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The Forth estuary: a nursery and overwintering area for North Sea fishes

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Abstract

The fish community of the Forth estuary, Scotland, has several components – estuarine resident species, diadromus migratory species, marine and freshwater adventitious species, marine juvenile migrants using the area as a nursery, and adults of marine species with seasonal migrations. The population changes during the period 1981–88 in six species representative of the last two categories are described here. The species are the juvenile gadoids, whiting, *Merlangius merlangus* (L.) and cod, *Gadus morhua* L., juvenile flatfish, plaice, *Pleuronectes platessa* L. and common dab, *Limanda limanda* (L.), and the adult clupeids, sprat, *Sprattus sprattus* (L.) and herring, *Clupea harengus* L.

The species' population changes are described in relation to aspects of wider significance such as commercial fishing for these species in North Sea areas. In particular, the underlying decline of the juvenile cod populations since 1981 in the Forth Estuary is discussed in relation to the recent reduction in commercial fishing quotas.

Introduction

The role of estuaries as nursery and overwintering areas for species of marine fish is well known on a qualitative basis but more studies are necessary to quantify this role (Blaber & Blaber, 1980; Haedrich, 1982). The often commercial importance of those species indicates the necessity of quantifying this aspect given the threats to estuaries imposed through effluent disposal, reclamation and the building of barrages. The loss of wet-land habitats (mud-flats, saltmarshes and other coastal areas) will ultimately threaten the populations of marine species using estuaries as nursery or overwintering areas (Claridge *et al.*, 1986).

The Forth is a major industrialized estuary draining to the North Sea from eastern Scotland and its nature, together with the activities in and around it, produce several threats to the biota including the fish populations (McLusky, 1987; Elliott *et al.*, 1988). The estuary has major chemical and oil receiving and processing operations and power generating stations as well as receiving municipal and distillery wastes. Each of these activities can effect the biological functioning of the area. In general, the estuary has mixed muddy bottom sediments, a maximum tidal range of 6 m and the depth below chart datum varies from 40 m at its seaward limit to < 2 m in its upper reaches.

Fish studies have been carried out in the Forth since the 1970's to describe the fish populations in relation to both the functioining of the ecosystem and the effects of natural and anthropogenic features (Poxton, 1987; Elliott *et al.*, 1988). Several studies have described the impact on the fish of environmental stressors such as hydrocarbon and heavy-metal contaminants (Elliott & Griffiths, 1986, 1987). The population dynamics

for species in the early part of the studies are given in Elliott & Taylor (1983) and the complete data and the growth of these species will be presented elsewhere. The somatic production of the estuarine fish community is described in Elliott & Taylor (in press).

The main aim here is to assess the seasonal and temporal patterns in the use of the estuary by several species and to describe the long-term changes in their populations. The analysis concentrates on marine teleost species dependent on the estuary: common dab and plaice (flatfish whose juveniles use the estuary as a nursery area), whiting and cod (demersal gadoids which use the estuary as a nursery area although adults are present in low numbers), and sprat and herring (pelagic clupeids which overwinter in the estuary). The other marine species, which have either an ill-defined estuarine requirement or occur only adventitiously in the estuary, are not considered in detail.

Methods

The data here are primarily from two demersal sampling programmes although midwater trawling has also been used. In programme 1, six stations in the upper part of the Forth estuary (Fig. 1), were sampled monthly at high water from February, 1984 to March, 1985. This programme was recommenced in May, 1988, although data from this latter period are not used here. The fishing gear used in this programme was a 2 m beam trawl of 13 mm mesh which is towed at 2.5 knots over 0.6 km per station (Gee, 1983; Kuipers, 1975). In programme 2, five stations in the lower part of the Forth estuary (Fig. 1), were sampled monthly at high and low tide from 1981 to 1985 and quarterly since then; the data to January, 1989 are given here. In the programme, a 2 m Agassiz trawl of 13 mm mesh was towed at 2.5–3 knots over 0.8 km per station (Eleftheriou & Holme, 1984). The speed of tow of the trawls

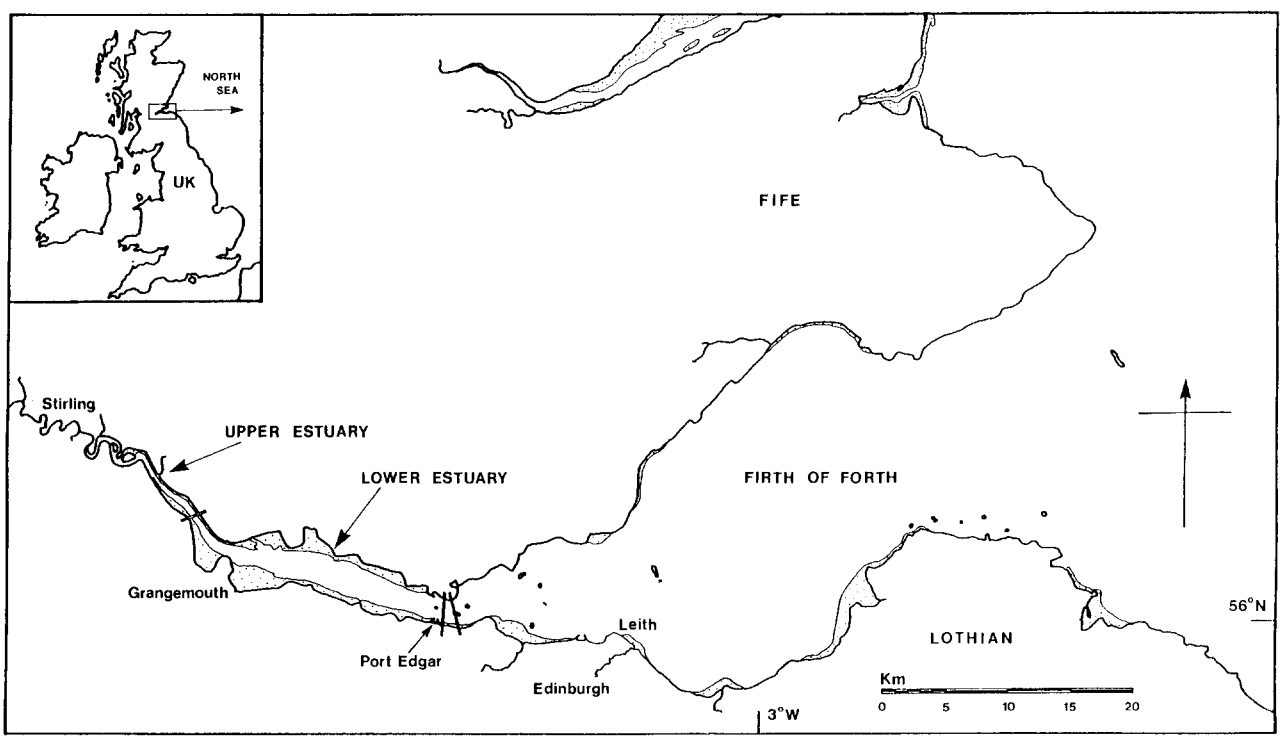

Fig. 1. The Estuary and Firth of Forth.

was greater than usual for this type of gear but was dictated by vessel and bottom conditions (Kuipers, 1975).

