ABUNDANCE, MOVEMENTS AND SIZE OF GADOIDS (TELEOSTEI) IN THE SEVERN ESTUARY

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(Figs. 1-7)

Samples collected regularly from the intake screens of power stations between July 1972 and June 1977 demonstrate that the Gadidae is the most abundant and diverse teleost family in the inner Bristol Channel and Severn Estuary. The first records for the Severn Estuary of two cold water species, northern rockling and Norway pout, which were present in appreciable numbers, may be related to the effects of the changes that commenced in south-western English waters during the 1960s. Maximum numbers of the five most abundant gadoids were attained in different years, with the greatest catches being recorded for whiting and poor cod in 1975/6, bib and pollack in 1974/5 and northern rockling in 1976/7. Peak abundance in the middle estuary was reached by whiting, bib, poor cod and pollack in the autumn and by northern rockling in the winter or early spring. The 0+ age class of these species, which was always by far the most predominant category, showed increases in mean length during their relatively short stay in the estuary. Movement out of the shallows of the inner Severn Estuary by whiting and also apparently by some other gadoids occurred when salinities fell below 10%. The size of poor cod and pollack in the autumn was not as great in 1974 as in 1975 and 1976, presumably reflecting the effect on growth of lower summer temperatures in the first of these years. Poor cod was represented by five age classes and attained at the end of the first to fifth years of life standard lengths of approximately 80 mm (≈4.8 g), 110 mm (≈11.7 g), 140 mm (≈23.0 g), 170 mm (≈39.6 g) and 210 mm (≈71.6 g) respectively.

INTRODUCTION

The term ‘estuarine-dependent’ has been coined in recognition of the significance of estuaries in providing extensive habitats for some stages in the life cycle of a wide range of marine fish (see Cronin & Mansueti, 1971; Pollard, 1976; Beal, 1980; Day, Blaber & Wallace, 1981). Since estuaries are particularly important to the young stages of many marine teleosts, they are sometimes referred to as fish nursery areas. The high productivity typically found in estuaries provides excellent conditions for the growth of juvenile fish, and the presence of a lower incidence of piscivorous fish than in marine environments reduces the likelihood of predation (Blaber & Blaber, 1980; Day et al. 1981). Moreover, the lowered salinities normally found in temperate estuaries of the Northern Hemisphere reduce the osmotic pressure differential between teleost fishes and their environment (Farmer & Beamish, 1969; Lutz, 1975); a feature which would be of particular benefit to small juveniles.

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The crucial role of estuaries in maintaining commercial fish production has been well illustrated by McHugh (1976), who calculated that 69% by weight of the commercial fish catch in the United States in 1970 could be classed as estuarine-dependent. With respect to the waters of Britain and north-western Europe, Wheeler (1969) has stated that 'the cod family (Gadidae) are of the greatest economic importance' amongst the many teleost families contributing to the commercial and recreational fisheries of the region.

Data on the biology of components of the fish fauna of the Severn Estuary and Bristol Channel during the 1970s have been obtained through analysing samples taken regularly from the large amounts of fish and other material collected on the intake screens of local power stations. This has resulted in the accumulation of biological information for a variety of fish species including twaite shad, *Alosa fallax* (Lacépède); northern rockling, *Ciliata septentrionalis* (Collett); five-bearded rockling, *C. mustela* (L.); whiting, *Merlangius merlangus* (L.); herring, *Clupea harengus* L.; river lamprey, *Lampetra fluviatilis* (L.); sandsmelt, *Atherina boyeri* Risso; and bass, *Dicentrarchus labrax* (L.) (Claridge & Gardner, 1977, 1978; Badsha & Sainsbury, 1978; Gardner, 1978; Titmus, Claridge & Potter, 1978; Abou Seedo & Potter, 1979; Palmer, Culley & Claridge, 1979; Palmer & Culley, 1983; Claridge & Potter, 1983). All these species showed consistent and marked seasonal changes in abundance.

