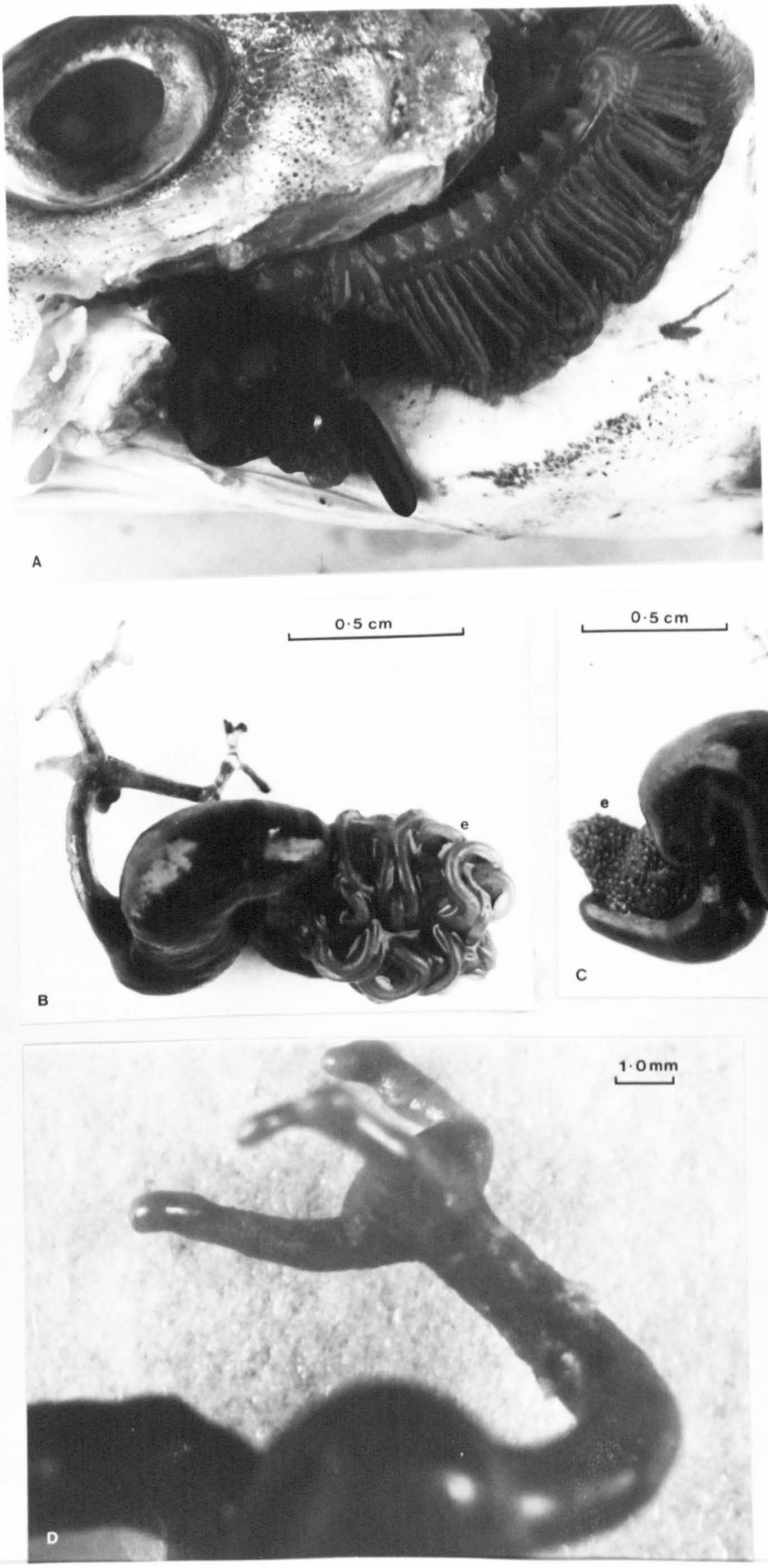


Plate 8 L.branchialis; life-cycle stages

A. gravid female in situ on whiting (operculum removed)

B. & C. gravid females showing stages in development of egg-strings (e)

D. detail of cephalothorax ('holdfast')

metamorphosis past initial flexure of the abdomen (Plates 7C and 8). At this stage of development the parasite has reached its final location in the blood-system, an activity likely to elicit a detectable response from the host. Division of the life-cycle on this basis has been applied previously (Kabata, 1958) and was particularly useful when the biochemical effects of L. branchialis were considered (see section 3.2.2, p66).

(i) Incidence and intensity of infection

Larvae occurred on the gill filaments of 96.7 percent flounders examined. Intensity of infection was also high with a mean 64.9 parasites per infected fish.

Of 659 whiting examined (table 3.3.8) 40.4 percent were infected with either stage. As many as five mature adults were found on one fish and 12.0 percent of all whiting carried more than one parasite.

Table 3.3.8 Infection of L. branchialis on whiting

Number of fish examined		659	
Number infected		266	
% infected		40.4	
Number of parasites		399	
Number of parasites per infected fish		1.5	
		Immature adults	mature adults
% of fish with	1 parasite	15.2	13.1
	2 "	6.4	3.5
	3 "	1.0	0.3
	4 "	0.4	0.1
	5 "	-	0.1
	7 "	0.1	-

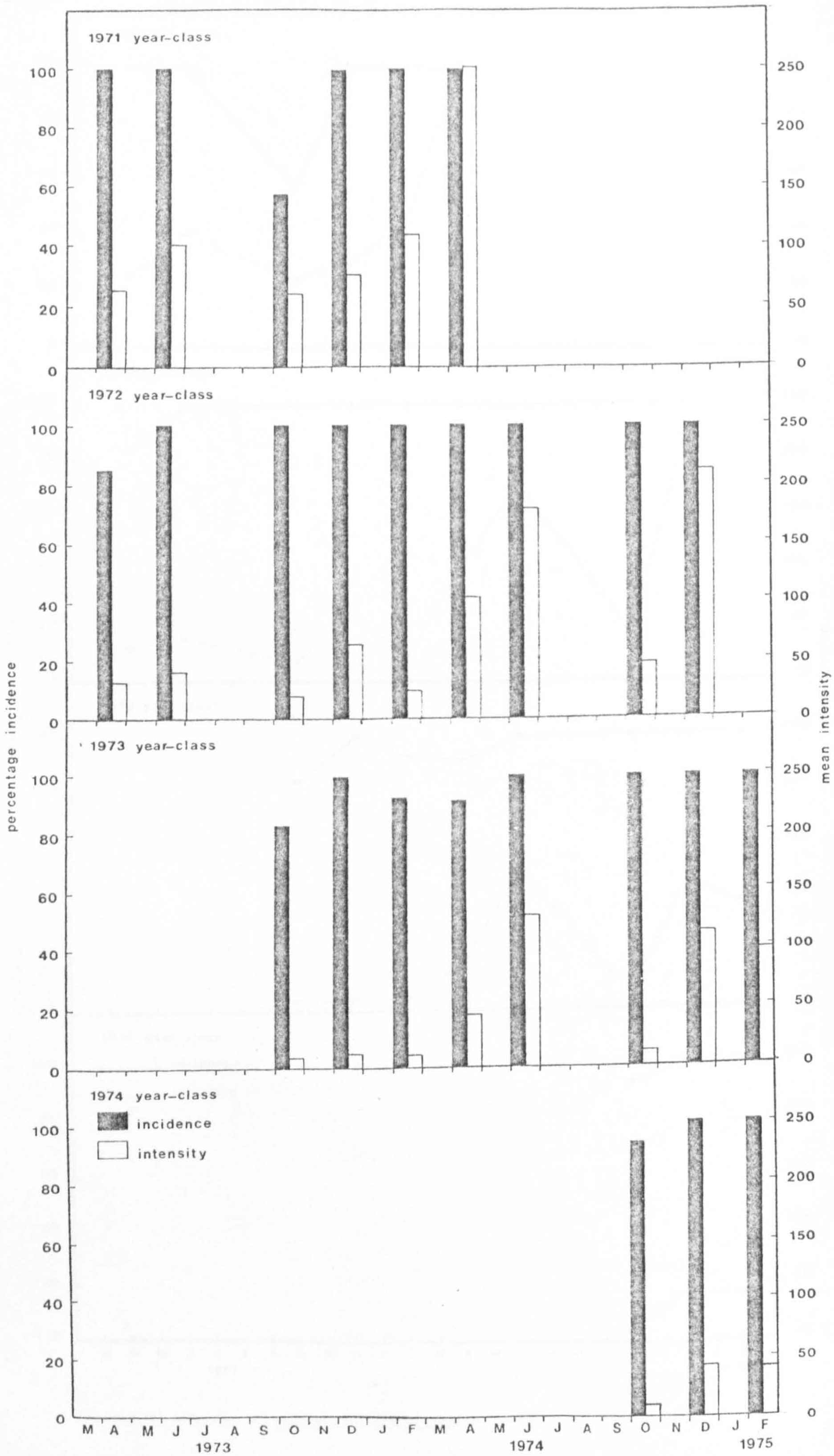


Fig. 3.3.10 Infection of Lernaeocera branchialis on flounder during 1973-75

(ii) Seasonal changes in incidence and intensity

Infection of flounders was high throughout the sampling period and total infection of the monthly samples was a regular occurrence (fig. 3.3.10). There was a suggestion of a seasonal pattern with two annual peaks of intensity in June and December. However, these maxima were only clearly observed in 1974 and were less pronounced in 1973.

In whiting (fig. 3.3.11A), infection exhibited similar seasonal fluctuations to flounder and a temporal relationship between the parasite's occurrence on its two hosts was apparent. Figure 3.3.11B shows that initial infection of the gadoid population, in November, was followed by an increase in the incidence of mature adults and these reached their peak some three or four months later. However, a second outbreak of infection did not lead to a similar increase in mature adults and their numbers declined throughout spring and early summer.

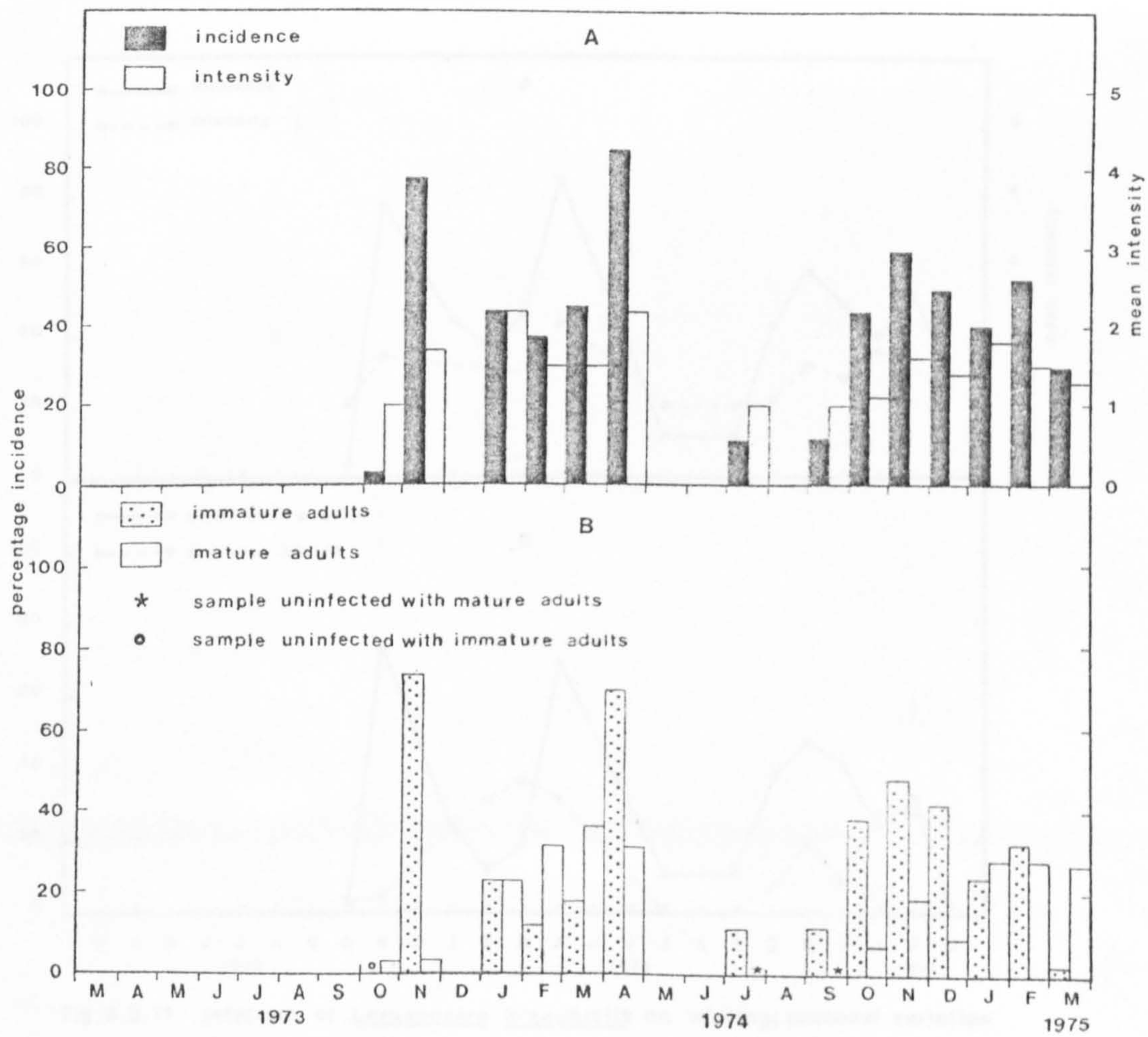


Fig. 3.3.11 Infection of Lernaeocera branchialis on whiting during 1973 - 75; variation of A. combined adult life cycle stages
B. separate adult stages

(iii) Changes in infection with size and age of host

In whiting (fig. 3.3.12), incidence of infection increased rapidly from 1.8 percent in fish below 7.5 centimetres to 56.1 percent in individuals between 12.5 and 14.9 centimetres. There was a slight decrease beyond this length but intensity continued to rise to a maximum 1.6 parasites per infected fish.

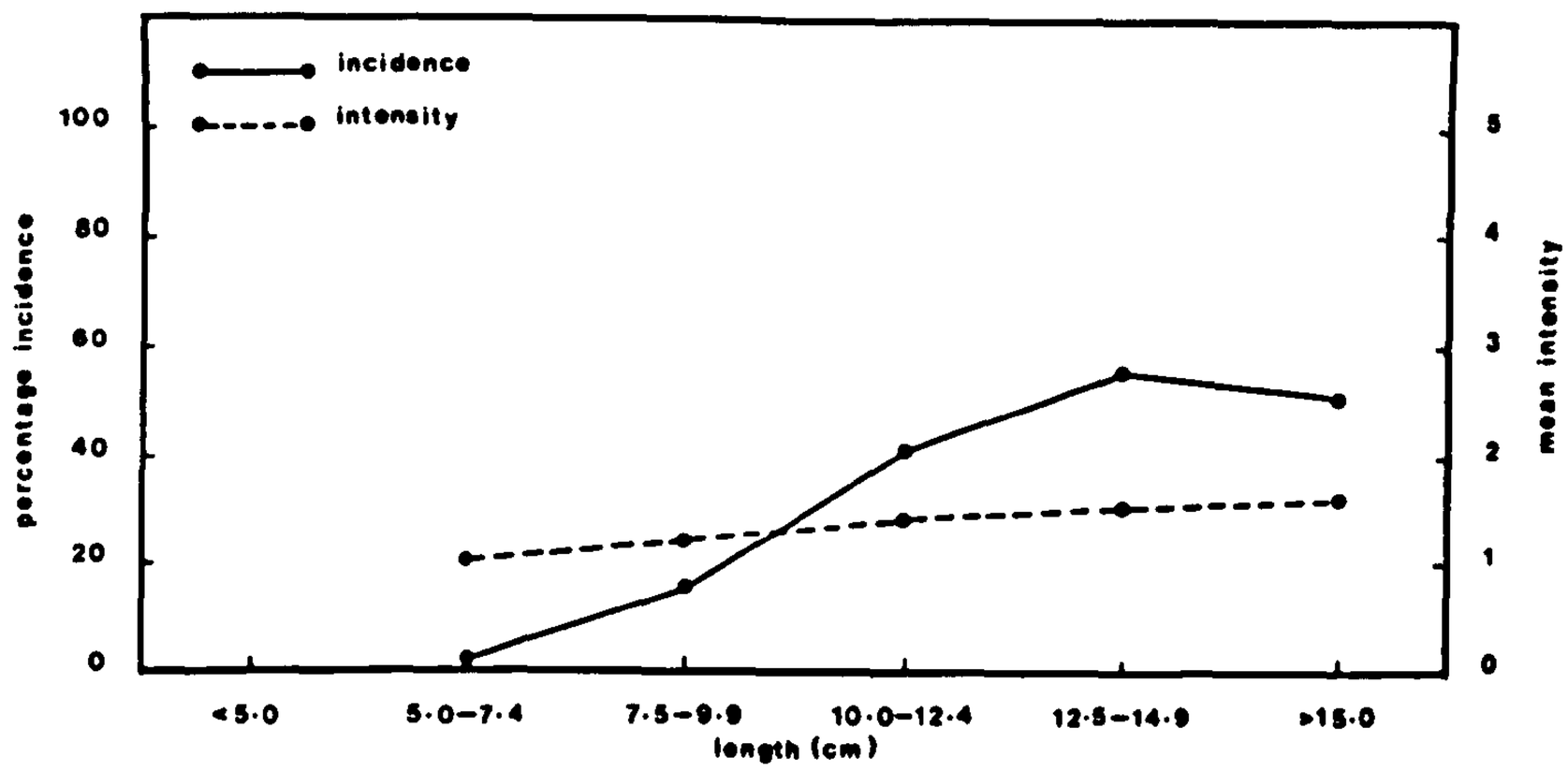


Fig. 3.3.12 Lernaeocera branchialis on whiting; variation of infection with length of host

In contrast, the level of infection in flounder showed little variation with age (table 3.3.9) but mean intensity increased rapidly from 20.7 in 0-group fish to 149.8 in 3-group individuals. The combined 4 and 5 year-olds showed some reduction from this value but their group was so small in numbers that the validity of this result is doubtful.

Table 3.3.9 Variation of L. branchialis infection with age of flounder

	Age class of fish (years)				
	0	1	2	3	4/5
Number of fish examined	69	187	127	31	5
Number infected	66	179	124	31	5
% frequency of infection	95.7	95.7	97.6	100	100
Number of parasites: ocular side	827	4795	6844	2869	308
blind side	537	3487	4576	1774	250
	1364	8282	11420	4643	558
Number of parasites per infected fish	20.7	46.3	92.1	149.8	111.6

(iv) Distribution

In flounder (table 3.3.10), there were significantly more larvae attached to the gill filaments of the ocular surface (χ^2; $P<0.001$) and numbers decreased steadily from gill arch one to four.

Table 3.3.11 shows that in whiting immature adults were most likely to infest the third gill arch (χ^2; $P<0.001$), then subsequently with an equal possibility of attaching to the second and fourth arches. Mature adults preferred the anterior of the branchial cavity; 73.8 percent were attached there.

Table 3.3.10 Distribution of L. branchialis larvae on gills of flounders (all ages)

Location	Number of parasites		Percentage of total	
	Ocular	Blind	Ocular	Blind
Filaments on gillarch				
1	6005	3961	22.9	15.1
2	4649	3277	17.7	12.5
3	3209	2328	12.2	8.9
4	1780	1040	6.8	4.0
Totals	15643	10606	59.6	40.4

Table 3.3.11 Distribution of L. branchialis in the branchial cavity of whiting

	Mature adults Branchial cavity			Immature adults Gill arch			
	Ant	Mid	Post	1	2	3	4
Number of parasites	31	4	7	12	32	124	45
% of total (immature or mature adults)	73.8	9.5	16.7	5.6	15.0	58.2	21.1

Lernaeocera lusci (Bassett-Smith)
(Copepoda: Lernaeoceridae)

(i) Incidence and intensity of infectión

Closely related to L. branchialis, L. lusci has a similar life-cycle with sole the intermediate and pouting the definitive host. Of 376 pouting examined, 14.9 percent were infected (table 3.3.12). Only mature adults were recovered, i.e. in the sense used to describe L. branchialis infections (p92). The majority of hosts carried only one parasite with four the maximum recorded.

Table 3.3.12 Infection of L. lusci on pouting

Number of fish examined	376
Number infected	56
% infected	14.9
Number of parasites	79
Intensity of infection (parasites per infected fish)	1.4
% of fish with 1 parasite	10.6
2 "	2.7
3 "	1.3
4 "	0.3

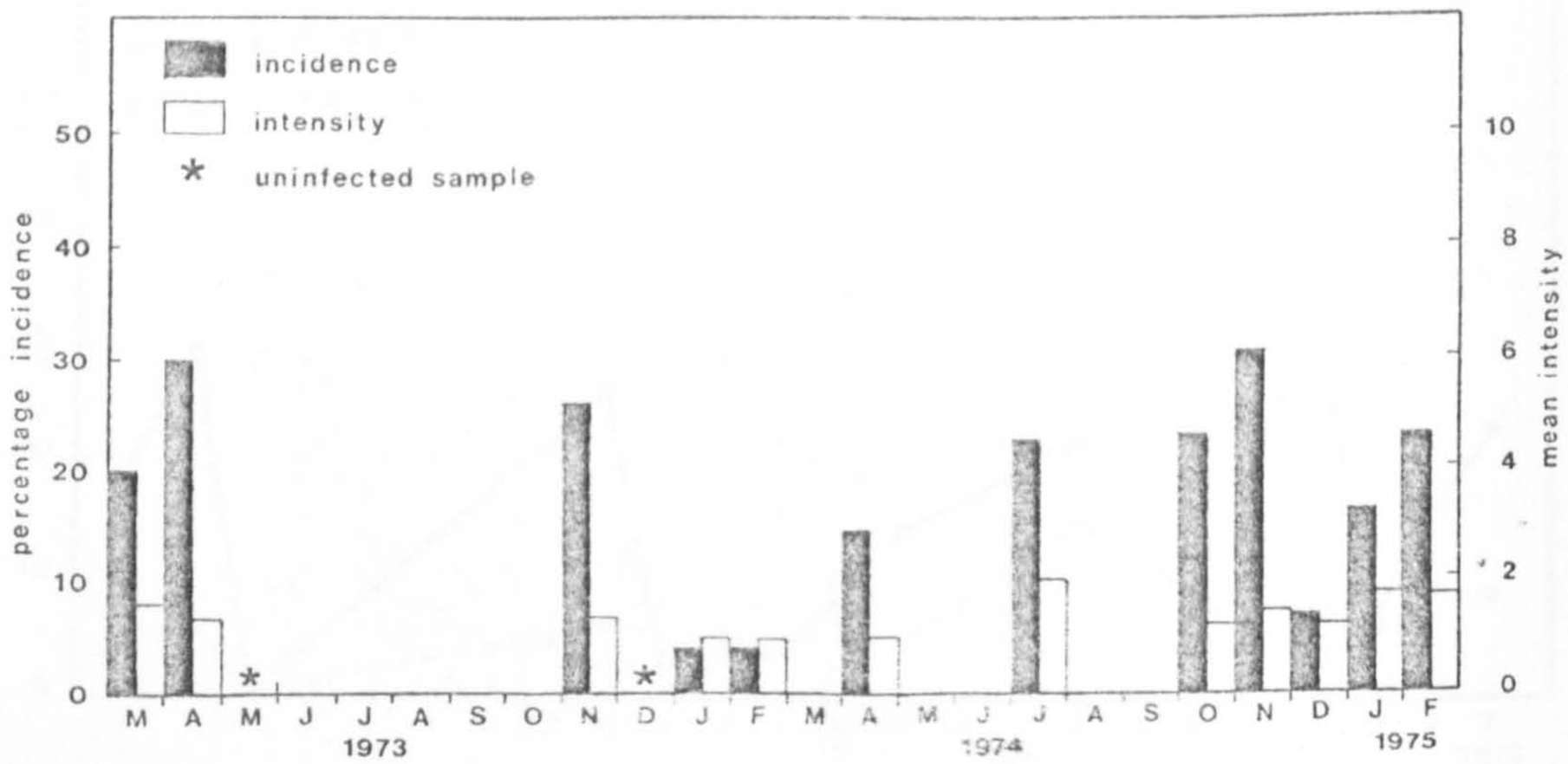


Fig. 3.3.13 Infection of Lernaeocera lusci on pouting during 1973-75

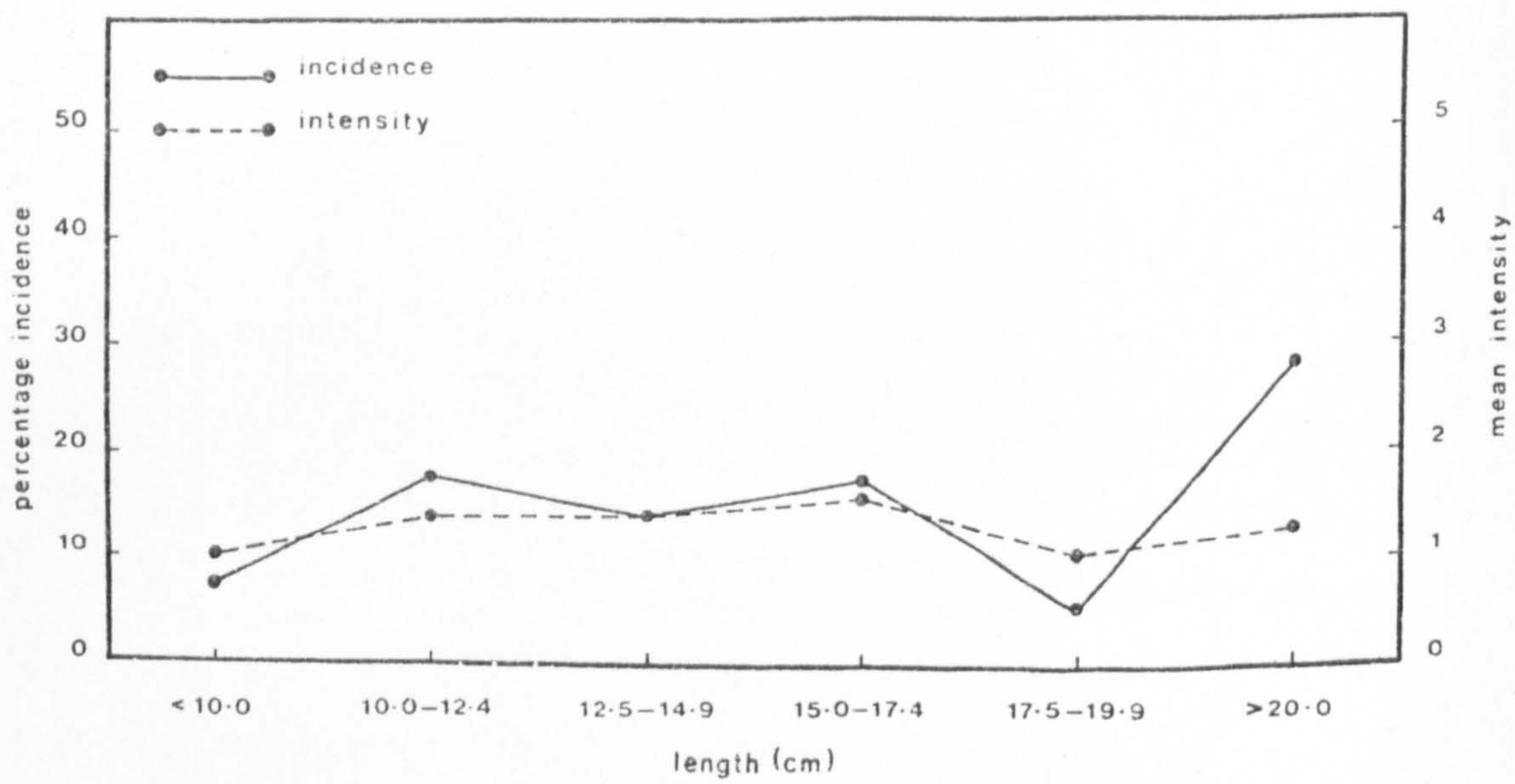


Fig. 3.3.14 Lernaeocera lusci on pouting; variation of infection with length of host

During 1974 the parasite's occurrence in the pouting population increased slowly from January to reach a maximum 30.4 percent infection in November (fig. 3.3.13). The degree of variation in intensity probably reflected the fact that, since percentage infection was generally low, a small number of heavily-infected pouting could significantly change the trend of this line at any time.

(ii) Changes in infection with size of host

Figure 3.3.14 shows that, in pouting under 20 centimetres, incidence of infection exhibited little change and was a mean 14.7 percent; beyond this length there was a sharp increase to 28.6 percent. It must be taken into account, however, that this was numerically the smallest group and the percentage only represents four fish.

(iii) Distribution

Unlike L. branchialis (p100), a majority of parasites was located on the gill arches. Of 56 parasites recovered there, 40 (71.4 percent) were attached to the first arch. A small number was also observed outside the branchial cavity, usually attached to the operculum although one protruded from the anus.

Clavella uncinata (Müller)
(Copepoda: Lernaeopodidae)

(i) Seasonal changes in incidence and intensity

In contrast to the lernaeocerids discussed above, the remaining parasites in this section have simple life-cycles involving single hosts. C. uncinata (Plate 9) infests whiting and, of 510 fish examined, 26.9 percent were parasitized (table 3.3.13, p106).

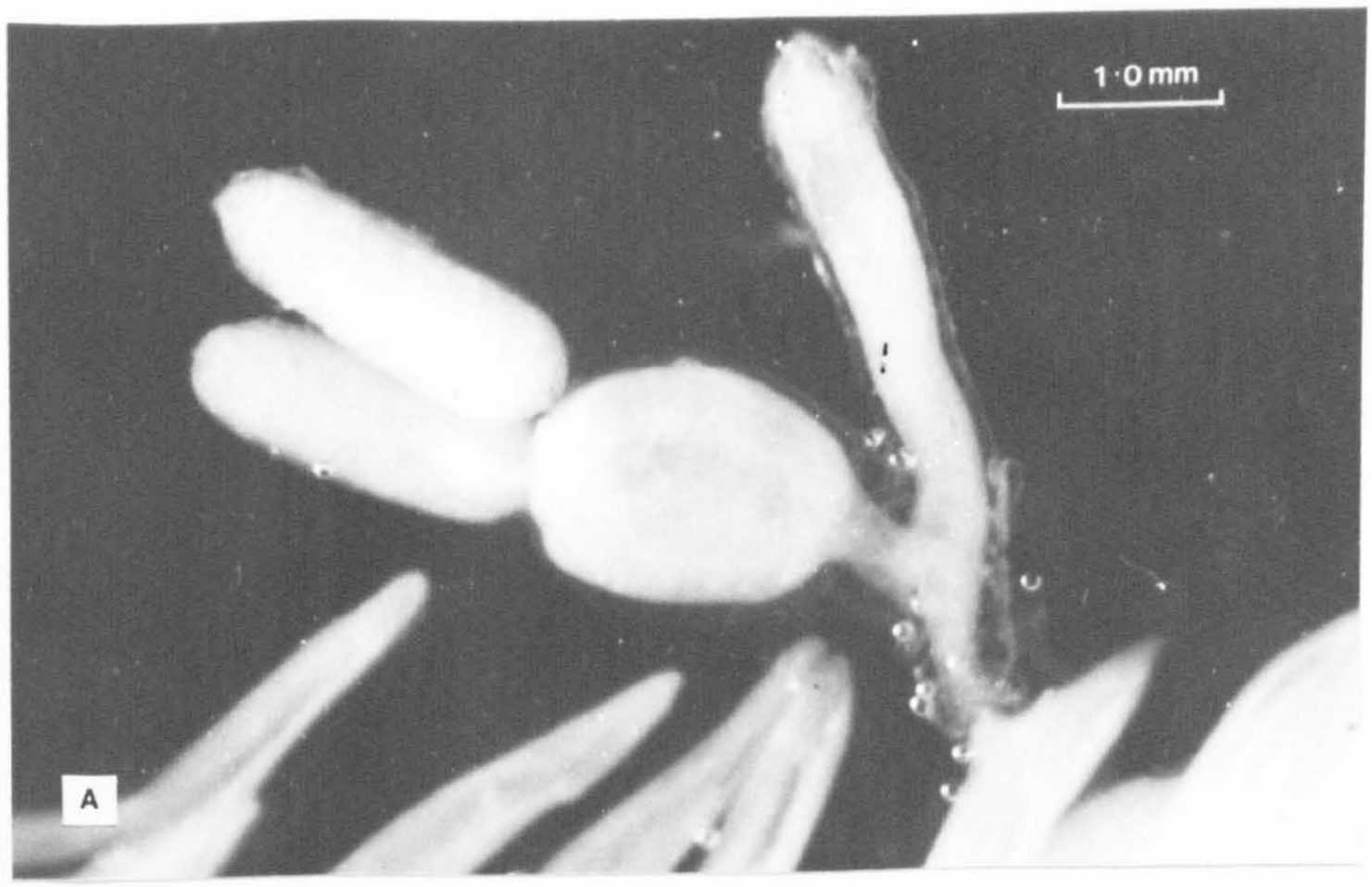


Plate 9 Clavella uncinata (Müller) infection on whiting

A. in situ on rakers of the first gill arch

B. detail of the cephalothorax

C. detail of the attachment disc, the bulla (b)

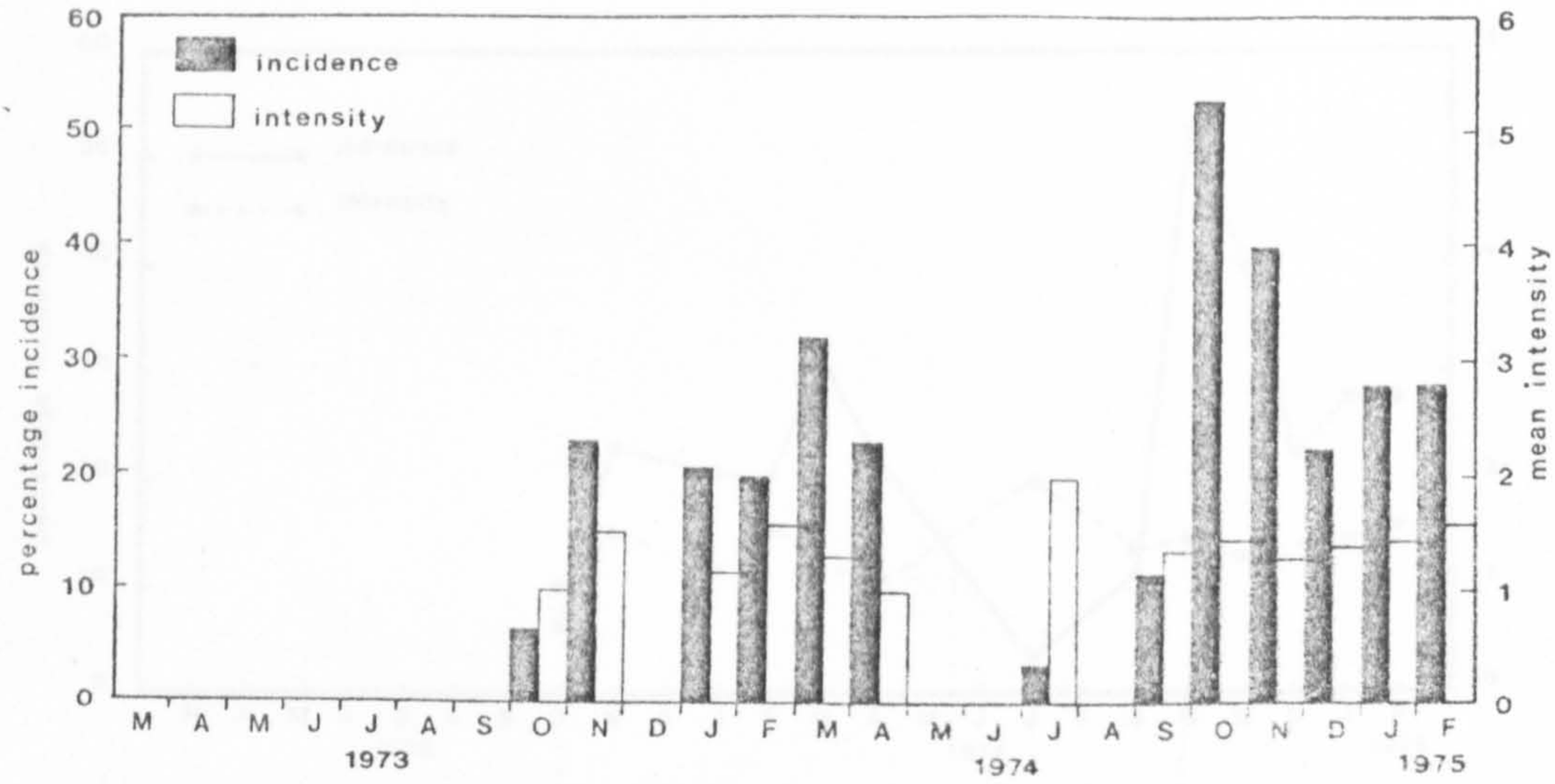


Fig. 3.3.15 Infection of Clavella uncinata on whiting during 1973–75

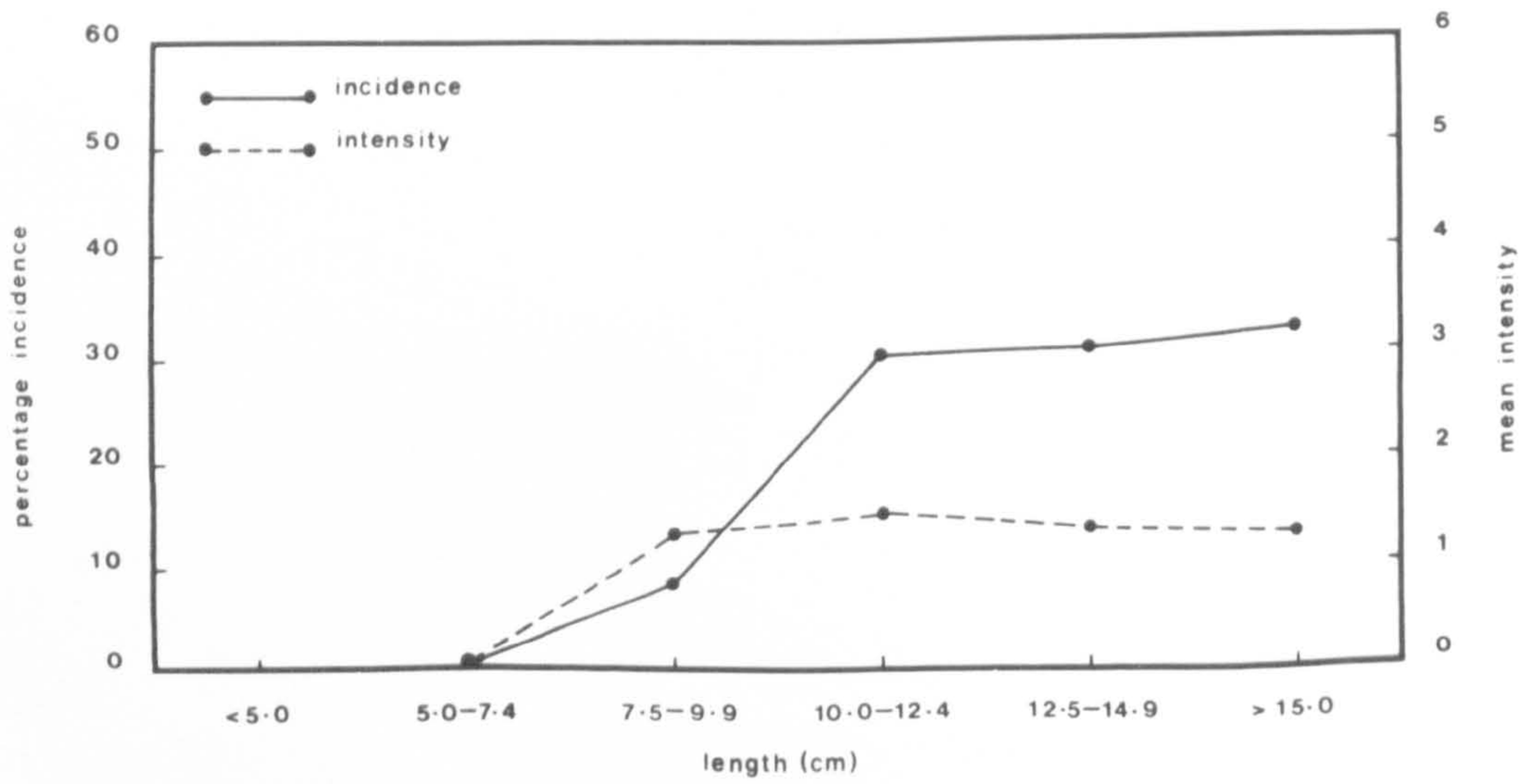


Fig. 3.3.16 Clavella uncinata on whiting; variation of infection with length of host

Table 3.3.13 Infection of C. uncinata on whiting

Number of fish examined	510
Number infected	137
% infected	26.9
Intensity of infection (parasites per infected fish)	1.4
% of fish with 1 parasite	18.8
2 "	6.3
3 "	1.6
4 "	-
5 "	0.2

Incidence of infection varied seasonally (fig. 3.3.15) and in 1973/74 fluctuated between 6.5 percent in October and 31.8 percent the following March. This cycle was repeated during the next season although the parasite occurred more frequently and, in October, infected 52.7 percent of whiting examined. With two peaks of infection per year, this pattern closely resembled that described for L. branchialis (p98).