The sampling programmes were designed mainly to assess the populations of estuarine species but this paper describes the smaller populations of marine species. Although sampling occured at both high and low water, data from only the former from both programmes have been used to describe the spatial patterns in community structure. Those data from both tidal states in programme 2 are used to describe the long-term population changes. In order to provide an initial calculation of the absolute abundance, a gear efficiency of 0.3 has been used (Gee, 1983; Kuipers, 1975). Finally, in order to allow a comparison of the fish stocks with other studies, the units of the ordinate axis of Fig. 4 to 11 should be multiplied by a factor of 0.21 to give abundance per 1000 m^2.

Results

Community structure

In the estuary, 36 species have been taken of which 8 were estuarine residents and most of the remainder were marine species (Table 1). Many of the latter are marine adventitious species (sole, dragonet, angler fish, *etc*) but in terms of abundance and biomass the marine juvenile and seasonal migrants are more important. However, the relative importance of these groups varies with time of year (see below and unpubl. data).

The recorded presence of each species in the categories at the eleven stations is given in Fig. 2. Each pie-diagram gives the proportion of sampling occurences at which, for instance, estuarine resident species were taken. The position of each station (a–k) on a salinity distribution typical for the Forth (high tide, median freshwater flow) is shown on the figure. This change among categories with respect to salinity shows the occurrence of estuarine residents varies little with progression up the estuary until the middle reaches (salinity $<25‰$) (Fig. 2). These indigenous species mostly reproduce in the estuary and spend most of the year there but may migrate into deeper waters during the winter. However, the dominant estuarine resident, flounder, *Platichthys flesus* spawns in the coastal area and uses the upper estuary as a nursery area. The proportion of species occurrences of marine juveniles decreases in the middle reaches (8–25‰) of the estuary and the marine seasonal migrants become of greater importance. As expected, marine adventitious species are not taken below 30‰ and diadromuos species, which migrate through the estuary to breed either in the sea or fresh-water, and fish with a fresh-water-estuarine habit are found mostly in the upper reaches.

The relative proportions of the biomass of the categories to which the dominant 12 species belong are shown for each year from 1982 to 1985 (when a full monthly set of samples was obtained for each year) (Fig. 3). In three of those years, the estuarine residents provided the greatest standing crop, but in 1985, the marine juvenile migrants provided the greatest biomass, a feature predominantly the result of good growth and recruitment of whiting (see below).

Long-term population changes

(i) Sprat and herring

These clupeids have a well defined pattern of seasonal estuarine usage and the greatest populations are found during January to March (Figs. 4 and 5). Sprat are more abundant than herring in these east-coast waters but there is a large degree of annual variability in both species' populations. For herring, the winter of 1981/2 had good populations, 1982/3 and 1985/6 intermediate and the remainder (1983/4, 1984/5, 1986/7, 1987/8 and 1988/9) were poor. However, the changed sampling interval in the latter years would have missed the annual maximum if it was delayed for any reason. In the case of sprat, the best years were 1985/6, 1983/4, 1986/7, with 1981/2, 1982/3, 1984/5, 1987/8 and 1988/9 being intermediate to poor.

Table 1. Fish Species Taken in the Forth Estuary.

Scientific Name	Common name	Category
Platichthys flesus (L.)	Flounder	ER*
Pomatoschistus minutus (Pallas)	Sand Goby	ER*
Liparis liparis (L.)	Sea Snail	ER*
Ammodytes tobianus L.	Sandeel	ER
Zoarces viviparus (L.)	Eelpout	ER*
Agonus cataphractus (L.)	Pogge	ER*
Myoxocephalus scorpius (L.)	Fatherlasher	ER*
Sygnathus acus L.	Great Pipefish	ER
Salmo salar L.	Salmon	CA
Anguilla anguilla (L.)	Eel	CA
Lampetra fluviatilis L.	River Lamprey	CA
Alosa fallax (Lacepede)	Twaite Shad	CA
Merlangius merlangus (L.)	Whiting	MJ*
Gadus morhua L.	Cod	MJ*
Pleuronectes platessa L.	Plaice	MJ*
Limanda limanda (L.)	Common Dab	MJ*
Sprattus sprattus (L.)	Sprat	MS*
Clupea harengus L.	Herring	MS*
Eutrigla gurnardus (L.)	Grey Gurnard	MS
Gasterosteus aculeatus L.	3-Spined Stickleback	FW
Cyclopterus lumpus L.	Lumpsucker	MA
Molva molva (L.)	Ling	MA
Solea solea (L.)	Dover Sole	MA
Callionymus lyra L.	Dragonet	MA
Pollachius virens (L.)	Saithe	MA
Trachurus trachurus (L.)	Scad	MA
Trisopterus minutus (L.)	Poor Cod	MA
Microstomus kitt (Walbaum)	Lemon Sole	MA
Buglossidium luteum (Risso)	Solenette	MA
Raja batis L.	Skate	MA
Pollachius pollachius (L.)	Pollack	MA
Trachinus vipera Cuvier	Lesser Weever	MA
Lophius piscatorius L.	Angler	MA
Pholis gunnellus (L.)	Butterfish	MS/ER
Hippoglossoides platessoides (Fabricius)	Long Rough Dab	ER/MA
Ciliata mustela (L.)	5-Bearded Rockling	ER/MA

In addition to the above, the following species have been very occasionally taken in recent years by other workers: *Salmo trutta* L., Sea Trout (CA); *Pomatoschistus microps* (Kroyer), Common Goby (MA); *Chirolophis ascanii* (Walbaum), Yarrell's Blenny (MA); *Dicentrachus labrax* (L.), Sea Bass (MA).

Key: ER, estuarine resident; CA, diadromous migrant; MJ, marine juvenile migrant; MS, marine seasonal migrant; FW, freshwater adventitious; MA, marine adventitious; * denotes dominant species whose biomass is included in Figure 3.