The present paper provides information on all members of the Gadidae collected at power stations in the Bristol Channel and Severn Estuary, emphasizing seasonal and annual trends in the abundance of the more numerous species. Detailed information on length and weight is given for all gadoids except whiting and the northern and five-bearded rocklings, for which such data have already been provided recently for the populations of these species in the Severn (Claridge & Gardner, 1977; Badsha & Sainsbury, 1978; Gardner, 1978). The data are considered in the context of freshwater discharge, salinity and temperature in an attempt to ascertain how environmental conditions might influence abundance and growth. Since considerable numbers of poor cod, *Trisopterus minutus* (L.), were obtained during this study, including representatives of several different age classes at Hinkley Point in the Bristol Channel, particular attention has been paid to describing the age structure and growth of this species.

**MATERIALS AND METHODS**

Gadoids were collected from the cooling water intake screens of two power stations in the inner Severn Estuary and one in the inner Bristol Channel (see Radford, Uncles & Morris, 1981 for definition of regions). All fish trapped by the screens over the previous 24 h were obtained once weekly between July 1972 and June 1977 (48 collections per year) from the station at Oldbury-upon-Severn, Gloucestershire (approximately 55 km downstream from Maisemore Weir). The numbers of each species of gadoid in each sample were recorded and where necessary corrected to correspond to an intake of $2.20 \times 10^9$ l, the daily volume of water passing through the screens during the autumn, winter and spring when the station was under full load and gadoids were most abundant. The data on annual abundance given in Table 1 represent the total number of fish caught in the once-weekly 24 h samples taken during that year, while the monthly values shown in Figs. 2–4 represent the mean number of fish taken in each of the four 24 h samples during the month.
Weekly collections were also obtained between September 1974 and June 1977 from Berkeley Power Station, which is located 7 km upstream from Oldbury. It should be noted that while the water drawn into the Oldbury Power Station comes from shallower inshore areas, the intake at Berkeley is positioned in the main deep water channel of this region of the estuary. Samples were taken monthly between October 1975 and May 1977 from the station at Hinkley Point, Somerset, which is situated in Bridgewater Bay in the Bristol Channel, approximately 60 km downstream from Oldbury. Since the material from the intake screens of the last two of these power stations had accumulated over variable periods of time, the fish samples could not be used for direct quantitative comparisons with those from Oldbury.

Between July 1974 and June 1977, the standard length and wet weight were recorded to the nearest 1 mm and 0·1 g for all gadoids. A one-way ANOVA was used to test whether the mean lengths of the o + age class of poor cod, bib and pollack in those months when they were first caught in the Severn were significantly different in 1974, 1975 and 1976. Where a significant difference was found, the S test of Scheffe (1959) was used to determine which means were different.

The otoliths of poor cod from Berkeley, Oldbury and Hinkley Point were removed, placed in glycerol and examined under reflected light against a black background for the presence of opaque and hyaline zones. The annuli laid down during each winter, as they also are in other gadoids (Raitt, 1968a), enabled the age and annual growth increments of this species to be determined (Fig. 5). Otoliths from some of the other gadoids were also examined in the above manner. In this study, age calculations have assumed the estimated time of spawning as the birthday.

Salinity at all power stations was recorded at the time of sampling between September 1974 and June 1977 (Fig. 1). Salinities at Oldbury for the months prior to September 1974 were estimated from the regression equation relating this parameter to freshwater discharge (see Results). Freshwater discharge data, which came from the records of the Severn–Trent Water Authority, were used to calculate the mean discharge for the week before sampling and the mean monthly discharge (Fig. 1).

**RESULTS**

*Environmental conditions*

Although freshwater discharge from the River Severn followed a seasonal pattern, reaching a peak between October and March, the maximum and minimum levels during the five-year study period showed considerable annual variation (Fig. 1). For example, the peak freshwater flow during the winter of 1975/6 was less than 100 m$^3$ s$^{-1}$, compared with over 400 m$^3$ s$^{-1}$ in the same period in 1976/7. Furthermore, flow rates were much lower in the summers of 1975 and 1976 than in those of other years. That freshwater discharge influences the salinity in the estuary can be clearly seen from the inverse trends shown in each year by these two parameters (Fig. 1). Moreover, while values declined to only 18‰ in the relatively dry winter of 1975/6, they fell to 6‰ in the winter of 1976/7 when the rate of freshwater flow was much higher. Similarly, values in excess of 28‰ were only reached during the summers of 1975 and 1976 when discharges were relatively low.