The majority of whiting infested with C. uncinata carried only one parasite but 8.1 percent of all fish had multiple infections. Parasitic intensity showed little seasonal fluctuation.

(ii) Changes in infection with size of host

Figure 3.3.16 shows that incidence and intensity of C. uncinata on whiting appear to be related to host size up to 12.5 centimetres; there was little change beyond this length.

(iii) Distribution

Of the 192 parasites located, 67.2 percent were attached to the first gill arch (table 3.3.14). They were not randomly distributed but almost entirely restricted to the long gill rakers. Most of the remainder were attached to the wall of the branchial cavity and several of these lay along the edge of the buccal cavity.

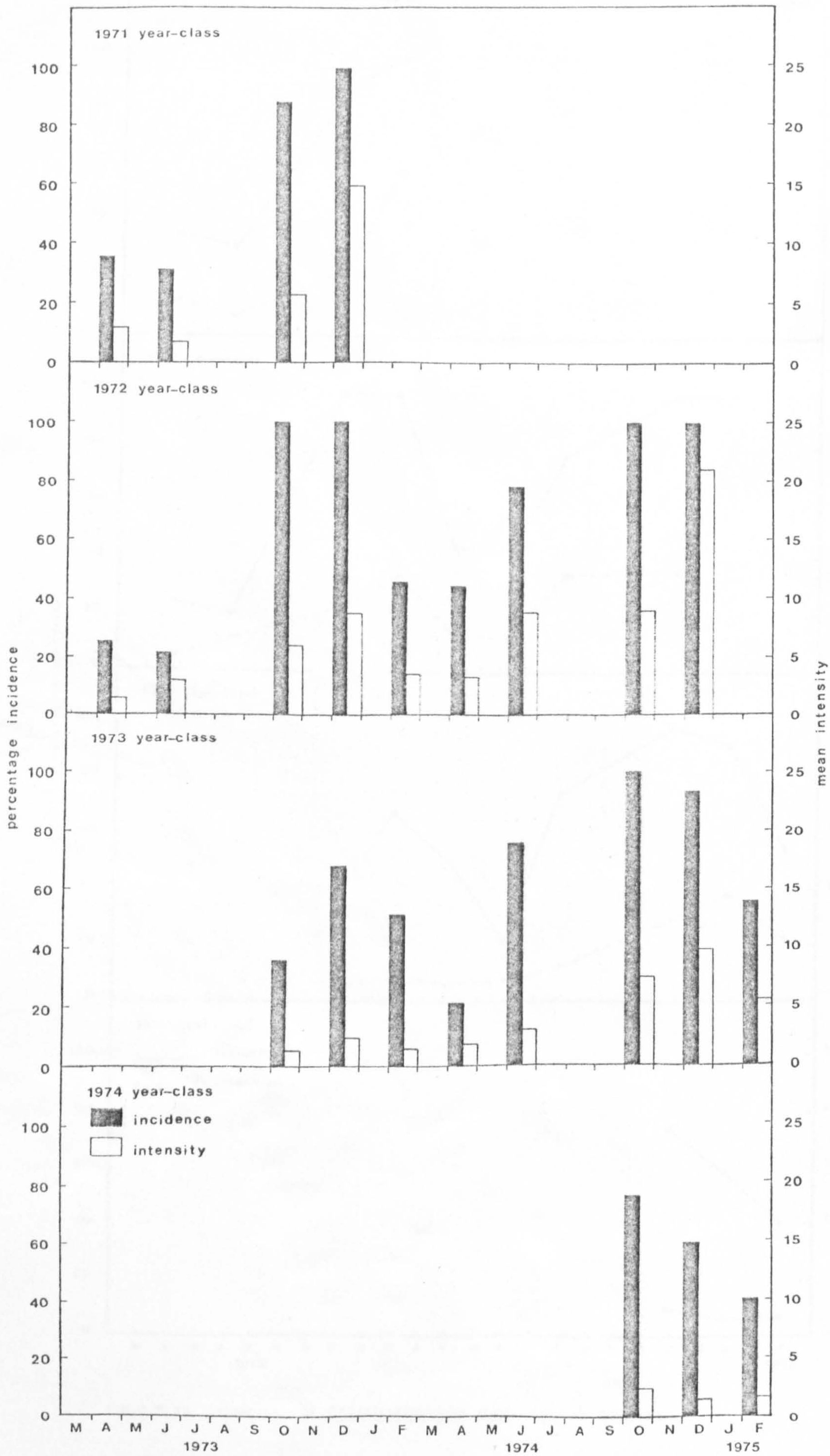


Fig. 3.3.17 Infection of Acanthochondria depressa on flounder during 1973–75

Table 3.3.14 Distribution of C. uncinata in the branchial cavities of whiting

Locality		Number of parasites	% of Total
Gill arch	1	127	67.2
	2	13	6.9
	3	1	0.5
	4	0	-
Wall of branchial cavity		43	22.8
Position uncertain (parasites detached)		5	2.7

Acanthochondria depressa (T. Scott)
(Copepoda: Chondracanthidae)

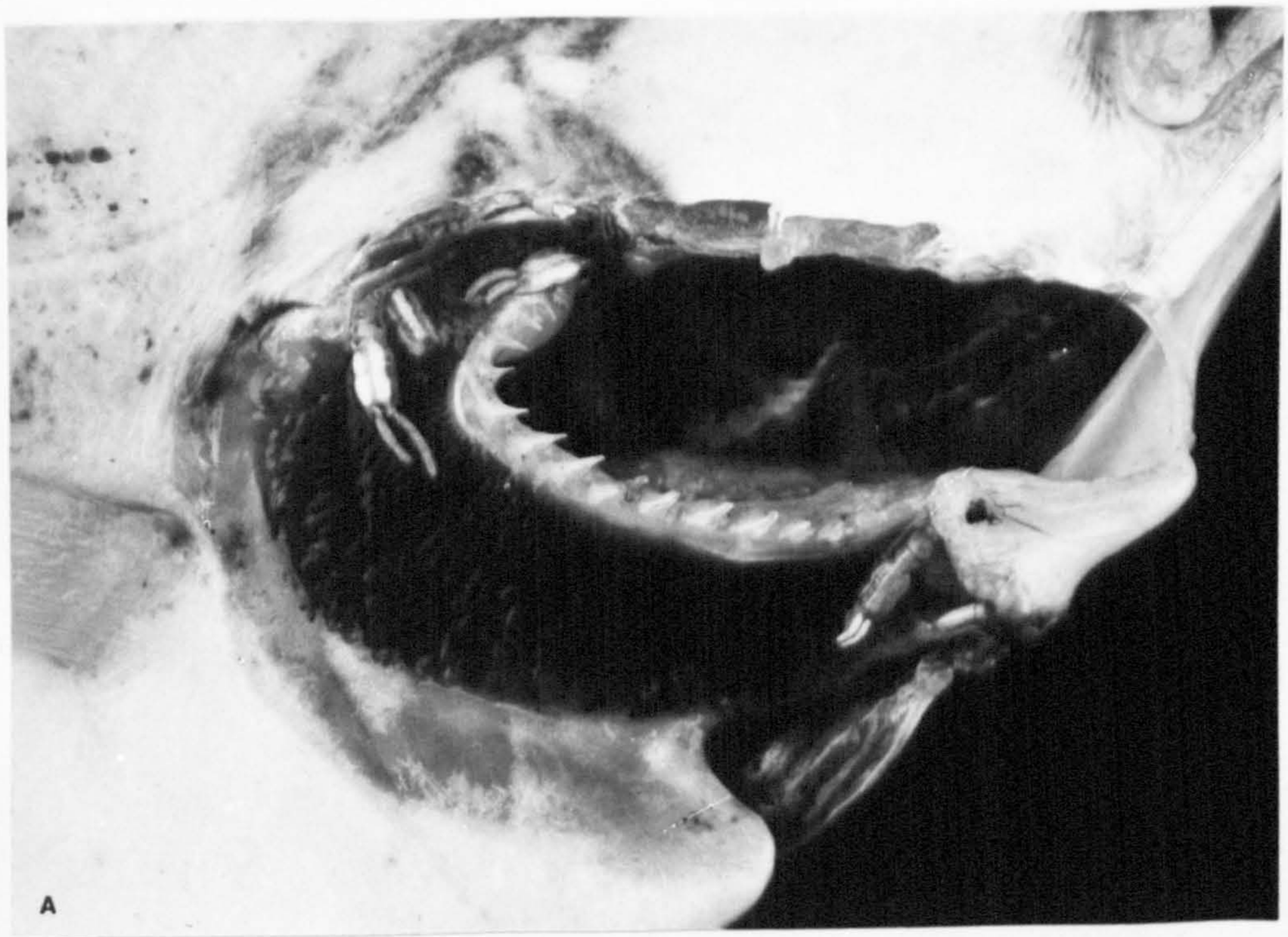
(i) Seasonal changes in incidence and intensity

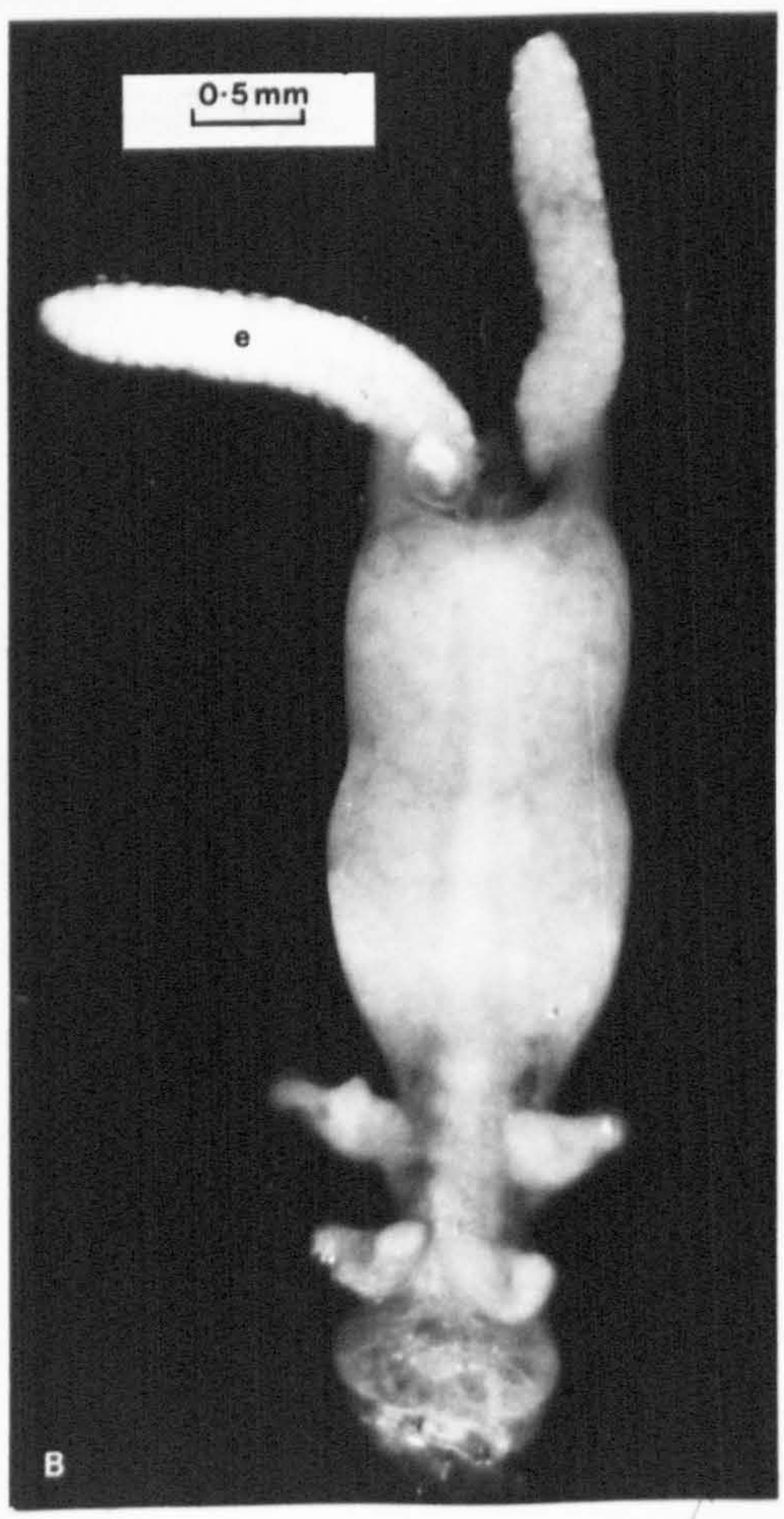
A. depressa (Plate 10) occurred on flounder throughout the sampling period (fig. 3.3.17); 56.2 percent of the total catch was affected. The results show clear seasonal fluctuations with maxima in the periods October to December and minima between February and June. During the former interval 100 percent infection was regularly recorded while, at the other extreme, only 21.4 percent of fish spawned in 1972 were infected by June 1973.

Intensity also varied seasonally; a mean 5.7 parasites per host was recorded for the sampling period but this fluctuated in December 1974 to a peak of 21.0 in 1972 year-class fish.

(ii) Changes in infection with age of host

Over the sampling period as a whole, frequency of infection (table 3.3.15) varied between a minimum of 50.0 percent, recorded for 4 and 5 year-olds, and a maximum of 68.8 percent in 3 year-olds. There was no definite relationship between age and frequency of infection (χ^2; $0.50>P>0.20$). Mean intensity, however, was clearly related to age and varied between 2.0 and 10.3 in 0- and 4/5-group flounders respectively.





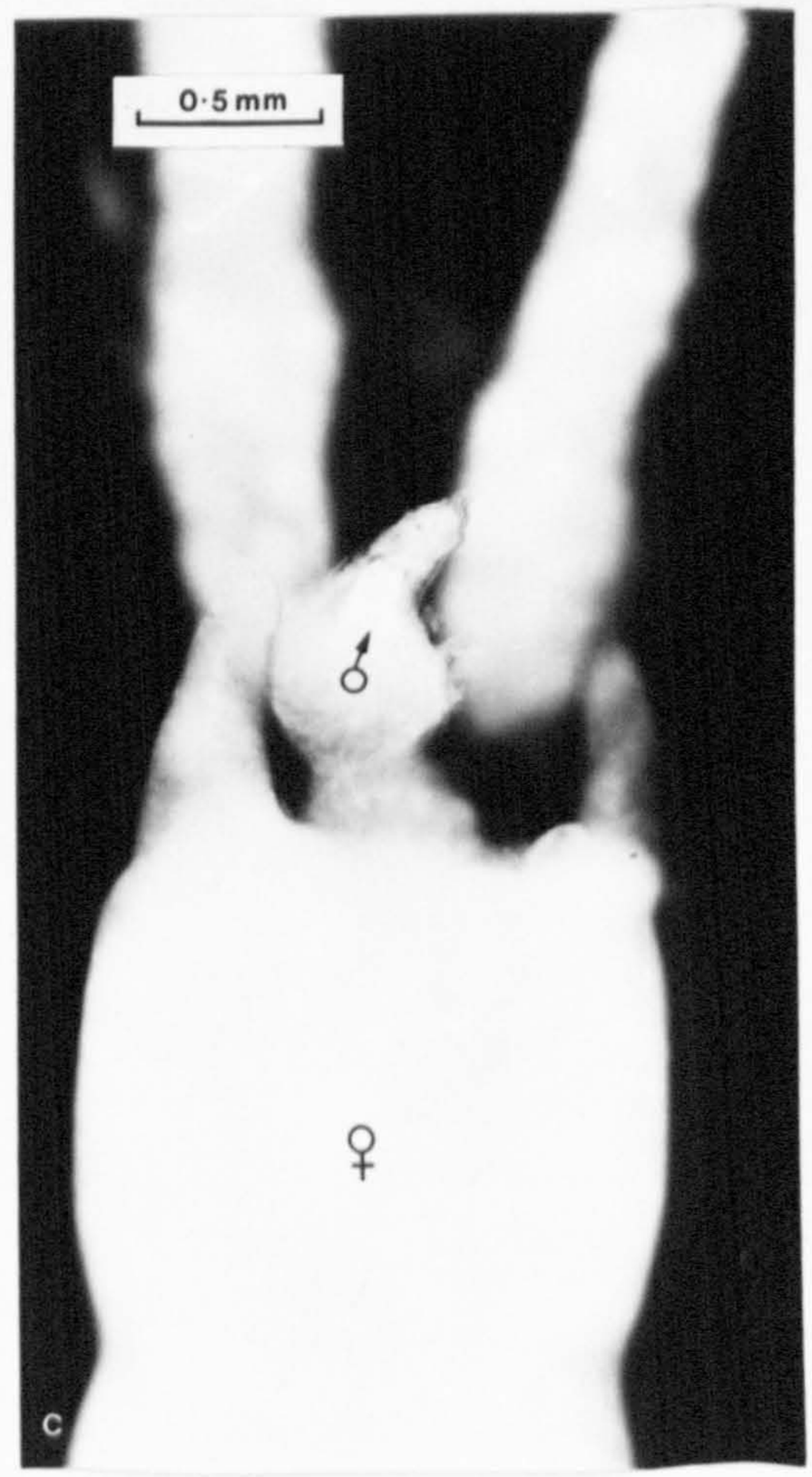


Plate 10 Acanthochondria depressa (T.Scott) infection on flounder

A. in situ in the branchial chamber, operculum removed

B. mature female with egg-strings (e)

C. detail of diminutive male

Table 3.3.15 A. depressa: variation of infection with age of flounder

		Age class of fish (years)				
		0	1	2	3	4/5
Number of fish examined		68	187	129	32	6
Number infected		42	97	73	22	3
% infected		61.8	51.9	56.6	68.8	50.0
Number of parasites:	ocular side	57	278	323	136	20
	blind side	29	162	235	91	11
	total	86	440	558	227	31
Number of parasites per infected fish		2.0	4.6	7.6	10.3	10.3

(iii) Distribution (table 3.3.16)

The parasite's developing stages showed a preference for the second gill arch on the ocular side (χ^2; $P<0.01$) but they were randomly distributed over the gills on the blind surface (χ^2; $0.20<P<0.50$). Adult stages, on the other hand, were not usually associated with the gill arches; their attachment sites were the walls of the branchial and buccal cavities. A significantly greater number was located on the ocular surface (χ^2; $P<0.001$), especially within the posterior pocket of the branchial cavity. A number was also situated anteriorly but very few were found in the mid-region. On the blind side the difference between posterior and anterior pockets was not so significant (χ^2; $0.10<P<0.20$).

Table 3.3.16 Distribution of A. depressa in branchial cavities of flounders

Location	Number of parasites		Percentage of total	
	Ocular	Blind	Ocular	Blind
Adult parasites				
buccal cavity	31	13	2.4	1.0
branchial cavity				
anterior region	221	145	16.8	11.0
middle region	15	12	1.1	0.9
posterior region	318	173	24.2	13.1
Developing stages				
gill arch 1	39	56	3.0	4.3
2	74	46	5.6	3.5
3	37	50	2.8	3.8
4	49	38	3.7	2.9
Totals	784	533	59.6	40.5

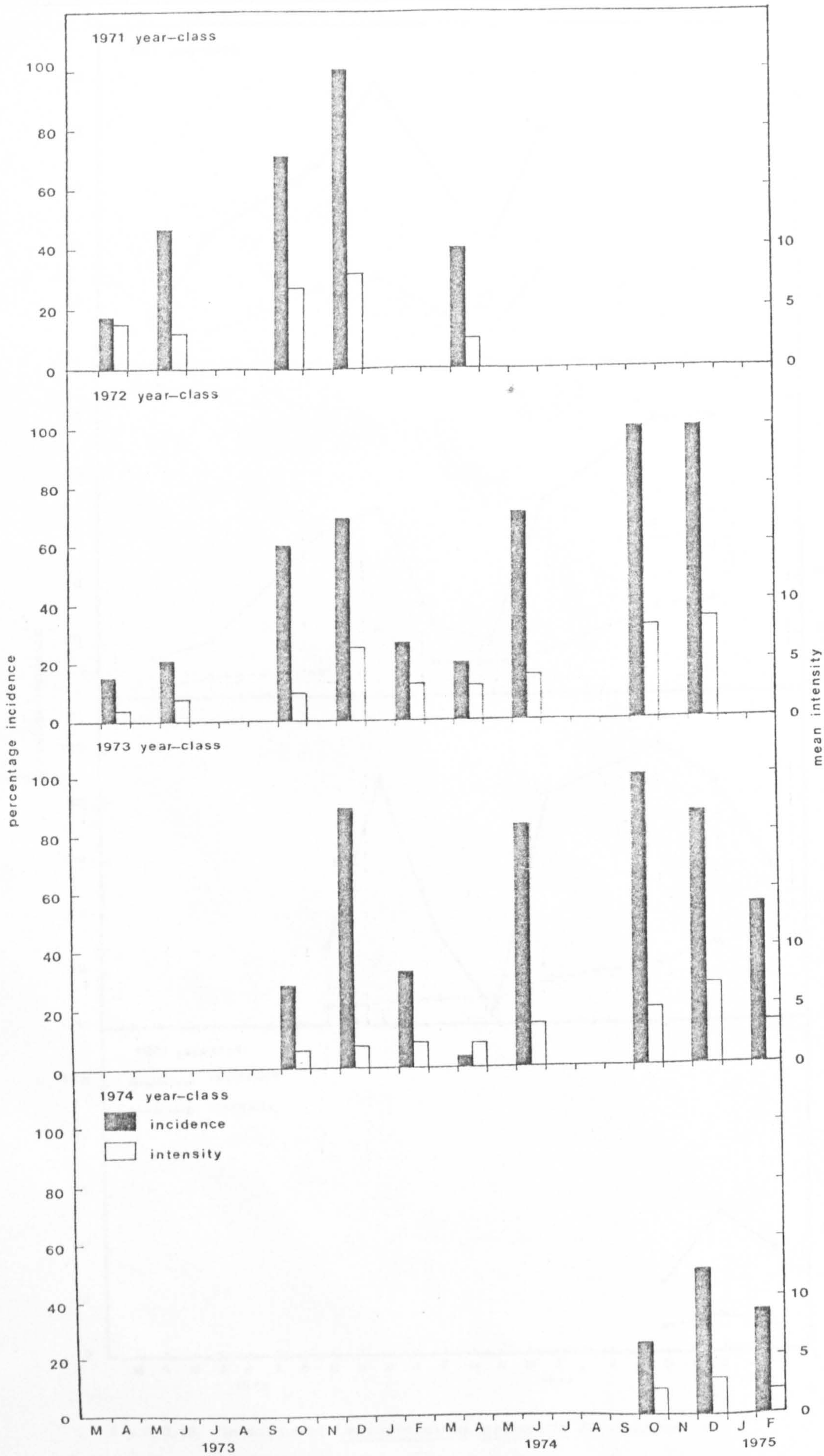


Fig. 3.3.18 Infection of Lepeophtheirus pectoralis on flounder during 1973–75

Lepeophtheirus pectoralis (Müller)
(Copepoda: Caligidae) (Plate 11)

(i) Seasonal incidence and intensity of infection

of 422 flounders examined, L. pectoralis occurred on 45 percent and with a mean intensity of 4.6 parasites per infected fish. The parasite displayed a clear seasonal cycle of infection (fig. 3.3.18) which resembled those of A. depressa (p108) and C. lingua (p87). Maxima, in some cases reaching 100 percent, were observed between October and December while minima, as low as 4.2 percent in the 1973 year-class, were consistently found in April. Intensity of infection, however, was variable.

(ii) Changes in infection with age of host

The parasite occurred in all age-groups of fish examined (table 3.3.17). A relationship between age and levels of infection was apparent; there was an increase in older hosts. However, like A. depressa (p108) this difference between groups was only significant for intensity (χ^2; $P<0.05$); incidence of infection exhibited much less variation.

Table 3.3.17 L. pectoralis: variation of infection with age of flounder

		Age-class of fish (years)				
		0	1	2	3	4/5
Number of fish examined		71	184	129	33	5
Number infected		36	73	59	19	3
% infected		50.7	39.7	45.7	57.6	60.0
Number of parasites:	ocular side	28	140	161	60	22
	blind side	52	145	157	92	15
	Total	80	285	318	152	37
Number of parasites per infected fish		2.2	3.9	5.4	8.0	12.3

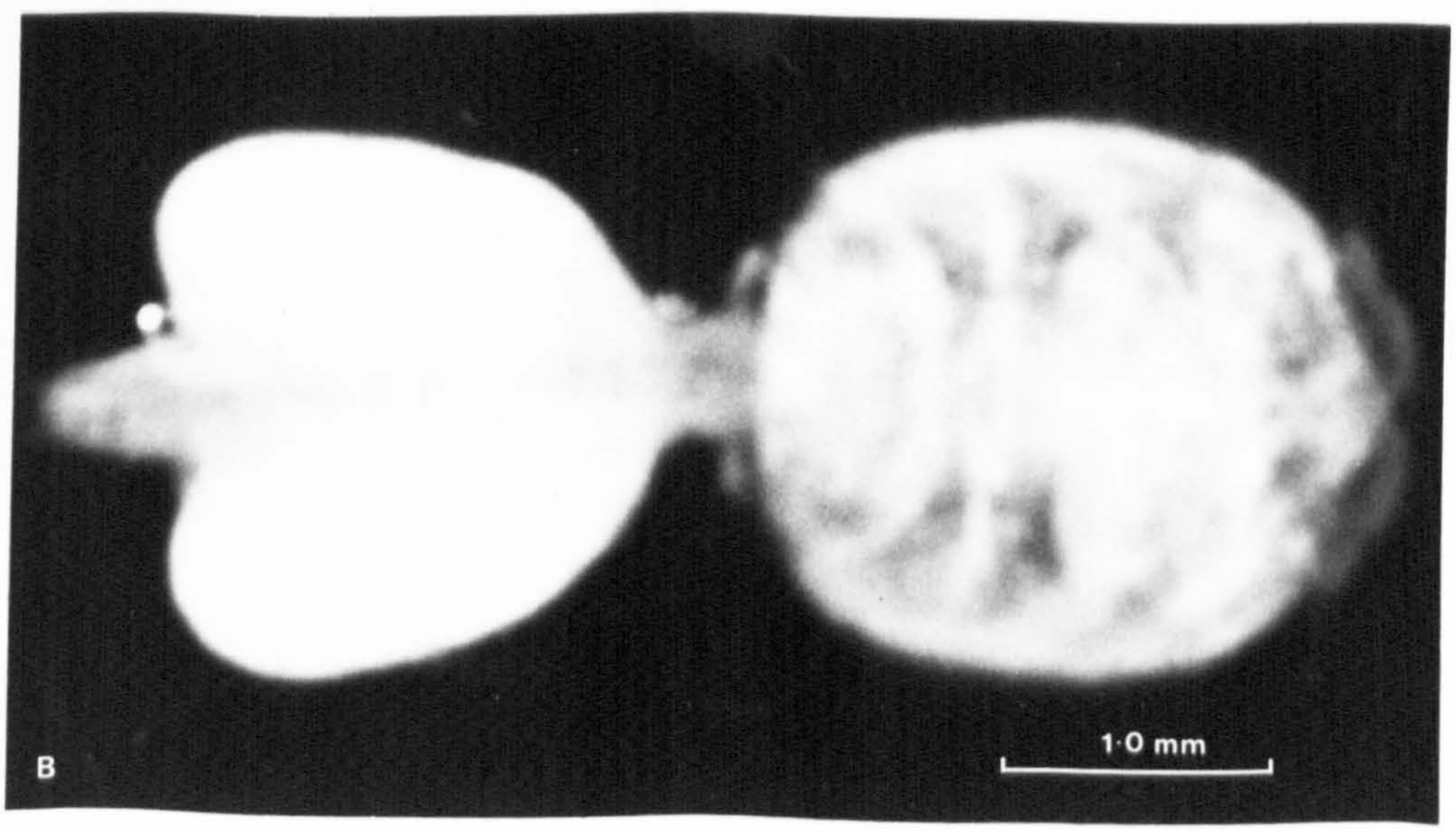


Plate 11 Lepeophtheirus pectoralis (Müller) infection on flounder
A. in situ under the pectoral fin
B. ventral view of a mature female

(iii) Distribution

The parasites were found over the entire body surface but were mainly associated with the paired fins (table 3.3.18). The majority (76.2 percent) were attached to, or under, both pectoral fins, with a significantly greater number on the blind surface (χ^2; $P<0.001$). However, the difference between numbers associated with each pelvic fin was not significant (χ^2; $0.10<P<0.20$) probably because of the proximity of these two fins to each other. The remaining parasites showed a preference for the ocular surface (χ^2; $P<0.001$).

Table 3.3.18 Distribution of L. pectoralis on flounders

Location	Number of parasites		Percentage of total	
	Ocular	Blind	Ocular	Blind
Associated with				
pectoral fin	285	379	32.7	43.5
pelvic fin	73	67	8.4	7.7
Body surface	53	15	6.1	1.7
Totals	411	461	47.2	52.9

'Chalimus' larvae

(i) Seasonal incidence and intensity of infection

The parasites considered here were probably not the developing stages of L. pectoralis (see p81); only 22.7 percent incidence of infection and an intensity of 2.7 parasites per infected fish were recorded for these larvae compared with 45 percent and 4.6 parasites for L. pectoralis (p112).

The familiar seasonal pattern was again displayed (fig. 3.3.19). Larval infection continued over the whole sampling period but fell consistently during winter to a minimum in February and then rising to a maximum in October.

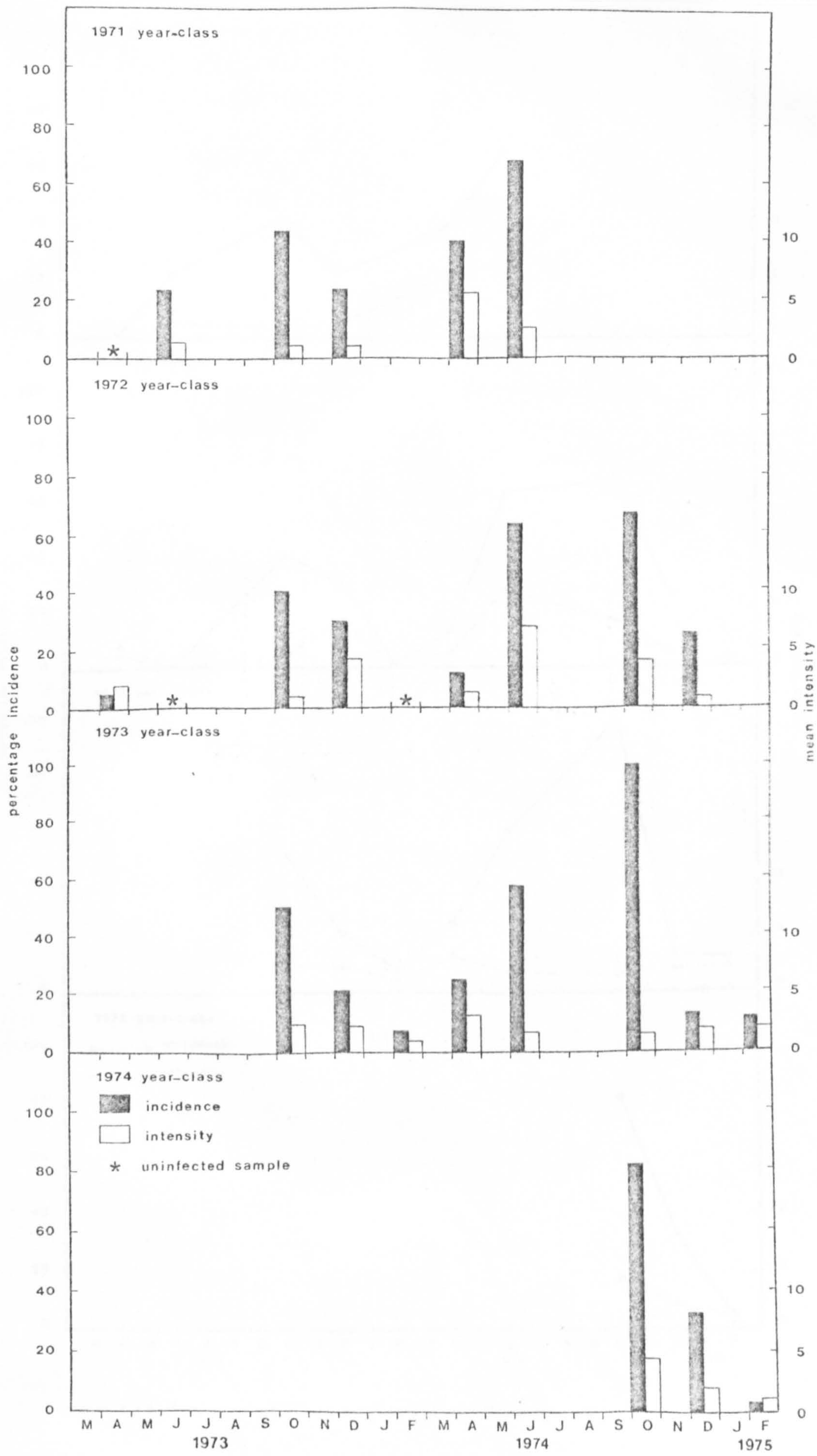


Fig. 3.3.19 Infection of 'Chalimus' larvae on flounder during 1973–75

(ii) Changes in infection with age of host

Table 3.3.19 shows that, unlike parasites of flounder discussed previously (p108, p112), there was little evidence of a relationship between infection and age. Parasites occurred most frequently in 0- and 3-group fish but intensity of infection showed little variation. Annual fluctuations (fig. 3.3.19) were apparently more important.