(ii) Plaice and common dab

These species have similar habits as bottom feeding flatfish which mainly crop the infaunal macroinvertebrates (Ajayi, 1983) but their estuarine requirements vary. Common dab have a well-defined seasonal occurrence as newly-settled individuals (size 3–7 cm) which stay in the estuary for a comparatively short time. The 0 + year-class first appears in September and reaches its annual maximum from October to December (Fig. 6). In comparison, plaice move into the estuary as 0^+ individuals in July and then move back to marine

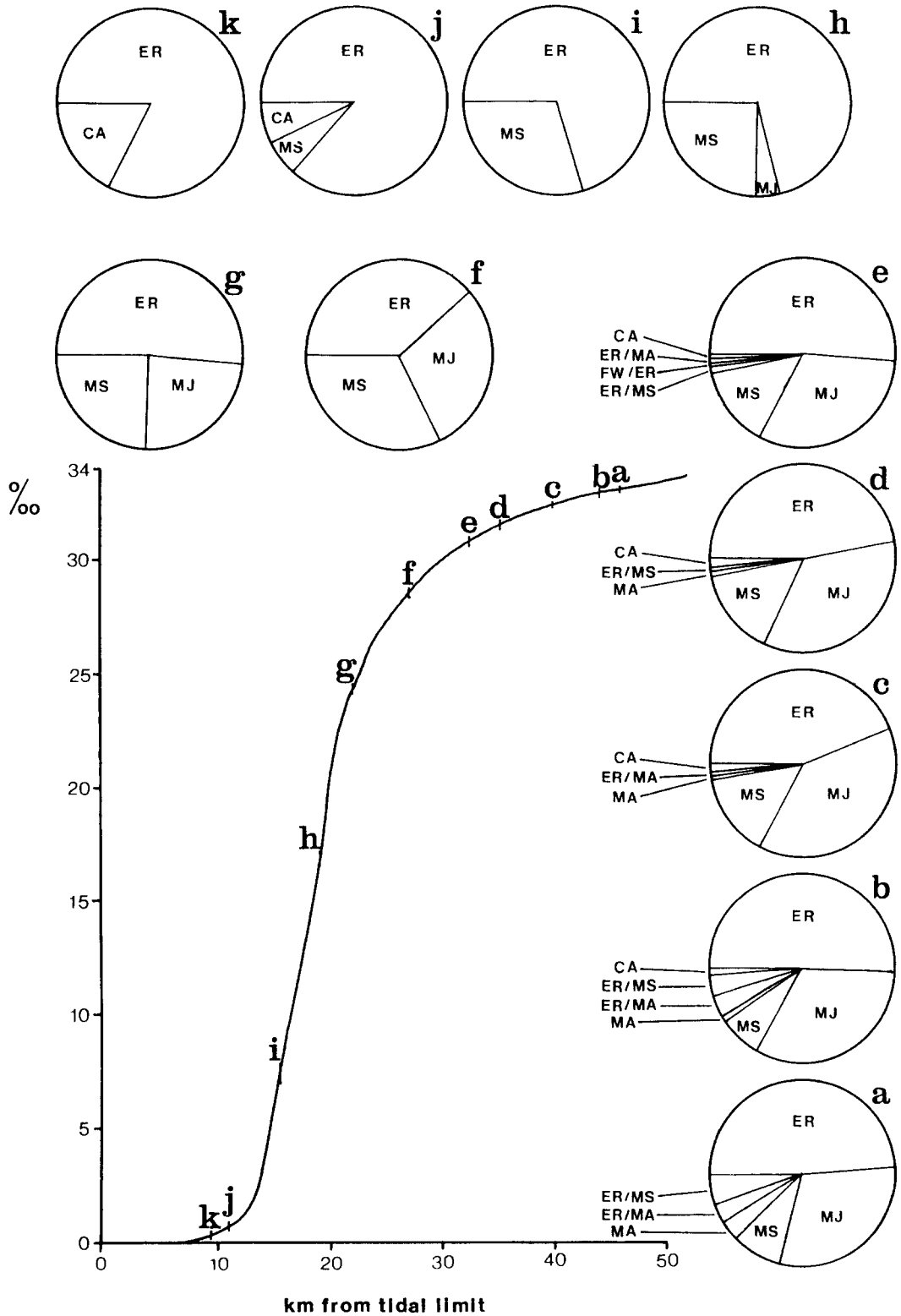

Fig. 2. The categories of fish at each sampling station (see text for details). The abbreviations for each category are as given in Table 1.

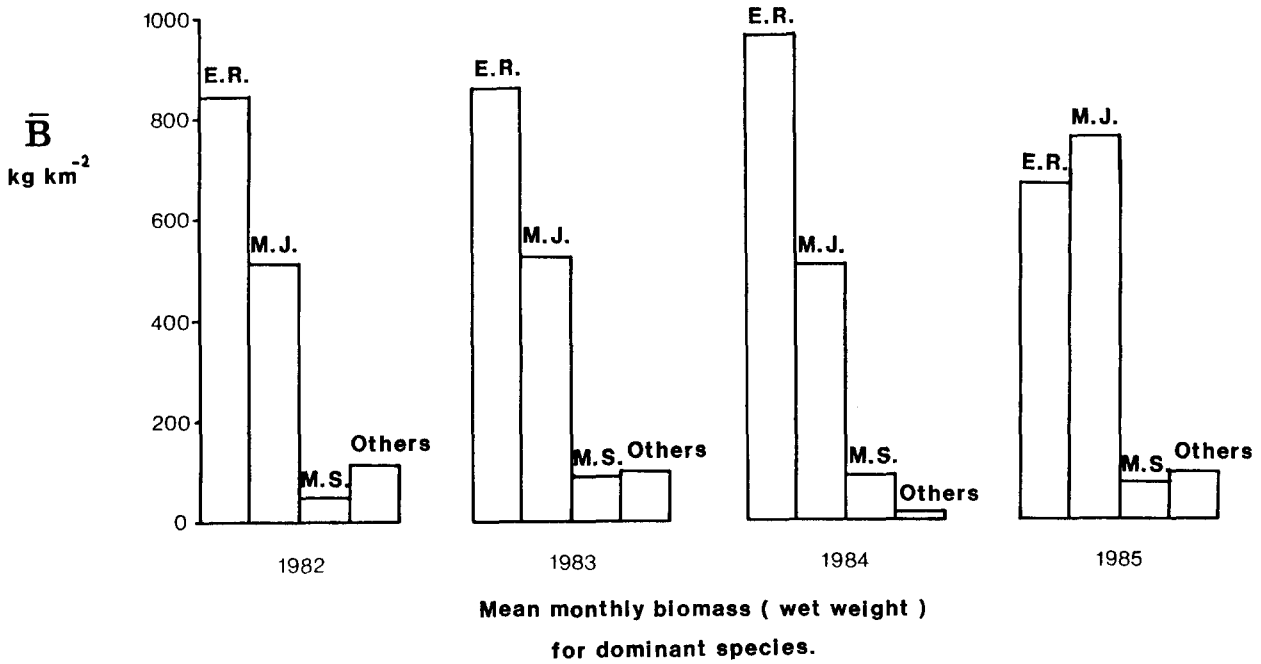

Fig. 3. The biomass (wet weight) of the dominant 12 species according to category (see Table 1).