The evidence seen in Fig. 1 for a strong inverse relationship between salinity and freshwater flow between September 1974 and June 1977 is borne out by the high correlation coefficient (−0·95) for the following relationship between the mean monthly values for salinity (S) and freshwater discharge (W) over this period. S = 46·2520 − 14·9171 log W. In view of the closeness of this relationship, the above equation was used to estimate the salinity in the months prior to September 1974 when this environmental parameter was not measured.
The trends shown by temperature followed a much more clearly sinusoidal pattern than either freshwater discharge or salinity (Fig. 1), indicating that temperatures were influenced less markedly by changes in discharge than was the case with salinity. At Oldbury, mean monthly temperatures fell to a minimum between December and March and reached a maximum in July or August (Fig. 1). However, the temperature range varied between years. For example, the mean monthly temperatures dropped to only 6 °C during the first three winters of the study period compared with values of approximately 4 °C in February 1976 and

Fig. 1. Temperature, salinity and freshwater discharge in the River Severn. The first two parameters were measured in the estuary at Oldbury at the time of sampling, whereas the discharge rates were recorded in fresh water at Tewkesbury.
January 1977. Conversely, mean monthly temperatures recorded during the summers of 1975 and 1976 were higher than in previous years, reaching a maximum of 21 °C compared with only 18 °C in 1974.

Salinity and temperature regimes at Berkeley were similar to those described for Oldbury, except during periods of heavy freshwater discharge, when the salinity declined to a slightly lower level. Compared with Oldbury and Berkeley, the salinities at Hinkley Point in the Bristol Channel were much more stable and rarely dropped below 30%, and the range in temperature was not quite so great.

Relative abundance of gadoids

Collections from Oldbury Power Station between July 1972 and June 1977 yielded 47,783 gadoids representing thirteen species (Table 1). This is a greater number of both fish and species than was obtained for any other family. Seven of these species were taken in sufficient numbers to provide data which allowed seasonal and annual trends in abundance to be determined (Figs. 2, 3, 4; Table 1).

Amongst the gadoids, the whiting, *Merlangius merlangus*, was the most numerous species at Oldbury in all years apart from 1972/3 when poor cod, *Trisopterus minutus* (L.), was more abundant (Table 1). The latter species assumed second place to whiting in 1973/4, 1974/5 and 1975/6, whilst bib, *Trisopterus luscus* (L.), occupied this position in 1976/7.

The gadoids contributed between 11.0 and 41.3% of the total numbers of all fish taken at Oldbury during each of the five years of this study. Whiting was the most abundant teleost in 1974/5 and 1975/6 and the second most abundant in 1973/4 and 1976/7 (Table 1). The poor cod ranked amongst the top ten species in four of the five years, and as high as fourth in 1975/6. The only other gadoid whose numbers ranked in the top ten in any year was the bib, which was ninth in 1974/5 and tenth in 1976/7.

The contribution to the total fish collection by whiting ranged from less than 2% in 1972/3 to more than 30% in both 1974/5 and 1975/6. Poor cod and bib contributed annually up to 5.9 and 1.2%, respectively. Norway pout, *Trisopterus esmarkii* (Nilsson); northern rockling, *Ciliata septentrionalis*; five-bearded rockling, *Ciliata mustela* and pollack, *Pollachius pollachius* (L.), never made up more than approximately 0.5% of the total fish catch in any year, and the maximum contribution made by the three-bearded rockling, *Gaidropsarus vulgaris* (Cloquet), and cod, *Gadus morhua* (L.), was always under 0.2% (Table 1). Corresponding values for hake, *Merluccius merluccius* (L.); tadpole fish, *Raniceps raninus* (L.); blue whiting, *Micromesistius poutassou* (Risso), and ling, *Molva molva* (L.) never exceeded 0.01%.

Seasonal and annual trends in the abundance of common species

Five of the seven most numerous species of Gadidae found in the Severn entered the shallows of the inner estuary in the late summer or autumn. Thus in each year whiting, bib, pollack, poor cod and five-bearded rockling almost
Table 1. The total number \((N)\) of each species of gadoid and their relative abundance \((\%\)\) and ranking \((R)\) amongst all species of lampreys and fish.

The two last rows give the total number of all lampreys and fish and the corresponding number of species.