Table 3.3.19 Variation of 'Chalimus' larval infection with age of flounder

		Age class of fish (years)				
		0	1	2	3	4/5
Number of fish examined		71	184	129	33	5
Number infected		31	30	25	10	0
% infected		43.7	16.3	19.4	30.3	
Number of parasites	ocular side	79	36	54	24	
	blind side	17	31	20	2	
	Total	96	67	74	26	
Number of parasites per infected fish		3.1	2.2	3.0	2.6	

(iii) Distribution

Larvae were distributed on both body surface and fins but, unlike L. pectoralis (p114), showed a preference for the former (table 3.3.20). A significantly greater number were associated with the ocular side (χ^2; $P<0.001$).

Table 3.3.20 Distribution of 'Chalimus' larvae on flounders

Location	Number of parasites		Percentage of total	
	Ocular	Blind	Ocular	Blind
Body surface	154	42	58.6	16.0
Fin surface	39	28	14.8	10.7
Totals	193	70	73.4	26.7

Table 3.3.21 Whiting uninfected and infected with copepod ectoparasites: logarithmic length-weight regressions and significance tests

Type of infection	No. of fish in sample	Regression equation	Significance tests			
			Regression lines		Slopes	
			Variance ratio F	Probability P	t	Probability P
Uninfected	227	log W = 3.082 log L -2.123	-	-	-	-
L. branchialis (immature adults)	101	log W = 3.185 log L -2.242	1.80	P>0.05 (NS)	-1.568	P>0.1 (NS)
L. branchialis (mature adults)	43	log W = 3.045 log L -2.158	31.83	P<0.001 (S)	0.240	P>0.1 (NS)
C. uncinata (all stages)	59	log W = 2.437 log L -1.407	26.17	P<0.001 (S)	7.186	P<0.001 (S)
L. branchialis and C. uncinata	78	log w = 2.930 log L -1.990	12.24	P<0.001 (S)	1.409	P>0.1 (NS)
November 1974 sample (all whiting)	296	log W = 3.197 log L -2.269	-	-	-	-

NS = not significant

S = significant

3.3.3 Effects of copepod ectoparasites: a detailed study of Lernaeocera branchialis (L.) on whiting

(a) Effects on length-weight relationship and condition factor

Table 3.3.21 gives results of regression analysis on whiting sampled during 1973 to 1975, uninfected and infected with copepod ectoparasites. Included for comparison is the regression equation for fish caught in November 1974 from which liver samples were taken (p66). With the exception of whiting infected with immature adult stages of *L. branchialis*, differences between regression lines for uninfected and infected fish were statistically significant. On the other hand, a significant difference between regression coefficients was recorded only in whiting infected with *C. uncinata*. Results indicate, therefore, that immature adults of *L. branchialis* have no effect on the host while *C. uncinata* and mature stages of *L. branchialis* separately cause a significant weight reduction. Surprisingly, fish infected with various stages of both parasite species were significantly heavier in this study.

Details of the November 1974 sample are given in table 3.3.22. The regression coefficient for these fish (3.197) did not differ significantly from 3 ($t = 0.585$; d.o.f. = 44) and so the transformed regression equation,

$$W = 5.38 \times 10^{-3} L^{3}$$

was used to calculate individual condition factors as described in section 2.2.2, p27. Mean values for infected whiting were slightly lower (table 3.3.22) but these variations were not statistically significant.

Table 3.3.22 Details of the November 1974 whiting sample

	Lernaeocera branchialis		
	Uninfected	Immature adults	Mature adults
Number of fish in sample	20	15	12
Mean length of fish	14.6	14.4	15.3
(range)	(12.6-16.4)	(12.0-16.7)	(12.2-22.8)
Mean weight of fish	30.6	28.7	33.5
(range)	(20.3-47.7)	(15.7-47.6)	(14.3-98.6)
Mean condition factor	0.96	0.94	0.87
Number of males	10	7	6
Number of females	10	7	6
Mean fulness of stomach	4.3	3.7	4.8
(points scale 0-8)			
Mean weight of stomach contents	2.4	0.6	2.3

(b) Effects on the liver (table 3.3.23)

The liver, which formed 3.2 percent of total body weight in uninfected fish, was not significantly reduced in weight by L. branchialis infections. On the other hand, mean weight of lipid extract was 51.4 percent lighter in whiting carrying the mature adult stage. This difference is significant at the 5 percent level. Immature adults had no effect in this respect: results were essentially as for uninfected whiting.

Table 3.3.23 Effects of L. branchialis on whiting

	Uninfected	L. branchialis	
		Immature adults	Mature adults
CONDITION FACTOR			
Number of samples	20	14	12
Mean CF	0.96	0.94	0.87
Range	0.80-1.08	0.86-1.03	0.79-0.95
LIVER WEIGHT			
Mean (% body weight)	3.2	2.8	2.6
Range	2.2-4.5	1.4-4.4	1.0-4.4
WEIGHT OF LIPID EXTRACT			
Mean (% liver weight)	32.5	32.2	15.8
Range	12.7-52.7	21.5-42.1	4.4-34.2
WEIGHT OF PHOSPHOLIPID			
Mean (mg/g liver wet weight)	14.7	15.9	10.2
Range	9.2-24.1	10.4-23.5	3.9-17.1
ACYL ESTER			
Mean (μeq/mg lipid)	3.6	3.8	2.9
Range	2.0-4.5	2.4-5.0	0.7-4.9
CHOLESTEROL			
Number of samples	20	14	8
Mean (% total lipid)	3.1	3.2	7.3
Range	1.1-6.0	1.6-8.2	2.3-22.3

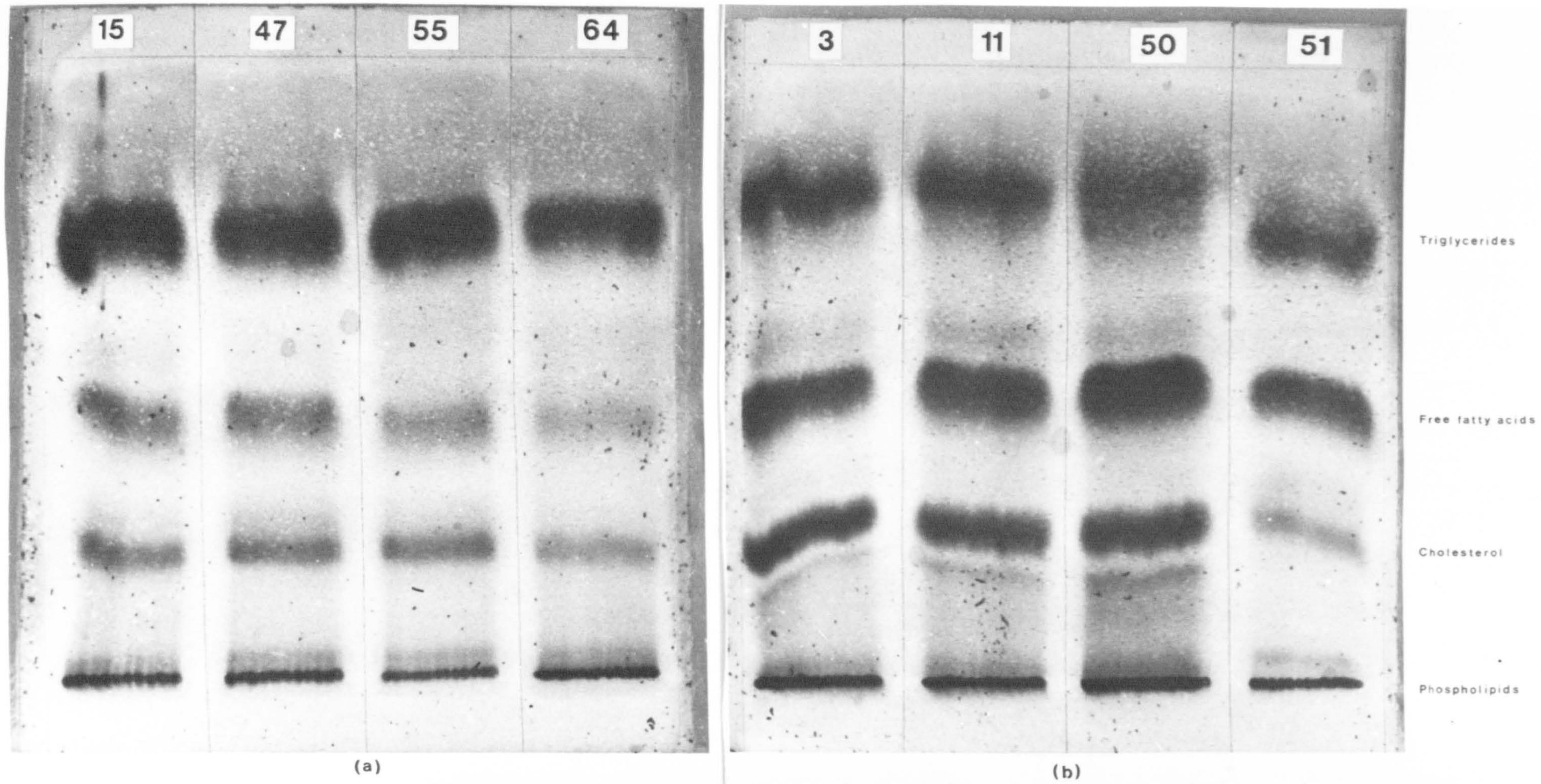


Fig 3.3.20 TLC chromatograms of lipid extracts from whiting (a) uninfected and (b) infected with L. branchialis

Typical TLC chromatograms of liver lipid extracts from uninfected and infected whiting are shown in fig. 3.3.20. The major components are phospholipids, triglycerides, cholesterol and free fatty acids. There was no significant difference in mean weight of phospholipid between fish uninfected and infected with immature adults (χ^2; $0.80<P<0.90$), but mature stages reduced levels by 30.3 percent. Triglyceride records on the other hand, were essentially the same in all three groups.

Cholesterol areas on TLC plates were considerably darker for most infected whiting even though similar quantities of lipid were applied. Quantified results confirmed that cholesterol levels were higher in whiting with mature parasites; on average, more than double those in uninfected forms. However, definite conclusions cannot easily be drawn from these results in view of the small numbers of fish analysed and variability of levels obtained.

Figure 3.3.21 shows a GLC chromatogram of whiting liver lipid (see table 3.3.24 for interpretation of individual peaks). Dominant fatty-acid components were hexadecanoic (16:0), octadecenoic (18:1), eicosapentaenoic (20.5) and docosahexaenoic (22:6) acids. Whiting in all three groups exhibited much variation, which appeared totally unrelated to the effects of parasitism by L. branchialis.

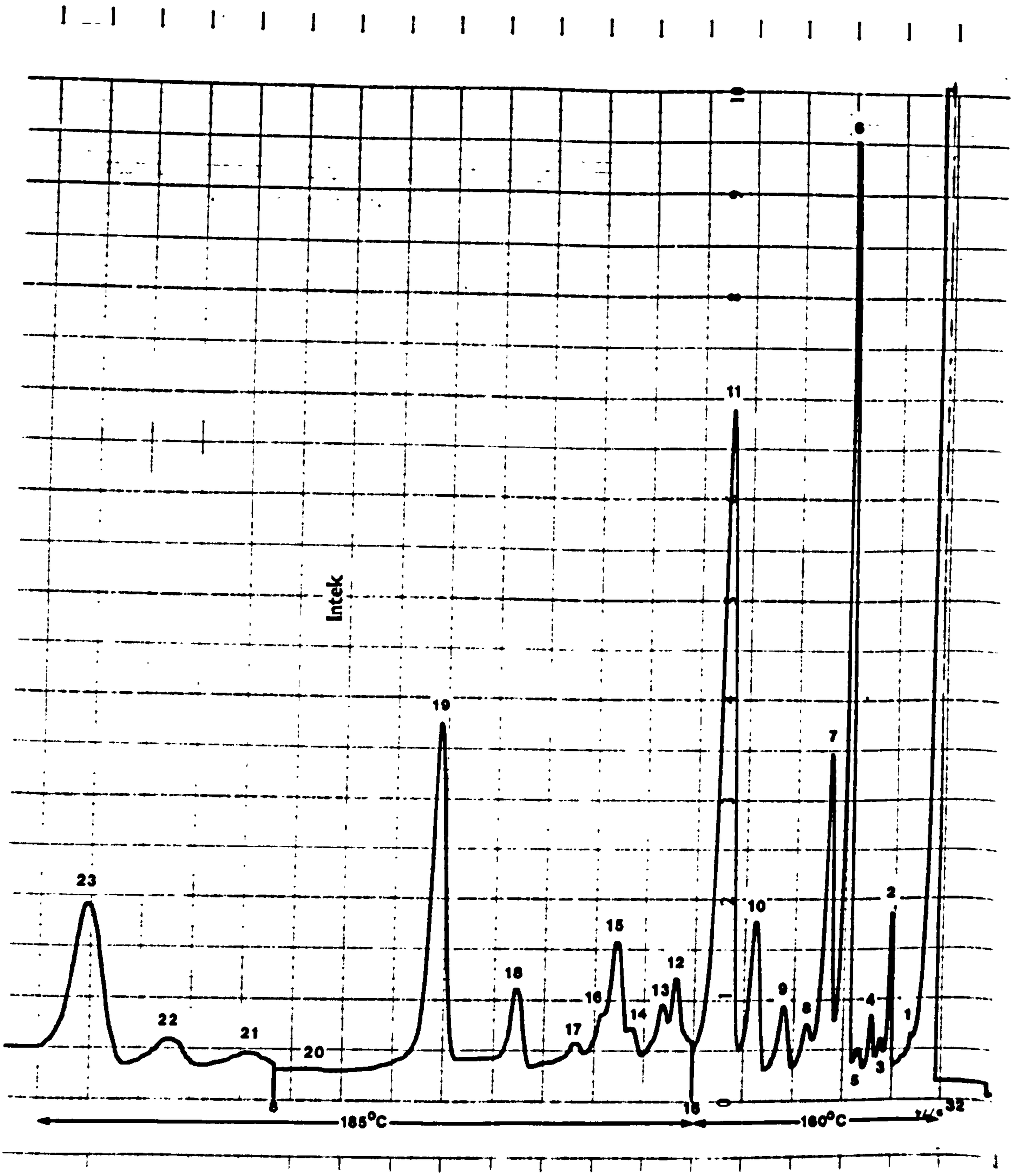


Fig.3.3.21 GLC chromatogram of fatty acid methyl esters from whiting liver

Table 3.3.24 Fatty acid composition of whiting liver (%)

Peak No.	Fatty Acid	Uninfected	*Lernaeocera branchialis*	
			Immature adults	Mature adults
1	12:0	trace	0.1	trace
2	14:0	2.0	1.8	1.8
3	14:1	0.2	0.1	trace
4	15:0	0.7	0.6	0.7
5	15:1	0.2	0.2	0.3
6	16:0	17.4	14.9	16.3
7	16:1	7.5	7.7	5.4
8	17:0	0.5	0.4	0.3
9	unknown A	1.4	1.7	1.1
10	18:0	6.9	6.2	5.6
11	18:1	21.2	25.0	19.0
12	18:2	1.6	1.3	1.4
13	unknown B	0.4	0.4	0.6
14	18:3	1.2	1.1	0.7
15	20:1	2.6	2.8	3.0
16	unknown C	0.3	trace	trace
17	unknown D	0.7	0.4	0.4
18	20:4	2.9	3.5	5.6
19	20:5	20.6	21.2	19.6
20	24:0	0.5	0.5	1.3
21	24:1	0.4	0.3	0.4
22	22:5	1.7	1.6	2.1
23	22.6	10.4	7.9	14.6

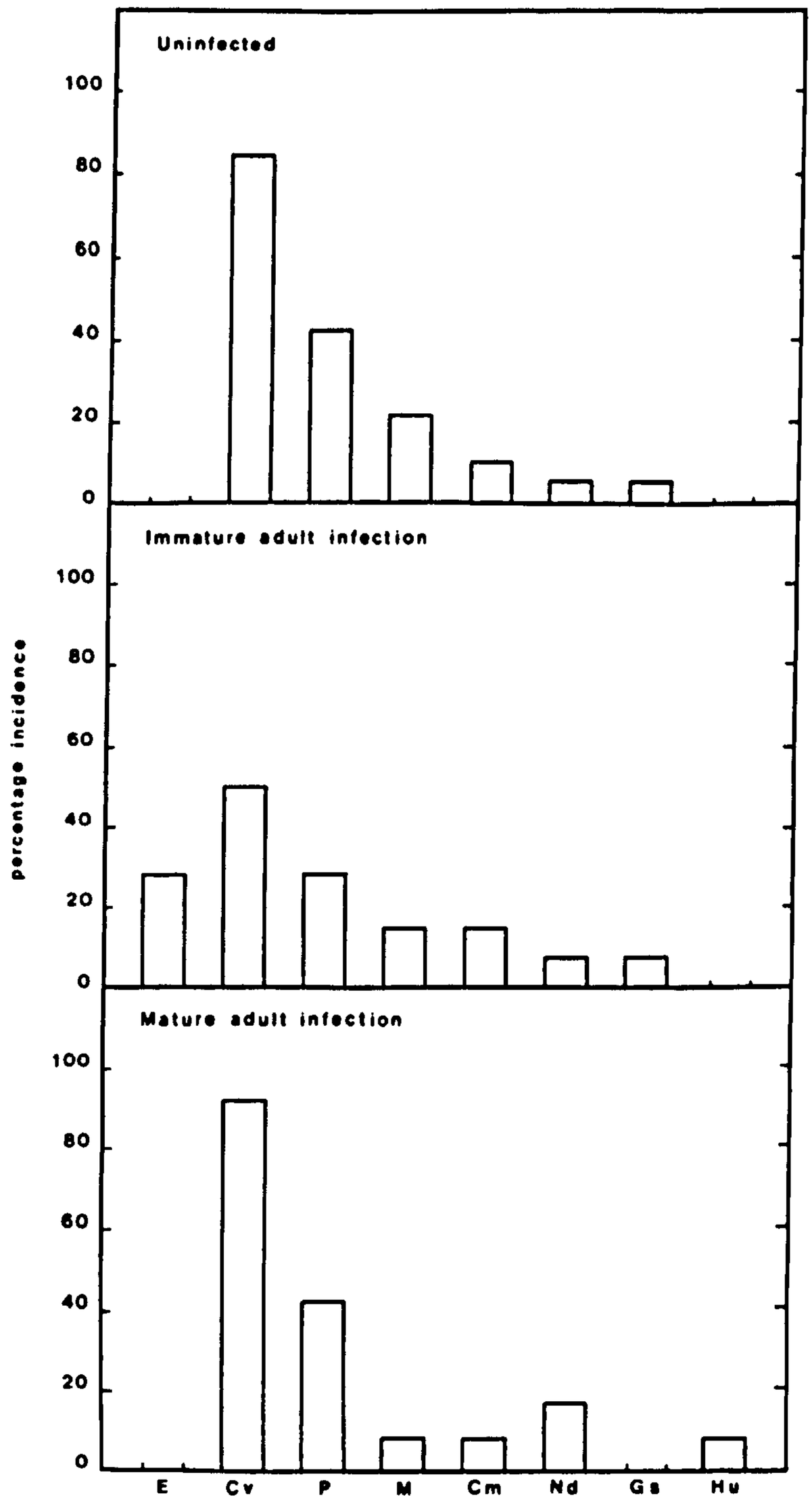


Fig.3.3.22 Effect of Lernaeocera branchialis infection on feeding in whiting; E=Empty, Cv=Crangon vulgaris, P=Pisces, M=Mysidacea, Cm=Carcinus maenas, Nd=Nereis diversicolor, Gs=Gammarus sp., Hu=Hydrobia ulvae

(c) Effects on diet

Whiting in the November 1974 sample fed predominantly on *Crangon vulgaris*, fish, mysids, *Carcinus maenas* and *Nereis diversicolor*. Individuals infected with immature adult parasites showed some reduction in feeding, measured by stomach 'fulness', weight of contents and numbers of empty stomachs (table 3.3.22, p119 and fig. 3.3.22). Only minor differences were recorded from groups infected with mature stages.

3.4 Discussion

Spawning of the four fish species investigated occurs principally between December and March in plaice and between March and May in the other three (Wheeler, 1969a). Plaice are planktonic in the early stages and feed on diatoms and minute larvae (Wheeler, 1969a). Young whiting, between 21 and 52 millimetres, are also planktonic and very dependent on copepods and diatoms for their food (Nagabhushanam, 1964). Flounders, at an equivalent stage of development, also feed on copepods but almost nothing is known of the initial pouting diet.

By the time they reach inshore waters flatfish have become bottom-living and whiting nektonic. Diets of the smallest whiting caught on the screens, between 5.0 and 7.0 centimetres, consisted of mysids, Crangon vulgaris, copepods and fish (fig. 3.3.2, p74). Those between 7.0 and 9.0 centimetres had, in addition, been feeding on Nereis diversicolor, Peloscolex benedeni, Hydrobia ulvae and amphipods. Pouting of equal length had a similar diet except that fish were absent and amphipods occurred more frequently than in whiting. Generally, small gadoids fed predominantly on fast-moving nektonic organisms.

In contrast, plaice under 5.0 centimetres preferred slow-moving or sedentary forms; they fed almost entirely on P. benedeni and cirratulid polychaetes (fig. 3.3.4, p79). Other workers (Scott, 1921; Edwards and Steele, 1968) have found copepods to be important dietary constituents of young plaice but in this study they occurred in only 4.8 percent of 0-group fish analysed. Larger 0-group individuals continued to feed on cirratulids and P. benedeni but increasing quantities of N. diversicolor, Nepthys caeca and molluscs were also taken. There was little qualitative difference between these and 0-group flounders (fig. 3.3.4, p79) except that P. benedeni and cirratulids occurred almost equally in flounder whereas in plaice the latter were more frequent.

Both flatfish fed less intensively in winter although an unusually large number of flounders with empty stomachs were also taken at other

times of the year (fig. 3.3.3, p77). Several workers (Hartley, 1940; Harder and Hempel, 1954; Hempel, 1956; Bregnballe, 1961; Blaxter, 1968) have shown flatfish feed most heavily at dusk and dawn and that stomach contents reach a minimum during the night. Fish are then most active and more easily caught. In this survey, greater numbers of flatfish were taken at night (see Appendix I, p202). They were often recovered alive perhaps having already digested the stomach contents; oligochaetes pass through the stomach in about two hours (Bregnballe, 1961). For this reason, intestinal contents were included when results were analysed. Gadoids also feed at night (Nagabhushanam, 1964) but the activity is not restricted as in flatfish. At Kingsnorth, most were dead on collection with food retained in the stomachs.

Seasonal fluctuations of dietary constituents may relate to changes within the populations of prey or predator organisms. In both flatfish species, seasonal distributions of P. benedeni were almost identical, reaching a minimum in late summer and a maximum in early spring (fig. 3.3.3, p77). These extremes did not agree with its change in abundance in the environment (Wharfe, 1975) but minima coincided almost exactly with an influx of 0-group plaice and flounders into the estuary (fig. 2.3.12, p48). These young individuals fed less profusely on P. benedeni than older fish.

Gadoids did not appear to fully exploit populations of abundant prey organisms either. For example, C. vulgaris occurs in very large numbers in the Medway and is still commercially exploited. It was recorded at Kingsnorth at all times (personal observation) and there was no evidence of a winter migration as reported from Dutch waters (Havinga, 1930; Boddeke, 1968). Numbers in screen samples declined between April and June 1974 but this did not reduce their frequency in the gadoid gut (fig. 3.3.1, p72). The shrimp occurred less often in the whiting diet during February 1974 and 1975 for unknown reasons but the further reduction in September 1974 coincided with an increased diet of sprats.

It is interesting that sprats did not occur more frequently in the whiting diet, particularly at times when they were most abundant in the estuary (fig. 2.3.11, p47). Large numbers of length 2.0 - 3.0 centimetres were caught on the screens between July and December and it may be that outside this period they are unavailable to young whiting because of their size. Other workers (Jones, 1954; Elkin, 1954) have in fact detected a preference by whiting for a fish diet when fish of a suitable size are available. The generally larger pouting may be less affected by sprat size and this may be why the occurrence of fish in their guts exhibited little seasonal variation.

A preference for fish may also have been responsible for reductions in mysids (fig. 3.3.1, p72). However, in this case both gadoids were affected and it would seem that changes in the mysid populations were more important. Mysids were particularly frequent in gadoids in July 1974 and their reduction over the next three months coincided with their reported decline in abundance in the estuary (Gordon-Clark, unpublished MIBiol. project, 1974). Similar changes in local populations may also have governed fluctuations of N. diversicolor and C. maenas in the diet of all four fish species (fig. 3.3.1, p72 and fig. 3.3.3, p77).

Examination of the gut contents showed that both gadoids and flatfish had been feeding on Hydrobia ulvae. Gastropod molluscs, especially H. ulvae and Littorina littorea (L.) are intermediate hosts of Cryptocotyle lingua (Stunkard, 1930) and it is, therefore, not surprising that all four fish species were infected (section 3.3.2, p81). Flounder was most heavily infested even though H. ulvae and L. littorea occurred most frequently in the guts of plaice. Accessibility of the host is a vital factor in any infection process and feeding in close proximity to a parasite source must increase the chance of being infected. However, other factors, such as length of parasitic exposure, age of host and area of the infection surface, must also be taken into consideration.

Metacercariae were not distributed randomly over the body surface; in gadoids they were concentrated above the lateral line while in pleuronectids they were most intense on the fins, gills and ocular surface of the body (table 3.3.6, p90). Experiments have indicated that cercariae are attracted by light and not by chemical stimuli emanating from the tissues (Stunkard, 1930). This, together with the settling behaviour of the flatfish, will ensure that cercariae make preferential contact with the ocular surface.

Metacercariae are retained for life (Stunkard, 1930) so any marked seasonal reduction must be due to a change in the host population. In all four fish species frequency of C. lingua fell during spring of 1974 (section 3.3.2, p84); this was attributed to the immigration of young uninfected fish into the estuary (fig. 2.3.12, p48). In whiting, however, the low incidence of C. lingua in April 1974 coincided with maximum intensity; Shotter (1973a) suggests that as fish migrate from inshore waters the more heavily-infected individuals are delayed.

0-group whiting entering estuarine waters were also free of L. branchialis; but infection was rapid and reached a peak soon after their inshore migration (fig. 3.3.11, p98). Maximum intensity of L. branchialis larvae on flounder followed 1 - 3 months after greatest numbers of mature adults were recorded on whiting. The parasite's occurrence on flounder was consistently high throughout the sampling period and it would appear, in agreement with Sproston and Hartley (1941) that parasite generations are produced continuously.

The incidence of L. branchialis in Medway whiting exceeded literature values (table 3.4.1). On the other hand, the occurrence of L. lusci was well below that observed by Slinn (1970). No metamorphosing stages of L. lusci were recovered from pouting and it must be assumed they were infested offshore. Sole is the intermediate host but no copepods were observed on the small sample of fish examined.

Table 3.4.1 Infection by Lernaeocera species: literature values (%)

Author	Study Area	Parasite species	
		L. branchialis	L. lusci
Shotter (1976)	Manx waters	23.1	-
Sproston & Hartley (1941)	Tamar Estuary	13.1	-
Slinn (1970)	Irish Sea	-	25.0
van den Broek (1977)	Medway Estuary	40.4	14.9

For all parasites, locating the host is important and methods employed may be similar. Kabata (1958) suggests rheotaxis is largely responsible for the unequal distribution of L. branchialis larvae on flounder. In the present study, the larvae showed a preference for the first gill-bar on the ocular side (p100). Developing stages of Acanthochondria depressa may be similarly affected even though they were attached in greatest numbers to the second arch. On the other hand, A. depressa adults were restricted almost entirely to the anterior and posterior branchial pockets (table 3.3.16, p110). Kabata (1959) determined that the distribution of Acanthochondria adults on different flatfish species is greatly affected by activity of the fish, the area of its gill chamber and the size of its gape. He showed that an increase in these factors is responsible for a decrease in parasite numbers. It would appear that the distribution of A. depressa adults on flounder is governed by the rate and volume of respiratory flow around the gill arches. In flounder, the posterior branchial pocket is presumably more protected and is, therefore, favoured as an infection site.

A parasite's location cannot always be explained simply in terms of respiratory currents. For example, on whiting distributions of C. uncinata and the early metamorphosing stages of L. branchialis were highly localized. The former showed a preference for the gill-rakers and spinose bosses of the first gill arch while the latter were mainly

attached to the third. Both parasites are probably carried into the branchial cavity with the respiratory current but the combination of factors which may be responsible for their final distribution is unknown.

Damage attributed to parasitic copepods is mainly the result of their attachment and feeding. The extent of injury can vary from small localized sores to complete emaciation and death of the host. Their effects are reviewed by Kabata (1970).

There was evidence in this study that both whiting and flounder were adversely affected by L. branchialis. Physical damage to the gill filaments of flounder was in some cases quite severe but restricted to their tips. Hypertrophy of tissue and destruction of respiratory folds must affect gaseous exchange to some degree. Respiratory efficiency of whiting is also likely to be affected; many mature parasites protruded from the branchial cavities preventing their closure, and pressure on the surrounding area had in several cases led to atrophy of sections of gill. C. uncinata is also intimately associated with the host tissue. Kabata and Cousens (1972) have described the formation of its attachment organ, the bulla. The cephalothorax is very mobile and can 'graze' mucus and blood cells from a circular area around the bulla.

Evidence that copepod parasites affect fish condition remains inconclusive. In this study, whiting infected with mature adults of L. branchialis were significantly lighter than uninfected fish (p118). The crucial factor appears to be the period of association between parasite and host; older infected whiting were emaciated and clearly lighter than uninfected contemporaries. This condition was not often seen in the first-year fish which formed the bulk of the November 1974 sample.

Fish infected with L. branchialis, however, are likely to show signs of metabolic disturbance following the parasite's penetration of its attachment site and the onset of feeding. Mann (1953) has detected characteristic features of secondary anaemia induced by blood-feeding

parasites; loss of haemoglobin and a drop in erythrocyte count. Results in the present study (section 3.3.3, p120) have shown that mature adults of L. branchialis had a marked effect on the whiting liver even though in many fish infection was not far advanced. Livers of infected fish were not significantly lighter but their lipid content was reduced by about 50 percent due mainly to lowering of phospholipid levels. On the other hand, cholesterol levels were higher in infected fish. The significance of this is not clear but in rats elevated cholesterol is associated with essential fatty acid (EFA) deficiency (Gurr and James, 1971). There was no suggestion of EFA deficiency here but increased cholesterol may, nevertheless, be indicative of stress.

The fatty acid composition of whiting liver lipids (table 3.3.24, p124) was comparable with the literature (Klenk and Eberhagen, 1962). Individual variation among uninfected and infected fish made sensible comparisons between them impossible.

Lipid levels in liver tissue are good indicators of physical disturbance; they represent reserves to be used in times of stress, whether dietary or parasitic in origin (see above). Also associated with fat metabolism is the accumulation of some pollutants, especially the lipophilic organochlorine compounds. The effects of varying pollutant levels, caused by a change in lipid content, on population growth and reproduction are likely to be subtle but may be a contributory factor in lowering growth or reproduction rates. Some of these aspects are discussed in the following section.

SECTION 4

POLLUTION STUDIES

4.1 Pollutants in the aquatic environment

4.1.1 Organochlorine pesticides and polychlorinated biphenyls

4.1.2 Heavy metals

4.2 Tissue selection and initial sample preparation

4.3 Organochlorine pesticides and polychlorinated biphenyls in animal tissues

4.3.1 Methods

(a) Introduction

(b) Procedure

(c) Interpretation of data

4.3.2 Results

(a) *Anguilla anguilla* (L.)

(b) *Merlangius merlangus* (L.)

(c) *Platichthys flesus* (L.)

(d) *Pleuronectes platessa* L.

(e) *Pomatoschistus minutus* (Pallas) *Sprattus sprattus* (L.) and *Crangon vulgaris* L.

4.4 Heavy metals in animal tissues

4.4.1 Methods

(a) Introduction

(b) Procedure

(c) Interpretation of data

4.4.2 Results

4.5 Discussion

Table 4.1.1 Chemical and common names of chlorinated hydrocarbons considered in this study

Aldrin	1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a-hexahydro-exo-1,4-endo-5,8-dimethano-naphthalene
αBHC γBHC (Lindane)	{ mixed isomers of 1,2,3,4,5,6-hexachlorocyclohexane
TDE (DDD)	1,1-dichloro-2,2-di-(4-chlorophenyl) ethane
DDE	1,1-dichloro-2,2-di-(4-chlorophenyl) ethylene
pp'-DDT	1,1,1-trichloro-2,2-di(4-chlorophenyl) ethane
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-exo-1,4-endo-5,8-dimethanonaphthalene
Endrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-exo-1,4-exo-5,8-dimethanonaphthalene
Heptachlor epoxide	epoxide of 1,4,5,6,7,8,8-heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene
Tetradifon	2,4,4',5-tetrachlorodiphenyl sulphone
PCBs	polychlorinated biphenyls

SECTION 4

POLLUTION STUDIES

Most of the industry around the Medway, in common with other river-systems in urban areas, is situated in the lower regions (section 1.3, p13). Apart from the obvious advantage of accessibility to overseas shipping, traditionally estuaries were considered natural disposal systems incapable of being seriously polluted. Today, however, with ever-increasing quantities of effluent and more information available on the hydrodynamics of polluted 'plugs' of water in inshore areas, toxic compounds are causing greater concern.

On the other hand, the Medway is atypical in that large sections of densely cultivated land are also situated in the lower reaches of the river (section 1.3, p15). On the south side of the estuary, significantly higher levels of organochlorine pesticides have been detected in *Mytilus edulis* and *Carcinus maenas* from Bedlam's Bottom, a site bounded by extensive orchards (Wharfe, 1975). Quantities of these chemicals, therefore, are still reaching estuarine waters, despite restrictions on their use, and are thus potentially capable of affecting the whole range of estuarine biota.

4.1 Pollutants in the aquatic environment

4.1.1 Organochlorine pesticides and polychlorinated biphenyls

The organochlorine compounds BHC and DDT (table 4.1.1) were both synthesized in the nineteenth century, but their insecticidal properties were not recognized until 1942. This in turn led to the development, during the Second World War, of related compounds including aldrin, dieldrin, endosulphan, endrin, heptachlor and lindane. Their introduction has greatly enhanced food production and done much to eradicate disease-transmitting arthropods. However, widespread use in large quantities, toxicity to non-target organisms and chemical stability have made them a potential hazard in the environment.

Widespread distribution of polychlorinated biphenyls (PCBs) has similarly been favoured by extensive use in industry since 1929. However, their persistence in the environment was not appreciated until 1966 when they were identified in Swedish wildlife samples (Jensen, 1966). Subsequently, a series of incidents, including their contamination of cooking oil in Japan in 1968 (Hutzinger et al, 1974) and implication in the Irish Sea bird wreck of 1969 (Holdgate, 1971), has resulted in sales restrictions being imposed.

Polychlorinated biphenyls are a group of structurally related compounds formed by chlorinating biphenyl. The product of manufacture is a mixture of several PCBs out of a theoretical total of 210. Not only are they chemically related to the organochlorine pesticides but their environmental effects are similar. Their persistence is due to thermal and chemical stability, resistance to oxidation and low solubility in water. These properties, coupled with their resistance to metabolic processes and solubility in lipids, enables PCBs to be concentrated within organisms.

Areas of organochlorine contamination include run-off in regions of high agricultural activity which, in the Medway, include both upper and lower reaches of the river(see p 15). Similar pollution occurs in mainly urban areas where PCBs may be used in a number of industrial processes. At their point of discharge into the hydrosphere chemical concentration may be high enough to cause acute poisoning of the fauna. Holden (1972) estimated that in 1967 approximately 13 percent of fish-kills in England and Wales, and about 25 percent in Scotland, were due to pesticides, mainly organochlorines. However, repopulation is usually rapid because, among other factors, a large proportion of the chemical quickly becomes concentrated into the bottom mud and vegetation (Bridges et al, 1963).