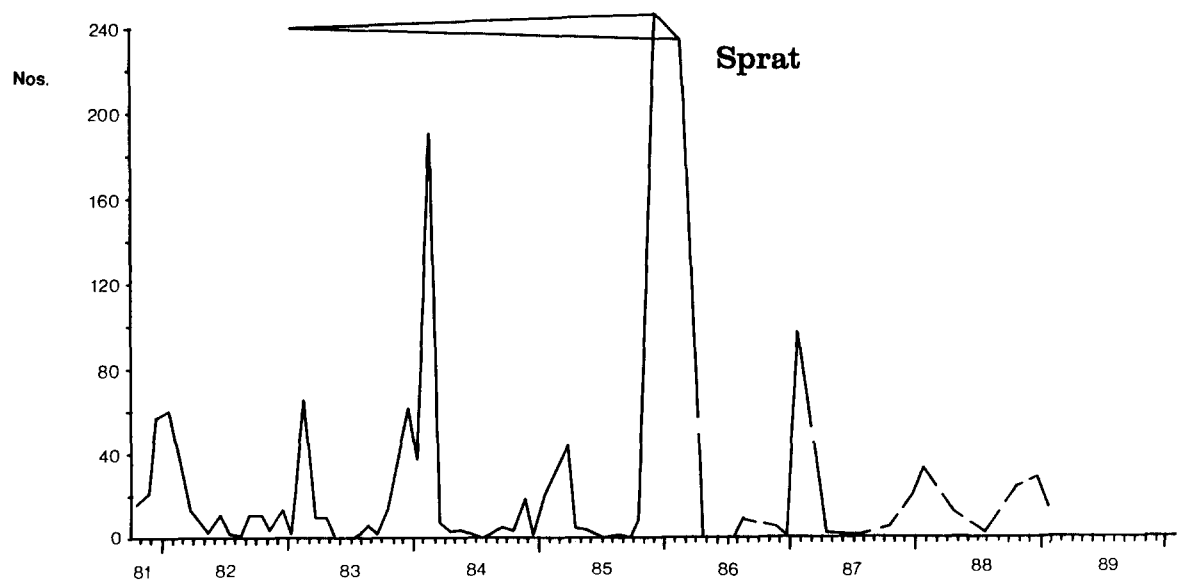

Fig. 4. The abundance of Sprat from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

areas the following year as 1^+ animals and there is no well-defined pattern of seasonal abundance with maxima in winter or summer (Fig. 7). Although plaice are found in the estuary for the whole year, successive cohorts do not usually overlap (unpubl. data).

The populations of common dab shown an extremely large annual variability – the 1984 and 1985 cohorts were very abundant in comparison to other years, 1982, 1987 and 1988 were the next best and 1981, 1983 and 1986 were relatively poor. The abundance of plaice in each year can be

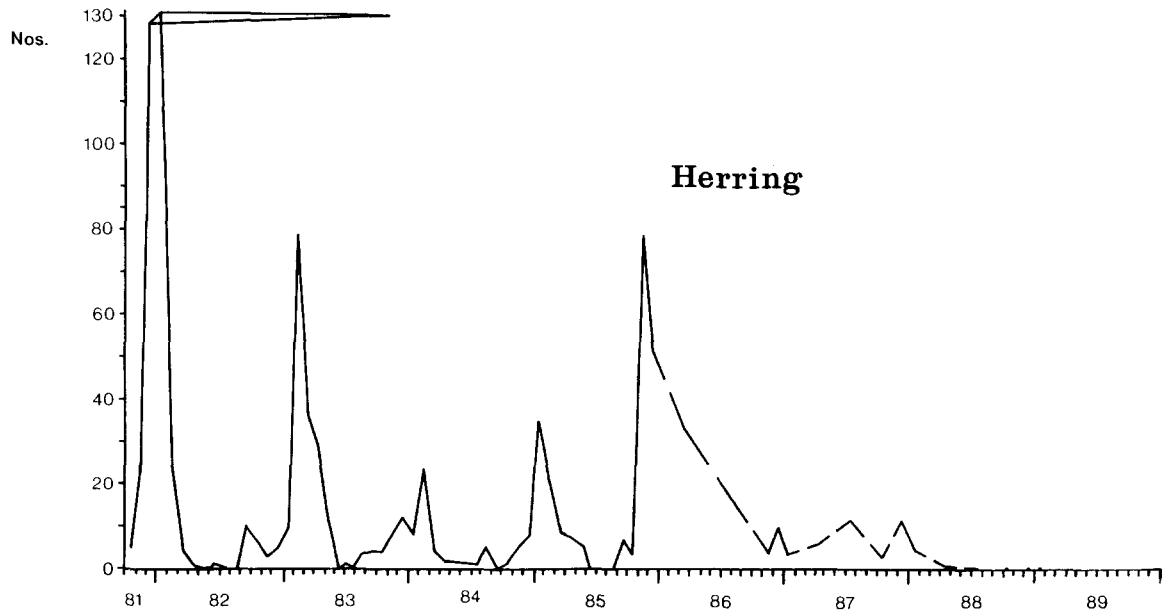

Fig. 5. The abundance of Herring from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

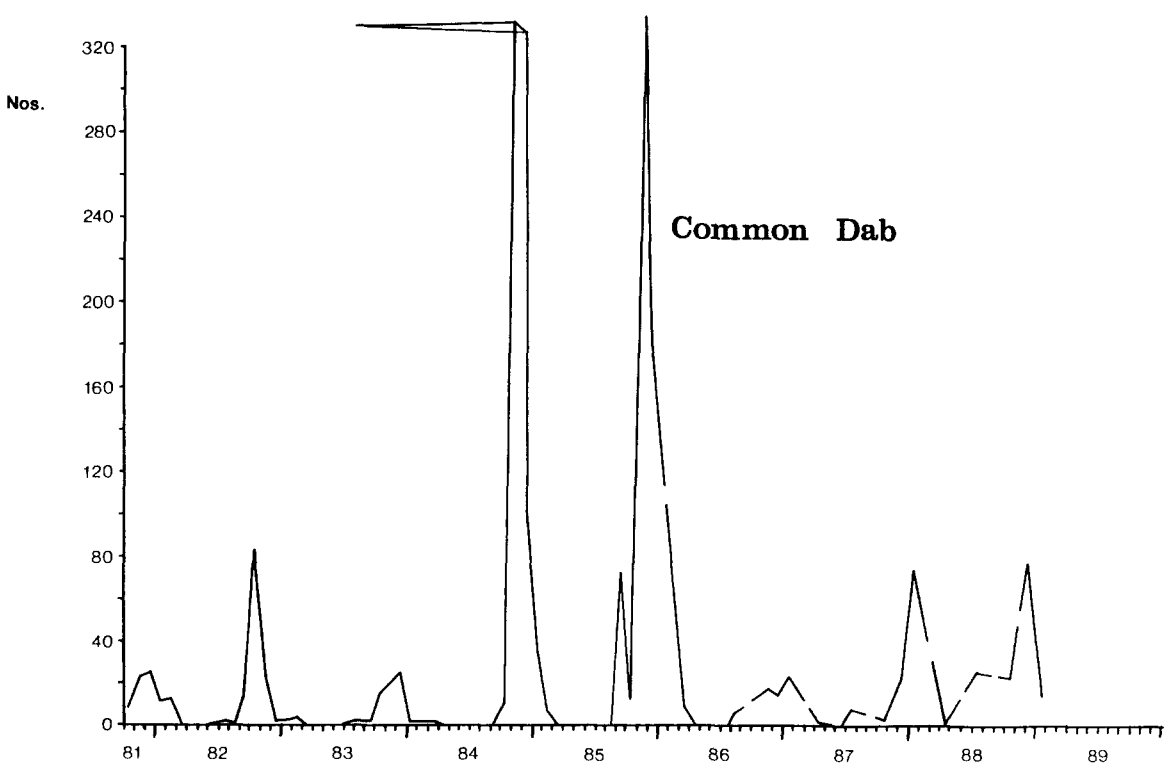

Fig. 6. The abundance of Common Dab from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