<table>
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<th>Species</th>
<th>1972/73</th>
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<tr>
<td></td>
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<td>(%)</td>
<td>(R)</td>
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*, Equal ranking with at least one other species.
invariably reached maximum abundance in either September, October or November (Figs. 2, 3). The mean daily numbers per month produced what was essentially a single annual peak for all these species except the poor cod, in which a second smaller peak was sometimes present between January and April (Fig. 3). In contrast to the other five species, the comparable values for northern rockling peaked in January, February or more commonly March (Fig. 3). However, the highly seasonal occurrence of all the above species contrasts markedly with the situation found with Norway pout (cf. Figs. 2, 3, 4), although
there was some evidence that the latter species tended to disappear at times from
the inner estuary during the summer and autumn.

The peak values for the monthly numbers of whiting increased successively
from 21 in 1972/3 to 1430 in 1976/7 (Fig. 2). Although a very similar trend
was followed by the total numbers obtained each year between 1972/3 and

![Graphs of fish numbers](image)

Fig. 3. The mean daily numbers of poor cod (*Trisopterus minutus*), five-bearded rockling (*Ciliata mustela*) and northern rockling (*Ciliata septentrionalis*) collected from Oldbury in each month between July 1972 and June 1977.

1975/6, with annual values rising from 164 to 15911, the trend was reversed in
the final year (1976/7) when the total was 10494 (Table 1). The increase in peak
values observed in the whiting in successive years is paralleled by the data for
the northern rockling (Fig. 3).

The similarity between the annual trends in abundance shown by whiting and
northern rockling (Figs. 2, 3) contrasts markedly with those exhibited by bib and pollack (Fig. 2). In both of these latter two species, the highest monthly peaks and greatest annual abundance were recorded in 1974/5 (Table 1). In the case of poor cod, by far the greatest monthly values (Fig. 3) and total abundance (Table 1) occurred in 1975/6. While the highest monthly peak for five-bearded rockling was reached in 1972/3 (Fig. 3), the largest annual catch was recorded in 1974/5 (Table 1).

![Norway pout](image)

Fig. 4. The mean daily numbers of Norway pout (*Trisopterus esmarkii*) collected from Oldbury in each month between July 1972 and June 1977.

Data for Norway pout showed the least variation among years, both in peak monthly values (Fig. 4) and in total numbers (Table 1), with the values for the latter ranging from a minimum of 24 in 1973/4 to a maximum of 78 in 1974/5.

**Size, age composition and growth of poor cod**

While representatives of as many as six age classes of poor cod were present in the pooled monthly samples from all three power stations (Fig. 5), the vast majority of fish greater than two years old came from Hinkley. Visual back-extrapolation of the growth curve for o + fish suggests a late winter or early spring spawning period; an estimate consistent with the peak breeding time given by Wheeler (1969) for this species in the English Channel. Young-of-the-year poor cod were first caught in the estuary in July and August at mean lengths of 31–58 mm (≈0.3–1.9 g). Using the data for 1977 and assuming a spawning time of March/April, this species reached mean lengths of approximately 80 mm (≈4.8 g), 110 mm (≈11.7 g), 140 mm (≈23.0 g), 170 mm (≈39.6 g) and 210 mm (≈71.6 g) at the end of the first five years of life respectively (Fig. 5).

During the autumn, when the maximum monthly numbers of fish were recorded, o + poor cod at Oldbury represented 93.7, 98.9 and 90.1% of the total numbers of this species caught in 1974, 1975 and 1976 respectively. Although
the numbers of older age classes were greater at Hinkley, the samples from this station were also dominated by 0+ fish.

A t test showed that the mean length of 0+ poor cod in August 1976 was significantly greater than in August 1974 ($P < 0.001$). ANOVA also demonstrated that the mean lengths in September and in October differed significantly in 1974, 1975 and 1976 ($P < 0.05$). Scheffé's S test revealed that while the values for each

![Graph showing standard length measurements for different year classes of poor cod (Trisopterus minutus) collected from the Severn Estuary and Bristol Channel between August 1974 and May 1977.](image)

of these months in 1975 and 1976 were not significantly different ($P > 0.05$), they were significantly greater than those recorded for the comparable months in 1974 ($P < 0.05$).