Organochlorine pesticides are transported to the oceans by river systems; but atmospheric dispersal is a more important source of contamination (Tarrant and Tatton, 1968) which has resulted in animals

far removed from the target area being affected (Sladen et al, 1966; George and Frear, 1966). PCBs are also adsorbed to particulate matter in the atmosphere; but in the coastal environment their release from dumped sewage sludge may be the major factor in their dispersal (Holden, 1970; Halcrow et al, 1974).

In the estuarine environment, pesticides are rarely discharged in concentrations likely to cause acute toxicity; but chronic toxicity, and sublethal effects associated with the slow accumulation of chlorinated hydrocarbons may be a consequence of their use upstream. Effects of sublethal concentrations on phytoplankton may impair photosynthesis (Walsh, 1972) or produce a change in species composition (Mosser et al, 1972). However, aquatic animals are more vulnerable because they can concentrate pollutants by factors ranging from a few to thousands of times (Edwards, 1973). Many sublethal effects are behavioural (Moore, 1967). Incapacitated animals with high levels of chlorinated hydrocarbons can have adverse effects on predator populations; such prey are caught more easily and preferentially.

Accumulation of organochlorine pesticides and PCBs in top carnivores has been well documented (Hunt and Bischoff, 1960; Robinson et al, 1967; Risebrough, 1969; Gustafson, 1970). Humans may be at risk where fish form an important part of the diet. For this reason safety limits have been imposed in many countries and legislation introduced to ban or restrict the use of these chemicals. Edwards (1973) has reviewed the legislation regarding organochlorine pesticides.

4.1.2 Heavy metals

Human deaths resulting from consumption of fish from Minamata Bay contaminated with methyl mercury focused public attention on the presence of metals in the environment at toxic levels (Kurland et al, 1960). Subsequent cases involving mercury in Sweden (Borg et al, 1966), cadmium in Japan (Yamagata and Shigematsu, 1970) and copper in the Netherlands

(Roskam, 1972) stimulated research in the field resulting in a sizeable literature on their presence, levels and effects. Excellent reviews are given by Friberg et al (1971), D'Itri (1972) and Waldichuk (1974).

Heavy metals, elements between atomic numbers 22 and 92 in the periodic table, occur naturally in geological formations and their erosion leads to the appearance of metals throughout the environment at 'normal background' levels. However, as a result of man's increasing utilization of these elements background levels have become greatly enhanced in certain industrial areas resulting in 'hot spots' of pollution (Abdullah et al, 1972).

Apart from the Swedish experience (Borg et al, 1966), there have been few other terrestrial cases of acute metal poisoning. The majority have been caused by the disposal of waste into the aquatic environment. The fate of this effluent is largely determined by physico-chemical factors. As in the case of chlorinated hydrocarbons, the greater part of it is taken up by sediments close to the injection source and adsorbed by the inorganic and organic particulate phases. That which remains in solution is available for uptake by the aquatic biota.

Trace elements are normal constituents of organisms and a number of them, including copper and zinc, are essential for life. Accordingly, all organisms have the ability to accumulate metals from their environment. Levels of essential elements in the body may be regulated to a certain degree by increased metal elimination. However, if ingested at sufficiently high levels and for long enough all elements are toxic (Underwood, 1974).

A number of trace elements, including mercury, lead and cadmium, have no known biological value, and are toxic at low concentrations. Because they are accumulated slowly the organisms involved rarely show overt symptoms of acute toxicity but may be a significant danger for animals higher in the food chain, including man.

Mercury is a particular hazard. In its inorganic form it is strongly adsorbed to sediment particles (Burrell, 1974). However, microbial

activity and chemical processes can result in the formation and remobilization of methyl mercury (Jernelöv, 1969; Langley, 1973). This compound is extremely toxic because of the ease with which it crosses the blood-brain barrier, causing disintegration of brain cells (Kurland et al, 1960).

Accumulation of heavy metals may in many cases be completely unrelated to man's influence. Research has shown that levels of methyl mercury in fish caught during the 1970s are no higher than in museum specimens collected some ninety years ago (Barber et al, 1972). Carnivores with high metabolic rates, such as tuna, are also able to concentrate significant mercury levels from the 'normal uncontaminated' environment. Such factors must be considered when safety standards for food are imposed (Peterson et al, 1973).

Since deposition of river-borne sediment and effluent from industrial and sewage outfalls adds to the metal load, estuaries have become a major link in the heavy metal cycle. As a result, estuarine organisms are especially at risk. In most cases levels are highest in seaweeds and invertebrates; several authors have suggested these plants and animals be used as biological indicators (Butterworth et al, 1972; Nickless et al, Preston et al, 1972) because they more closely reflect metal contamination of the environment than fish which are able to alter their locations by ranging more extensively.

4.2 Tissue selection and initial sample preparation

Medway fish species suitable for human consumption were analysed for a range of organochlorine pesticides (table 4.1.1, p135), polychlorinated biphenyls and heavy metals, mercury, cadmium, copper, lead and zinc. They included eel, Anguilla anguilla, whiting, Merlangius merlangus, flounder, Platichthys flesus and plaice, Pleuronectes platessa. In addition brown shrimp, Crangon vulgaris, sand goby, Pomatoschistus minutus and sprat, Sprattus sprattus were studied, being common dietary constituents

of whiting. Other invertebrates, food of flounder, plaice and eel, were examined in a parallel study (Wharfe, 1975).

Samples were collected from the screens (section 2.2.1, p23) between March 1974 and April 1975. They were analysed monthly for chlorinated hydrocarbons, bimonthly for heavy metals. Shrimps, sand gobies and sprats were analysed whole and to reduce individual variation fifty-specimen bulk samples were formed in each case. The other species were split into groups relating to their length and sex; size divisions were based on average lengths-for-ages (Wheeler, 1969a). Lateral musculature, liver, gut wall and gonad were the tissues selected for examination. A sample for analysis was formed by combining tissues from twelve or more individuals, depending on the amount of tissue available.

Whole bodies, muscle and gut wall were initially mashed with a hand-mincer while liver and gonad were cut up with scissors. Only tissues to be analysed for chlorinated hydrocarbons were then homogenized.

4.3 Organochlorine pesticides and polychlorinated biphenyls in animal tissues

4.3.1 Methods

(a) Introduction

Gas-liquid chromatography with electron-capture detection has become the established technique for the analysis of organochlorine pesticides and polychlorinated biphenyls. The usual procedure involves solvent extraction of the residues, followed by 'clean-up' of the extract, the separation of most pesticides from PCBs and finally their chromatographic determination.

Holden (1973) lists the methods currently in use internationally. The procedure employed in this study was based on that in use by the Ministry of Agriculture, Fisheries and Food, Burnham-on-Crouch.

Table 4.3.1 Concentrations of chlorinated hydrocarbons in working standards

STANDARD SOLUTION/ chlorinated hydrocarbon	CONCENTRATION mg/litre (ppm)
I	
aldrin	0.02
α BHC	0.01
y BHC	0.01
heptachlor epoxide	0.02
DDE	0.05
TDE	0.05
DDT	0.10
II	
dieldrin	0.05
endrin	0.05
tetradifon	0.05
PCB	
Aroclor 1254	1.00

Table 4.3.2 Instrumentation for chlorinated hydrocarbon analysis

Gas chromatograph	Pye Unicam series 104
Detector	Ni^{63} E.C.D.
Column	glass (6 ft x ¼ inch OD)
Packing	3% OV_1 on 100-120 mesh diatomite CQ
Carrier gas	nitrogen
Flow rate	75 ml/min
Column temperature	175°C
Detector temperature	175°C
Injection head temperature	240°C
Applied potential	150 µs
Attenuation	5×10^2
Chart recorder	Servoscribe RE511
Chart speed	1 cm/minute
Solvent	hexane
Sample size	1 - 10 µl
Syringe	Hamilton 10 µl

(b) Procedure

(i) Extraction

Homogenized samples were accurately weighed; 4 grams of liver and up to 10 grams of the other homogenates were each added to 30 grams of Analar anhydrous sodium sulphate and mixed to a dry powder.

Each was extracted for three hours with 100 millilitres of cleaned hexane in a Soxhlet apparatus as described by Wharfe (1975). The cooled extract was made up to volume, with hexane, in a 100 millilitre graduated flask.

(ii) Solids content

To determine the aliquot size to be used in the next stage, 50 millilitres of extract were evaporated to dryness in a tared 100 millilitre beaker on a steam bath and dried for an hour in an air oven at 105°C.

(iii) 'Clean-up' and PCB-organochlorine pesticide separation:

Dry, partially deactivated alumina and silica columns were used to remove fat and other contaminants and to simultaneously separate the extract into two fractions (Holden and Marsden, 1969). Fraction I contained, if present, PCBs, DDE and aldrin while fraction II contained the remaining pesticides. Both fractions were reduced to one millilitre and analysed by GLC (stage v below).

(iv) Standard solutions

Two multistandard solutions were made up from pure pesticide samples, and a separate PCB standard solution was prepared. The dilution scheme is shown in Appendix IV, p229. Concentrations of chlorinated hydrocarbons in the working standards are shown in table 4.3.1.

(v) GLC analysis

Samples and standard solutions were analysed by a Pye Unicam series 104 GLC with radioactive nickel (Ni^{63}) source electron-capture detector. Instrumental conditions for the system are given in table 4.3.2. Operating parameters were set so that a 10 microlitre injection of working standard gave a full-scale deflection for the highest peaks. At these concentrations all standards gave linear calibrations through the origin.

(c) Interpretation of data

Measurement of peak heights was the method used in the quantitative interpretation of chromatograms. Calibration curves were drawn for each organochlorine pesticide. PCB quantification was based on the average of the three peak heights marked 1-3 in fig. 4.3.3, p147; they represent isomers or mixtures of isomers which appear to be more persistent in wildlife samples than earlier peaks, and are similar in most commercial PCB formulations.

4.3.2 Results

Figures 4.3.1, 4.3.2 and 4.3.3 (p145-147) are typical gas-liquid chromatograms obtained with each of the three standard solutions while figures 4.3.4 and 4.3.5 (p148 and 149) represent the chlorinated hydrocarbons and PCBs in a sample of flounder liver.

Quantifiable results were obtained for dieldrin, DDE, DDT, TDE and PCBs. Traces only of aldrin, α BHC, y BHC and endrin were recorded but, because of considerable interference, levels were not estimated. Heptachlor epoxide and tetradifon were not present in any samples.

Tables 4.3.3 - 4.3.7 present monthly levels of hexane-extracted fats and Σ DDT (DDE + TDE + DDT), dieldrin and PCBs, in the six fish species and one crustacean analysed. With few exceptions, mentioned below, levels of PCBs and dieldrin were, respectively, higher and lower than Σ DDT. A comparison of separate tissues showed that, in general, and with the exception of eel, levels were highest in liver, followed by gut wall and muscle tissues. The few gonad results indicated levels comparable with those in the musculature. Where whole bodies were analysed greatest concentrations usually occurred in sprat, then sand goby and brown shrimp.

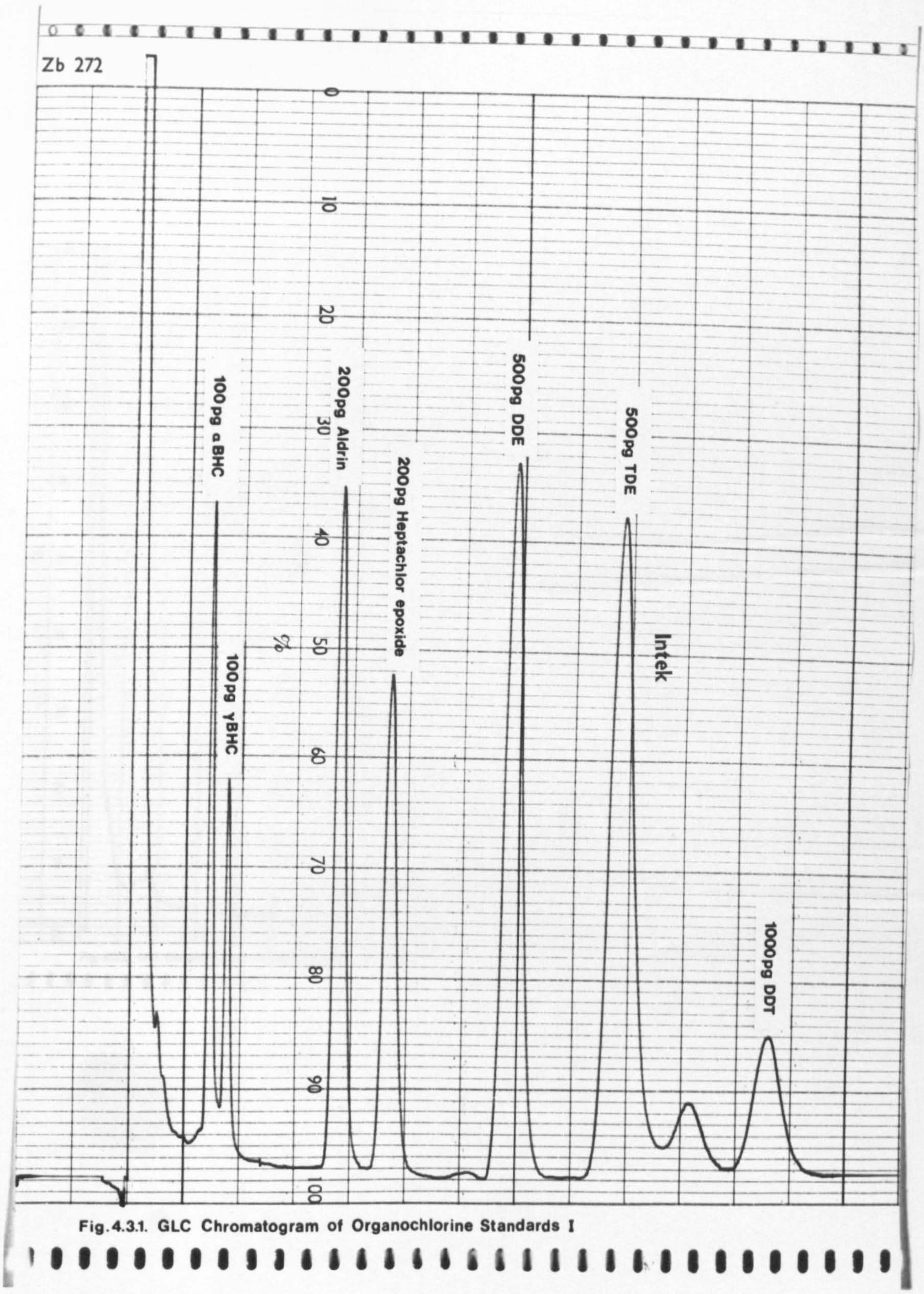


Fig. 4.3.1. GLC Chromatogram of Organochlorine Standards I

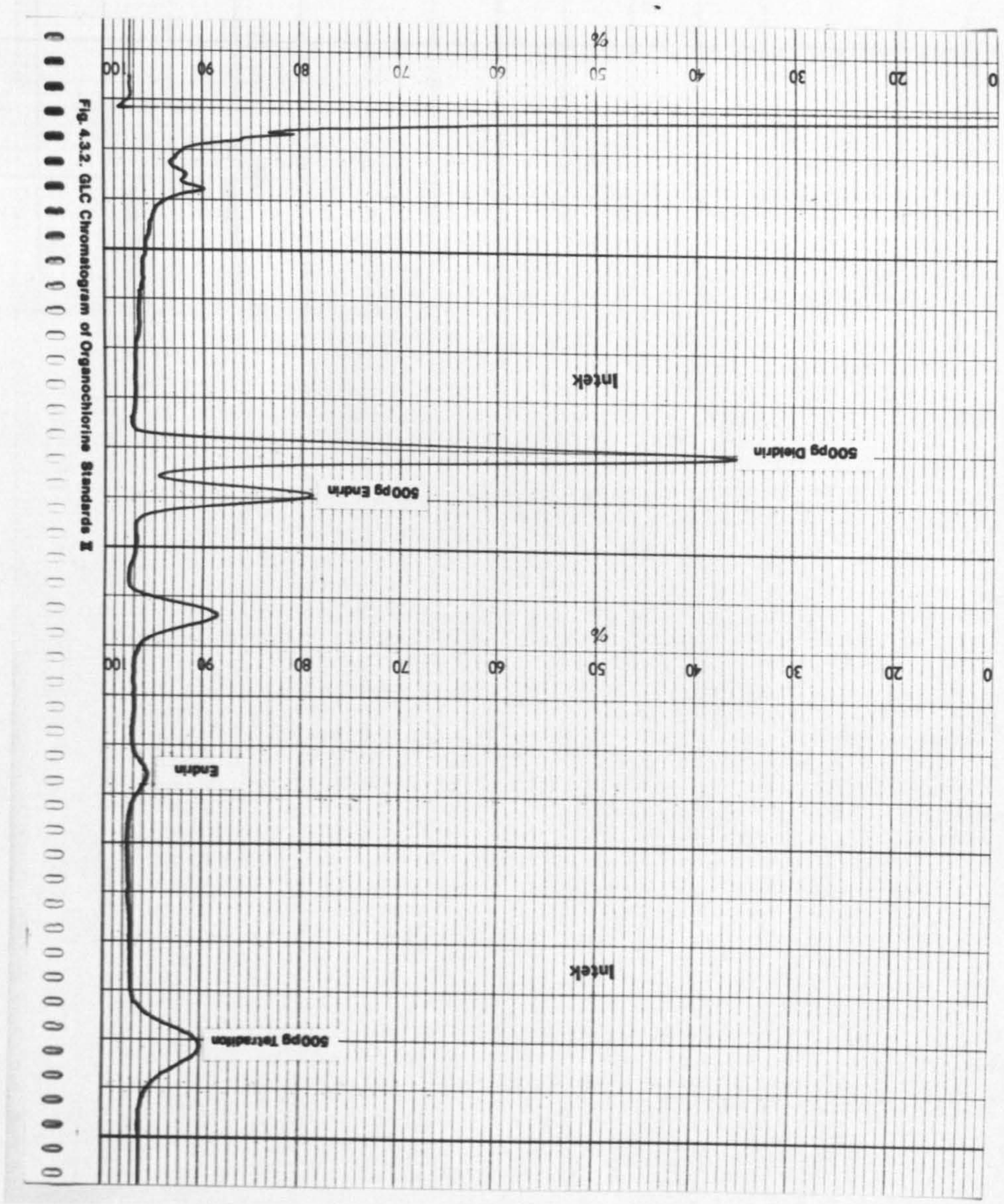


Fig. 4.3.2. GLC Chromatogram of Organochlorine Standards II

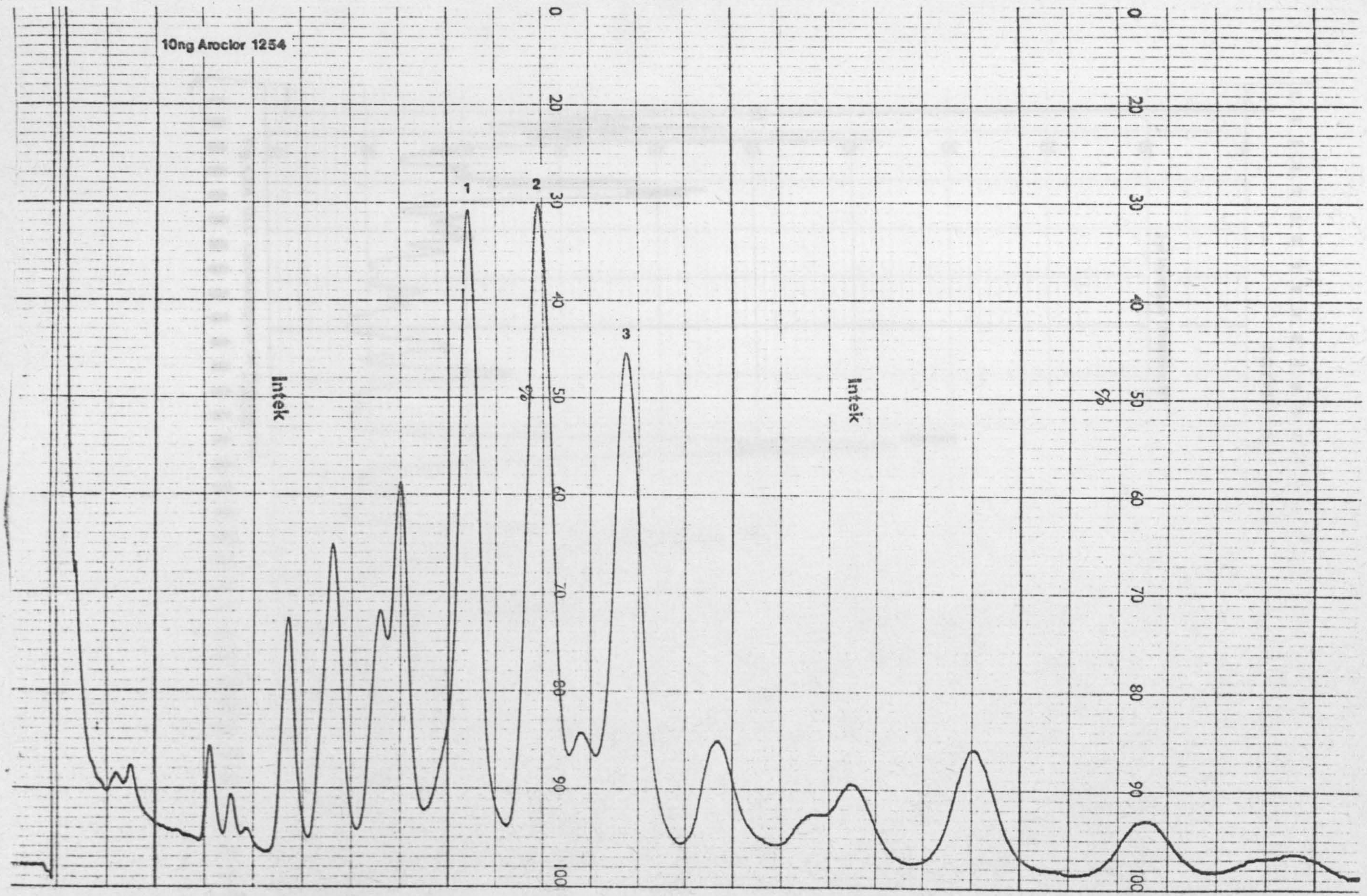


Fig. 4.3.3. GLC Chromatogram of PCB Standard

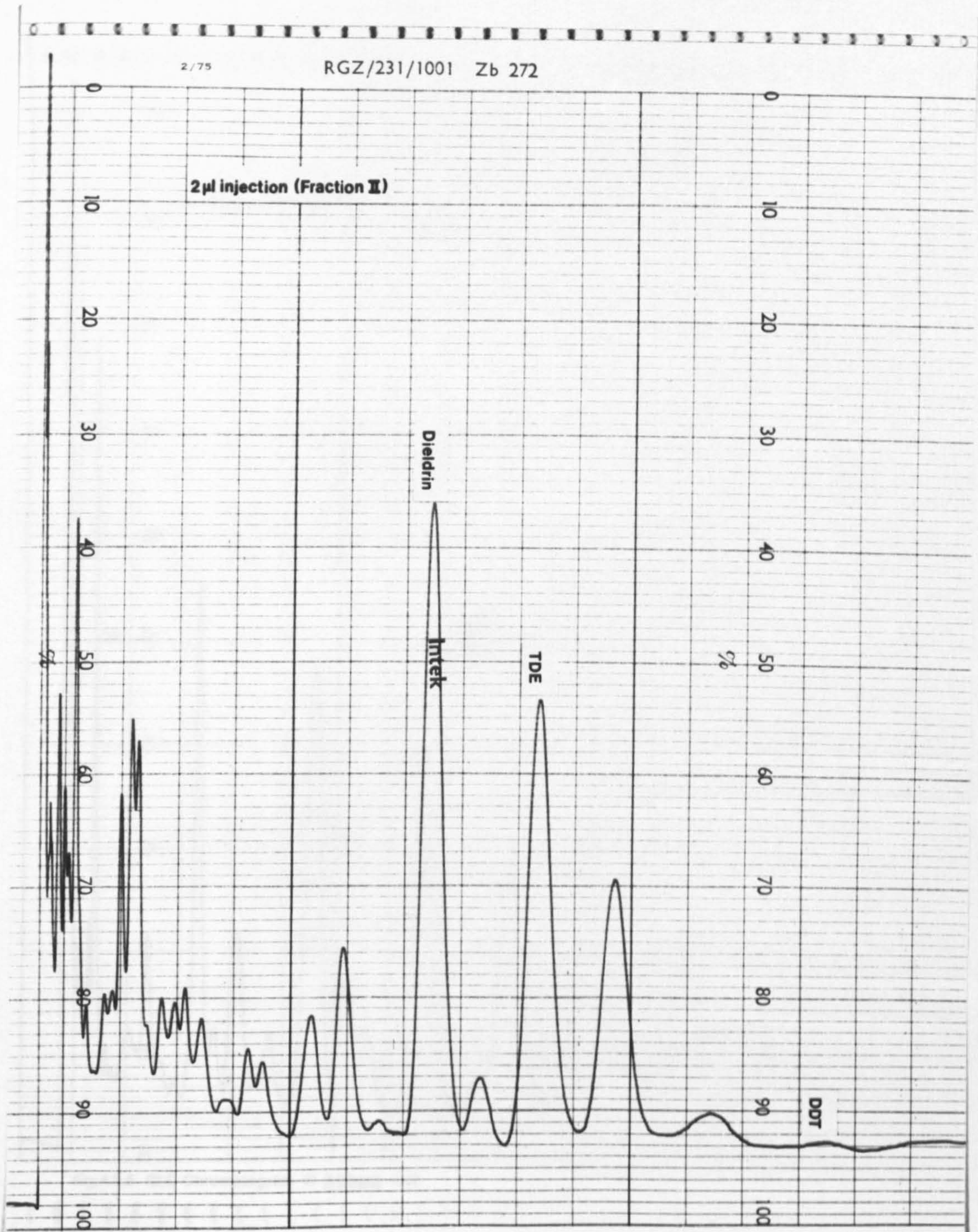


Fig. 4.3.4. GLC Chromatogram of P. flesus liver

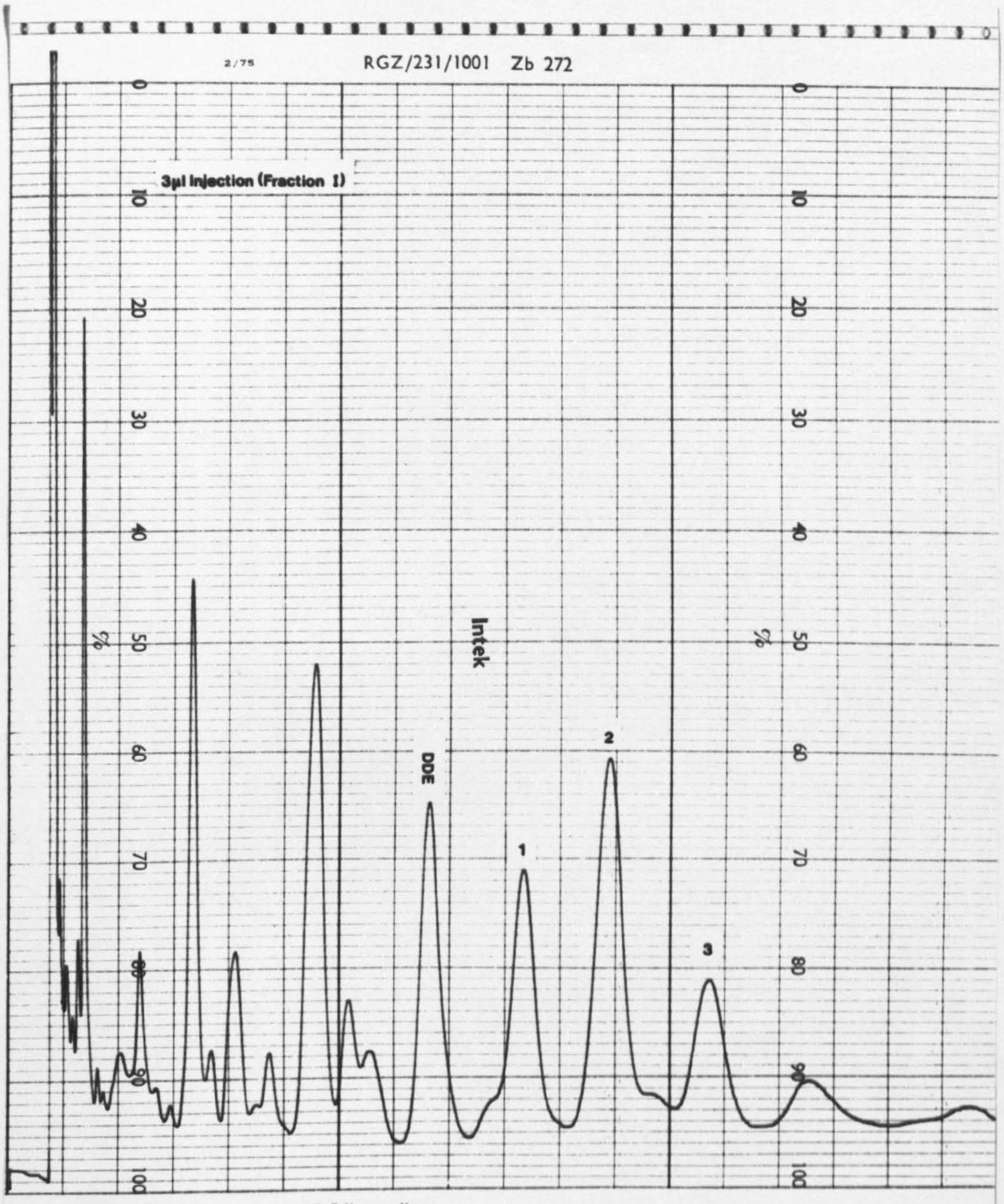


Fig.4.3.5. GLC Chromatogram of P.flesus liver

Table 4.3.3 Levels of chlorinated hydrocarbons (mg/g wet weight) in tissues of *A. anguilla*

Tissue/ Pollutant	1974										1975		
	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Muscle (size gp.<30.0cm)													
Hexane-extractable fat (%)	2.54	6.64	2.00	5.34	3.88	2.18	4.35	4.79	nd	nd	nd	nd	nd
ΣDDT	199.20	296.27	178.10	279.60	224.00	108.82	61.30	216.34	nd	nd	nd	nd	nd
Dieldrin	22.0	192.00	53.30	78.00	99.00	33.30	28.30	89.33	nd	nd	nd	nd	nd
PCB	796.00	1020.00	540.00	1040.00	720.00	424.00	335.00	720.00	nd	nd	nd	nd	nd
Muscle (size gp.>30.0 cm)													
Hexane-extractable fat (%)	3.22	16.67	nd	7.10	6.67	5.76	7.08	17.78	0.71	11.26	14.79	nd	nd
ΣDDT	139.10	365.20	nd	272.20	151.84	222.00	205.20	807.20	12.26	239.50	198.60	nd	nd
Dieldrin	53.00	232.00	nd	137.20	34.24	91.90	70.00	197.20	2.90	85.00	88.00	nd	nd
PCB	590.00	1520.00	nd	1320.00	744.00	1030.00	850.00	1960.00	40.00	875.00	1170.00	nd	nd
Liver (size gp. <30.0 cm)													
Hexane-extractable fat (%)	4.32	3.65	2.02	4.22	1.43	1.63	1.61	2.31	nd	nd	nd	nd	nd
ΣDDT	158.19	175.75	83.56	251.36	76.82	78.84	172.10	76.65	nd	nd	nd	nd	nd
Dieldrin	78.52	90.00	37.37	79.01	59.07	40.05	66.00	26.50	nd	nd	nd	nd	nd
PCB	1236.00	1538.00	640.00	1605.00	875.00	853.00	553.00	465.00	nd	nd	nd	nd	nd
Liver (size gp. >30.0 cm)													
Hexane-extractable fat (%)	nd	4.79	nd	3.30	1.28	nd	2.50	4.24	9.60	4.14	13.24	nd	nd
ΣDDT	nd	61.30	nd	133.45	81.50	nd	65.25	84.30	120.00	93.75	159.60	nd	nd
Dieldrin	nd	8.50	nd	58.00	37.00	nd	33.15	40.25	38.40	57.25	75.60	nd	nd
PCB	nd	1005.00	nd	1250.00	863.00	nd	800.00	800.00	880.00	438.00	1160.00	nd	570.00

nd = not determined

(a) A. anguilla (table 4.3.3)

Chlorinated hydrocarbon levels were generally higher in muscle tissue than in liver but there was considerable variation between groups. Highest levels of ΣDDT, dieldrin and PCB, 807.2, 232.0 and 1960.0 nanogram per gram (ppb) respectively, occurred in eel muscle (>30 cm size group) sampled in April (dieldrin) and October (ΣDDT and PCB). Minimum values were recorded in November in this same fish group but the levels (12.3 ppb ΣDDT, 2.9 ppb dieldrin and 40.0 ppb PCB) were unusually low compared with other results. The quantity of extractable fat in this sample, 0.7 percent, was equally reduced suggesting some loss of material during extraction.

Seasonal results were extremely variable with no regular pattern. Similarly, there was no clear relationship between pesticide levels and size; values were usually higher only in muscle tissues of larger fish.

Table 4.3.4 Levels of chlorinated hydrocarbons (ng/g wet weight) in tissues of *M. merlangus*

Tissue/ Pollutant	1974										1975	
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Muscle (size gp. 0-14.9 cm)												
Hexane-extractable fat (%)	0.16	0.48	nd	nd	0.43	nd	0.20	0.15	0.12	0.08	0.15	1.46
ΣDDT	14.20	31.52	nd	nd	14.12	nd	7.84	7.24	6.42	6.72	9.84	10.44
Dieldrin	4.32	9.20	nd	nd	6.60	nd	2.40	3.60	3.54	2.92	3.04	2.92
PCB	68.00	160.00	nd	nd	76.00	nd	40.00	10.00	80.00	44.00	68.00	34.00
Muscle (size gp 15.0-21.9 cm)												
Hexane-extractable fat(%)	0.22	0.22	nd	nd	nd	nd	nd	0.13	0.10	0.02	0.07	0.08
ΣDDT	16.12	14.00	nd	nd	nd	nd	nd	12.52	5.92	ns	7.10	10.20
Dieldrin	4.52	4.08	nd	nd	nd	nd	nd	5.12	2.80	0.60	3.52	3.40
PCB	64.00	60.00	nd	nd	nd	nd	nd	50.00	96.00	ns	16.00	20.00
Liver												
Hexane-extractable fat (%)	26.65	31.00	nd	nd	15.33	nd	11.49	13.11	29.90	27.38	36.86	30.76
ΣDDT	3110.26	4152.50	nd	nd	726.77	nd	1265.90	2100.00	1211.67	1615.65	4012.50	2851.65
Dieldrin	1096.15	947.92	nd	nd	251.37	nd	286.13	646.00	376.04	386.73	755.10	378.22
PCB	10385.00	9500.00	nd	nd	2680.00	nd	5030.00	4850.00	5859.00	6026.33	6238.00	7771.50
Gut wall												
Hexane-extractable fat (%)	1.22	0.50	nd	nd	nd	nd	nd	1.00	1.12	0.45	0.18	0.94
ΣDDT	66.03	25.31	nd	nd	nd	nd	nd	41.33	41.99	16.34	8.12	71.47
Dieldrin	21.49	3.56	nd	nd	nd	nd	nd	17.52	10.02	7.79	2.52	20.20
PCB	340.00	282.00	nd	nd	nd	nd	nd	129.00	271.00	66.00	20.00	139.00

nd = not determined

(b) M. merlangus (table 4.3.4)

Unlike eel, pesticide and PCB levels generally were highest in liver and lowest in muscle tissue. Maximum values were recorded during March and April; 4152.5 ppb ΣDDT, 1096.2 ppb dieldrin and 10385.0 ppb PCB, between thirty and sixty times greater than in the gut wall. The latter were comparable with the highest levels in muscle tissue while in other cases these contained mere traces of chlorinated hydrocarbons. Muscle tissue was analysed in two size-groups of whiting but there was little difference between them.

A full set of seasonal results could not be obtained through lack of material. Therefore, seasonal analysis of results proved impossible.

(c) P. flesus (table 4.3.5, overleaf)

Five separate tissues were tested; pollutant levels were generally highest in the liver followed, in descending order of concentration, by gut wall, ovary, muscle and testis. Results were, however, quite variable.

Maximum values for ΣDDT (1298.4 ppb), dieldrin (386.2 ppb) and PCB (6773.0 ppb) occurred in livers of fish taken in October, January and May respectively. At the other extreme, trace amounts were analysed in muscle tissue during December and in gonads during May and February.