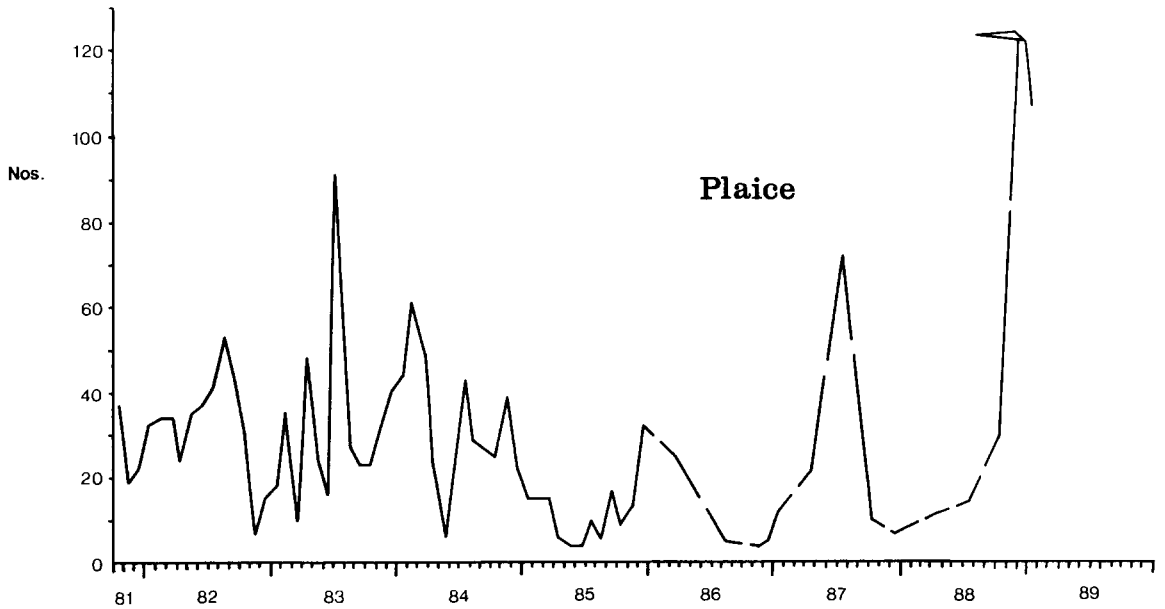

Fig. 7. The abundance of Plaice from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

ranked from the best year 1988, then 1983, 1987,1982, 1984, 1985, to the poorest year, 1986.

(iii) Whiting and cod

Whiting move into the estuary as young juveniles (0^+ individuals) at a size of 5 cm from May onwards and remain in the estuary for a year before emigrating as 15–18 cm 1^+ individuals the following summer. This cycle produces winter maxima and summer minima (Fig. 8). The most abundant cohorts produced were in 1984, then 1981, 1987, 1988, 1983, 1985, 1986, with 1982 being the poorest. The juvenile cod show a similar seasonal pattern which produces the overwinter modes show a similar seasonal pattern which produces the overwinter modes shown in the temporal trends (Fig. 9). These fish migrate into the estuary as newly-metamorphosed individuals during the summer and then emigrate from the area as 1^+ fish the following year. In contrast to the whiting, and with the exception of 1982, cod 0^+ year-class strength since 1981 has shown an underlying decreasing trend until in 1986 and 1987 there was no recruitment into the estuary. There was a slight recovery of the population in October 1988 in which moderately good catches were taken.

(iv) Eelpout

It is necessary to give an assessment of the population changes of the marine species in relation to those for the estuarine residents. In addition to identifying the differing seasonal usage of the estuary, this feature assesses the long-term health of the populations originating in the North Sea in relation to those indigenous estuarine populations. As an example, a long-term abundance plot is given for the eelpout, *Zoarces viviparus*, (Fig. 10). The species shows a bimodal annual pattern with peaks during spring, possibly due to the return of adults from overwintering in deeper waters, and in summer as the newly-produced young are taken during sampling. The greatest populations were present during 1987, 1988 and 1982 although these patterns are complicated by the presence in the population of several cohorts (Elliott & Taylor, in press).

The population changes of the above species have been calculated as monthly averages for all years sampled to indicate the temporally-averaged seasonal usage (Fig. 11). The histograms show the strong seasonal patterns of dab, sprat, herring and, to a lesser extent, whiting. In particular, they show the high estuarine, winter dependence of the marine fishes. The respective maximum and mini-

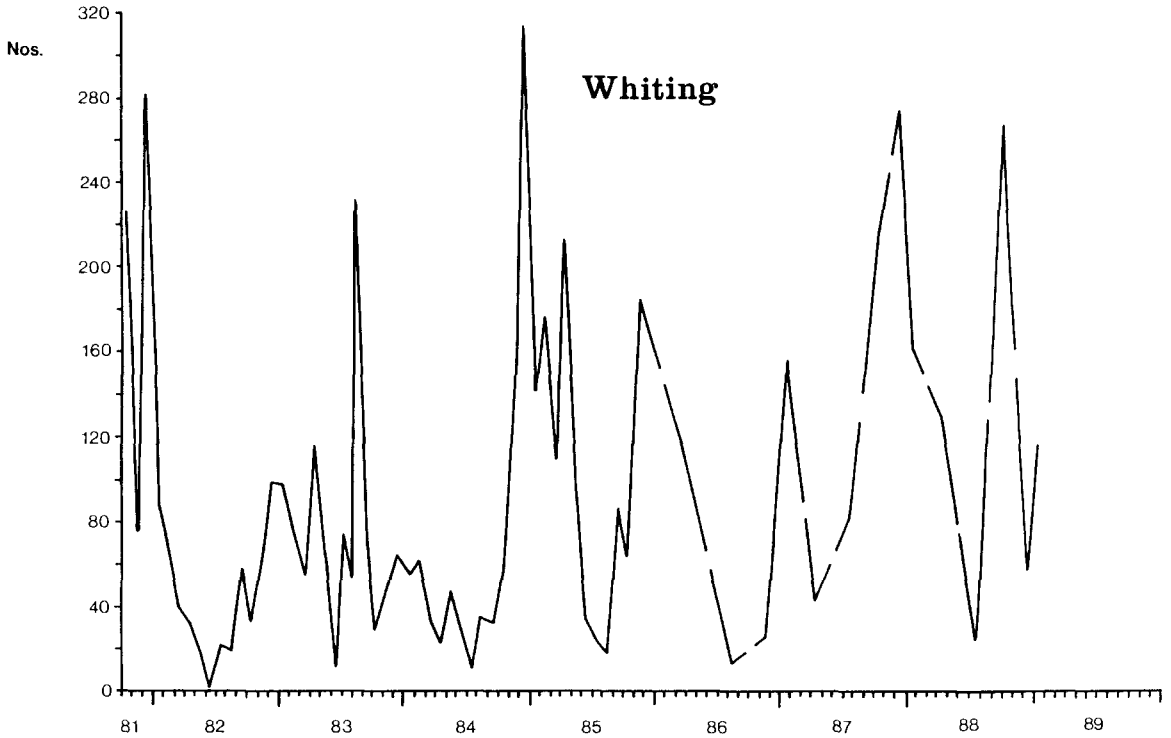

Fig. 8. The abundance of Whiting from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