Length and weight data for bib, pollack and Norway pout

ANOVA demonstrated that the mean lengths of bib from Oldbury and Berkeley were not significantly different ($P > 0.05$) in either September or October of 1974, 1975 and 1976. For this reason, all the length data for these two months, when bib were most abundant in the inner estuary, and for the preceding
...and following months, have been pooled (Fig. 6). The single modal length class, representing 0+ fish, increased from 40–49 mm in August to 70–79 mm in November/December (Fig. 6). This represents an increase in mean length from

![Graph showing length-frequency histograms for bib (Trisopterus luscus) and pollack (Pollachius pollachius). Data for bib in 1974, 1975 and 1976 have been pooled. Hatched area on pollack frequency histograms denotes data for 1975 and 1976. In this and Fig. 7, the sample size for each of the length-frequency histograms is given.]

46·0 mm (≈ 1·6 g) to 75·7 mm (≈ 6·0 g). While the smallest 0+ fish collected during 1974, 1975 and 1976 lay within the 30–39 mm class range (Fig. 6), one animal of 26 mm was taken in the last sample of this study in June 1977. Only six
bib greater than 130 mm were caught in the inner estuary. These fish, which were collected in March 1975 (133, 135 and 143 mm), March 1976 (152 mm), June 1976 (163 mm) and May 1977 (150 mm), all came from Berkeley and were approximately one year old. Much larger fish, with 15 more than 200 mm and a maximum length of 292 mm, were taken from Hinkley in the Bristol Channel.

The mean lengths of pollack at Oldbury and Berkeley in September, October and November/December of 1975 never differed more than 3 mm from those recorded for the same months in 1976, but each of these monthly means was always 12.5–20 mm greater than at the comparable time in 1974. ANOVA demonstrated significant differences in length in September ($P < 0.01$), October ($P < 0.01$) and November/December ($P < 0.05$) and Scheffé's $S$ test showed that in each case the mean lengths for 1975 and 1976 were not significantly different ($P > 0.05$) but did differ from those of 1974 ($P < 0.05$). For these reasons, the length data for pollack in 1975 and 1976 have been plotted separately from those of 1974 in the size–frequency histograms (Fig. 6).

The length–frequency histogram for pollack in the inner estuary in September 1974 was unimodal, with a pronounced peak occurring at 100–109 mm (Fig. 6). This corresponds to a mean length of $101.2$ mm ($\equiv 12.5$ g). A comparison of the distribution of the lengths of these $o+$ fish in the histograms for September to November/December indicates some growth over this period. The incidence of larger pollack was greater at Hinkley in the Bristol Channel, with four fish exceeding 200 mm, the longest of which was 288 mm.

Small Norway pout (30–38 mm) were first collected in August. The $o+$ age class did not become conspicuous, however, until the period between November and March when it produced a well-defined modal length class of 80–89 mm (Fig. 7), which corresponds to a weight range of 3.6–5.0 g. While the numbers of

Fig. 7. Length–frequency histograms for Norway pout (Trisopterus esmarkii) based on pooled data for all years.
this age group were much lower between April and June, those of the larger fish, i.e. 140–220 mm, were greater (Fig. 7). This group, with a modal length class at 170–179 mm (\(\equiv 34.7–40.5\) g), comprised numerous 1+ fish, with a few 2+ individuals. This parallels the situation recorded by Raitt (1968a) for marine populations.

Norway pout were invariably in an emaciated condition and showed a high incidence of gill and eye parasites. The gills of more than 21 % of 244 fish were infected with the crustacean *Lernaeocera branchialis* and the scleral cartilage of the eyes of more than 90 % of all fish collected were packed with the cysts of the cnidosporidian *Myxobolus aeglefini*. The latter infection was also found by Raitt (1965) in Norway pout in other British waters.

**Data on the six least common gadoids**

Cod were rare or absent at Oldbury in all years except 1974 when a total of 66 0+ individuals, ranging in length from 55 to 145 mm (\(\equiv 2.1–41.0\) g), were caught between late August and December. Collections from the nearby Berkeley Power Station support the view that cod entered the estuary in greater numbers in the autumn of 1974 than in any other year. Between October 1975 and May 1977 a total of nine larger cod (245–561 mm) was obtained from Hinkley Point Power Station in the Bristol Channel during the months of October to March.

Nine blue whiting were collected during this study, eight of which came from Oldbury and Berkeley between December and June. Examination of otoliths showed that these fish, which measured 171–224 mm (\(\equiv 44.9–94.4\) g) were in the second year of life. A number of blue whiting of a similar size range and age (0+ and 1+) have been found in the inshore waters of the west coast of Scotland (Gordon, 1977a).