Again, too few results over summer, through lack of material, obscured any seasonal pattern that may have emerged. However, there were indications in both muscle and liver tissues of ΣDDT and PCB levels increasing with fish length, but dieldrin values actually decreased slightly.

Table 4.3.5 Levels of chlorinated hydrocarbons (ng/g wet weight) in tissues of *P. flesus*

Tissue/ Pollutant	1974										1975	
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Muscle Size gp 0-7.9 cm												
Hexane-extractable fat (%)	0.73	nd	nd	nd	nd	nd	0.44	0.28	0.34	nd	nd	0.32
ΣDDT	51.28	nd	nd	nd	nd	nd	22.00	22.26	16.02	nd	nd	20.42
Dieldrin	19.49	nd	nd	nd	nd	nd	6.92	8.84	8.40	nd	nd	15.70
PCB	164.00	nd	nd	nd	nd	nd	94.00	47.00	105.00	nd	nd	37.00
Muscle Size gp 8.0-13.9 cm												
Hexane-extractable fat (%)	0.60	nd	nd	0.60	nd	nd	0.35	0.28	0.34	0.47	0.27	0.32
ΣDDT	13.12	nd	26.52	62.20	nd	nd	11.32	22.26	16.02	19.52	6.52	20.42
Dieldrin	13.72	nd	4.00	21.76	nd	nd	7.80	8.84	8.40	9.40	4.80	15.70
PCB	104.00	nd	104.00	216.00	nd	nd	78.00	47.00	105.00	80.00	90.00	37.00
Muscle Size gp 14.0-19.9 cm												
Hexane-extractable fat (%)	0.25	0.20	0.67	nd	0.18	nd	nd	nd	0.11	0.03	0.21	0.32
ΣDDT	22.52	57.60	77.80	nd	31.32	nd	nd	nd	6.32	0.20	5.52	20.42
Dieldrin	6.00	10.80	24.80	nd	10.12	nd	nd	nd	2.66	0.80	3.92	15.70
PCB	110.00	142.00	352.00	nd	62.00	nd	nd	nd	48.00	ns	52.00	37.00
Muscle Size gp >20.0 cm												
Hexane-extractable fat (%)	nd	nd	0.13	0.31	nd	nd	nd	0.14	nd	nd	nd	nd
ΣDDT	nd	nd	29.42	8.92	nd	nd	nd	117.72	nd	nd	nd	nd
Dieldrin	nd	nd	4.10	2.12	nd	nd	nd	20.40	nd	nd	nd	nd
PCB	nd	nd	nd	182.00	40.00	nd	nd	338.00	nd	nd	nd	nd

nd = not determined

Table 4.3.5 Contd.

Tissue/ Pollutant	1974										1975	
	Mar.	Apr.	May	June	July	Aug..	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Liver Size gp 0.13.9 cm												
Hexane-extractable fat (%)	5.94	5.84	10.04	12.63	3.74	nd	6.64	3.55	11.78	23.68	10.34	14.19
ΣDDT	480.27	586.80	371.13	409.00	366.11	nd	326.42	1298.44	381.71	333.95	679.83	1031.75
Dieldrin	146.67	85.00	188.14	115.00	119.61	nd	77.04	242.41	252.57	283.72	386.21	380.00
PCB	2400.00	2230.00	1443.00	1590.00	1929.00	nd	1321.00	5340.00	2143.00	2221.00	1220.00	1750.00
Liver Size gp 14.0->20.0 cm												
Hexane-extractable fat (%)	nd	nd	9.22	nd	nd	nd	nd	nd	7.54	4.18	9.65	14.19
ΣDDT	nd	nd	1007.12	nd	nd	nd	nd	nd	282.81	104.80	468.19	1031.75
Dieldrin	nd	nd	239.67	nd	nd	nd	nd	nd	163.29	43.00	194.50	380.00
PCB	nd	nd	6773.00	nd	nd	nd	nd	nd	1292.00	340.00	1510.00	1750.00
Gut Wall												
Hexane-extractable fat (%)	nd	1.19	1.41	1.25	nd	nd	nd	nd	1.13	0.41	0.97	1.09
ΣDDT	nd	169.96	107.17	53.52	nd	nd	nd	nd	37.00	14.92	48.19	32.90
Dieldrin	nd	39.00	36.38	11.04	nd	nd	nd	nd	18.61	6.60	24.80	17.49
PCB	nd	770.00	439.00	193.00	nd	nd	nd	nd	221.00	64.00	90.00	94.00
Ovary												
Hexane-extractable fat (%)	0.20	0.31	trace	nd	0.09	nd	nd	nd	nd	nd	0.19	0.52
ΣDDT	34.99	44.75	0.22	nd	10.72	nd	nd	nd	nd	nd	19.32	40.54
Dieldrin	15.72	8.50	trace	nd	7.20	nd	nd	nd	nd	nd	9.52	33.48
PCB	157.00	180.00	trace	nd	176.00	nd	nd	nd	nd	nd	50.00	95.00
Testis												
Hexane-extractable fat (%)	nd	nd	nd	nd	nd	nd	nd	nd	0.80	nd	nd	1.07
ΣDDT	nd	nd	nd	nd	nd	nd	nd	nd	14.82	nd	nd	5.44
Dieldrin	nd	nd	nd	nd	nd	nd	nd	nd	5.82	nd	nd	9.00
PCB	nd	nd	nd	nd	nd	nd	nd	nd	94.00	nd	nd	trace

nd = not determined

Table 4.3.6 Levels of chlorinated hydrocarbons (ng/g wet weight) in tissues of *P. platessa*

Tissue/ Pollutant	1974										1975	
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Muscle Size gp 0 - 7.9 cm												
Hexane-extractable fat (%)	0.21	0.39	nd	1.14	0.41	0.13	0.01	0.35	0.25	0.67	0.50	0.36
ΣDDT	12.04	25.42	nd	37.67	15.92	6.52	5.72	10.80	9.92	20.54	23.97	20.80
Dieldrin	4.40	8.20	nd	11.11	6.32	3.72	2.20	5.40	4.92	7.90	8.33	7.98
PCB	46.00	62.00	nd	156.00	50.00	68.00	14.00	50.00	88.00	73.00	155.00	48.00
Muscle Size gp 8.0 - 13.9 cm												
Hexane-extractable fat (%)	0.08	0.32	0.18	0.28	nd	0.13	0.15	nd	0.25	0.15	0.21	0.11
ΣDDT	5.44	13.04	9.80	9.00	1.92	6.52	7.36	nd	9.92	8.52	4.72	3.12
Dieldrin	1.60	2.72	3.60	5.40	1.32	3.72	3.08	nd	4.92	3.52	4.52	1.80
PCB	28.00	60.00	40.00	60.00	10.00	68.00	30.00	nd	88.00	40.00	28.00	22.00
Muscle Size gp 14.0 - 19.9 cm												
Hexane-extractable fat (%)	0.10	nd	0.22	nd	nd	nd	nd	0.12	0.09	0.15	0.14	0.07
ΣDDT	13.80	nd	6.52	nd	nd	nd	nd	4.00	4.72	3.60	5.92	3.72
Dieldrin	2.12	nd	3.40	nd	nd	nd	nd	1.72	1.88	1.60	3.12	2.32
PCB	trace	nd	56.00	nd	nd	nd	nd	trace	56.00	trace	34.00	32.00
Liver												
Hexane-extractable fat (%)	3.90	13.16	nd	4.68	5.54	1.53	4.15	12.76	6.53	5.77	6.06	3.96
ΣDDT	279.37	613.96	467.99	181.80	177.70	75.83	120.25	181.80	450.61	142.00	258.72	388.25
Dieldrin	109.67	227.91	89.93	82.00	80.25	15.19	67.50	86.61	189.50	89.25	102.98	187.50
PCB	1190.00	1814.00	2158.00	780.00	675.00	646.00	850.00	872.00	1843.50	813.00	1511.00	1090.00
Gut Wall												
Hexane-extractable fat (%)	0.74	1.71	1.87	0.94	nd	1.04	nd	0.88	0.89	1.06	0.56	0.79
ΣDDT	28.59	42.40	54.62	17.66	nd	72.47	nd	11.01	14.57	11.00	9.55	20.06
Dieldrin	12.46	24.73	9.22	12.99	nd	12.62	nd	6.25	7.08	7.32	5.80	15.77
PCB	153.00	212.00	255.00	169.00	nd	110.00	nd	69.00	115.50	54.00	74.00	93.00

nd = not determined

(d) P. platessa (table 4.3.6)

In plaice, chlorinated hydrocarbon levels were again highest in liver and lowest in muscle tissue. Maximum concentrations of ΣDDT, dieldrin and PCBs were recorded in April and May; 614.0, 227.9 and 2158.0 ppb respectively. Concentrations in the musculature were similar although lower in larger plaice, i.e. those between 14.0 and 19.9 centimetres. Also in this group PCBs occurred in only trace amounts during March, October and December and levels at these times were below both ΣDDT and dieldrin.

Monthly results were irregular but there was some suggestion, in liver and muscle tissues of the smallest plaice analysed, of reduced pollutant levels during August and September.

Table 4.3.7 Levels of chlorinated hydrocarbons (ng/g wet weight) in *C. vulgaris*, *P. minutus* and *S. sprattus*

Species/ Pollutant	1974										1975			
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Crangen vulgaris														
Hexane-extractable fat (%)	0.33	0.21	0.59	nd	0.51	0.28	0.19	0.27	0.27	0.44	0.42	0.42	0.83	nd
ΣDDT	13.00	11.60	38.84	nd	2.72	4.86	6.52	8.50	10.32	19.10	13.30	81.32	14.00	nd
Dieldrin	7.40	3.40	4.40	nd	1.56	1.20	1.80	2.00	4.92	4.80	6.80	20.24	8.00	nd
PCB	56.00	44.00	68.00	nd	22.00	68.00	20.00	trace	96.00	275.00	95.00	68.00	40.00	nd
Pomatoschistus minutus														
Hexane-extractable fat (%)	nd	nd	nd	nd	nd	3.05	2.90	2.57	2.99	3.43	3.56	2.56	1.55	nd
ΣDDT	nd	nd	nd	nd	nd	72.76	80.64	172.50	125.11	159.35	144.72	167.00	76.44	67.92
Dieldrin	nd	nd	nd	nd	nd	42.88	39.84	77.00	57.33	63.50	40.00	48.30	27.20	24.24
PCB	nd	nd	nd	nd	nd	264.00	376.00	400.00	460.00	430.00	528.00	435.00	232.00	158.00
Sprattus sprattus														
Hexane-extractable fat (%)	5.55	3.40	4.07	4.67	7.72	3.47	6.34	4.58	9.73	7.32	6.17	3.56	2.08	nd
ΣDDT	311.20	174.40	278.00	255.40	261.00	178.60	274.00	189.60	300.60	355.20	504.60	318.00	207.20	nd
Dieldrin	95.00	29.50	73.00	91.00	94.60	62.60	114.00	65.60	142.00	80.00	138.00	70.60	36.00	nd
PCB	1040.00	615.00	820.00	740.00	880.00	1027.00	1440.00	715.00	1180.00	830.00	910.00	1470.00	748.00	nd

nd = not determined

(e) P. minutus, S. sprattus and C. vulgaris (table 4.3.7)

In P. minutus, levels of ΣDDT and dieldrin reached a maximum of 172.5 and 77.0 ppb respectively in October and a minimum of 67.9 and 24.2 ppb respectively in April 1975. Monthly results were variable but with highest levels determined between October and February. The greatest PCB value (528.0 ppb) also occurred within this period, the lowest in April 1975.

In S. sprattus, as in P. minutus, highest values for all three pollutants, 504.6 ppb ΣDDT, 142.0 ppb dieldrin and 1470.0 ppb PCB, were analysed in fish taken between November and February. Lowest values occurred in April 1974.

In C. vulgaris, abnormally high levels of ΣDDT (81.3 ppb) and dieldrin (20.2 ppb), compared with remaining samples, were recorded in February 1975. The highest mean monthly level of PCB (275.0 ppb) occurred in December while minimum levels of all three pollutants, 2.7 ppb ΣDDT, 1.2 ppb dieldrin and a trace of PCB, were recorded in shrimps sampled between July and October.

Results of correlation analyses between hexane-extractable fat and dieldrin levels are presented in table 4.3.8 (overleaf). For all three pollutants strong correlations ($P<0.01$) existed for eel muscle (size-class >30.0 centimetres), whiting muscle (0 - 14.9 centimetres) and gut wall, flounder muscle (14.0 - 19.9 centimetres), plaice muscle (0 - 7.9 centimetres) and where whole bodies were analysed. No relationship existed between fat and residue levels in liver tissues.

Table 4.3.8 Correlations between hexane-extracted fat and dieldrin in animal tissues

Species	Length (cm)	Tissue	Correlation coefficient	Degrees of Freedom	Probability (P)
A. anguilla	<30	muscle	0.778	7	0.02>P>0.01
	>30	"	0.814	9	P<0.01
	<30	liver	0.675	7	0.05>P>0.02
	>30	"	0.441	8	P>0.1
C. vulgaris	-	whole	0.949	11	P<0.001
M. merlangus	0-14.9	muscle	0.914	8	P<0.001
	15.0-21.9	"	0.724	6	0.05>P>0.02
	0-21.9	liver	0.398	8	P>0.1
	0-21.9	gut wall	0.833	6	P=0.01
P. flesus	8.0-13.9	muscle	0.694	7	0.05>P>0.02
	14.0-19.9	"	0.921	7	P<0.001
	0-13.9	liver	0.491	10	P>0.1
	0-19.9	gut wall	0.623	6	P=0.1
P. platessa	0-7.9	muscle	0.902	10	P<0.001
	8.0-13.9	"	0.598	9	0.1>P>0.005
	14.0-19.9	"	0.580	6	P>0.1
	0-19.9	liver	0.484	10	P>0.1
	0-19.9	gut wall	0.442	9	P>0.1
P. minutus	-	whole	0.878	7	P<0.01
S. sprattus	-	whole	0.806	12	P<0.001

4.4 Heavy metals in animal tissues

4.4.1 Methods

(a) Introduction

(i) Analysis for mercury

The most common methods of mercury determination in biological samples are colorimetric determination with dithizone, neutron activation analysis and atomic absorption spectroscopy.

Colorimetric analysis is the basis of the official method recommended by the Analytical Methods Committee (1965). Most methods require some sample preparation (oxidation) to release the mercury from its bonds in organic molecules. This is achieved by burning or by acid digestion. The official method employs digestion with a nitric-sulphuric acid (10:1) mixture followed by mercury extraction with dithizone and its spectroscopic determination. Several workers have adopted the system (Mayer, 1970; Milton and Hoskins, 1947; Rolfe et al, 1955) but, in comparison, the method is insensitive and lengthy.

Neutron activation analysis involves neutron activation of the naturally occurring mercury isotopes in the sample. Their concentration is then determined by detecting radiations from the resulting radioactive species. The method has been employed by several workers (Smith, 1963; Sjöstrand, 1964; Kosta and Byrne, 1969) but as it involves the use of a nuclear reactor it is expensive although highly sensitive.

Atomic absorption spectroscopy is now the most commonly used analytical method for total mercury determinations. The conventional flame technique, however, is not sufficiently sensitive to measure small quantities of mercury (Hatch and Ott, 1968; Lindstedt, 1970) and flameless atomisation is used by the majority of workers in the field (Armstrong and Uthe, 1971; Skare, 1972; Braun and Husbands, 1971). It has also been employed in this study and is described below (p164).

Full details of the above methods are given by D'Itri (1972), Holden (1973) and Morriss (1973).

(ii) Analysis for cadmium, copper, lead and zinc

Flame atomic absorption spectroscopy is the most commonly used system in this case. The basic principle is that the sample solution is aspirated into a high temperature flame where it is predominantly converted to free atoms in the ground state. Radiation corresponding to a resonance frequency of the element is focused through the atomic vapour and absorbed accordingly.

Alternative methods of atomisation may be employed. In this study a graphite furnace was used in analyses for cadmium and lead. This electrothermal method is more sensitive, by an order of magnitude, than flame atomisation. Cadmium levels in tissues analysed were well within range of the graphite furnace but near the detection limits of the flame technique. Problems experienced with the flameless technique have been due mainly to matrix interference, especially where the volatility of the matrix nears that of the analyte (Segar and Gilio, 1973; Ediger, 1975). However, this does not seem to occur with cadmium (Schramel, 1973; Boshoff, 1975). On the other hand, in lead analyses Schramel (1973) found that pure standards gave absorbance signals three times higher than those with inorganic matrix added. Consequently, lead levels in this study may in all cases be rather too low.

(b) Procedure

Analysis for mercury

(i) Digestion

Up to 4 grams of liver and upto 10 grams of the other tissues were each accurately weighed and digested by 20 millilitres of 1:1 Analar nitric and sulphuric acids as described by Wharfe (1975). After digestion the solutions, including acid blanks, were transferred to 100 millilitre volumetric flasks and made up to volume with deionised water.

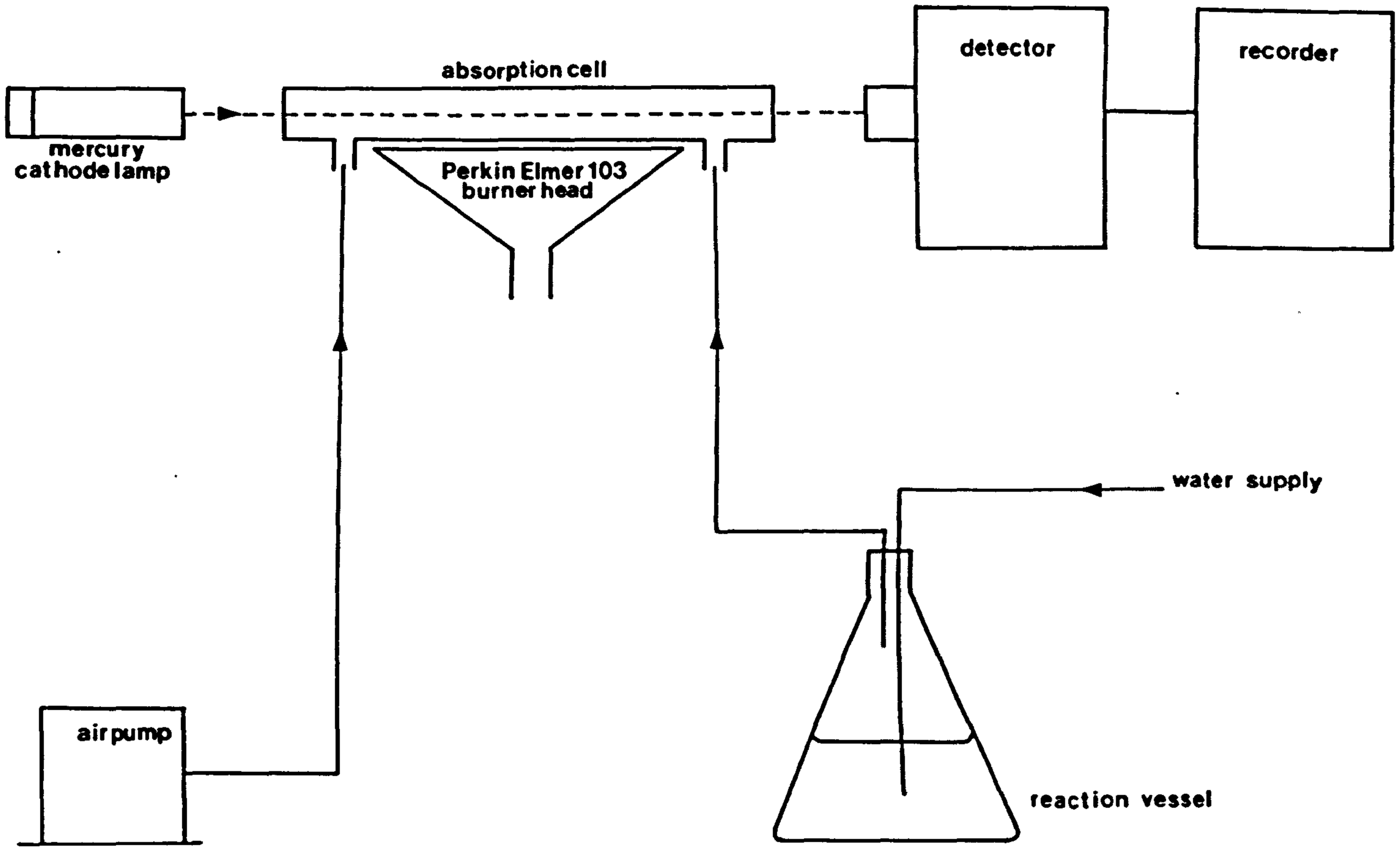


Fig.4.4.1. Mercury flameless absorption cell

(ii) Standard solutions

A mercury stock solution was prepared: 0.1354 gram of mercuric chloride was dissolved in 0.5 M sulphuric acid and made up to one litre in a volumetric flask. A working stock solution was prepared fresh by making one millilitre of the above up to 100 millilitres with deionised water. By taking 0.2, 0.4, 0.8 and 1.2 millilitres of working stock solution and making each up to 100 millilitres standards were prepared containing 0.2, 0.4, 0.8 and 1.2 microgram of mercury per 100 millilitres respectively.

(iii) Atomic absorption spectroscopy

Standard solutions and samples were analysed by a Perkin Elmer 103 atomic absorption spectrophotometer with the flameless absorption cell in position (fig. 4.4.1). Instrumental conditions for the system are given in table 4.4.1. The mercury cathode lamp was allowed to stabilize after which the instrument was adjusted to give a maximum signal.

Table 4.4.1 Instrumentation used in the detection of mercury

Spectrophotometer	Perkin Elmer 103
Light source	Perkin Elmer intensitron mercury cathode lamp
Lamp current (ma)	3
Wavelength (nm)	253.7
Wavelength dial setting	154
Slit setting (nm)	0.7
Gain (%)	75
Damping	1
Mode	Absorption
Expansion	6 turns approximately
Recorder	10 mV Speedomax W
Recorder speed	75 centimetres per hour

A 25 millilitre aliquot of the most concentrated standard was introduced into the reaction vessel (100 millilitre Quickfit flask) along with 25 millilitres of deionised water. After mixing, 2 millilitres of 20 percent stannous chloride solution (20 grams Fison's stannous chloride dissolved in 25 - 30 millilitres of Analar hydrochloric acid, made up to 100 millilitres with deionised water and stored over tin in an amber bottle) were added and the stopper immediately replaced. The system was given 30 seconds to equilibrate after which tap water was run in at a rate to fill the vessel in 30 seconds.

Mercury vapour was retained in the absorption tube for 60 seconds by the water pressure and air pressure from the small diaphragm pump. The recorder was adjusted to give a plateau maximum at the 70 percent scale after which the system was quickly cleared by removal of the stopper and action of the pump.

All remaining standards and samples were run in duplicate. Between each sample a water blank was run and the glassware rinsed with concentrated nitric acid and deionised water.

Analysis for cadmium, copper, lead and zinc

(i) Digestion

Tissue samples were taken as for mercury tests (p162) and each digested by Aristar nitric acid (Wharfe, 1975). The digests, and acid blanks, were made up to volume with deionised water in 50 millilitre volumetric flasks.

(ii) Standard solutions

A multi-element stock solution, containing all four metals, was prepared. The dilution scheme is shown in Appendix IV (p230).

(iii) Atomic absorption spectroscopy

Flame atomisation: Cd, Cu, Zn

Operating parameters for the Perkin Elmer 103 instrument used are given in table 4.4.2. Each cathode lamp was allowed time to stabilize after which the instrument was set to give a maximum signal.

Table 4.4.2 Operating parameters for Perkin Elmer 103 Spectrophotometer

	Cd	Cu	Zn
Light source	Pye 611484	PE intensitron (multi-element)	Activion 5534
Lamp current (ma)	3	10	12.5
Wavelength (nm)	228.3	324.7	213.9
Wavelength dial setting	0.7	0.7	0.7
Angle of burner head	parallel	parallel	45°
Flame type	air-acetylene (lean)	air-acetylene (lean)	air-acetylene (rich)
Air setting	1250	1250	1250
Acetylene setting	1420	1420	1390
Gain setting (%)	75	75	75
Mode setting	Int 10	Int 3	Int 3
Expansion (turns)	9 approx	6 approx	9 approx

The most concentrated standard was atomised first and the expansion control adjusted to give a full deflection on the atomic absorption scale.

Flameless atomisation: Cd, Pb

The PE 103 was used in conjunction with a 'home-made' electrothermal atomiser (Boshoff, 1975). Operating parameters for the spectrophotometer are given in table 4.4.3.

Table 4.4.3 Operating parameters for the Perkin Elmer 103 using electrothermal atomisation

	Cd	Pb
Light source	Pye 611484	Pye 611277
Lamp current (ma)	3	3
Wavelength (nm)	228.8	283.3
Wavelength dial setting	110	206
Slit setting (nm)	0.7	0.7
Gain (%)	75	75
Damping	1	1
Expansion (turns)	0	0

The atomiser used nitrogen as the purge gas at a flow rate of 1000 millilitres per minute and 10 millilitres per minute during atomisation. The water flow rate was 300 millilitres per minute and the temperature programme was as follows:

	Start	Drying	Charring	Atomisation
Temperature (^{o}C)	45	110	425	Ramp mode
Time (secs)		25	25	Ramp mode to $2200^{o}C$

A 10 mV Speedomax W chart recorder with a one-second full-scale deflection response was used to record the data. The spectrometer's operating parameters were maximized with the graphite furnace in position and nitrogen and water flows on.

The programme was run several times to establish background levels and to condition the furnace. A 20 microlitre aliquot was taken from the most concentrated standard using an Eppendorf micropipette with disposable polypropylene tips, and injected into the furnace. The temperature programme was initiated and the system adjusted to give a full-scale deflection on the chart recorder.

Remaining standards, samples and blanks were similarly treated.

(c) Interpretation of data

Standard calibration curves were drawn based on readings from the atomic absorption scale (flame atomisation) and on recorded peak and plateau heights (flameless atomisation). Typical standard curves resulting from the determination of mercury and cadmium are shown in figures 4.4.2 and 4.4.3.

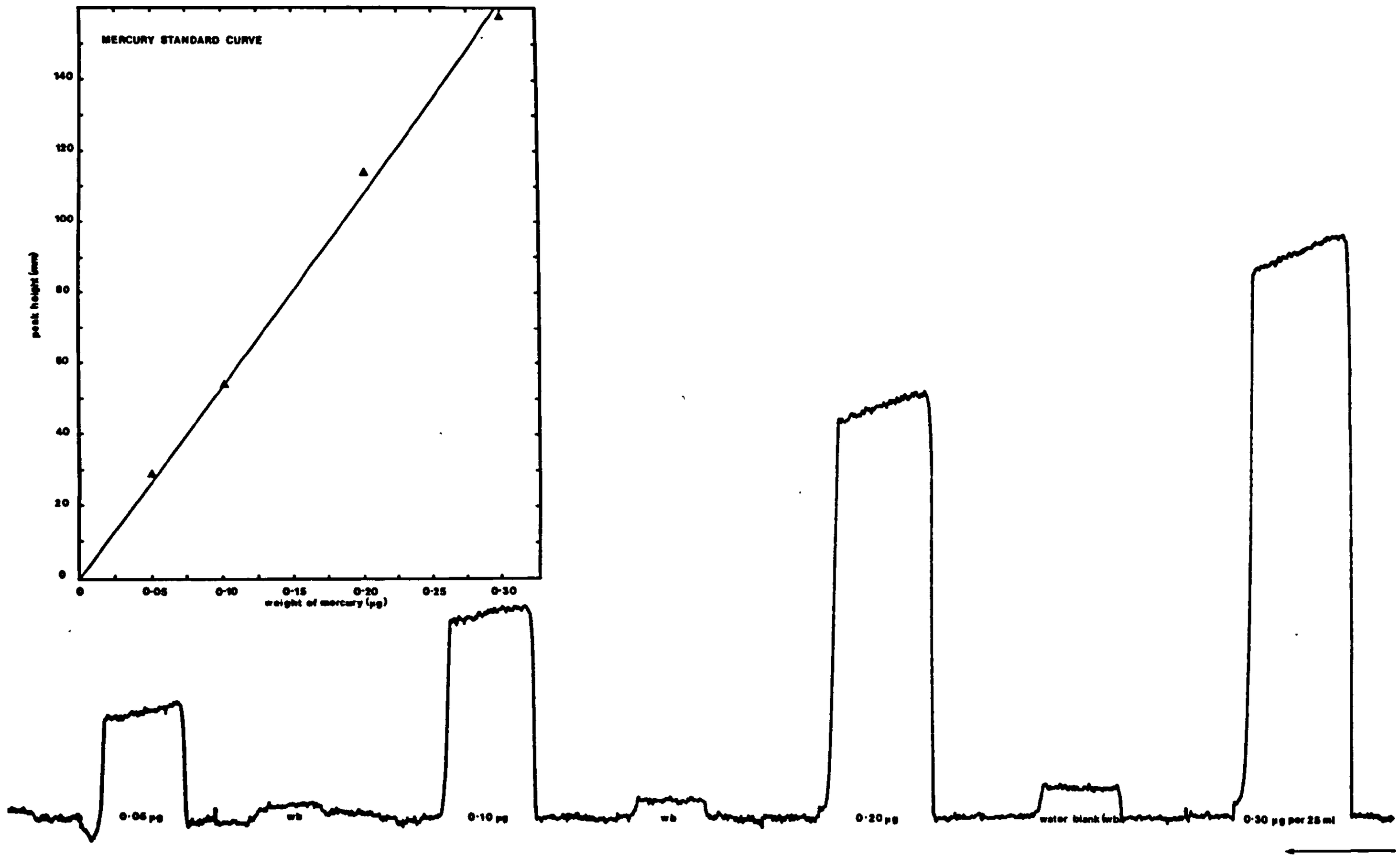


Fig.4.4.2 Mercury standards

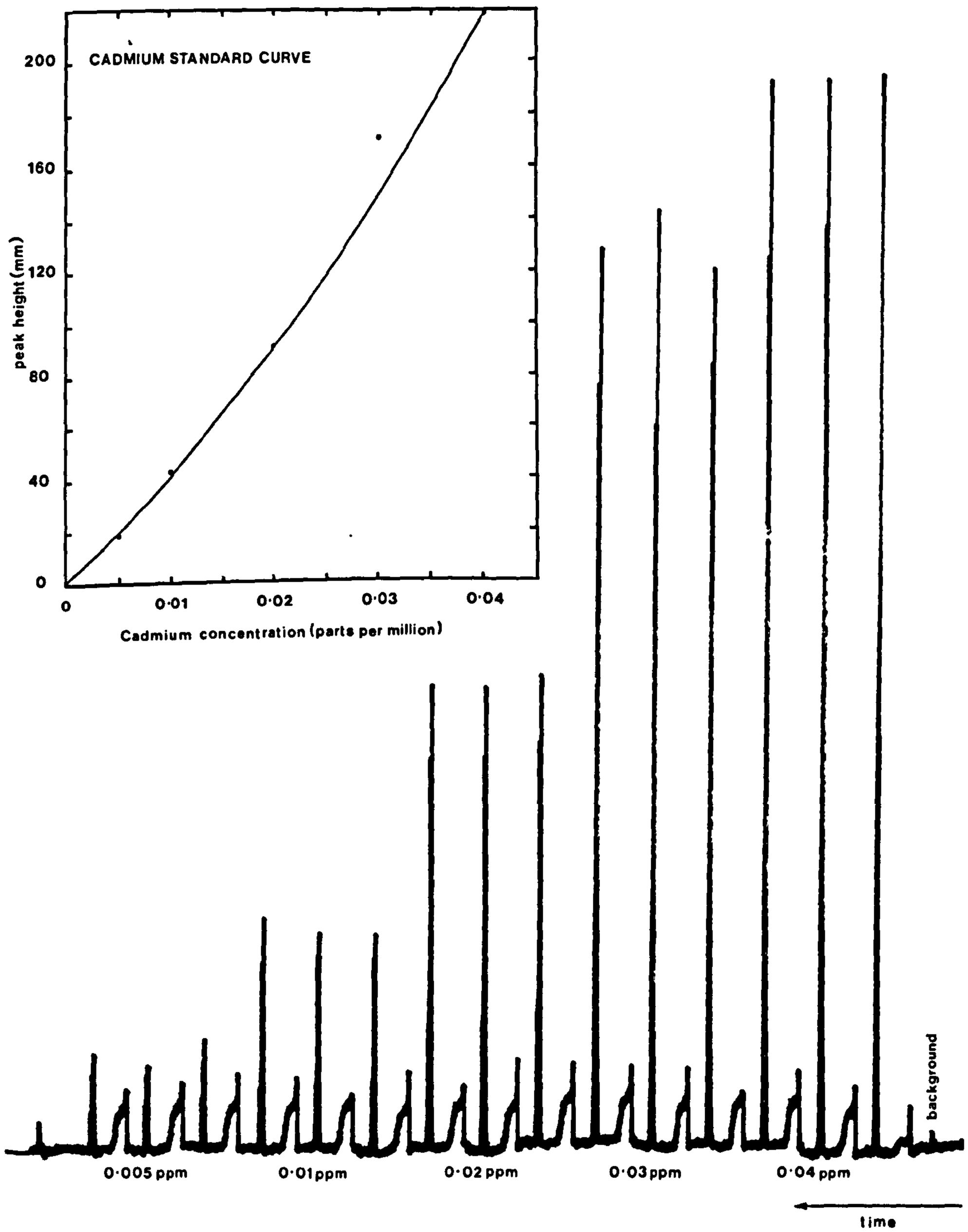


Fig.4.4.3. Cadmium standards

4.4.2 Results

Table 4.4.4 presents seasonal levels of five heavy metals; mercury, cadmium, copper, lead and zinc, in a range of fish tissues and one crustacean. Cadmium levels quoted are the results using flame atomisation detection.

Highest mercury levels were recorded in livers of the larger eels (>30.0 centimetres) with concentrations consistently above 1.5 parts per million (ppm). In all other cases levels were below 1.0 ppm and most under 0.5 ppm. This included C. vulgaris where mercury values lay within the range of levels recorded in fish tissues. With the exception of eels, concentrations appeared to be slightly higher in the musculature although generally they were rather variable.

There was some indication of mercury levels increasing with fish length; in flounder, concentrations varied from 0.04 ppm in fish below 8.0 centimetres to 0.64 ppm in individuals over 20.0 centimetres. Similar increases occurred in plaice and eel muscle.

In contrast to mercury, the mean monthly cadmium level in C. vulgaris, 0.60 ppm, was higher than in fish tissues where concentrations were regularly below 0.5 ppm. The element was evenly distributed through fish tissues although levels appeared to be slightly higher in liver and gut wall than in the musculature. A comparison of seasonal results showed that in several tissues - eel muscle and liver, flounder muscle and gut, plaice muscle, sand goby and shrimp - levels were lowest in summer.

Higher copper levels were detected in liver than in gut wall or muscle tissues. The maximum value, 32.79 ppm, occurred in eel liver and only flounder and shrimp tissues contained comparable concentrations on occasion. In all other species levels fell below 4 ppm. Where muscle tissues from several size-classes were analysed concentrations usually decreased with length.

Table 4.4.4 Seasonal heavy metal levels (ppm wet weight)

Species/ tissue	Length (cm)	Hg			Cd			Cu			Pb			Zn		
		1974 Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.
Muscle																
A. anguilla	<30.0	0.50	0.16	0.27	0.17	0.06	0.15	0.61	0.62	0.50	0.25	0.60	nd	26.75	20.40	22.85
	>30.0	0.45	0.54	0.59	0.16	0.10	0.13	0.47	0.44	0.40	1.25	0.66	1.25	30.06	21.96	29.95
M. merlangus	0-14.9	0.80	0.23	0.33	0.15	0.13	0.10	0.65	0.75	0.30	0.33	0.18	0.37	10.78	10.78	5.98
	15.0-21.9	0.40	nd	0.34	0.28	nd	0.13	0.75	nd	0.20	0.46	nd	0.25	11.98	nd	6.29
P. flesus	0-7.9	nd	0.12	0.04	nd	0.07	0.06	nd	1.33	1.29	nd	0.21	0.35	nd	17.97	18.41
	8.0-13.9	0.29	0.11	0.07	0.07	0.06	0.08	1.00	0.80	0.50	0.47	0.32	0.37	19.46	14.27	16.46
	14.0-19.9	0.58	0.16	0.17	0.07	0.06	0.08	0.30	0.30	0.30	0.18	0.10	0.72	16.46	7.97	12.48
	>20.0	0.64	nd	nd	0.06	nd	nd	0.30	nd	nd	0.33	nd	nd	14.48	nd	nd
P. platessa	0-7.9	nd	nd	0.15	nd	0.06	0.13	nd	0.91	1.15	nd	0.48	0.92	nd	12.51	9.98
	8.0-13.9	0.20	0.21	0.15	0.14	0.09	0.13	1.15	0.50	1.15	1.00	0.95	nd	14.23	8.26	9.98
	14.0-19.9	0.22	nd	0.32	0.15	nd	0.13	1.17	nd	0.50	1.40	nd	0.90	10.76	nd	9.30

nd = not determined

Table 4.4.4 Cont.