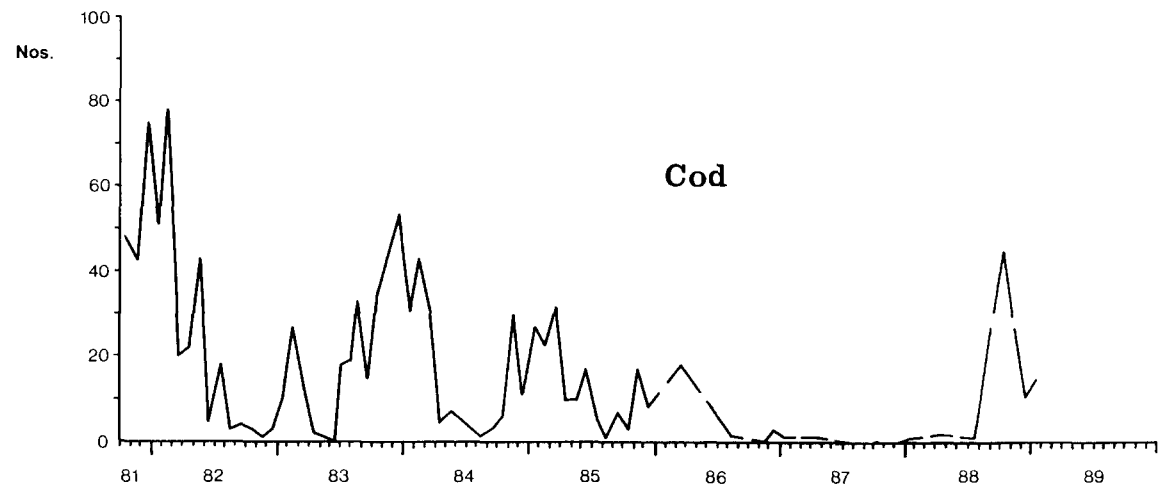

Fig. 9. The abundance of Cod from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

mum population size for each species is: dab, November and May–June; sprat, December–February and April–October; herring, November–February and May–October; whiting, December and June; cod, February and July–September. Plaice were most abundant in July but did not show a well-defined minimum. Finally, as described above, eelpout had a bimodal seasonal distribution.

As an indication of the similarity between the

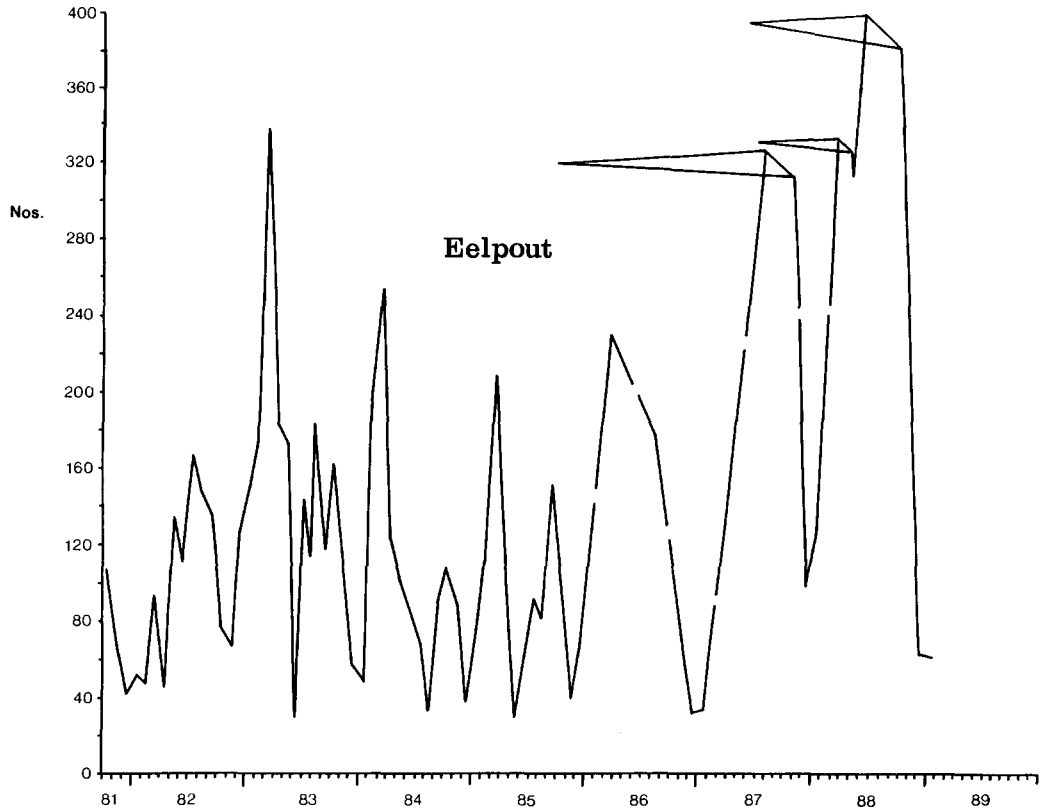

Fig. 10. The abundance of Eelpout from 1981 to 1989 (ordinate represents the total catch from ten trawls, see text).

annual patterns of these species, their abundances were inter-correlated using non-parametric (Spearman rank) coefficients (Table 2). The major feature is that during the period October, 1981 to April, 1988, the abundances of sprat, herring, dab and whiting were strongly inter-correlated thus indicating their similarly high winter usage of the estuary.