Hake were also caught only sporadically in the Severn Estuary and Bristol Channel during the study. The lengths of 44 fish taken in the area ranged from 74 to 276 mm (\(\equiv 2.1–217.7\) g).

Ling were rare and only taken at Oldbury and Berkeley. The standard lengths of the four individuals obtained ranged from 90 to 192 mm (\(\equiv 3.7–37.1\) g).

Tadpole fish were only collected from Oldbury and Berkeley. The standard length of the 14 fish examined ranged from 87 to 192 mm (\(\equiv 9.4–130.6\) g).

Three-bearded rockling were found at Oldbury, Berkeley and Hinkley Point between December and April. The standard length of 32 individuals ranged from 154 to 420 mm (\(\equiv 28.5–668.0\) g).

**DISCUSSION**

When considering the significance of the numbers of the various species recorded in this paper, it is important to recognize that the values given for Oldbury are based on 24 h samples taken once weekly. The abundance data given in Table 1 thus represent only approximately one-seventh of the total number that would have been taken at the Power Station in a week. Likewise, since the values shown in Figs. 2–4 correspond to the mean of the once-weekly catches
in each month, they represent only approximately one-thirtieth of those that would have been obtained over the whole month. It should also be noted that when a species was abundant at Oldbury, it was also present in large numbers at the nearby Berkeley Power Station and at Hinkley Point in the Bristol Channel. For these reasons, the collections of, for example, a total of 15911 whiting between July 1975 and June 1976 must reflect an entry of exceptionally large numbers of this species into the estuary in that year.

The data presented in this paper show that the gadoids make an extremely important contribution to the fish fauna of the Severn Estuary. This point is well illustrated by the very high ranking of whiting, poor cod and, in some years, also bib amongst the large total number and diversity of fish collected annually from Oldbury (Table 1). Moreover, northern rockling, pollack, Norway pout and five-bearded rockling were each amongst the seventeen most abundant teleosts in at least one of the five years of the study.

Ten of the thirteen species of gadoids collected between 1972 and 1977 were recorded in the extensive reviews of the fish fauna of the Severn Estuary and Bristol Channel by Matthews (1933) and Lloyd (1941). The three exceptions were northern rockling, Norway pout and blue whiting. Although the first of these species was described by Wheeler (1969) as an offshore fish which was not recorded for British waters until 1960, our data demonstrate that in some years it is quite common in the Severn Estuary. Since nearly 250 Norway pout were collected during the current study, the same would appear to be true for this species. During 1979, Norway pout and also blue whiting, of which nine were taken in our study, appeared for the first time in abundance in the western English Channel (Southward & Mattacola, 1980). Considerable numbers of blue whiting and smaller catches of Norway pout were also taken in trawls in the eastern English Channel at the same times (Blacker, 1981). Southward & Mattacola (1980) suggest that this incursion may be related to the creation of a vacant niche for these mid-water or planktonic feeders (Raitt & Adams, 1965) as a result of the heavy exploitation of the south-western stocks of mackerel. However, since Norway pout and the North Atlantic stocks of blue whiting are 'northern' fish (Raitt, 1968b, c; Raitt & Mason, 1968), their increase in the waters off Plymouth parallels the situation found with other cold-water species. This may be attributable to climatically related changes that have occurred in the waters off south-west England since the 1960s (Southward, 1980; Southward & Mattacola, 1980). While Blacker (1981) does not find the niche-creation hypothesis very plausible and believes that the blue whiting in the English Channel come from stocks to the south and west of Plymouth, he concedes that the entry of Norway pout into the region may be related to ecosystem changes. If a decline in water temperature is the main factor influencing the southwards movement of certain species, such changes could also be invoked to account for the considerable numbers of the cold-water northern rockling which have appeared in the Severn Estuary during the 1970s.