Species/ tissue	Length (cm)	Hg			Cd			Cu			Pb			Zn		
		1974 Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.	Mar.	Jul.	Nov.
LIVER																
A. anguilla	<30.0	nd	0.38	0.32	0.40	0.18	0.15	32.79	4.99	6.99	0.84	nd	nd	61.60	43.88	40.42
	>30.0	1.83	1.55	1.72	0.30	0.29	0.45	29.93	19.90	27.17	1.35	1.50	3.94	66.84	63.84	78.88
M. merlangus	0-21.9	0.33	nd	nd	0.18	nd	0.13	2.33	nd	2.49	1.54	nd	0.25	32.40	nd	24.24
P. flesus	0-13.9	0.21	0.27	nd	0.22	0.15	nd	7.38	18.46	nd	1.35	0.53	nd	58.81	48.81	nd
	>14.0	nd	nd	0.08	0.17	nd	0.18	13.52	nd	23.01	1.45	nd	1.31	16.82	nd	75.94
P. platessa	0-19.9	nd	nd	nd	0.17	nd	0.21	2.98	nd	3.74	1.41	nd	1.20	40.19	nd	36.42
GUT WALL																
M. merlangus	0-21.9	0.26	nd	0.19	0.21	0.14	0.08	1.77	1.15	1.30	0.46	0.67	0.20	24.96	23.38	20.93
P. flesus	0->20.0	0.21	0.12	nd	0.21	0.13	0.23	2.30	1.00	4.78	1.12	0.35	0.70	40.78	30.37	37.34
P. platessa	0- 19.9	0.12	0.03	0.07	0.25	nd	0.20	2.82	nd	1.89	1.65	nd	1.00	27.18	nd	27.89
OVARY																
P. flesus	0->20.0	0.12	nd	nd	0.08	nd	nd	2.38	nd	nd	0.12	nd	nd	146.84	nd	nd
WHOLE BODY																
C. vulgaris	-	0.21	0.12	0.16	0.60	0.56	0.60	21.85	15.61	18.20	1.30	1.22	1.15	31.06	21.59	26.63
P. minutus	-	0.24	0.12	0.17	0.25	0.20	0.26	1.30	1.40	1.00	1.65	0.82	0.97	28.47	24.96	30.75
S. sprattus	-	0.18	0.12	0.18	0.26	0.29	0.30	1.07	1.12	1.16	0.70	1.59	0.91	43.22	31.90	39.93

nd = not determined

Table 4.4.5 Determination of cadmium by flame and flameless atomic absorption spectroscopy (concentrations ppm wet weight)

Species	A. anguilla				M. merlangus				C. vulgaris	P. minutus	S. sprattus
Tissue	muscle		liver		muscle		liver	gut	whole body	whole body	whole body
Size class (cm)	<30	>30	<30	>30	0-14.9	15-21.9					
FLAME	0.17	0.12	0.24	0.37	0.13	0.21	0.15	0.15	0.59	0.24	0.29
FLAMELESS	0.06	0.12	-	0.58	0.06	0.08	0.15	0.05	0.19	0.05	0.09

Species	P. flesus								P. platessa				
Tissue	muscle				liver		gut	gonad	muscle			liver	gut
Size class (cm)	0-7.9	8-13.9	14-19.9	>20	I	II			0-7.9	8-13.9	14-19.9		
FLAME	0.06	0.07	0.07	0.06	0.18	0.17	0.19	0.08	0.08	0.11	0.14	0.18	0.22
FLAMELESS	0.07	0.07	0.06	0.22	0.18	0.17	0.09	0.08	0.04	0.12	0.10	0.18	0.02

Lead levels were highest (3.94) in livers from eels caught in November but at other times of the year concentrations in this tissue were comparable with those in other fish, i.e. usually less than 1 ppm.

Zinc levels were high, reaching 146.84 ppm in flounder ovary. Unfortunately only one sample of this tissue was analysed and the result may be unusually high. Eel muscle and liver again contained maximum zinc concentrations for these tissues, 30.06 and 78.88 ppm respectively; levels in the gut were usually above those in the musculature and similar to C. vulgaris, P. minutus and S. sprattus. For both lead and zinc lowest results generally were coincident with summer months and occurred in smaller-sized fish.

Cadmium levels determined by flame and flameless atomic absorption spectroscopy are presented in table 4.4.5. In flounder and plaice concentrations obtained by the two methods were similar but in other species flame results generally were higher. However, the difference between sets, of the order 0.1-0.4 ppm, is low enough not to be of ecological significance.

Table 4.5.1 Comparison of chlorinated hydrocarbon levels with the literature

Author	Species	Tissue	Concentration ng/g (ppb)		
			ΣDDT	Dieldrin	PCB
Koeman et al (1967)	sprat	whole body	140.0	200.0	nd
Huschenbeth (1972)	"	"	161.0	22.0	292.0
van den Broek (1977)	"	"	277.5	84.0	955.0
Koeman et al (1967)	herring	whole body	110.0	270.0	nd
Robinson et al (1967)	"	"	80.0	57.0	nd
Jensen et al (1969)	"	"	390.0	nd	nd
Robinson et al (1967)	plaice	whole body	20.0	40.0	nd
Jensen et al (1967)	"	"	10.0	nd	nd
van den Broek (1977)	"	muscle	10.0	4.0	47.0
	"	liver	291.5	116.8	1237.4
Robinson et al (1967)	whiting	whole body	20.0	40.0	nd
van den Broek (1977)	"	muscle	11.0	4.0	56.5
	"	liver	2311.0	529.0	6447.0
Foehrenbach (1972)	flounder	whole body	60.0	40.0	nd
Huschenbeth (1972)	"	"	14.0	3.0	63.0
van den Broek (1977)	"	muscle	30.0	10.0	114.0
	"	liver	610.0	208.0	2608.0
Huschenbeth (1972)	eel	whole body	747.0	8.0	nd
	"	"	1671.0	123.0	nd
van den Broek (1977)	"	muscle	250.0	94.0	866.0
	"	liver	115.5	50.0	919.0
Huschenbeth (1972)	shrimp	whole body	15.0	3.0	78.0
van den Broek (1977)	"	"	19.6	5.9	77.5

nd = not determined

4.5 Discussion

Chlorinated hydrocarbon and heavy metals analysed in this survey were within range of values in the literature (tables 4.5.1 and 4.5.2). Most previous studies have been performed on whole animals but where direct comparisons were possible dieldrin levels in this survey were average while ΣDDT and PCB results inclined toward the maximum part of the range. Comparatively high values were not unexpected as most comparable work has been on organisms from offshore rather than from estuarine waters. Metal concentrations, on the other hand, were low compared with other workers' results which possibly reflects low background levels in the study area.

Despite their comparatively high concentrations in fish tissues (table 4.5.3, p180), neither dieldrin nor ΣDDT has been detected in water from the estuary and PCBs only in trace amounts (Wharfe, 1975). Although fish may accumulate chlorinated hydrocarbons to levels 10^3 to 10^5 times those in the ambient water (Hammond et al, 1972), Macek and Korn (1970) consider food-chain concentration to be the major source. There was some evidence for this in the present study with mean levels of chlorinated hydrocarbons greater in the gut wall than in the musculature (table 4.5.3, p180). Concentrations were also higher in whole bodies of sprat and sand goby than in shrimp. Sand goby, at a position further along the food chain than the crustacean, had accumulated levels of chlorinated hydrocarbons some five to ten times greater. Concentrations in sprat tissue were still higher even though, like C. vulgaris, sprat is mainly a plankton feeder.

However, the greater lipid content of sprat tissue, varying between 2.1 and 9.7 percent body weight, compared with sand goby (1.6 - 3.6 percent) and shrimp (0.2 - 0.8 percent), must also be considered a factor because lipid and chlorinated hydrocarbon levels were highly correlated in these organisms. They were also in fish analysed by Earnest and Benville (1971) but, generally, views expressed in the literature are divided

Table 4.5.2 Comparison of heavy metal levels with the literature

Author	Species	Tissue	Concentration µg/g wet weight (ppm)				
			Hg	Cd	Cu	Pb	Zn
Andersen et al (1973)*	S. sprattus	whole body		<0.2-0.7	2.6-8.5	<0.3-21.8	85-210
Wright (1976)	"	muscle		0.24±0.14	4.61±4.07		19.54±38.69
van den Broek (1977)	"	whole body	0.16	0.29	1.08	1.03	38.45
MAFF (1971)	P. flesus	whole body	0.08-2.5				
Underdal (1969)	"	"	0.13-0.68				
Hardisty et al (1874)*	"	"		5.6±0.29		25.1±0.87	132.8±0.55
Peden et al (1973)	"	"		0.68			7.2
	"	"		1.67			20.5
van den Broek (1977)	"	muscle	0.04-1.15	0.06-0.08	0.30-1.33	0.10-0.72	7.97-19.46
	"	liver	0.08-0.27	0.15-0.22	7.38-23.01	0.53-1.45	48.81-75.94
MAFF (1971)	P. platessa	whole body	0.09-0.60				
Johnels et al (1967)	"	"	0.031-0.076				
	"	"	0.071-3.10				
Wright (1976)	"	muscle		1.44	0.5		30.20
	"	liver		2.91	1.89		341.88
van den Broek (1977)	"	muscle	0.15-0.32	0.05-0.15	0.50-1.73	0.48-1.40	8.26-14.46
	"	liver		0.16-0.21	1.47-4.22	0.95-1.87	36.42-42.21
MAFF (1971)	M.merlangus	whole body	0.15-0.83				
Hardisty et al (1974)*	"	"		6.2±0.19		24.0±0.98	124.8±0.51
Peden et al (1973)	"	"		0.09			21.8
van den Broek (1977)	"	muscle	0.23-0.80	0.10-0.28	0.20-1.00	0.18-0.46	5.98-11.98
		liver	0.33	0.13-0.18	1.33-3.49	0.25-1.54	24.24-32.40

* ppm dry weight

whether such relationships exist. It was noteworthy, however, that the two parameters were not correlated in tissues serving as fat storage depots, especially the liver. No explanation is offered for this observation.

The behaviour of trace metals in the environment differs generally from chlorinated hydrocarbons in that there is little evidence in the literature of food chain concentration. This is especially true of essential elements such as copper and zinc; these elements are usually higher in invertebrates because fish can actively regulate their concentrations (Cross et al, 1973). However, in the present study, comparatively high copper levels in C. vulgaris, ranging between 9.49 and 25.48 ppm (table 4.5.4, p182), were undoubtedly due mainly to the copper-based respiratory pigment, haemocyanin.

Although there were no indications that copper and zinc accumulate, mercury levels increased with fish size. In eel muscle, chlorinated hydrocarbon levels were also higher in larger individuals, coincident with a rise in lipid content (table 4.5.3, p180). Concentration and size were similarly related in studies by Bache et al (1972) and Edwards (1973). However, these parameters were inversely related in Medway whiting and plaice muscle suggesting considerable interspecific variation.

Seasonal results proved inconclusive. Wharfe (1975), studying the invertebrate fauna, detected high levels of DDT during summer months of 1973 but not the following year. In the present study, no summer rise in pesticides, associated with increased spraying activity, was recorded. Similarly, Bjerk (1973) detected no seasonal increase in tissues of cod sampled near the mouth of a Norwegian fjord but there was a significant rise further upstream. Sampling nearer the agricultural source may have been necessary in the present study to detect a similar increase. On the other hand, summer is a period of change in the estuary with individuals of many species emigrating and being replaced by newly-spawned fish (section 2.3.4, p44). Therefore, many fish analysed may

have entered the sampling area only recently. Also, the use of DDT and dieldrin has been strictly controlled since 1970 (Edwards, 1973) so agricultural spraying may no longer be an important source of these chemicals.

A shorter exposure period may also help explain the unusual seasonal results in which metal levels were apparently reduced in summer (table 4.4.4, p171). Differences in most cases were due probably to individual variations but fish from offshore areas where metal concentrations are lower (Preston et al, 1972) may be a contributing factor.

Seasonal comparisons of chlorinated hydrocarbon levels in some tissues were prevented by lack of material during summer months. However, monthly results generally were variable and highest concentrations were not restricted to any particular season.

Chemical concentrations measured in this study were low and, in the case of metals, indicated little more than background levels. In fact, there is no evidence in the literature that heavy metal pollution is anything more than a problem restricted to those waters on which much industry is sited. Concentrations in the Medway as in British coastal waters generally (Preston et al, 1972), are not significantly higher than in the open Atlantic Ocean. Dumping in the sea of the more toxic elements, mercury and cadmium, is now severely restricted (Royal Commission, 1972) while heavier fines are being imposed on local industries polluting the environment. However, considering the long half-lives of these elements, vigilance needs to be maintained in all inshore areas.

Table 4.5.3 Summary of chlorinated hydrocarbon levels (ng/g wet weight)

Species/ tissue	Length (cm)	No. of Samples	Hexane-extractable fat (%)	Mean concentrations ng/g (p.p.b.) (range in brackets)		
				ΣDDT	Dieldrin	PCB
A. anguilla						
muscle	<30.0	9	4.0 (2.0-6.6)	195.5 (61.3-296.3)	77.1 (8.0-192.0)	699.4 (335.0-1250.0)
"	>30.0	13	10.3 (0.7-22.3)	300.3 (139.1-807.2)	111.1 (34.2-232.0)	1032.6 (40.0-1960.0)
liver	<30.0	8	2.7 (1.4-4.3)	134.2 (76.7-251.4)	57.0 (26.5-90.0)	970.6 (305.0-1605.0)
liver	>30.0	14	5.9 (1.3-13.2)	96.9 (54.5-159.6)	43.3 (8.5-75.6)	866.9 (425.0-1250.0)
C. vulgaris						
whole	-	12	0.4 (0.2-0.8)	18.7 (2.7-81.3)	5.5 (1.2-20.2)	77.5 (trace-275.0)
M. merlangus						
muscle	0-14.9	10	0.3 (0.1-1.5)	11.5 (5.8-31.5)	4.2 (2.4-9.2)	66.0 (10.0-160.0)
"	15.0-21.9	7	0.1 (0.1-0.2)	11.0 (5.9-16.1)	3.4 (0.6-5.1)	51.0 (16.0-96.0)
liver	0-21.9	14	26.8 (13.1-39.7)	2311.0 (630.7-4240.0)	529.0 (175.0-1096.2)	6447.2 (2680.0-10385.0)
gut wall	0-21.9	8	0.7 (0.2-1.2)	35.9 (8.1-71.5)	11.4 (2.5-21.5)	164.1 (20.0-240.0)
P. flesus						
muscle	0-7.9	9	0.4 (0.3-0.7)	23.9 (12.3-51.3)	12.1 (5.2-24.0)	94.6 (36.0-168.0)
"	8.0-13.9	14	0.4 (0.3-0.6)	23.1 (6.2-62.2)	10.3 (3.4-24.0)	91.1 (36.0-216.0
"	14.0-19.9	10	0.2 (0.1-0.7)	24.8 (0.2-77.8)	7.7 (0.8-24.8)	84.0 (36.0-482.0)

Table 4.5.3 Contd.

Species/ tissue	Length (cm)	No. of Samples	Hexane-extractable fat (%)	Mean concentrations ng/g (p.p.b.) (range in brackets)		
				ΣDDT	Dieldrin	PCB
P. flesus Cont.						
muscle	>20.0	4	0.2 (0.1-0.3)	49.8 (8.9-117.7)	8.9 (2.1-25.8)	186.7 (40.0-338.0)
liver	0-13.9	11	9.9 (3.6-23.7)	569.6 (326.4-1031.8)	206.9 (77.0-386.2)	2144.3) (1220.0-5340.0)
	>14.0	6	8.0 (4.2-9.7)	650.3 (104-1338.6)	210.0 (43.0-380.0)	3073.0 (340.0-10079.0)
gut wall	0->20	8	1.1 (0.4-1.4)	62.6 (14.9-170.0)	21.6 (6.1-39.0)	261.5 (64.0-439.0)
ovary	0->20	6	0.2 (0.0-0.5)	30.1 (0.2-44.8)	12.4 (72.-33.5)	109.7 (50.0-180.0)
testis	0->20	2	0.9 (0.8-1.1)	10.1 (5.4-14.8)	7.4 (5.8-9.0)	47.0 (trace-94.0)
P. platessa						
muscle	0-7.9	11	0.4 (0.1-1.1)	17.2 (5.7-37.7)	6.4 (2.2-11.1)	73.6 (14.0-156.0)
"	8.0-13.9	11	0.2 (0.1-0.3)	7.2 (1.9-13.0)	3.3 (1.3-5.4)	43.1 (10.0-88.0)
"	14.0-19.9	7	0.1 (0.1-0.2)	6.0 (3.6-13.8)	2.3 (1.7-3.4)	25.4 (32.0-56.0)
liver	0-19.9	13	6.2 (1.5-13.2)	291.5 (75.8-614.0)	116.8 (15.2-228.0)	1237.4 (646.0-2634.0)
gut wall	0-19.9	11	1.0 (0.6-1.9)	26.9 (5.9-72.5)	11.0 (5.7-24.7)	129.1 (54.0-255.0)
P. minutus						
whole	-	10	2.8 (1.6-3.6)	118.5 (67.9-172.5)	46.7 (24.2-77.0)	364.8 (158.0-528.0)
S. sprattus						
whole	-	14	5.3 (2.1-9.7)	277.5 (174.4-504.6)	84.0 (36.0-138.0)	955.0 (587.0-1476.0)

Table 4.5.4 Summary of heavy metal results

Species/ tissue	Length (cm)	Mean concentrations (ppm wet weight) (range) (number of samples				
		Hg	Cd	Cu	Pb-	Zn
A. anguilla						
muscle	<30.0	0.36 (0.16-0.27) (4)	0.17 (0.05-0.40) (5)	0.65 (0.30-1.00) (11)	0.48 (0.25-0.70) (3)	23.82 (14.99-30.24) (10)
muscle	>30.0	0.54 (0.34-0.87) (6)	0.12 (0.08-0.18) (6)	0.50 (0.30-1.00) (14)	1.05 (0.60-1.82) (6)	27.17 (13.94-36.41) (17)
liver	<30.0	0.35 (0.32-0.38) (2)	0.24 (0.15-0.40) (3)	14.92 (4.99-32.79) (3)	0.84 (1)	51.87 (40.42-65.57) (4)
liver	>30.0	1.73 (1.55-2.06) (4)	0.37 (0.27-0.59) (6)	25.05 (o.00-36.93) (9)	2.68 (1.35-5.29) (4)	71.86 (54.68-95.82) (6)
C. vulgaris						
whole body	-	0.17 (0.11-0.26) (5)	0.59 (0.53-0.65) (6)	18.55 (9.49-25.48) (15)	1.22 (1.15-1.30) (3)	26.43 (13.50-35.77) (15)
M. merlangus						
muscle	0-14.9	0.45 (0.23-0.80) (3)	0.13 (0.10-0.15) (3)	0.70 (0.30-1.00) (3)	0.29 (0.18-0.37) (3)	9.18 (5.98-10.78) (3)
muscle	15.0-21.9	0.37 (0.34-0.40) (2)	0.21 (0.13-0.28) (2)	0.60 (0.20-1.00) (2)	0.36 (0.25-0.46) (2)	9.13 (6.29-11.98) (2)

Table 4.5.4 Cont.

Species/ tissue	Length cm)	Mean concentrations (ppm wet weight) (range) (number of samples				
		Hg	Cd	Cu	Pb	Zn
liver	0-21.9	0.33 (1)	0.15 (0.13-0.18) (2)	2.41 (1.33-3.49) (4)	0.89 (0.25-1.54) (2)	28.32 (24.24-32.40) (2)
gut wall	0-21.9	0.23 (0.19-0.26) (3)	0.15 (0.08-0.21) (3)	1.40 (0.50-2.46) (6)	0.45 (0.20-0.67) (3)	23.09 (20.93-24.96) (3)
P. minutus						
whole body	-	0.16 (0.04-0.24) (6)	0.24 (0.20-0.28) (4)	1.13 (0.50-1.50) (7)	1.00 (0.55-1.65) (4)	28.73 (24.96-33.25) (4)
S. sprattus						
whole body	-	0.16 (0.09-0.27) (6)	0.29 (0.05-0.60) (7)	1.08 (0.50-1.99) (14)	1.03 (0.70-1.59) (4)	38.45 (19.00-46.21) (16)
P. flesus						
muscle	0-7.9	0.10 (0.04-0.20) (4)	0.06 (0.06-0.07) (2)	1.31 (1.29-1.33) (2)	0.28 (0.21-0.35) (2)	18.19 (17.97-18.41) (2)
muscle	8.0-13.9	0.17 (0.04-0.37) (7)	0.07 (0.06-0.08) (3)	0.77 (0.50-1.00) (3)	0.39 (0.32-0.47) (3)	17.15 (14.27-19.46) (4)
muscle	14.0-19.9	0.46 (0.11-0.90) (7)	0.07 (0.06-0.08) (3)	0.30 (0.30-0.30) (3)	0.33 (0.10-0.72) (3)	12.30 (7.97-16.46) (3)

Table 4.5.4 Cont.

Species/ tissue	Length (cm)	Mean concentrations (ppm wet weight) (range) (number of samples)				
		Hg	Cd	Cu	Pb	Zn
muscle	>20.0	0.64 (0.13-1.15) (2)	0.06 (1)	0.30 (1)	0.33 (1)	14.48 (1)
liver	0-13.9	0.24 (0.21-0.27) (2)	0.18 (0.15-0.22) (2)	12.92 (7.38-0.22) (2)	0.94 (0.53-1.35) (2)	53.81 (48.81-58.81) (2)
liver	>14.0	0.08 (1)	0.18 (0.17-0.18) (2)	18.27 (13.52-23.01) (2)	1.38 (1.31-1.45) (2)	68.88 (61.82-75.94) (2)
gut wall	0->20.0	0.17 (0.13-0.21) (2)	0.19 (0.13-0.23) (3)	2.69 (1.00-4.78) (3)	0.72 (0.35-1.12) (3)	36.16 (30.37-40.78) (3)
ovary	0->20.0	0.12 (1)	0.08 (1)	2.38 (1)	0.12 (1)	146.84 (1)
P. platessa						
muscle	0- 7.9	0.15 (1)	0.08 (0.05-0.13) (4)	1.13 (0.50-1.73) (4)	0.70 (0.48-0.92) (2)	11.91 (9.98-13.83) (3)
muscle	8.0-13.9	0.19 (0.15-0.21) (4)	0.11 (0.08-0.15) (7)	0.93 (0.50-1.30) (6)	0.97 (0.95-1.00) (2)	11.67 (8.26-14.46) (4)
muscle	14.0-19.9	0.27 (0.22-0.32) (2)	0.14 (0.13-0.15) (3)	0.82 (0.50-1.30) (4)	1.15 (0.90-1.40) (2)	10.03 (9.30-10.76) (2)

Table 4.5.4 Cont.

Species/ tissue	Length (cm)	Mean concentrations (ppm wet weight) (range) (number of samples				
		Hg	Cd	Cu	Pb	Zn
liver	0-19.9	-	0.18 (0.16-0.21) (3)	3.28 (1.47-4.22) (5)	1.34 (0.95-1.87) (3)	38.93 (36.42-42.21) (3)
gut wall	0-19.9	0.07 (0.03-0.12) (3)	0.22 (0.20-0.25) (2)	2.36 (1.79-3.20) (4)	1.33 (1.00-1.65) (2)	27.53 (27.18-27.89) (2)

SECTION 5

GENERAL DISCUSSION

As outlined in the Introduction (section 1, p8), this study of the various factors affecting fish populations of the Medway Estuary, was undertaken in the absence of previous investigations.

Power station sampling proved to be a very useful method of obtaining regular fish supplies quantitatively, bearing in mind the reservations discussed earlier (section 2.4.1, p 53), and it provided information on seasonal migrations of the most common species. Local fish movements, however, proved impossible to determine; dietary constituents provided no clues, partly because of the widespread occurrence in the estuary of the most common prey organisms (Wharfe, 1975) and lack of precise data on local distributions of the rarer food items. Despite such restrictions and difficulties, much information was gathered regarding the Medway fish populations and their behaviour.

During the survey 59 fish species were collected, 13 of which accounted for more than 90 percent of each month's total (section 2.3.3, p 39). Short-term fluctuations, even between consecutive day and night samples, were largely a consequence of changes in the sprat population, the most abundant species (section 2.4.3, p 58). Consecutive sprat samples fluctuated in numbers and often also in age structure, suggesting that relative proportions of age-groups vary between shoals (fig. 2.3.1, p31).

Seasonal fluctuations in catch were attributed largely to annual fish migrations. Evidence from changes in monthly length-frequency data (figs. 2.3.9 - 2.3.11, p45 - p47) was supported by seasonal variation in occurrence of those ectoparasites restricted to inshore waters, notably Cryptocotyle lingua (section 3.3.2, p84).

The inshore migration appears to be made mainly by rapidly-growing young individuals of herring, gadoids whiting and pouting, and flatfishes

flounder, plaice, dab and sole (fig. 2.3.12, p48). Whiting and pouting were restricted almost entirely to first-year individuals although plaice and flounder contained individuals up to, and including, 4 and 5 year-olds respectively.

In contrast to these sea-breeding types, inshore migrations are also made by mature individuals of other species to spawn, with resident types, in estuarine waters. Breeding populations of both the lesser and great pipefish were observed; great pipefish only occurred between February and June and in the latter stages of this period males with fully-formed young in their brood-pouches were often taken in screen samples.

The estuary is also used by eels, sticklebacks and lamperns, which move through the area on migrations between the fresh-water and marine environments. Lamperns occurred only rarely in qualitative samples but the other two species were taken regularly.

The habitat offers shelter and a rich and varied food supply. The fine alluvium, which is the dominating substrate in the lower estuary (section 1.1, p9), contains the mollusc H. ulvae and tubificid P. benedeni in numbers reaching 90,000 and 50,000 per square metre respectively (Wharfe, 1975); P. benedeni, in particular, is heavily exploited by plaice and flounder (section 3.3.1, p75). Nektonic organisms such as mysids and brown shrimps equally are abundant and are the main dietary constituents of whiting and pouting (section 3.3.1, p70).

Evidence in this study (section 4.5, p176) suggested the diet was responsible, at least in part, for increasing organochlorine levels of fish tissues, but even closely related species with similar diets may exhibit some variability due to differences in habitat and rate of chemical uptake (Moore, 1967). For example, levels of chlorinated hydrocarbons were always higher in flounder tissues than in plaice. The latter is restricted to the lower estuary while flounder, because of its greater tolerance of reduced salinities, may migrate upstream to areas where these pollutants may be more concentrated. With industry mainly located

on the lower estuary (section 1.3, p13), metal results were not expected to show similar differences; in fact, they were quite variable (section 4.4.2, p170) with lead levels slightly higher in plaice than in flounder.

Eel and flounder were similar in that chlorinated hydrocarbon levels (table 4.5.3, p180) were comparatively high in their tissues while metal concentrations, especially in the musculature, varied little from other species (table 4.5.4, p182). Eels can also spend quite long periods upstream feeding and growing in freshwater (Wheeler, 1969a). However, high lipid levels and a longer exposure period must be contributing factors in raising concentrations in their tissues; the larger eels in the study were considerably older than individuals of other species (based on Wheeler, 1969a).

Generally, levels of heavy metals and chlorinated hydrocarbons were low in the range of tissues analysed. It is doubtful whether concentrations of these chemicals will increase significantly in the short-term because both groups of pollutants are now more strictly controlled through a greater awareness of their toxicity and persistence in the environment. The greater threat appears to be from oil pollution, not only major spillages but the continuous discharge of small amounts of oil from ships unloading at refineries and from refinery outfalls. Wharfe (1975) considered this latter problem and found polluted conditions approximately 1½ kilometres on either side of the BP outfall at Grain; the black sulphide sediment often had a petroleum odour and numbers of invertebrate species and total numbers of individuals were reduced.

Benthic organisms are not the only ones to be affected; C. vulgaris disappeared completely in November 1966 following the 'Seestern' spillage (section 1.3, p13) and none were caught until the following August (Harrison and Buck, 1967). Therefore, apart from the direct influence that toxic effluents may exert, fish may also be affected indirectly via their food supply.

Pressures of parasitism, like those of pollution, are also greater in inshore waters than offshore. Fish entering the estuary, both newly-spawned and older individuals, generally were free of ectoparasites (section 3.4, p130). The more crowded conditions inshore aid transmission and fish were soon infected with a number of ectoparasite species.

Their effects on fish populations are difficult to evaluate individually, as in the present study, because the control population is itself infected with other parasites, which may be as stressful, or more so. L. branchialis was shown to lower fish weight significantly (section 3.3.3, p118) but whiting infected with both L. branchialis and C. uncinata were significantly heavier than uninfected specimens. However, it is a fact that obviously emaciated whiting taken at Kingsnorth were invariably infected with L. branchialis and, on average, the lipid content of their livers was reduced by more than half. If this condition is due solely to the copepod, its effects appear to be similar to starvation. No reduction in feeding was observed in the small sample of mainly 0-group fish examined (section 3.3.3, p126) but this may be a factor in older fish where the infection is longer established.

In a heavily polluted area, the relationship between the parasite and a host which has accumulated organochlorines in the liver would prove an interesting study. As the infection progresses and the host's fat reserves are depleted, organochlorines will be released into the general circulation and become available to the parasite in its blood diet. If the latter can remove organochlorines in any quantity, their effects on the parasite may serve to offset some of the physiological effects that it has on the fish host. In the Medway, however, organochlorine levels in fish tissues were not high and parasitism appears to be a greater stress factor than pollution. Of course, an indirect effect of such low-level pollution may be to lower an individual's resistance to infection but, with no prior data to consult, this question remains.

In the future, limited development around established concerns on the lower estuary, as outlined in the Economist Intelligence Unit report of 1973, should have minimal impact on the area with little or no loss of habitat. Any further encroachment would greatly affect the amenity value of the area which is recognised nationally and internationally to be of outstanding scientific importance (Countryside Commission, 1970; Nature Conservancy, 1971). It is hoped that the present study will provide a basis for future, long-term monitoring in this significant area.

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ACKNOWLEDGEMENTS

A considerable number of people have provided active assistance or given encouragement during this study; without their help the project would have been far less comprehensive.

The authorities of the CEGB power station at Kingsnorth allowed ready access to the site and granted laboratory facilities during the sampling period. I would like to thank, in particular, staff in the station laboratory and in the Maintenance and Efficiency departments.

I am further indebted to individuals at various local institutions who were consulted; Mr. M.E. Thorne, Medway Ports Authority; Messrs. I.S. Gascoine and R.W. Baker, Southern Water Authority, and Mr. L. Wadhams, Rochester Oyster and Floating Fishery.

The biochemical section of this study was carried out in the Biology Department at York University and several enjoyable months were spent working with Dr. M.G. Rumsby and his team of research assistants. Much encouragement and knowledge was gained during this period for which I am very grateful.

I would further like to express my thanks to those members of the Biology, Chemistry and Statistics Departments, City of London Polytechnic, who have assisted with the research, especially Dr. J.R. Wharfe, Dr. J.D. Barnes and Mr. R. Illsley. A number of technical staff was also involved namely: Mr. P. Greener, sampling; Mr. A. Campbell, photography and Mr. R. Cowley, instruments.

Dr. J. Johnston supervised the work and, with Mr. W.B. Broughton criticized the script; their assistance is gratefully acknowledged.

APPENDIX I

Details of screen and trawl samples taken between May 1973 and August 1975.

Details of day samples

Date	1973								1974											1975					
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Apr	May	Jul	Aug
Length of sample (hours + mins)	7.30	8.00	7.30	8.00	7.30	8.00	7.00	6.30	8.00	7.45	7.35	7.30	7.45	8.00	7.30	7.00	7.30	8.00	3.00	4.30	7.30	7.15	6.45	7.00	4.00
No. of pumps	3	1	1	2	1	2	3	2	3	2	3	1	1	1	1	2	2	2	3	4	3	3	3	2	3
A.anguilla		6	3		4	1				1	4	4		18	6	8	5	3	2	1		40	13	2	11
A.cataphractus								5	1									3	1						
A.cuculus			1					3					1						6	1					
A.minuta											1			2								1	9		
A.presbyter	2				1	42	19			5	15	1	3	35	4	4	1		1			4			
B.belone															2										
B.pholis											1										1				
C.harengus	6					184	154	89	137	9	8	7		21	5	9	35	279	70	69	29	26	8	33	
C.labrosus		1						2										4	3				1		
C.lyra		4		1			2	1		2						1	2	4				1	1		
C.mustela							3	1	2									2	3	3					
C.reticulatus								1																	
D.labrax		1			2	52	49	59	6	1	4	3				4	6	19	10	2	4	1	2		
E.lucius																		1							
G.aculeatus	1	2							5	2	1	1	1		1	1	1	1		3	3		3	10	
G.morhua						2													3						
G.niger														4									2		
L.limanda	1					25	22	31	18	3	2					2	7	22	32	14	6	7	2		
L.liparis								1											2	2					
M.merlangus						192	161	5	3	2				10		15	211	192	130	151	8	18	9		
O.eperlanus	1		1				1												1	1					
P.flesus	23	1				8	9	12	7	25	6	11		1		7	4	7	4	21	7	24	64	3	3

Details of day samples cont.

Date	1973								1974											1975					
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Apr	May	Jul	Aug
Length of sample (hours + mins)	7.30	8.00	7.30	8.00	7.30	8.00	7.00	6.00	8.00	7.45	7.35	7.30	7.45	8.00	7.30	7.00	7.30	8.00	3.00	4.30	7.30	7.15	6.45	7.00	4.00
No. of pumps	3	1	1	2	1	2	3	2	3	2	3	1	1	1	1	2	2	2	3	4	3	3	3	2	3
P.fluviatilis																		1							
P.microps		2	10									2	4	8	3	2	13	1		2				2	
P.minutus	1			1	3	170	137	35	19	14	13			33	7	82	45	124	38	36	7	6	2	1	16
P.platessa	6	1	23		3	28	34	3	10	5	4	1	1	11	15	9	7	9	4	6	4	4	8	20	4
P.pollachius								2																	
R.rutilus																		1							
S.acus	19	5								1	7	7	1								1	9	37		
S.erythrophthalamus																		1							
S.rostellatus	3	15	1		10	105	24	1	3		7	13	4	28	8	104	41	14	3	8	8		10	4	4
S.solea	6		1	1		5	13	1	3	12	6		4	23	8	4	1	4	3		1	6	7	12	
S.sprattus	300	855	16	2	11	495	692	412	1220	121	156	164	37	429	181	103	538	785	546	1516	750	272	558	225	2
S.trutta																						2			
S.typhle	1																								
T.bubalis								1																	
T.luscus	2					4	5	7	5					1		1	5	13	96	10	4	5	10		
T.minutus								18										1	28	13	3	1	2		
T.trachurus														1					2						
T.vipera									1														1		
T.viviparus	1		1							1								1		1					
Total numbers	373	893	57	5	34	1313	1325	690	1440	204	235	214	56	625	240	356	922	1492	988	1860	836	427	749	312	40
Total weight (g)	1860	2051	721	48	157	5236	6815	5089	6195	6865	1236	1293	314	2825	993	1143	4610	11406	13581	10281	2052	14499	9627	2508	763
No. of species	15	11	9	4	7	14	15	21	15	15	15	11	9	15	11	16	16	24	22	19	15	17	20	10	6

Details of night samples

Date	1974										1975			
	Feb.	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Feb	Mar	Apr	May
Length of sample (hours + mins)	16.00	16.10	16.30	16.30	16.45	16.30	16.30	16.45	16.45	16.00	16.45	16.30	16.45	17.00
No. of pumps	3	2	3	1	1	1	1	2	2	2	3	2	3	3
A. alosa														1
A. anguilla	113	6	48	24	9	32	22	57	31	2	1	7	48	154
A. brama														1
A. cataphractus	8	8							1	10	2	6		3
A. cuculus	1		2					1	1	3	3	1	1	11
A. minuta		3	1	3	3	3								8
A. presbyter	4	14	241	8	4	162	12	100	7		3	1	24	9
A. tobianus	1										1			
B. belone			1								1			
B. pholis	1													
C. carassius	1													
C. harengus	117	87	129	13	4	51	9	290	82	450	73	131	118	38
C. labrosus	1					1				2			4	
C. lyra	5			2				7	1	2		1		11
C. mustela	13	2	1	1						12	8	9	1	
D. labrax	39	3	5	1		6		18	13	12	8	9	3	14
G. aculeatus	20	13	18	12	11			7		4	20	13	7	21
G. morhua		1									2	2		
G. niger				2		5	4	2	2		1	2	21	18
L. limanda	98	19	5	5			1	15	7	39	5	25	7	6
L. liparis	20	1												

Details of night samples cont.