Discussion

Estuarine dependency

The estuarine fish community comprises several components each with differing requirements in the particular habitat. Those components may use the estuary during their whole life cycle, for

Table 2. Rank Correlation Matrix of the Abundances of Each Species

	Sprat	Herring	Plaice	Dab	Cod	Whiting
Herring	0.62 ***					
Plaice	0.07 ns	0.01 ns				
Dab	0.50 ***	0.49 ***	− 0.09 ns			
Cod	0.41 **	0.26 *	0.38 *	0.10 ns		
Whiting	0.47 ***	0.54 ***	− 0.16 ns	0.51 ***	0.16 ns	
Eelpout	− 0.01 ns	0.01 ns	0.21 ns	− 0.22 ns	− 0.04 ns	0.01 ns

The Spearman rank-correlation coefficient for each species pair is given based on 59 degrees of freedom.
Key: ns, not statistically significant; * = $0.05 \geq p > 0.01$; ** = $0.01 \geq p > 0.001$; *** = $p \leq 0.001$

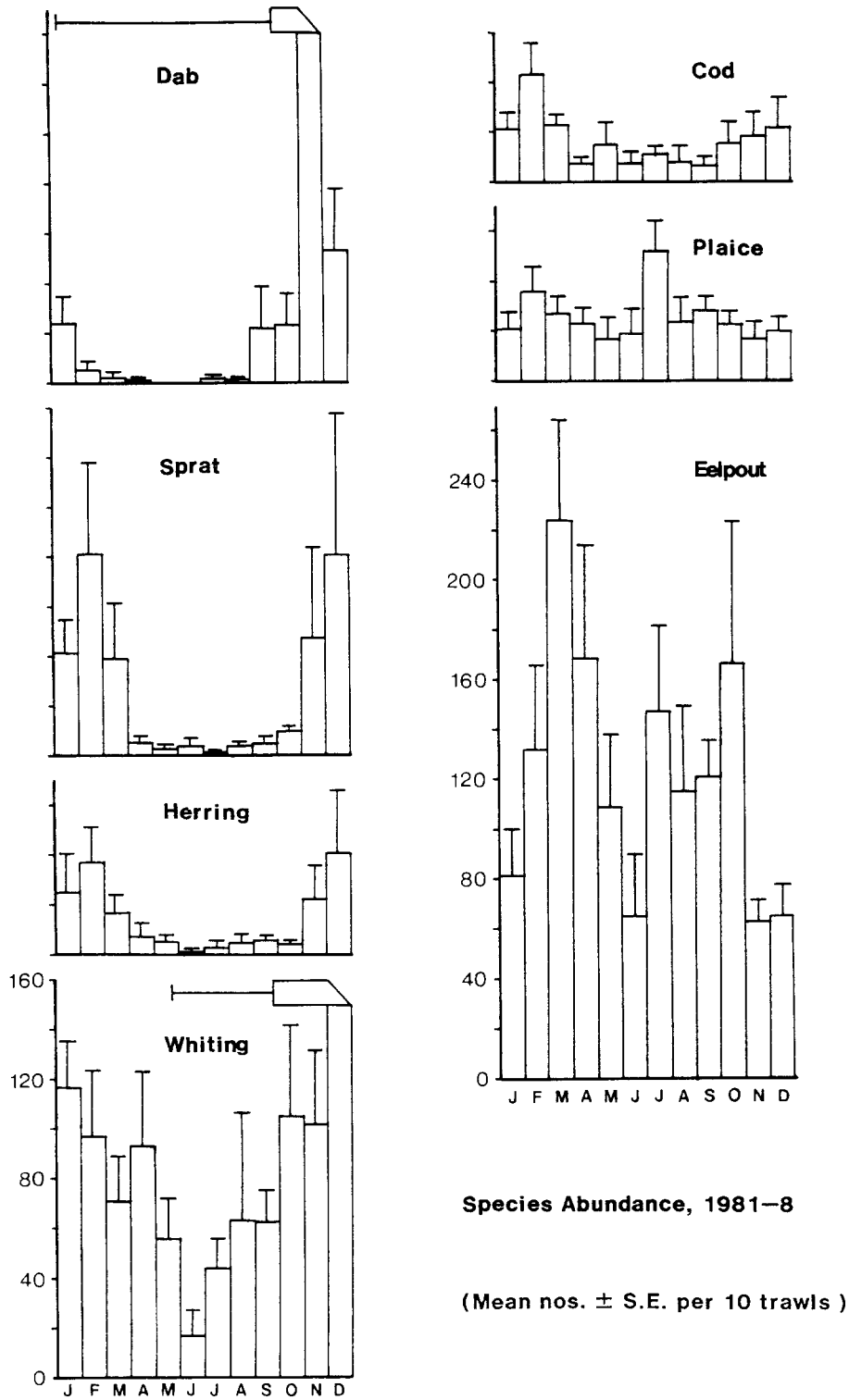

Fig. 11. Monthly averages for the abundance of each species, 1981 to 1988 ($\bar{x} \pm$ standard error, numbers per 10 trawls, see text).

differing seasons or for different parts of the life-cycle. The cause of the estuarine dependence of many marine species is unknown but may be physiological or behavioural or related to feeding preferences. Estuarine usage by marine juveniles may be a strategy to reduce the osmotic potential differences between the organisms and their environment thus reducing stress (Lutz, 1975). In addition, in relation to the particular temperature regime of estuarine waters, the differing temperature preferences for different species and sizes within a species can also contribute to the observed patterns (Fonds, 1979).

In the case of the winter usage by clupeids, it is possible that the turbid estuarine areas, especially in the middle reaches where these species are found, provide protection from piscivorous fish. As well as the reduced water clarity, compared to the open coast, estuaries are considered to have fewer such predators (Blaber & Blaber, 1980). However, it is more likely that the estuarine winter dependence results from the fish using the colder waters to reduce their basal metabolic rate at a time of non-feeding (pers. obs. and R. Bailey, DAFS, Aberdeen, pers. comm.). These clupeids feed on zooplankton but the winter maximum in fish abundance is not correlated with the zooplankton biomass in the estuary (Taylor, 1984). However, in the Medway estuary, in which several marine species had a shorter residence time than in the Forth, Van den Broek (1979) suggested that adverse weather conditions in coastal areas produce winter, inshore migrations of some species as they search for food and shelter.

In addition to any possible physiological reason for estuarine usage, a more likely cause is the presence of high prey densities and hence favourable feeding areas. However, the seasonal and estuarine demands of species with similar habits may still result in a degree of partitioning of the available resources. For example, the cod and whiting occur in the Forth at the same time of year and as similar sizes and therefore they may compete for both space and food. Jones (1978) suggests that direct competition in gadoids is avoided either as the result of differences in prey-preference (as different species or different life-stages/sizes of the same prey species) or because they take the same prey but at a different time or place. In the Forth, although juvenile cod and whiting both mainly take epibenthic crustaceans, and the common shrimp (*Crangon crangon* L.) is a major prey item, they have slightly different prey preferences and feeding areas (Crossan, 1985; unpubl. data).

The importance of the Forth as a gadoid nursery area is similar to many other estuaries. This may be the result of an active migration by the 0 + cohort rather than a passive drift of larvae or post-larvae (Hardisty & Huggins, 1975; Gordon, 1977; Claridge & Potter, 1984). However, the young may use the tides to migrate to and from the estuaries (Claridge, *et al.*, 1986).

Seasonal usage

The timing of the peak populations in the Forth can be compared with other estuaries. The Forth maxima for sprat, herring and whiting are slightly later by 1–2 months than those in the Severn estuary (Claridge and co–workers) and are much later than for the West Scottish coast for whiting (Gordon, 1977) but they agree with those found for the Medway, another North Sea west coast estuary (Van den Broeck, 1979; Wharfe *et al.*, 1983). In common with the Forth, dab in the Medway were abundant in the winter and absent for most of the year (Wharfe *et al.*, 1983). However, unlike the Forth, whiting in the Medway were absent for much of the year and sprat did not have a well-defined seasonal pattern. In comparison with the Wadden Sea, the Forth cod and whiting maxima are earlier but that for dab is the same time of year (Fonds, 1979). These geographical differences may be caused by widespread hydrophysical changes, e. g. temperature, in relation to the species' tolerances.