Our data demonstrate the highly seasonal nature of many fish movements into
and out of the Severn Estuary. The close correspondence between the clearly
defined peaks in the monthly numbers of whiting, poor cod, bib and pollack show
that the timing of these migrations was very similar, suggesting that these four
species were responding to similar environmental stimuli. The declines in
abundance in the late autumn/early winter occurred during the period when
temperature and salinity were falling rapidly and freshwater discharge was rising.
However, an attempt to regress declines in fish numbers between successive weeks
with corresponding changes in both salinity (which shows a close inverse
relationship with freshwater discharge) and also temperature revealed no con-
sistent interrelationship. If there was a tendency for fish numbers to fall in concert
with declines in salinity, the evidence for such trends was apparently masked by
the variability in sample size in successive weekly samples; a feature possibly
caused by the schooling behaviour of juvenile gadoids. None the less, it is almost
certainly relevant that the mean monthly catch of whiting was much higher in
December 1975 than in the same month of the previous and following years when
the mean monthly salinity was very much lower (cf. Figs. 1, 2). Moreover, an
examination of the weekly data for all years showed that no whiting was taken
at salinities less than 6% and only very reduced numbers were ever obtained in
salinities below 10%. This accounts for the capture of only two whiting in the
wet periods of January, February and March 1977 compared with consistent but
small captures in the comparable but drier months of the previous year (cf.
Figs. 1, 2). The data on poor cod also indicate that very low salinities affect this
species. For example, in some years this species also showed a second less pro-
nounced peak in abundance in the late winter/early spring after salinities had
started rising from their minimum winter levels.

While there is evidence that a pronounced decline in the numbers of some
species occurred in the Oldbury region of the estuary when salinities were very
low, this does not apply to the northern rockling, which reached peak abundance
during the winter or early spring and was collected in large numbers when
salinities reached exceptionally low levels, such as occurred in February and
March 1977.

Although emphasis in the above discussion has been placed upon the proposed
effect of very low salinities on the distribution of some species in the estuary, the
possibility that increased freshwater discharge also affects juvenile fish movement
cannot be discounted. However, since the velocity due to freshwater discharge
in the estuary at Oldbury rarely approaches 5% of that resulting from tidal action
(P. J. Radford, personal communication), even the most extreme flooding is
unlikely to increase markedly the chances of fish being flushed out of the region.
In the context of the possible effects of environmental conditions, the greater
lengths of poor cod and pollack in some months in the autumn of 1975 and 1976
compared with the corresponding months in 1974 might reflect the influence on
growth and possibly also spawning times of higher summer temperatures in the
two later years. This situation also pertained with bass (Claridge & Potter, 1983).

It is evident that the shallower regions of the inner Severn Estuary are
colonized predominantly by the o+ age class of the more abundant gadoid species. This view is based on the fact that, in collections from Oldbury, all the bib and all but one pollack were in their first year of life. Furthermore, the o+ age class of poor cod contributed between 90.1 and 98.9% to the total numbers of this species each year. Similarly, the work of Gardner (1978) demonstrated for whiting that, although a number of 1+ fish were found at Oldbury, samples each year consistently comprised an extremely high proportion (>99.5%) of first-year fish. While the situation at Berkeley parallels quite closely that found at Oldbury, it was apparent that larger o+ and, to a certain extent, the 1+ fish of the above four species were collected more frequently at the former station which draws its intake from the main deep water channel of the estuary. This implies that at least some gadoids tend to move from shallower regions into deeper water as they increase in size. The higher incidence at Hinkley of 2+ and older age classes of poor cod, whiting (Gardner, 1978) and bass (Claridge & Potter, 1983) than at Oldbury and Berkeley demonstrates that the inner estuary is selectively penetrated by the first and, to a lesser extent, the second age classes of many marine species, and thus substantiates the view that estuaries are important fish nursery areas.

The above generalizations regarding the role of estuaries do not hold for Norway pout and northern rockling in the Severn. For example, the numbers of the larger representatives of the former species, i.e. >1+, collected from the inner estuary during the current study exceeded those of the o+ age class. Northern rockling was unusual in that, while three age classes were present in quite large numbers at Oldbury and Berkeley, this species was comparatively rare at Hinkley (Claridge & Gardner, 1977). Moreover, representatives of all three age classes approached sexual maturity in the late winter or early spring just before leaving the Oldbury region of estuary.