Date	1974										1975			
	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Feb	Mar	Apr	May
Length of sample (hours + mins)	16.00	16.10	16.30	16.30	16.45	16.30	16.30	16.45	16.45	16.00	16.45	16.30	16.45	17.00
No. of pumps	3	2	3	1	1	1	1	2	2	2	3	2	3	3
L. montagui											1			
M. merlangus	146	24	12	1	7	36		430	1003	909	93	150	101	101
M. scorpius	1		1											
O. eperlanus	3	1	1			1				1	1	5	3	5
P. flesus	156	36	16	10	2	5	1	4	2	13	15	79	28	171
P. fluviatilis	2													2
P. microps			3	5	3	5	2	4	4	1		7	2	2
P. minutus	335	182	215	9		213	31	1357	203	142	71	227	27	39
P. platessa	46	31	19	3	11	36	11	30	12	12	20	56	33	22
P. pollachius	1													
P. pungitius										1				
S. acus	1	4	31	21	7				1		2	10	66	141
S. rhombus	1													
S. rostellatus	6	29	28	50	10	70	1	186	95	89	14	9	4	58
S. solea	66	70	37	6	10	42	12	4	1	4	1	5	34	26
S. sprattus	5541	632	650	1491	91	424	77	277	673	2276	2153	953	1186	1440
T. luscus	32	3	4			7	1	9	77	216	69	177	79	126
T. minutus	1				1					4	45	85	21	36
T. trachurus					1		1	7						
Z. viviparus	1					3		1				2	2	1
Total numbers	6681	1169	1468	1667	174	1102	185	2806	2216	4204	2613	1972	1820	2465
Total weight (g)	3399	16865	8746	4823	1725	7815	1472	10011	16900	33247	10674	23373	14499	38747
No. of species	31	21	22	19	15	18	14	20	19	22	25	25	23	27

Details of trawl samples

	1973		1974		1975
	Aug.	Nov.	May	Nov.	Jun.
A. cataphractus		1	7	7	
C. lyra	34				
G. niger	4	7			
L. limanda			3	7	6
L. liparis		3		2	
M. merlangus		29			1
P. flesus		1	23	2	8
P. microps	1				
P. minutus	52	1			
P. platessa	153	9	8	6	34
R. clavata					4
S. caniculus			3		
S. solea	22		11	1	20
S. sprattus	5				
T. lucerna					2
T. luscus		40		3	4
T. vipera					1
Z. viviparus		1			
Total numbers	271	92	55	28	80
Total weight (g)	1400	4729	8497	2028	7499
No. of species	7	9	6	7	9

APPENDIX II

Catch statistics of all species
collected in screen samples

Appendix II. Catch statistics of all species collected in screen samples

	Numbers in quantitative samples	Percentage of grand total	Weight in quantitative samples (g)	Percentage of grand total	Length & weight characteristics	
					Length (range)	Weight (range)
A. brama	1	<0.1	2	<0.1		2.00
A. cataphractus	48	0.1	306	0.1	4.2 - 11.8	0.89 - 23.58
A. alosa	1	<0.1				
A. tobianus	2	<0.1	24	<0.1	13.8 - 15.7	10.14 - 14.00
A. anguilla	586	1.3	21638	6.7	13.9 - 67.8	3.35 - 789.00
A. minuta	34	0.1	12	<0.1	3.9 - 5.0	0.50 - 1.30
A. cuculus	36	0.1	714	0.2	3.6 - 24.9	0.78 - 269.50
A. presbyter	726	1.6	3088	0.9	3.6 - 12.9	0.59 - 20.46
B. bellone	4	<0.1	10	<0.1	7.5 - 15.4	0.71 - 4.75
B. pholis	3	<0.1	32	<0.1	7.6 - 14.9	7.85 - 16.79
C. lyra	48	0.1	392	0.1	4.1 - 18.4	0.43 - 86.02
C. reticulatus	1	<0.1	14	<0.1	10.6	13.67
C. carassius	1	<0.1	7	<0.1	6.1	6.75
C. mustela	61	0.1	2467	0.8	8.8 - 21.2	6.86 - 104.76
C. harengus	2770	6.0	14921	4.6	2.6 - 22.3	0.50 - 65.06
C. labrosus	19	<0.1	1246	0.4	7.4 - 31.4	5.25 - 384.24
D. labrax	356	0.8	3673	1.1	4.4 - 24.7	1.35 - 262.73
E. lucius	1	<0.1	10	<0.1	10.6	10.13
G. morhua	10	<0.1	166	<0.1	8.7 - 18.9	5.06 - 74.50.

Appendix II contd.

Species	Numbers in quantitative samples	Percentage of grand total	Weight in quantitative samples (g)	Percentage of grand total	Length & weight characteristics	
					Length (range)	Weight (range)
G. aculeatus	182	0.4	214	0.1	2.8 - 7.3	0.25 - 4.48
G. niger	63	0.1	138	<0.1	3.2 - 9.7	0.56 - 17.46
G. cernua	2		29		5.0 - 9.9	2.60 - 26.51
L. fluviatilis	3		117		20.6 - 43.0	20.50 - 69.00
L. limanda	426	0.9	6168	1.9	3.5 - 24.5	0.64 - 237.00
L. liparis	26	<0.1	350	0.1	5.2 - 10.1	3.82 - 23.00
L. montagui	1	<0.1	2	<0.1	4.8	2.43
L. piscatorius	1		-		-	-
M. merlangus	4120	8.9	44307	13.6	5.1 - 19.2	1.27 - 62.58
M. scorpius	2	<0.1	176	<0.1	14.7 - 18.9	64.36 - 112.05
O. operlanus	26	0.1	888	<0.3	7.9 - 22.0	3.71 - 112.50
P. fluviatilis	5	<0.1	19	<0.1	5.7 - 6.2	3.39 - 4.39
P. flesus	785	1.7	19598	6.0	4.3 - 29.5	2.00 - 428.50
P. platessa	562	1.2	5844	1.8	3.2 - 18.7	0.58 - 116.83
P. pollachius	3	<0.1	126	<0.1	11.9 - 18.8	13.12 - 72.71
P. microps	87	0.2	74	<0.1	2.5 - 4.7	0.17 - 1.50
P. minutus	3841	8.3	8482	2.6	2.8 - 7.7	0.23 - 6.15
P. pungitius	1	<0.1	1	<0.1	3.9	0.53
R. clavata	1		10		14.0	10.02

Appendix III contd.

	Numbers in quantitative samples	Percentage of grand total	Weight in quantitative samples (g)	Percentage of grand total	Length & weight characteristics	
					Length (range)	Weight (range)
R. cimbrius	1		77		17.9	77.00
R. rutilus	1	<0.1	19	<0.1	9.6	18.72
S. trutta	2	<0.1	-	-	-	-
S. erythrophthalmus	1	<0.1	-	-	3.3	0.43
S. scombrus	1		-		-	-
S. maximus	1		-		-	-
S. rhombus	1	<0.1	14	<0.1	9.6	13.53
S. solea	439	0.9	5868	1.8	5.4 - 33.0	1.33 - 450.00
S. sprattus	28250	61.1	56731	17.5	2.1 - 13.3	0.25 - 32.88
S. acus	371	0.8	2150	0.7	16.6 - 44.6	5.54 - 44.60
S. rostellatus	1067	2.3	358	0.1	6.8 - 15.8	0.09 - 1.28
S. typhle	1	<0.1	-	-	11.5	0.47
T. bubalis	2	<0.1	57	<0.1	9.0 - 10.7	23.19 - 33.50
T. marmorata	1		-		-	-
T. vipera	1	<0.1	9	<0.1	8.5	9.44
T. trachurus	12	<0.1	654	0.2	4.0 - 31.0	0.77 - 327.92
T. luscus	968	2.1	30462	9.4	4.8 - 26.3	1.43 - 325.00
T. minutus	259	0.6	6842	2.1	6.8 - 23.4	2.00 - 164.84
Z. viviparus	15	<0.1	299	0.1	11.3 - 26.9	8.29 - 73.85

APPENDIX III

Length/weight characteristics of Medway fish species

Monthly length/weight characteristics of A. anguilla

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
April	44	37.3	80.23	-3.154	3.153
June/July	9	32.4	72.39	-4.123	3.871
Sept/Oct	16	28.0	39.52	-3.652	3.572
November	20	37.5	144.77	-3.348	3.376
1974					
Jan/Feb	17	45.6	217.09	-3.059	3.138
April	65	33.1	63.66	-3.215	3.217
May	27	30.8	37.25	-3.029	3.073
June	11	32.7	62.84	-3.502	3.439
July	52	30.1	57.58	-2.905	3.061
August	28	28.5	34.17	-1.722	2.227
September	65	27.9	35.27	-2.581	2.835
October	35	33.3	99.56	-3.122	3.234
1975					
March	7	40.7	146.47	-3.505	3.419

Monthly length/weight characteristics of A. presbyter

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
March	6	10.8	14.10	-1.948	2.913
April/May	18	9.7	9.55	-1.916	2.848
September	14	6.9	3.17	-1.646	2.548
October	29	6.8	3.40	-1.955	2.943
November	22	6.7	2.83	-1.653	2.562
1974					
March	19	8.1	6.38	-2.212	3.221
April	232	6.8	2.86	-1.962	2.900
May	5	6.7	3.04	-1.888	2.876
July	119	8.6	7.30	-1.678	2.702
August	8	9.7	11.15	-1.908	3.016
September	81	6.2	2.85	-2.143	3.217

Monthly length/weight characteristics of C. harengus

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
September	119	8.2	5.71	-1.867	2.835
October	71	8.2	5.88	-1.934	2.903
November	144	8.5	6.76	-1.951	2.950
December	40	9.8	9.39	-2.103	3.071
1974					
January	110	10.1	10.58	-2.074	3.047
February	108	10.0	9.66	-2.186	3.145
March	55	10.0	9.32	-2.054	2.989
April	124	9.3	7.91	-2.016	2.979
May	13	8.8	6.23	-1.934	2.860
July	16	6.5	3.44	-1.966	3.031
September	111	6.2	2.97	-1.798	2.802
October	26	6.8	4.44	-1.859	2.941
November	226	9.8	4.33	-1.675	2.680
December	51	7.5	6.96	-1.926	2.998
1975					
January	43	7.4	4.52	-1.760	2.771
February	90	7.5	5.36	-1.969	2.960
March	106	7.3	4.71	-1.852	2.824

Monthly length/weight characteristics of D. labrax

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
September	45	6.4	4.70	-2.121	3.398
October	62	6.2	4.52	-2.053	3.309
November	56	6.6	4.92	-2.074	3.325
December	52	7.1	6.44	-1.973	3.205
1974					
January	16	6.5	4.22	-2.074	3.288
February	39	6.9	7.65	-2.149	3.396
March-July	15	8.9	40.61	-1.990	3.216
September	21	5.1	2.37	-1.612	2.797
October	19	5.3	2.57	-1.764	2.995
November	31	9.2	33.94	-1.876	3.117
December	10	9.8	30.78	-1.887	3.135
1975					
Jan/Feb/Mar	15	7.3	15.98	-2.178	3.464

Monthly length/weight characteristics of G. aculeatus

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1974					
February	20	5.0	1.61	-2.108	3.289
March	14	5.1	1.87	-1.362	2.297
April	20	4.9	1.75	-1.604	2.615
May	13	4.8	1.71	-1.851	3.021
June	10	4.6	1.48	-1.979	3.232
August--Jan 1975	14	4.4	1.11	-1.220	1.959
February	23	4.7	1.45	-2.085	3.320
March	13	4.7	1.31	-1.990	3.081

Monthly length/weight characteristics of L. limanda

Month	Number of fish	Mean length (cm)	Mean Weight (g)	log a (intercept)	b (regression coefficient)
1973					
September	27	4.8	2.07	-2.028	3.118
October	58	5.1	2.59	-2.207	3.377
November	46	8.4	10.18	-2.149	3.299
December	30	11.3	24.67	-2.385	3.532
1974					
January	106	10.3	17.79	-2.043	3.173
February	95	8.8	12.47	-2.048	3.170
March	22	9.6	12.19	-1.485	2.558
April/May/ Aug	26	7.1	4.90	-1.702	3.057
September	15	4.6	2.41	-1.841	3.010
October	14	4.2	1.15	-2.228	3.622
November	61	9.7	21.69	-1.863	3.048
December	32	13.0	41.19	-1.928	3.103
1975					
January	16	8.9	14.38	-1.858	3.007
February	11	7.0	9.08	-1.879	3.060
March	25	6.9	8.48	-1.962	3.114
June (trawl)	6	15.0	72.25	-1.852	3.121

Monthly length/weight characteristics of *M. merlangus*

Month	Number of fish	Mean Length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
September	99	10.4	10.75	-2.315	3.240
October	369	9.5	8.78	-2.284	3.240
November	151	11.8	17.43	-2.268	3.207
Nov(trawl)	29	15.8	43.89	-1.885	2.900
December	11	10.9	14.90	-2.088	3.058
1974					
January	39	10.4	8.02	-2.133	3.042
February	126	12.3	16.71	-2.125	3.040
March	25	12.8	18.42	-1.494	2.458
April	13	12.9	18.81	-1.834	2.759
July	37	7.5	4.16	-2.196	3.201
September	158	8.4	6.23	-2.228	3.193
October	382	9.4	9.25	-2.061	3.043
November	299	10.9	13.25	-2.269	3.197
December	98	11.4	16.23	-2.225	3.177
1975					
January	167	11.2	15.15	-2.205	3.132
February	106	10.4	10.79	-1.964	2.872
March	150	11.0	14.34	-2.012	2.930

Monthly length/weight characteristics of P. flesus

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
March	33	14.0	62.73	-1.530	2.799
April	27	13.6	65.78	-1.499	2.734
May	27	13.1	43.84	-1.274	2.557
June	8	15.6	75.21	-1.804	3.029
August	7	17.0	107.11	-1.392	2.748
September	21	9.0	6.15	-1.592	2.799
October	8	6.9	7.11	-2.127	3.371
November	47	7.6	7.92	-1.862	3.096
December	28	10.0	28.68	-1.723	2.981
1974					
January	52	14.7	77.65	-1.680	2.918
February	154	10.5	34.13	-1.782	3.033
March	61	11.3	29.93	-1.790	3.004
April	30	12.3	39.38	-1.653	2.870
May	21	14.9	66.24	-1.579	2.820
May(trawl)	22	17.6	111.06	-1.182	2.570
September	14	8.7	12.71	-1.862	3.134
November	35	12.7	60.19	-1.751	3.029
December	20	15.4	149.42	-1.658	2.963
1975					
January	64	14.0	81.14	-1.704	2.972
February	22	9.7	22.09	-2.045	3.338
March	79	10.8	36.37	-1.880	3.118
June (trawl)	8	16.0	92.06	-1.291	2.677

Monthly length/weight characteristics of *P. minutus*

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
July	10	4.1	1.10	-1.825	2.946
Aug(trawl)	50	4.9	1.77	-2.230	3.495
September	71	5.8	2.45	-2.094	3.213
October	140	5.8	2.31	-2.368	3.556
November	117	6.1	2.61	-2.169	3.293
December	33	5.7	2.36	-2.144	3.281
1974					
January	44	6.0	2.77	-1.812	2.896
February	226	6.0	2.64	-2.026	3.131
March	177	5.7	2.45	-1.689	2.733
April	146	5.6	2.07	-1.583	2.532
May	8	5.3	1.79	-0.987	1.700
July	220	5.6	2.38	-2.053	3.206
August	31	5.2	2.01	-2.167	3.375
September	318	5.4	2.13	-2.244	3.479
October	237	5.4	2.00	-2.195	3.382
November	249	5.6	2.38	-2.169	3.367
December	37	5.8	2.68	-1.918	3.069
1975					
January	109	5.8	2.64	-2.117	3.311
February	71	5.4	2.35	-2.074	3.288
March	226	5.4	2.23	-1.940	3.102

Monthly length/weight characteristics of P. platessa

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
May	6	12.3	33.72	-2.158	3.310
July	30	4.6	1.94	-1.890	3.222
August	7	4.2	1.04	-2.077	3.344
Aug(trawl)	151	5.2	3.52	-1.702	2.933
September	22	5.8	3.59	-2.375	3.597
October	36	5.8	3.40	-2.306	3.525
November	47	5.8	3.25	-1.051	2.756
December	9	5.6	2.13	-2.244	3.412
1974					
January	40	7.9	13.03	-1.984	3.151
February	44	9.0	18.80	-2.016	3.176
March	37	10.5	25.35	-1.924	3.114
April	23	7.8	8.73	-1.934	3.149
May	4	10.6	20.74	-1.500	2.714
June	12	6.4	7.36	-1.716	2.953
July	49	6.7	7.83	-1.800	3.050
August	23	6.4	5.70	-1.863	3.169
September	39	5.9	3.57	-2.187	3.480
October	20	7.3	13.13	-1.911	3.175
November	26	8.0	21.42	-1.873	3.125
December	28	8.5	23.04	-1.823	3.078
1975					
January	33	9.8	22.96	-1.874	3.099
February	24	9.5	20.47	-1.885	3.140
March	56	9.2	18.28	-2.063	3.284
June (trawl)	32	13.5	53.61	-1.616	2.935

Monthly length/weight characteristics of *S. rostellatus*

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
June	15	10.4	0.46	-4.856	4.393
August	9	9.9	0.30	-3.608	3.038
September	50	10.6	0.37	-4.414	3.816
October	103	10.5	0.33	-4.571	3.944
November	26	10.4	0.31	-4.122	3.503
1974					
March	29	10.9	0.33	-3.794	3.177
April	37	10.8	0.37	-4.231	3.632
May	61	10.6	0.40	-3.859	3.331
June	10	11.3	0.67	-3.706	3.336
July	94	11.8	0.86	-3.530	3.177
August	8	10.7	0.68	-4.487	4.088
September	188	9.2	0.31	-4.124	3.659
October	129	9.9	0.33	-4.251	3.728
November	91	9.8	0.31	-4.326	3.770
1975					
January	11	10.0	0.37	-4.215	3.649
February	16	10.0	0.23	-3.997	3.349
March	9	10.4	0.34	-3.454	2.916

Monthly length/weight characteristics of *S. solea*

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
March	6	10.1	7.70	-2.509	3.287
April	12	9.9	13.64	-2.201	3.148
May	6	8.0	7.03	-1.660	2.624
July	7	10.5	12.05	-2.239	3.261
August	6	13.1	32.00	-2.447	3.488
Aug (trawl)	22	9.8	16.65	-2.156	3.285
October	12	12.7	49.29	-2.449	3.467
November	25	9.3	11.00	-2.346	3.364
1974					
January	13	7.7	3.99	-1.986	2.910
February	64	8.0	5.60	-1.660	2.603
March	81	8.4	7.39	-2.145	3.107
April	44	10.0	13.25	-2.111	3.052
May(trawl)	11	25.4	278.91	-1.906	3.058
June	10	16.2	51.46	-1.415	2.530
July	65	11.6	17.71	-2.076	3.095
August	19	10.8	33.40	-1.724	2.808
October - March 1975	17	12.6	16.96	-2.375	3.378
June (trawl)	20	20.4	186.00	-2.073	3.191

Monthly length/weight characteristics of S. sprattus

Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
March	13	9.5	10.27	-2.122	3.121
April	100	5.1	1.58	-2.224	3.181
May	86	5.0	1.27	-2.144	3.116
June	161	5.1	1.21	-2.361	3.436
September	109	3.2	0.16	-2.035	3.040
October	204	5.6	2.02	-2.158	3.153
November	400	5.9	2.09	-2.037	3.017
December	157	6.2	2.34	-2.012	2.974
1974					
January	252	6.4	2.68	-2.137	3.131
February	189	6.6	2.83	-2.040	3.008
March	191	6.3	2.56	-1.765	2.685
April	272	5.1	1.41	-2.027	2.994
May	233	5.2	1.50	-2.276	3.346
June	93	4.5	0.89	-2.509	3.682
July	409	5.7	2.12	-1.958	2.975
August	130	4.0	1.01	-2.305	3.419
September	163	4.8	1.44	-2.117	3.160
October	300	5.5	1.95	-1.887	2.909
November	506	6.2	2.99	-2.312	3.491
December	437	5.2	1.77	-2.400	3.556
1975					
January	342	6.2	2.62	-2.031	3.066
February	351	6.0	2.05	-2.243	3.259
March	247	6.1	2.34	-1.879	2.858

Monthly length/weight characteristics of *T. luscus*

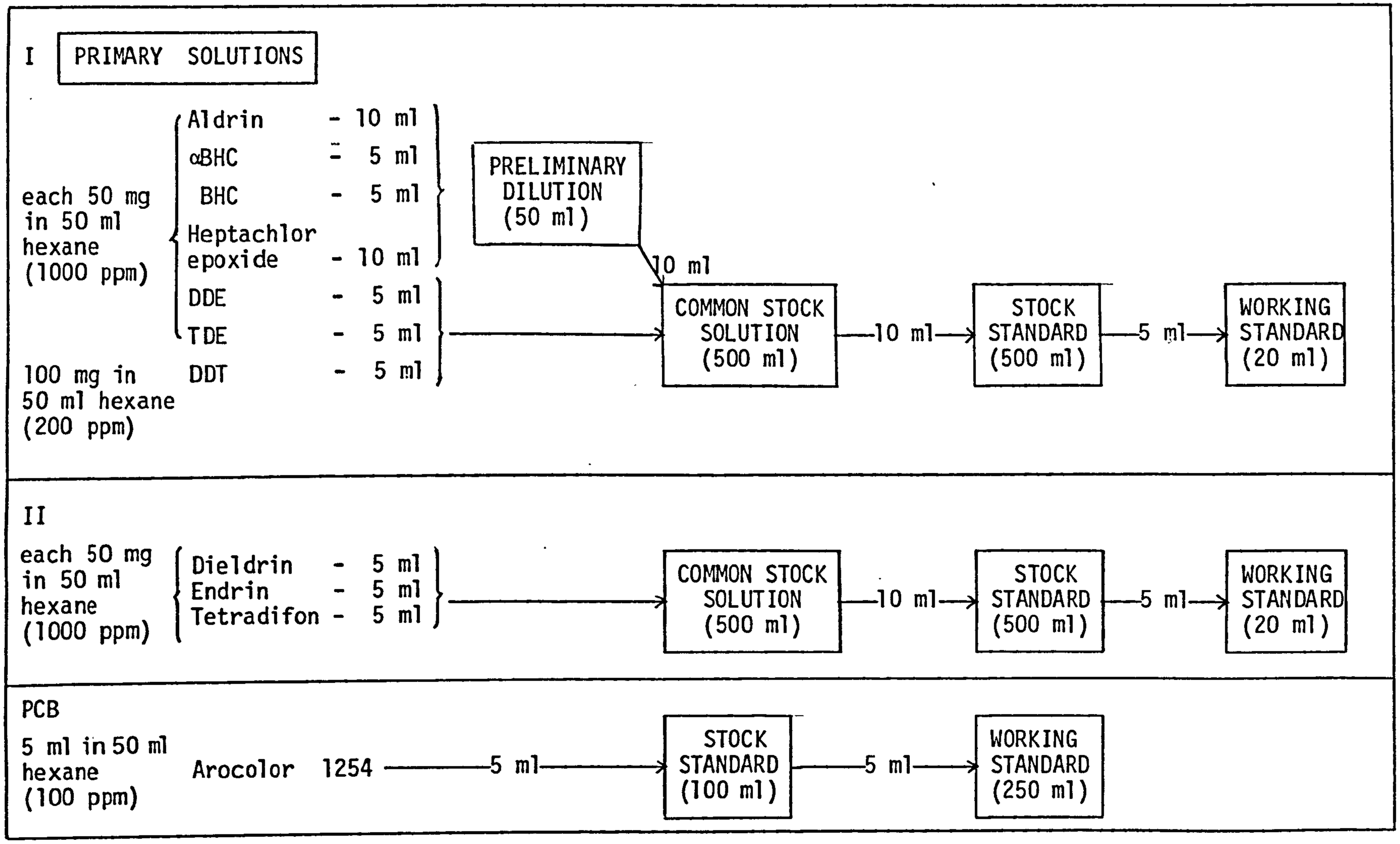
Month	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
1973					
March	34	13.2	34.63	-2.095	3.227
April	10	13.1	33.11	-2.827	3.845
May	9	14.5	47.22	-2.600	3.651
November	55	16.6	86.00	-2.176	3.312
Nov(trawl)	30	16.8	71.54	-2.188	3.318
December	52	14.8	49.84	-1.915	3.029
1974					
January	50	15.0	44.71	-2.322	3.372
February	32	14.2	44.40	-2.191	3.251
July	7	7.0	5.38	-2.030	3.204
October	70	11.1	27.25	-1.971	3.147
November	122	13.6	41.84	-2.145	3.271
December	41	13.5	45.44	-2.259	3.400
1975					
January	29	13.0	34.62	-2.250	3.391
February	73	12.7	31.98	-1.929	3.070
March	177	14.8	50.82	-2.140	3.258

Length/weight characteristics of less common fish species

Species/date	Number of fish	Mean length (cm)	Mean weight (g)	log a (intercept)	b (regression coefficient)
S. acus					
April 1974	39	34.8	23.03	-3.694	3.266
May	27	32.8	20.17	-3.541	3.162
June	9	32.3	21.80	-2.841	2.762
March 1975	10	32.4	18.33	-4.465	3.780
T. minutus					
Dec 1973	18	15.0	56.72	-2.226	3.288
Dec 1974	29	16.3	70.17	-2.303	3.360
Jan 1975	21	13.8	41.33	-2.379	3.426
February	48	10.1	16.28	-2.688	3.674
March	83	11.7	28.49	-2.614	3.603
A. cataphractus	56	8.3	8.84	-2.147	3.256
A. cuculus	26	10.3	30.05	-1.698	2.901
A. minuta	11	4.3	0.79	-2.734	4.123
B. belone	5	12.9	3.47	-2.852	2.969
C. labrosus	11	15.2	65.75	-0.929	2.097
C. lyra	38	8.7	12.15	-1.947	2.980
C. mustela					
Jan 1974	9	14.5	58.32	-2.418	3.420
November	14	12.7	25.87	-0.903	2.086
Jan 1975	11	13.5	34.74	-2.555	3.550
G. morhua	15	14.8	118.59	-2.496	3.407
G. niger	32	7.2	8.83	-1.889	3.259
L. liparis	26	8.0	12.26	-1.702	3.057
O. eperlanus	24	16.2	56.11	-1.954	2.992
T. trachurus	10	11.5	65.11	-1.805	2.926
Z. viviparus	12	18.1	31.08	-2.459	3.110

APPENDIX IV

Preparation of standard chlorinated hydrocarbon and heavy metal solutions


I
PRIMARY SOLUTIONS
each 50 mg in 50 ml hexane (1000 ppm)
Aldrin - 10 ml
αBHC - 5 ml
BHC - 5 ml
Heptachlor epoxide - 10 ml
DDE - 5 ml
TDE - 5 ml
100 mg in 50 ml hexane (200 ppm)
DDT - 5 ml
PRELIMINARY DILUTION (50 ml)
10 ml
COMMON STOCK SOLUTION (500 ml)
10 ml
STOCK STANDARD (500 ml)
5 ml
WORKING STANDARD (20 ml)
II
each 50 mg in 50 ml hexane (1000 ppm)
Dieldrin - 5 ml
Endrin - 5 ml
Tetradifon - 5 ml
COMMON STOCK SOLUTION (500 ml)
10 ml
STOCK STANDARD (500 ml)
5 ml
WORKING STANDARD (20 ml)
PCB
5 ml in 50 ml hexane (100 ppm)
Arocolor 1254
5 ml
STOCK STANDARD (100 ml)
5 ml
WORKING STANDARD (250 ml)

Heavy metals: preparation of standard solutions

A multi-element stock solution was prepared: one gram each of cadmium and zinc metals, 1.598 gram of lead nitrate and 2.5 gram of copper metal were dissolved in 10 - 15 millilitres of Aristar nitric acid and made up to volume with deionised water in a one litre volumetric flask.

50 millilitres of this solution was made up to 500 millilitres with deionised water to give a working stock solution. Further dilutions were carried out for every fresh batch of samples as follows:

Zinc and copper analysis by flame atomic absorption -

0.5	millilitre	made	up	to	100	millilitres	gave	0.5	ppm	zinc	and	1.25	ppm	copper
1.0	"	"	"	"	"	"	"	1.0	"	"	"	2.50	"	"
3.0	"	"	"	"	"	"	"	3.0	"	"	"	7.50	"	"
4.0	"	"	"	"	"	"	"	4.0	"	"	"	10.00	"	"
6.0	"	"	"	"	"	"	"	6.0	"	"	"	-	"	"

Cadmium analysis by flame atomic absorption -

10 millilitres of working stock solution were made up to 100 millilitres with deionised water. From this

0.5	millilitre	made	up	to	100	millilitres	gave	0.05	ppm	cadmium	solution
1.0	"	"	"	"	"	"	"	0.10	"	"	"
2.0	"	"	"	"	"	"	"	0.20	"	"	"
4.0	"	"	"	"	"	"	"	0.40	"	"	"
6.0	"	"	"	"	"	"	"	0.60	"	"	"

Cadmium and lead analysis by flameless atomic absorption (graphite furnace) -

10 millilitres of working stock solution were made up to 100 millilitres with deionised water and 10 millilitres of this resulting solution was made up to 100 millilitres with deionised water. Then

0.5	millilitre	made	up	to	100	millilitres	gave	a	0.005	ppm	solution
1.0	"	"	"	"	"	"	"		0.010	"	"
2.0	"	"	"	"	"	"	"		0.020	"	"
4.0	"	"	"	"	"	"	"		0.040	"	"
5.0	"	"	"	"	"	"	"		0.050	"	"

Chlorinated Hydrocarbons in Macroinvertebrates and Fish from the Lower Medway Estuary, Kent.

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The topography of the lower Medway estuary has been recorded elsewhere (Wharfe, 1975). Recognised as an area of international scientific importance by a working party under the guidance of the Nature Conservancy Council (1971), it has been the subject of extensive ornithological studies (Gilham, 1955; Humphreys, 1963, 1967; Harrison, 1972; Harrison et al, 1972). Harrison et al (1972) indicate the estuary to be the fifth most important in Britain for its breeding and migratory birds, and perhaps the most important for its diversity of species.

During ecological studies on the lower Medway estuary (Wharfe, 1975, 1976, 1977; Van den Broek, 1977) levels of specific pollutants were determined in a range of invertebrates and fish. In the absence of previous work of this kind in the area, and with increasing evidence of the possible harmful effects of chlorinated hydrocarbons on marine organisms and bird life in particular (Cramp et al, 1964; Walker et al, 1967; Holden and Marsden, 1967), it is the purpose of this paper to set out the results of analyses undertaken for a range of organochlorine pesticides and polychlorinated biphenyls (PCBs). Heavy metal levels, in the same organisms, have been reported (Wharfe and Van den Broek, 1977).

Macroinvertebrates were sampled bimonthly from nine shore sites on the lower Medway estuary (Fig.1). Fish and shrimps were collected bimonthly from Kingsnorth power station intake screens. Pooled samples for analysis, each consisting of at least twenty individuals, were taken from mussels,

Mytilus edulis L (>4cm shell length);shore crabs,Carcinus maenas (L) (>4cm carapace width);periwinkles,Littorina littorea (L) (>I.8cm shell width) and ragworms,Nereis diversicolor Müller. Pooled samples of fifty shrimps, Crangon vulgaris L,and selected tissues from a range of fish in varying size classes were analysed from Kingsnorth.

After Soxhlet extraction with n-hexane,the samples were cleaned and fractionated by column chromatographic techniques (Holden and Marsden, I969). Samples were analysed by gas chromatography,on a column of 5% OVI on IOO-200 mesh Diatomite CQ,fitted with a Ni63 electron capture detector. The lipid content of the sample was determined by evaporating half of the original IOOml extract.

Results and Discussion

Samples were screened for α- and γ-BHC,DDT,TDE,DDE,heptachlor epoxide, aldrin,endrin,dieldrin,endosulphan,tetradifon and the PCB,Aroclor I254. Of these,only DDT and its metabolites,dieldrin and PCBs were detected in quantifiable amounts. Traces of aldrin,α- and γ-BHC and endrin were found but,because of the extremely low levels,they were not quantified.

A summary of the levels found is given in tables I and 2.Details of seasonal levels have been reported by Wharfe (I975) and Van den Broek (I977). There was little evidence of any seasonal variation in levels of pesticides or PCBs in either invertebrates or fish.. The exception was that,during the summer months of I973,higher levels of DDT and its metabolites were found in samples of M.edulis from Bedlams Bottom,an area bounded by extensive orchards. However,this pattern was not repeated the following year and prevents further comment. In general,levels of DDT and dieldrin residues in invertebrates from the lower Medway estuary are comparable with the range of values reported in the literature (Robinson et al,1967;Jensen et al, I969).It is interesting to note,however,that levels in M.edulis and C.maenas were higher than values reported from Liverpool Bay (Riley and Wahby,I977).

The distrbution of PCBs showed highest concentrations at Lower Upnor and Gillingham,sites in the vicinity of industrialised areas.Significant

differences between sites were detected in samples of M.edulis and L.littorina, and there appeared to be a gradual reduction of PCB levels in invertebrates sampled at sites downstream. Levels of PCBs in M.edulis were no higher than those quoted by Jensen et al (1969) from Swedish waters but above those reported by Riley and Wahby (1977) for samples of M.edulis, C.vulgaris and C.maenas from Liverpool Bay (table 3).

The lipophilic nature of these chemicals often results in their storage in the fatty tissues. However, the hexane-extractable content, predominantly fats, of the invertebrates analysed, revealed extremely low levels with average figures of 1.5% total body weight in M.edulis, 0.5% in C.maenas, 0.4% in C.vulgaris and 0.25% in L.littorea. Holden (1962) reported correlations between levels of accumulated pesticide and lipid content. In the present study, levels of hexane-extractable fat were generally higher in fish samples (table 2), especially their livers. Significant correlations between hexane-extractable fat and dieldrin levels were found in muscle tissues of eel, Anguilla anguilla (L), ($r=0.778$ for specimens <30 cm length, $r=0.814$ for specimens >30 cm length), muscle tissues of whiting, Merlangius merlangus (L), ($r=0.914$ for specimens 0-15 cm length), muscle tissues of flounder, Platichtys flesus (L), ($r=0.921$ for specimens 14-20 cm length), muscle tissues of plaice, Pleuronectes platessa L, ($r=0.902$ for specimens 0-8 cm length) and whole bodies of gobies, Pomatoschistus minutus (Kroyer), ($r=0.878$) and sprats, Sprattus sprattus (L), ($r=0.806$). Despite higher hexane-extractable fat levels in liver samples, no correlation was found with concentrations of dieldrin. Similarly, there was no evidence of any relationship with DDT or PCBs.

A comparison of the tissue showed that, with the exception of eels, chlorinated hydrocarbon levels were highest in the liver, followed by gut wall and muscle tissues. The few gonad results were comparable with muscle tissue levels. Literature on chlorinated hydrocarbon levels in separate

fish tissues is sparse,but in muscle tissues,which in most cases accounts for at least ninety percent of the total body weight,levels were similar to those found in whole bodies by other workers (Robinson et al,1967; Jensen et al,1969;Huschenbeth,1973;Foehrenbach,1972;Holden,1972).However, a recent study by Riley and Wahby(1977) shows levels of total DDT,dieldrin and PCBs in fish tissues sampled from Liverpool Bay to be much lower than levels in fish tissues from the Medway,even though solvent extratable fat levels were similar. This may well reflect the higher concentrations found within estuaries,as the highest concentrations found in whiting from the Medway were comparable with the Clyde data (Holden,1972).