Increases in the abundance of these marine species are the result of seasonal and tidal immigrations as well as recruitment whereas the decreases are caused by emigration and mortality. The patterns of population size of each species described here give an indication of the carrying capacity of the estuary and suggest a strongly seasonal demand on the prey populations in the estuary. The relatively high winter predation pres-

sure by the gadoids in particular and the marine flatfish to a lesser extent is similar to that produced in estuaries by wading birds and wildfowl and complements the high summer predation pressure by the estuarine residents (Evans, 1981; Elliott & Taylor, in press). Finally, the high production and productivity (turnover ratios) of these fast growing and abundant juvenile stages illustrate their important role in the functioning of estuaries (Elliot & Taylor, in press).

Long-term changes

The trawling methods used here are not necessarily the most suitable for the pelagic clupeid populations although it is considered that they do produce data which indicate overall trends. There are very few comparable data from elsewhere for the same years although similar studies are being carried out on the Tyne estuary (NE England) by Pomfret and co-workers (e. g. Pomfret *et al.*, 1988). Unpublished data indicate that good years for the herring in the Forth do not match those in the Tyne estuary and that the best years in the Forth gave intermediate populations in the Tyne.

The gadoid population changes shown in the Forth can be also contrasted with those for other areas. The juvenile (1 +) fish survey carried out by DAFS Marine Laboratory, Aberdeen, shows that in the North Sea proper, the 1986 and 1987 cod recruitments were poor, 1984 and 1982 were also low, 1983 was good and 1985 was very good (D. Armstrong, DAFS, pers. comm.). With the exception of 1985, this pattern agrees broadly with that for the Forth. The recent poor populations in the North Sea may dictate that a low sampling intensity, as in the Forth, would be unlikely to capture the few cod present. In addition, sampling of the Tyne estuary has also taken very few cod since 1986 (Pomfret, Northumbrian Water Authority, Newcastle, unpubl.) and has also shown that 1984 was a poor year for cod in the lower reaches of that estuary.

The poor and decreasing catches of cod in the Forth are cause for concern and reflect widespread changes occurring to this species (Gordon, SMBA, Oban, and Armstrong, DAFS, pers. comm.). The decrease in breeding stocks and the low abundance of juveniles in many areas has contributed to the reduction in cod catch quotas recently imposed by the European Commision. In addition, at present there is a commercial fishing ban, imposed in 1983, on sprat fishing in certain estuarine areas (west of 3° W in the Forth). This ban is designed to protect the commercial North Sea herring stocks as large biomasses of juvenile herring are taken with sprats. Any effects of that ban are not yet evident in these estuarine catches.

Finally, using a subjective analysis, there is no correlation between the whiting catches in the Forth and Tyne estuaries. The resulting situation in these estuaries, with large whiting populations and very few cod, is similar to that found in the Severn (Claridge & Potter, 1984). However, the latter estuary had many other gadoid species present.

In a similar study of long-term population changes, Rauck (1979) assessed fish usage in the Wadden Sea from 1954 to 1974 and classified the species as increasing, decreasing and constant. In that study, dab, sprat and cod abundances were increasing although still distorted by very good and very poor years; herring and whiting were decreasing whereas the abundances of plaice and eelpout were stable. This classification is less useful over a shorter data series as in the Forth in which, with the exception of cod, there were no well defined increasing or decreasing trends.

Size of the Forth populations

In order to assess the importance of the Forth populations in the context of the North Sea, the total populations in the Forth have been calculated (Table 3). The data given are based on both the maximum per 10 trawls in the monthly averages and the maximum abundance sampled and they have been corrected for the area sampled and gear-efficiency (Table 3). The figures are given both for the estuary as a whole and, to allow direct comparison with the extensive data for the Wadden Sea (Daan, 1978; Dankers & de Veen, 1979), as abundance per 1000 m^2.

This data treatment indicates that the estuary supports 0.54%, 0.45% and 0.05% of the North Sea stocks of similar sized plaice, cod and

Table 3. The Maximum Populations of Each Species in the Forth Estuary.

Species	Whole estuary (X 10^6)		Per 1000 m^2	
	LT Ave.	Max. Recorded	LT Ave.	Max. Recorded
Sprat	1.18	6.04	25.4	130
Herring	0.59	2.72	12.8	58.4
Plaice	0.75	1.34	16.2	28.7
Common dab	2.34	5.95	50.2	128
Cod	0.62	1.13	13.3	24.4
Whiting	2.65	4.56	57.0	98.1
Eelpout	3.26	6.43	70.2	138

LT Ave. is the long-term average of the abundance of each species over the whole study period; Max. Recorded is the maximum abundance recorded over the whole study period.

herring, repectively (Bannister, 1978; Daan, 1978; Burd, 1978). In comparison with the Wadden Sea, the Forth maximal densities are greater for all species except plaice, although Dankers & de Veen do not give the complete data for the former area. In the case of plaice, the Forth and Wadden Sea populations are similar. However, such overall comparisons of stock size should be regarded with caution. This is due to the many assumptions involved in sampling and the resultant calculations (see also Dankers & de Veen, 1979).

Final comments

Several questions should be answered in any assessment of the usage of estuaries by marine fishes. Firstly, what is the usage in qualitative and quantitative terms? Secondly, what is the basis for the estuarine dependence – feeding, physiological or behavioural? Thirdly, if the dependence is for feeding, what prey are taken and does resource partitioning occur between species with similar habits? Fourthly, what is the species' growth while in the estuary and is it related to population size, i. e. is there resource control? Finally, by using these industrialised estuaries, how susceptible are the fish to the accumulation of persistent contaminants?

Some of the above questions have been answered for the Forth and most have been answered for the Wadden Sea and areas of the Baltic. However, further quantitative assessments are needed to determine the importance of many North Sea estuarine areas for marine fishes. It is particularly notable that estuarine areas are often not studied by Governmental laboratories responsible for fish stock assessment. The data here and those for elsewhere indicate that, in order to understand the estuarine and inshore fish population trends, a coordinated monitoring exercise (such as the European coordinated programme for the macrobenthos, Lewis, 1984) is needed.

Conclusions

1 The Forth, in common with many estuaries, supports overwintering populations and juveniles of marine species which are an important part of the estuarine fish community.

2 The estuarine populations of these species can reflect more widespread changes in the species and more studies are needed to assess their abundance, biomass and population dynamics.

3 The Forth supports approximately 0.5% of the North Sea stocks of certain sizes-classes of some commercially important species.

4 The estuarine dependence of the marine species can result in them being exposed to several threats. These include the loss of habitat and feeding areas (following reclamation or through poor water quality), increased mortality as part of a by-catch or from industrial abstraction intakes, or the uptake of persistent contaminants.

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