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Table 1 Summary of Macroinvertebrate Chlorinated Hydrocarbon Level

Homogeneous samples all of at least 20 individuals (adults)

Mean levels and range $ng.g^{-1}$ (ppb) wet weight

	DDT+ Metabolites	Dieldrin	PCBs
L. littorea			
Bedlams Bottom	4.0 (0.0 - 21.2)	1.6 (0.0 - 13.4)	14.4 (0.0 - 64.0)
Motney Hill	4.9 (0.0 - 19.8)	1.3 (0.0 - 7.6)	34.2 (10.0 - 94.0)
East Rainham	2.2 (0.0 6.7)	1.1 (0.0-3.5)	20.2 (0.0 - 72.0)
Gillingham	3.0 (0.0 - 16.1)	0.3 (0.0 - 1.0)	54.1 (20.0 - 178.0)
Lower Upnor	6.3 (0.0 - 20.0)	1.3 (0.0 - 6.5)	63.4 (36.0 - 104.8)
Hoo	4.5 (0.0 - 19.8)	1.0 (0.0 - 4.8)	29.1 (10.0 - 52.0)
Damhead Creek	1.5 (0.0 - 4.0)	0.6 (0.0 - 3.0)	21.2 (10.0 - 35.6)
BP Colemouth Creek	1.0 (0.0 - 2.0)	0.4 (0.0 - 2.2)	14.8 (10.0 - 32.0)
Isle of Grain	1.7 (0.0 - 5.5)	0.1 (0.0 - 0.8)	16.3 (0.0 - 88.0)
C.maenas			
Bedlams Bottom	25.7 (6.2 - 49.4)	10.7 (2.0 - 22.6)	52.1 (30.0 - 76.0)
Motney Hill	13.1 (0.0 - 18.0)	6.6 (0.0 - 13.4)	66.3 (20.0 - 142.0)
East Rainham	6.4 (0.0 - 17.6)	3.0 (0.0 - 13.2)	50.9 (0.0 - 84.0)
BP Colemouth Creek	4.8 (0.0 - 12.4)	1.0 (0.0 - 4.6)	40.4 (30.0 - 66.0)
Isle of Grain	4.9 (0.0 - 10.2)	0.8 (0.0 - 3.2)	64.1 (30.0 - 100.0)

TABLE 1 continued

<u>M. edulis</u>			
Bedlams Bottom	71.8 (10.8 - 226.0)	11.1 (0.0 - 62.4)	95.3 (44.0 - 210.4)
Motney Hill	32.6 (11.0 - 54.2)	11.5 (2.0 - 34.0)	106.2 (58.0 - 161.6)
Gillingham	27.4 (7.4 - 52.6)	6.3 (2.0 - 20.0)	133.6 (70.0 - 195.0)
Lower Upnor	26.9 (7.6 - 49.2)	7.8 (2.0 - 17.8)	162.0 (104.0 - 268.0)
Hoo	24.6 (8.7 - 55.1)	6.4 (1.6 - 21.0)	129.6 (62.0 - 168.0)
Damhead Creek	11.0 (0.0 - 25.0)	4.0 (0.0 - 17.6)	70.4 (50.0 - 116.0)
<u>N. diversicolor</u>			
All sites	0.9 (0.0 - 4.4)	3.0	37.0 (0.0 - 125.0)
<u>C. vulgaris</u>			
Kingsnorth	18.7 (2.7 - 81.3)	5.5 (1.2 - 20.2)	77.5 (0.0 - 275.0)

BLE 2 SUMMARY OF FISH CHLORINATED HYDROCARBON LEVELS

Mean levels and range $ng.g^{-1}$ wet weight

ecies	Length cm	No. of Samples	Hexane Extractable Fat %	DDT+ Metabolites	Dieldrin	PCBs
anguilla						
scle	<30.0	9	4.0 (2.0-6.6)	195.5 (61.3-296.3)	77.1 (8.0-192.0)	699.4 (33.5-1
scle	>30.0	13	10.3 (0.7-22.3)	300.3 (139.1-807.2)	111.1 (34.2-232.0)	1032.6 (40-196
ver	<30.0	8	2.7 (1.4-4.3)	134.2 (76.7-251.4)	57.0 (26.5-90.0)	970.6 (305-160
ver	>30.0	14	5.9 (1.3-13.2)	96.9 (54.5-159.6)	43.3 (8.5-75.6)	866.9 (425-1250
merlangus						
scle	0-14.9	10	0.3 (0.1-1.5)	11.5 (5.8-31.5)	4.2 (2.4-9.2)	66.0 (10-160
scle	15.0-21.9	7	0.1 (0.1-0.2)	11.0 (5.9-16.1)	3.4 (0.6-5.1)	51.0 (16-96)
ver	0-21.9	14	26.3 (13.1-39.7)	2311.0 (630.7-4240.0)	529.0 (175.0-1096.2)	6447.2 (2630-1
wall	0-21.9	8	0.7 (0.2-1.2)	35.9 (8.1-71.5)	11.4 (2.5-21.5)	164.1 (20-34
flesus						
scle	0-7.9	9	0.4 (0.3-0.7)	23.9 (12.3-51.3)	12.1 (5.2-24.0)	94.6 (36-168
scle	8.0-13.9	14	0.4 (0.3-0.6)	23.1 (6.2-62.2)	10.3 (3.4-24.0)	91.1 (36-21
scle	14.0-19.9	10	0.2 (0.1-0.7)	24.8 (0.2-77.8)	7.7 (0.8-24.8)	84.0 (36-25
scle	>20.0	4	0.2 (0.1-0.3)	49.8 (8.9-117.7)	8.9 (2.1-25.8)	186.7 (40-33
er	0-13.9	11	9.9 (3.6-23.7)	569.6 (326.4-1298.4)	206.9 (77.0-386.2)	2144.3 (1220-53
er	> 14	6	8.0 (4.2-9.7)	650.3 (104.8-1333.6)	210.0 (43.0-380.0)	3073.0 (340-10
wall	0-20	8	1.1 (0.4-1.4)	62.6 (14.9-170.0)	21.6 (6.6-39.0)	261.5 (64-437
ry	0-20	6	0.2 (0.0-0.5)	30.1 (0.2-44.3)	12.0 (7.2-33.5)	109.7 (50-180
tis	0-20	2	0.9 (0.3-1.1)	10.1 (5.4-14.8)	7.4 (5.8-9.0)	47.0 (0-94)

TABLE 2 SUMMARY OF FISH CHLORINATED HYDROCARBON LEVELS

Mean levels and range $ng.g^{-1}$ wet weight

Species	Length cm	No. of Samples	Hexane Extractable Fat %	DDT+ Metabolites	Dieldrin	PCBs
A.anguilla						
muscle	<30.0	9	4.0 (2.0-6.6)	195.5 (61.3-296.3)	77.1 (8.0-192.0)	699.4 (33.5-1250
muscle	>30.0	13	10.3 (0.7-22.3)	300.3 (139.1-807.2)	111.1 (34.2-232.0)	1032.6 (40-1960)
liver	<30.0	8	2.7 (1.4-4.3)	134.2 (76.7-251.4)	57.0 (26.5-90.0)	970.6 (305-1605)
lever	>30.0	14	5.9 (1.3-13.2)	96.9 (54.5-159.6)	43.3 (8.5-75.6)	866.9 (425-1250)
M.merlangus						
muscle	0-14.9	10	0.3 (0.1-1.5)	11.5 (5.8-31.5)	4.2 (2.4-9.2)	66.0 (10-160)
muscle	15.0-21.9	7	0.1 (0.1-0.2)	11.0 (5.9-16.1)	3.4 (0.6-5.1)	51.0 (16-96)
liver	0-21.9	14	26.3 (13.1-39.7)	2311.0 (630.7-4240.0)	529.0 (175.0-1096.2)	6447.2 (2630-1038
gut wall	0-21.9	8	0.7 (0.2-1.2)	35.9 (8.1-71.5)	11.4 (2.5-21.5)	164.1 (20-340)
P.flesus						
muscle	0-7.9	9	0.4 (0.3-0.7)	23.9 (12.3-51.3)	12.1 (5.2-24.0)	94.6 (36-168)
muscle	8.0-13.9	14	0.4 (0.3-0.6)	23.1 (6.2-62.2)	10.3 (3.4-24.0)	91.1 (36-216)
muscle	14.0-19.9	10	0.2 (0.1-0.7)	24.8 (0.2-77.8)	7.7 (0.8-24.8)	84.0 (36-252)
muscle	>20.0	4	0.2 (0.1-0.3)	49.8 (8.9-117.7)	8.9 (2.1-25.8)	186.7 (40-333)
liver	0-13.9	11	9.9 (3.6-23.7)	569.6 (326.4-1298.4)	206.9 (77.0-386.2)	2144.3 (1220-5345)
liver	> 14	6	8.0 (4.2-9.7)	650.3 (104.8-1333.6)	210.0 (43.0-380.0)	3073.0 (340-10 079
[illegible]	0-20	8	1.1 (0.4-1.4)	62.6 (14.9-170.0)	21.6 (6.6-39.0)	261.5 (64-437)
[illegible]ry	0-20	6	0.2 (0.0-0.5)	30.1 (0.2-44.3)	12.0 (7.2-33.5)	109.7 (50-180)
testis	0-20	2	0.9 (0.3-1.1)	10.1 (5.4-14.8)	7.4 (5.8-9.0)	47.0 (0-94)

TABLE 2 SUMMARY OF FISH CHLORINATED HYDROCARBON LEVELS

Mean levels and range $ng.g^{-1}$ wet weight

Species	Length cm	No. of Samples	Hexane Extractable Fat %	DDT+ Metabolites	Dieldrin	PCBs
A.anguilla						
muscle	<30.0	9	4.0 (2.0-6.6)	195.5 (61.3-296.3)	77.1 (8.0-192.0)	699.4 (33.5-125
muscle	>30.0	13	10.3 (0.7-22.3)	300.3 (139.1-807.2)	111.1 (34.2-232.0)	1032.6 (40-1960)
liver	<30.0	8	2.7 (1.4-4.3)	134.2 (76.7-251.4)	57.0 (26.5-90.0)	970.6 (305-1605)
lever	>30.0	14	5.9 (1.3-13.2)	96.9 (54.5-159.6)	43.3 (8.5-75.6)	866.9 (425-1250)
M.merlangus						
muscle	0-14.9	10	0.3 (0.1-1.5)	11.5 (5.8-31.5)	4.2 (2.4-9.2)	66.0 (10-160)
muscle	15.0-21.9	7	0.1 (0.1-0.2)	11.0 (5.9-16.1)	3.4 (0.6-5.1)	51.0 (16-96)
liver	0-21.9	14	26.3 (13.1-39.7)	2311.0 (630.7-4240.0)	529.0 (175.0-1096.2)	6447.2 (2630-1038
gut wall	0-21.9	8	0.7 (0.2-1.2)	35.9 (8.1-71.5)	11.4 (2.5-21.5)	164.1 (20-340)
P.flesus						
muscle	0-7.9	9	0.4 (0.3-0.7)	23.9 (12.3-51.3)	12.1 (5.2-24.0)	94.6 (36-168)
muscle	8.0-13.9	14	0.4 (0.3-0.6)	23.1 (6.2-62.2)	10.3 (3.4-24.0)	91.1 (36-216)
muscle	14.0-19.9	10	0.2 (0.1-0.7)	24.8 (0.2-77.8)	7.7 (0.8-24.8)	84.0 (36-252)
muscle	>20.0	4	0.2 (0.1-0.3)	49.8 (8.9-117.7)	8.9 (2.1-25.8)	186.7 (40-333)
liver	0-13.9	11	9.9 (3.6-23.7)	569.6 (326.4-1298.4)	206.9 (77.0-386.2)	2144.3 (1220-5345)
liver	> 14	6	8.0 (4.2-9.7)	650.3 (104.8-1333.6)	210.0 (43.0-380.0)	3073.0 (340-10 079
gut wall	0-20	8	1.1 (0.4-1.4)	62.6 (14.9-170.0)	21.6 (6.6-39.0)	261.5 (64-437)
ovary	0-20	6	0.2 (0.0-0.5)	30.1 (0.2-44.3)	12.0 (7.2-33.5)	109.7 (50-180)
testis	0-20	2	0.9 (0.3-1.1)	10.1 (5.4-14.8)	7.4 (5.8-9.0)	47.0 (0-94)

Table 2 (contd.)

Species	Length cm.	No. of Samples	Hexane Extractable Fat%	DDT+ Metabolites	Dieldrin	PCBs
P.platessa						
muscle	0-7.9	11	0.4 (0.1-1.1)	17.2 (5.7-37.7)	6.4 (2.2-11.1)	73.6 (14-156)
muscle	8.0-13.9	11	0.2 (0.1-0.3)	7.2 (1.9-13.0)	3.3 (1.3-5.4)	43.1 (10-88)
muscle	14.0-19.9	7	0.1 (0.1-0.2)	6.0 (3.6-13.8)	2.3 (1.6-3.4)	25.4 (32-56)
liver	0-19.9	13	6.2 (1.5-13.2)	291.5 (75.3-614.0)	116.8 (15.2-228.0)	1237.4 (646-2654)
gut wall	0-19.9	11	1.0 (0.6-1.9)	26.9 (5.9-72.5)	11.0 (5.7-24.7)	129.1 (54-255)
P.minutus						
whole	-	10	2.8 (1.6-3.6)	118.5 (67.9-172.5)	46.7 (24.2-77.0)	364.8 (158-528)
S.sprattus						
whole	-	14	5.3 (2.1-9.7)	277.5 (174.4-504.6)	84.0 (29.5-142.0)	955.0 (587-1475

TABLE 3 COMPARATIVE CHLORINATED HYDROCARBON LEVELS

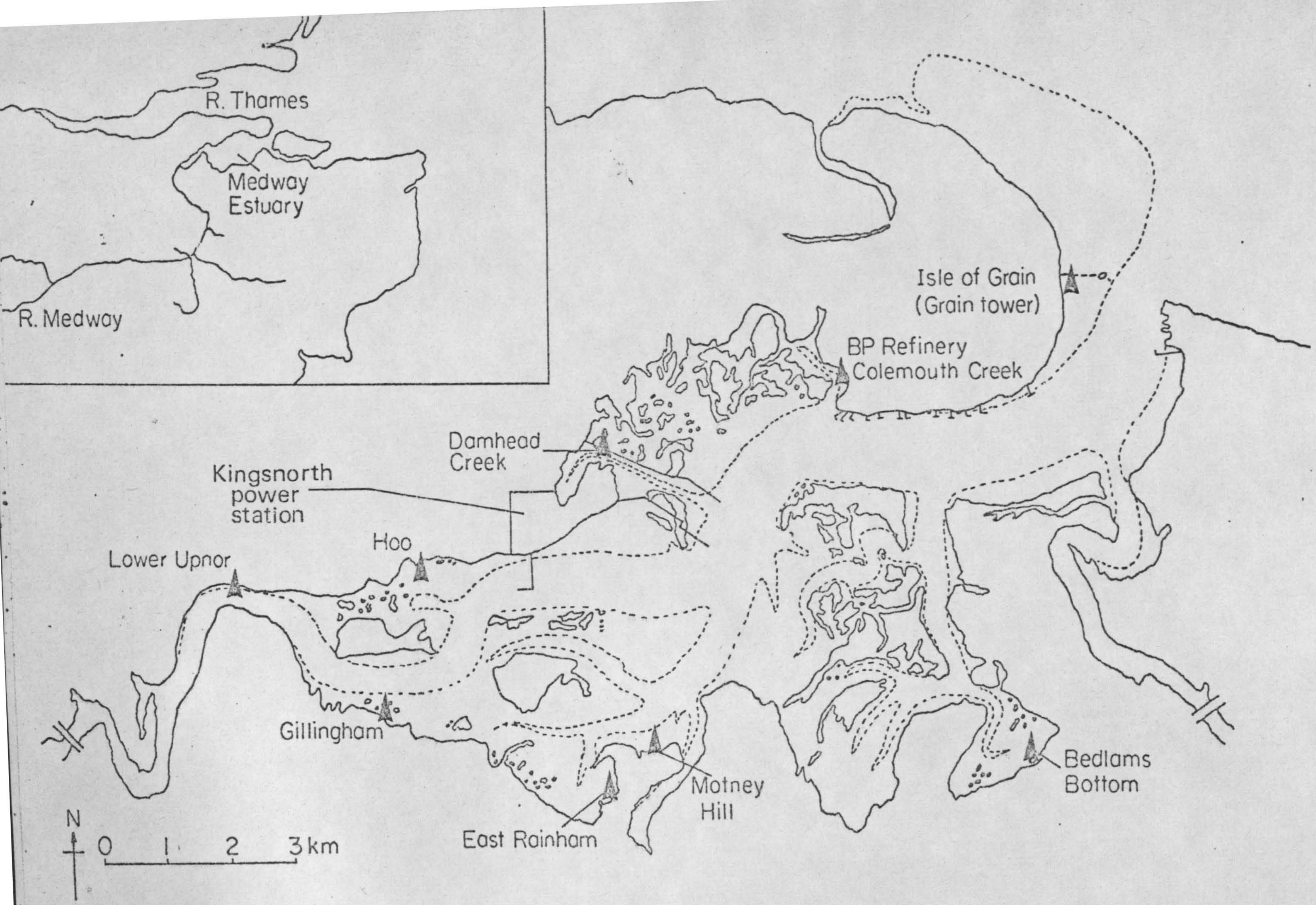
($ng.g^{-1}$ wet weight)

ORGANISM	LOCATION		ΣDDT	DIELDRIN	PCB
Mytilus edulis	Medway		0-226	0-63	44-268
	Liverpool Bay*		2	-	20
Carcinus maenas	Medway		0-50	0-23	0-142
	Liverpool Bay*		0.5	3	8
Crangon vulgaris	Medway		2-82	1-21	0-275
	Liverpool Bay*		0.5	2	7
Merlangius merlangus	Medway	muscle	5-17	0.6-6	16-96
		liver	630-4240	175-1096	2500-1050
	Liverpool Bay*		<1	7	80
	Clyde		1000-2000	540-690	4000-8000

* RILEY AND WAHBY, 1977

§ HOLDON, 1972

Figure I Sampling sites on the lower Medway estuary.


R. Thames
Medway
Estuary
R. Medway
Isle of Grain
(Grain tower)
BP Refinery
Colemouth Creek
Damhead
Creek
Kingsnorth
power
station
Hoo
Lower Upnor
Gillingham
Motney
Hill
East Rainham
Bedlams
Bottom
N
0 1 2 3 km

assist the 300–500 vessels passing daily through and across the Dover Strait. The service covers an area between Eastbourne and Ramsgate on the English coastline and Cap d'Alprech and Dunkerque on the French coastline and operates by constant radar surveillance and regular radio broadcasts. Navigational information is broadcast twice-hourly from purpose built stations on both sides of the English Channel and during periods of poor visibility the frequency of transmissions is increased to 4 per hour.

Large, fast vessels with deep draughts and restricted manoeuvrability will benefit most from the scheme by being kept informed of the location of 'rogue' vessels which ignore established routeing schemes and increase the danger of collisions.

This service is the latest in a series of measures designed to establish a comprehensive navigational code for these waters. In June 1967 a recommended routeing scheme was introduced, followed by a deep-draught route in April 1972. In the same year support measures were introduced by a Dover Strait Surveillance Scheme. From July 1977 ships of all contracting IMCO states will have to observe the present traffic lanes. By 1978 improved buoyage will have been completed incorporating special marks to delineate the separation scheme and short term or recent hazards.

Scotland

Gulf Oil Corporation is to sponsor a series of environmental study scholarships for the Scottish Field Studies Association (SFSA). Over the five years 1977–1981, Gulf will provide 25 scholarships a year of up to £100 for education staff and senior students in the UK to attend week-long courses at the SFSA residential field centre at Kindrogan in Scotland.

Called Gulf Scholarships, they will enable teachers and others in biology, geography and allied subjects to improve their field knowledge and teaching skills in environmental science. Where appropriate, subject matter will include environmental planning associated with onshore oil developments.

Applications for scholarships will be invited and considered by the Executive committee of the Association (membership of which includes Professor Holliday of Aberdeen University and Professor Coppock of Edinburgh University).

REPORTS

Heavy Metals in Macroinvertebrates and Fish from the Lower Medway Estuary, Kent

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Since the Second World War, expansion of the Medway towns of Rochester, Chatham and Gillingham and industrial development in this area have increased the threat of pollution in the lower estuary. During ecological studies on the lower Medway estuary, macroinvertebrates and fish were analysed for five heavy metals, mercury, zinc, copper, lead and cadmium, periodically from April 1973–January 1976. In the absence of previous work of this kind in the area, this paper sets out the results and discusses their significance.

Macroinvertebrates were sampled bimonthly from nine shore sites on the lower Medway estuary (Fig. 1). Fish and shrimps were collected bimonthly from Kingsnorth power station intake screens. Pooled sampled of at least twenty individuals of mussles, *Mytilus edulis* L. (>4 cm shell length); shore crabs, *Carcinus maenas* (L.) (>4 cm carapace width); periwinkles, *Littorina littorea* (L.) (>1.8 cm shell width) and ragworms, *Nereis diversicolor* Müller, were analysed from each site. Pooled samples of fifty shrimps, *Crangon vulgaris* L. and selected tissues of a range of fish of varying size classes were analysed from Kingsnorth.

After wet digestion all samples were analysed by standard techniques, zinc, copper, lead and cadmium by flame atomic absorption and mercury by flameless atomic absorption. Lead in fish was determined in a graphite furnace.

Results

Levels of five metals, mercury, zinc, copper, lead and cadmium in a range of macroinvertebrates and fish are presented (Tables 1 & 2). Seasonal differences were not evident and in general all levels were low. Mercury residues were comparable with reported values (Morris, 1973; Ministry of Agriculture, Fisheries and Food, 1971; Dalgaard-Mikkelsen, 1969; Johnels *et al.*, 1967) with the exception of eel livers from the larger size class (>30.0 cm). Lack of comparable data prevents further comment.

TABLE 1
Mean concentrations and range of metals in macroinvertebrates from the lower Medway estuary. (mg/kg wet wt).

	Hg	Zn	Cu	Pb	Cd
Littorina littorea (L.) (periwinkle)					
Bedlams Bottom	0.17 (0.15–0.20)	15.5 (13.4–18.0)	25.8 (24.5–27.0)	0.28 (0.10–0.50)	0.43 (0.35–0.50)
Motney Hill	0.09 (0.08–0.10)	23.4 (18.0–32.5)	31.6 (24.5–40.0)	0.58 (0.45–0.75)	0.50 (0.35–0.70)
East Rainham	0.24 (0.15–0.33)	18.0 (16.5–21.3)	36.1 (34.0–38.3)	0.47 (0.15–0.63)	0.63 (0.45–1.08)
Gillingham	0.14 (0.05–0.22)	21.3 (18.5–25.0)	28.8 (26.5–31.3)	2.31 (1.80–2.88)	0.90 (0.40–1.93)
Lower Upnor	0.15 (0.10–0.25)	24.3 (15.4–30.4)	26.8 (24.2–29.2)	3.03 (1.12–3.30)	0.82 (0.58–1.00)
Hoo	0.13 (0.03–0.27)	18.6 (15.0–26.7)	25.2 (19.5–33.9)	1.81 (1.35–2.33)	0.57 (0.45–0.80)
Damhead Creek	0.19 (0.14–0.23)	16.2 (14.3–17.3)	23.8 (23.5–26.0)	0.81 (0.05–1.10)	0.59 (0.50–0.75)
BP Colemouth Creek	0.14 (0.11–0.16)	15.9 (13.8–19.5)	28.0 (24.0–31.5)	0.95 (0.50–1.55)	0.50 (0.33–0.80)
Isle of Grain	0.13 (0.11–0.16)	17.6 (15.9–20.5)	26.9 (21.5–32.0)	0.66 (0.45–1.15)	0.46 (0.25–0.63)
Carcinus maenas (L.) (shore crab)					
Bedlams Bottom	0.25 (0.14–0.39)	25.1 (23.0–26.5)	22.8 (17.5–27.0)	0.38 (0.10–0.75)	1.03 (0.80–1.18)
Motney Hill	0.14 (0.08–0.19)	33.0 (29.0–35.5)	22.4 (21.0–26.5)	1.09 (0.70–1.70)	1.21 (1.05–1.35)
East Rainham	0.16 (0.11–0.19)	31.6 (25.8–33.0)	29.9 (26.5–33.0)	0.73 (0.30–1.38)	1.03 (0.75–1.45)
Gillingham	0.25 (0.18–0.33)	28.8 (20.0–34.8)	20.9 (13.5–25.0)	1.78 (1.25–2.62)	1.21 (1.00–1.35)
Lower Upnor	0.20 (0.11–0.32)	32.9 (27.5–40.0)	15.4 (15.0–16.3)	3.32 (2.33–4.13)	2.07 (1.10–3.00)
Hoo	0.14 (0.10–0.17)	38.8 (31.4–48.3)	16.4 (15.3–17.5)	1.56 (1.13–2.00)	1.18 (0.95–1.40)
Damhead Creek	0.15 (0.11–0.16)	28.1 (24.8–32.0)	25.5 (22.0–27.5)	0.73 (0.30–1.30)	0.96 (0.80–1.10)
BP Colemouth Creek	0.21 (0.15–0.29)	31.2 (23.0–41.8)	28.6 (22.3–38.0)	1.37 (1.10–1.75)	1.27 (0.85–1.50)
Isle of Grain	0.29 (0.22–0.44)	30.7 (27.0–35.0)	31.4 (27.5–41.0)	1.46 (0.62–2.25)	1.00 (0.80–1.35)
Mytilus edulis L. (mussel)					
Bedlams Bottom	0.30 (0.19–0.46)	31.6 (25.5–4.32	1.9 (0.5–3.8)	0.75 (0.45–1.20)	0.73 (0.63–0.90)
Motney Hill	0.14 (0.05–0.21)	32.2 (28.0–35.8)	2.3 (1.5–3.0)	1.20 (0.75–1.58)	0.71 (0.55–0.88)
Gillingham	0.14 (0.10–0.16)	33.6 (22.8–48.3)	2.0 (0.5–2.5)	1.76 (1.05–2.23)	1.19 (1.01–1.40)
Lower Upnor	0.14 (0.11–0.19)	41.8 (26.0–58.8)	2.3 (1.5–3.0)	2.17 (1.50–3.00)	1.18 (1.01–1.50)
Hoo	0.14 (0.07–0.18)	29.0 (26.3–37.0)	2.2 (1.5–2.5)	1.91 (1.23–2.25)	1.01 (0.90–1.20)
Damhead Creek	0.18 (0.14–0.22)	41.6 (40.5–42.3)	2.0 (1.5–2.5)	1.42 (0.78–1.65)	1.21 (1.15–1.25)
Nereis diversicolor Müller (ragworm)					
Bedlams Bottom	—	37.5	—	1.0	—
Motney Hill	—	23.1	2.4	2.2	0.4
East Rainham	—	22.6	3.0	4.8	0.3
Gillingham	—	24.2	4.0	0.1	0.4
Lower Upnor	—	28.7	3.4	0.4	0.5
Hoo	—	23.6	1.6	0.8	0.2
Damhead Creek	—	22.0	2.1	0.8	0.3
BP Colemouth Creek	—	26.5	4.0	0.7	0.2
Isle of Grain	—	25.5	5.1	—	—
Crangon vulgaris L. (shrimp)					
Estuary	0.17 (0.11–0.26)	26.4 (13.5–35.8)	18.5 (9.5–25.5)	1.22 (1.15–1.30)	0.59 (0.53–0.65)

TABLE 2
Mean concentrations and range of metals in fish from the lower Medway estuary (mg/kg wet weight).
Number of samples shown in brackets after mean concentration.

	Size class (cm)	Hg	Zn	Cu	Pb	Cd
Anguilla anguilla (L.) (eel)						
Muscle	30.0	0.36(4) (0.16–0.27)	23.8(10) (15.0–30.2)	0.6(11) (0.3–1.0)	0.48(3) (0.25–0.70)	0.17(5) (0.50–0.40)
Muscle	30.0	0.54(6) (0.34–0.87)	27.2(17) (13.9–36.4)	0.5(14) (0.3–1.0)	1.05(6) (0.60–1.82)	0.12(6) (0.08–0.18)
Liver	30.0	0.35(2) (0.32–0.38)	51.9(4) (40.4–65.6)	14.9(3) (5.0–32.8)	0.84(1)	0.24(3) (0.15–0.40)
Liver	30.0	1.73(4) (1.55–2.06)	71.9(6) (54.7–95.8)	25.1(9) (9.0–36.9)	2.68(4) (1.35–5.29)	0.37(6) (0.27–0.59)
Merlangius merlangus (L.) (whiting)						
Muscle	0–14.9	0.45(3) (0.23–0.80)	9.2(3) (6.0–10.8)	0.7(3) (0.3–1.0)	0.29(3) (0.18–0.37)	0.13(3) (0.10–0.15)
Muscle	15.0–21.9	0.37(2) (0.34–0.40)	9.1(2) (6.3–12.0)	0.6(2) (0.2–1.0)	0.36(2) (0.25–0.46)	0.21(2) (0.13–0.28)
Liver	—	0.33(1)	28.3(2) (24.2–32.4)	2.4(4) (1.3–3.5)	0.89(2) (0.25–1.54)	0.15(2) (0.13–0.18)
Gut wall	—	0.23(3) (0.19–0.26)	23.1(3) (20.9–25.0)	1.4(6) (0.5–2.5)	0.45(3) (0.20–0.67)	0.15(3) (0.08–0.21)
Platichthys flesus (L.) (flounder)						
Muscle	0–7.9	0.10(4) (0.04–0.20)	18.2(2) (18.0–18.4)	1.3(2)	0.28(2) (0.21–0.35)	0.06(2) (0.06–0.07)
Muscle	8.0–13.9	0.17(7) (0.04–0.37)	17.2(4) (14.3–19.5)	0.8(3) (0.5–1.0)	0.39(3) (0.32–0.47)	0.07(3) (0.06–0.08)
Muscle	14.0–19.9	0.46(7) (0.11–0.90)	12.3(3) (8.0–16.5)	0.3(3)	0.33(3) (0.10–0.72)	0.07(3) (0.06–0.08)
Muscle	20.0	0.64(2) (0.13–1.15)	14.5(1)	0.3(1)	0.33(1)	0.06(1)
Liver	0–13.9	0.24(2) (0.21–0.27)	53.8(2) (48.8–58.8)	12.9(2) (7.4–18.5)	0.94(2) (0.53–1.35)	0.18(2) (0.15–0.22)
Liver	14.0	0.08(1)	68.9(2) (61.8–76.0)	18.3(2) (13.5–23.0)	1.38(2) (1.31–1.45)	0.18(2) (0.17–0.18)
Gut wall	—	0.17(2) (0.13–0.21)	36.2(3) (30.4–40.8)	2.7(3) (1.0–4.8)	0.72(3) (0.35–1.12)	0.19(3) (0.13–[illegible])
Ovary	—	0.12(1)	146.8(1)	2.4(1)	0.12(1)	0.08(1)
Pleuronectes platessa L. (plaice)						
Muscle	0–7.9	0.15(1)	11.9(3) (10.0–13.8)	1.1(4) (0.5–1.7)	0.70(2) (0.48–0.92)	0.08(4) (0.05–0.13)
Muscle	8.0–13.9	0.19(4) (0.15–0.21)	11.7(4) (8.3–14.5)	0.9(6) (0.5–1.3)	0.97(2) (0.95–1.00)	0.11(7) (0.08–0.15)
Muscle	14.0–19.9	0.27(2) (0.22–0.32)	10.0(2) (9.3–10.8)	0.8(4) (0.5–1.3)	1.15(2) (0.90–1.40)	0.14(3) (0.13–0.15)
Liver	—	—	38.9(3) (36.4–42.2)	3.3(5) (1.5–4.2)	1.34(3) (0.95–1.87)	0.18(3) (0.16–0.21)
Gut wall	—	0.07(3) (0.03–0.12)	27.5(2) (27.2–27.9)	2.4(2) (1.8–3.2)	1.33(2) (1.00–1.65)	0.22(2) (0.20–0.25)
Pomatoschistus minutus (Krøyer) (sand goby)						
Whole body	—	0.16(6) (0.04–0.24)	28.7(4) (25.0–33.3)	1.17(7) (0.5–1.5)	1.00(4) (0.55–1.65)	0.24(4) (0.20–0.28)
Sprattus sprattus (L.) (sprat)						
Whole body	—	0.16(6) (0.09–0.27)	38.5(16) (19.0–46.2)	1.1(14) (0.5–2.0)	1.03(4) (0.70–1.59)	0.29(7) (0.50–0.60)

Levels of the essential elements, zinc and copper (Table 1), in periwinkles and shore crabs are similar, as are zinc levels in mussels and ragworms. Levels of copper in periwinkles and shore crabs are higher than values for mussels and ragworms, probably on account of the copper containing respiratory pigment, haemocyanin, in the gastropod and the crustacean. All values fall within the reported ranges (Steele *et al.*, 1973; Wright, 1976).

Levels of zinc and copper in fish livers were higher than muscle concentrations for all species (Table 2) and tended to be higher in larger specimens. In general, levels in the bottom-dwelling eels are higher than in plaice and

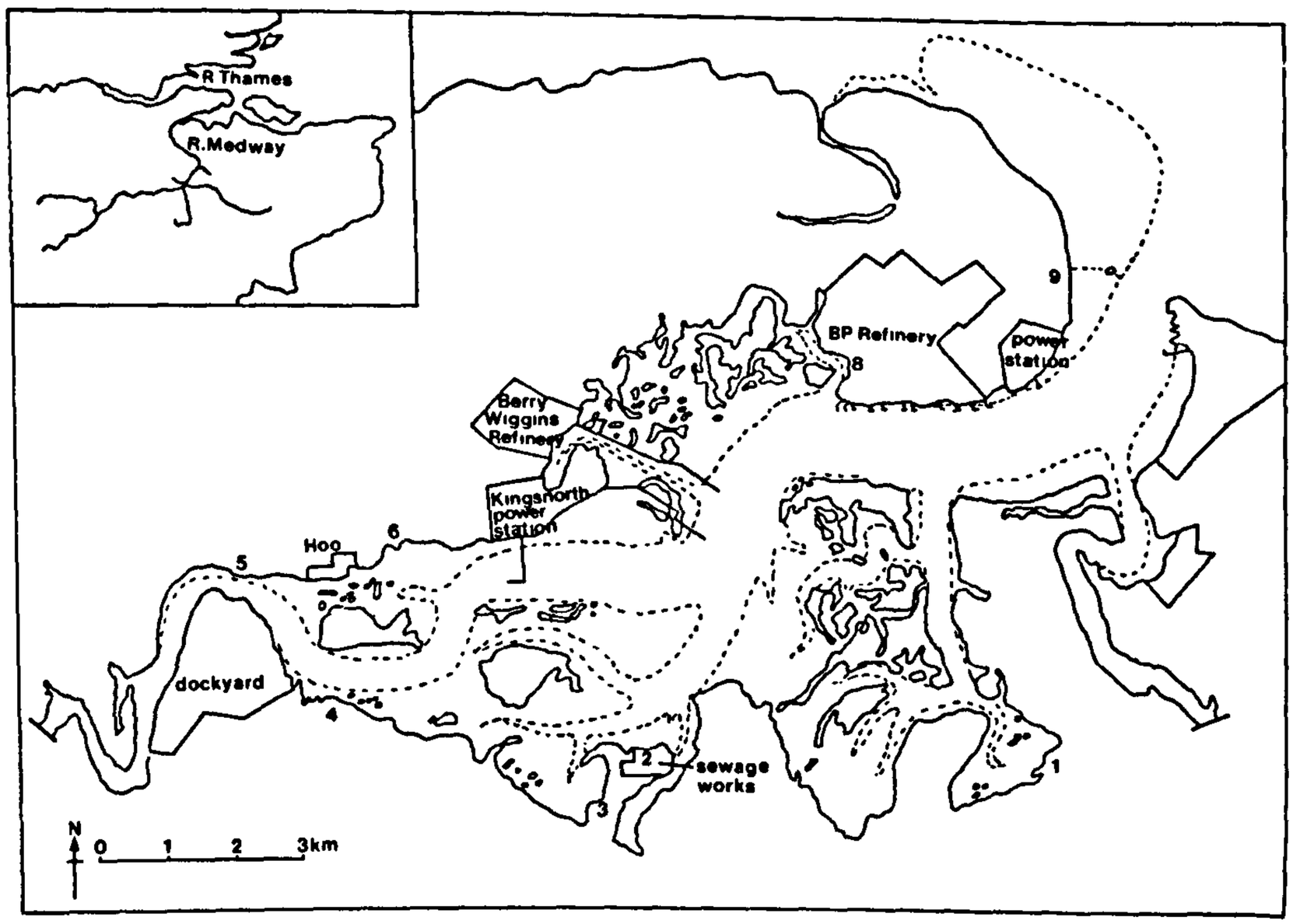

Fig. 1 Sampling sites on the lower Medway estuary: 1: Bedlams Bottom; 2: Motney Hill; 3: East Rainham; 4: Gillingham; 5: Lower Upnor; 6: Hoo; 7: Damhead Creek; 8: BP Colemouth Creek; 9: Isle of Grain.

flounder, which in turn are higher than levels in whiting. Zinc levels are lower than those reported from the Northumberland coast (Wright, 1976) although results are similar to other reported values (Holden & Topping, 1972; Peden *et al.*, 1973).

Concentrations of lead, and to a lesser extent cadmium, in mussels, shore crabs and periwinkles were higher in the vicinity of industrialized areas at Gillingham and Lower Upnor. Levels were lower in invertebrates from downstream sites although values are comparable with the literature (Steele *et al.*, 1973; Wright, 1976). Lead and cadmium in fish were generally higher in liver samples although all levels were low and no higher than reported values (Hardisty *et al.*, 1974; Wright, 1976).

Discussion

Studies on the trace element composition of organisms reveal that fourteen are known to be essential to animal life, including zinc and copper, with a further twenty to thirty occurring constantly in low but variable levels (Underwood, 1974). Of the latter group, lead, cadmium and mercury appear to have little biological significance and are known to be toxic at low concentrations. Levels of metals in animals from the lower Medway estuary were low, although higher values of lead and cadmium were found in the vicinity of industrialized areas.

There is no commercial fishery in the area and although there is some local activity the levels reported are not an immediate problem. Information on fish diets and the levels found in invertebrates show little evidence of any accumulation, although it should be noted that smaller size class of prey usually taken were not analysed. Sediment and water samples were not analysed in the present study.

The work was undertaken during the tenure of ILEA research assistantships in the Biological Sciences Department at the City of London Polytechnic.

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