The relative paucity of published information on gadoids in other British estuaries, based on sampling programmes carried out at frequent and regular intervals, makes it difficult to compare the situation in the Severn with that found in other estuarine environments. Indeed, most of the numerous quantitative information on the young stages of these species comes from studies in sea lochs and inshore marine areas. However, the marked increase in the abundance of whiting in the inner Severn Estuary during the middle 1970s parallels the situation that occurred during the same period in the Thames (Wheeler, 1979). Similarly, the time when o+ whiting started appearing in numbers in the Severn Estuary (August/September) is a little earlier than the period when the numbers of what is presumably the same age class of whiting started rising in the Medway Estuary (van den Broek, 1979). This timing is slightly later than that when whiting invade inshore areas on the west coast of Scotland. Since poor cod was numerous in the Severn Estuary during the studies of Matthews (1933) and ourselves, but was not regarded by Lloyd (1941) as common between 1938 and 1940, this species also undergoes marked annual fluctuations in abundance. o+ poor cod appeared in bottom trawls off the west coast of Scotland in June and July (Gordon & De Silva, 1980), one to two months earlier than in the Severn.

While young Norway pout entered inshore Scottish waters in July (Gordon,
appreciable numbers of the 0+ age class of this species were not found in the Severn Estuary until December and January, when in general they had already reached lengths of at least 70 mm. Bib started appearing in the inner Severn Estuary in August, which is rather earlier than in either the Medway (van den Broek, 1979) or the Thames (Huddart & Arthur, 1971). These differences in time are reflected by differences in body size, with bib from the Thames measuring 80–123 mm compared with 30–80 mm in the Severn. Although Wheeler (1979) describes the pollack as having a ‘strong affinity with rocky shores and reefs’, it was taken in appreciable numbers at Oldbury where the substrate is soft.

During the 1930s the first 0+ representatives of whiting, bib, pollack and poor cod in the Tamar Estuary were taken in May, May, June and July respectively (Hartley, 1940), which in each case was one to three months earlier than was recorded in the current study of the Severn. These differences may be attributable to an earlier spawning time and faster initial growth rate favoured by the presence of higher water temperatures off south-western England in the 1930s than in the 1970s (Maddock & Swann, 1977).

The movement of whiting and poor cod into inshore nursery areas in Scottish waters is believed to represent an active migration of juveniles rather than being a result of passive larval drift (Gordon, 1977c; Cooper, 1980). It therefore seems highly likely that the above species also enter the Severn Estuary as juveniles, but use tidal action to aid their passage up the estuary. In view of the relatively large size at which 0+ pollack and Norway pout are first found, similar generalizations almost certainly pertain with these two species. If these conclusions are correct, the above four gadoids differ from species such as bass which enter estuaries as post-larval stages measuring only 10–14 mm (P. R. Dando, personal communication).

Our data show that the 0+ poor cod and bib started appearing in the inner estuary when their lengths reached 25–50 mm, as is the case with whiting (Gardner, 1978), while the entry of pollack did not commence until they had attained lengths of over 60 mm. The young of all three species grew during their time in the estuary. Comparison between the time of peak abundance for the 0+ age class of abundant gadoids at Oldbury with the time at which their larval and post-larval stages were captured by trawling in the Bristol Channel during 1974 (Russell, 1980), provides information on the movement patterns of three of the more common species. For example, the occurrence of peak numbers of very young whiting in the Bristol Channel in mid-April and of the 0+ stages at Oldbury during September and October of 1974 demonstrates that this species took, on average, five to six months to enter the shallower regions of the inner estuary. A similar comparative approach for the pollack and poor cod yields a value of five months. Assuming that the larvae and post-larvae were approximately one to three weeks old, the nursery habitats provided in the inner estuary were not typically reached by the above three gadoids until they were at least five to six months old.

The data presented in this paper demonstrate that the Severn Estuary is used
extensively by the $0+$ age class of several species of gadoids, particularly the whiting. Since this parallels the situation with bass (Claridge & Potter, 1983) and in some years also herring (Titmus et al. 1978), it provides further evidence that the Severn Estuary is more important as a fish nursery area than was implied in a recent report by the Department of Energy, United Kingdom (1981). The large numbers of young whiting, bib, poor cod and pollack found in the Severn Estuary suggest that these species could be classed as estuarine-dependent. However, this widely used term should not be taken to imply that all representatives of these species always have to enter an estuary at some stage in their life cycle. Clearly other coastal areas and embayments, such as those found in the Bristol Channel for example, can frequently provide alternative habitats with shallow, sheltered conditions suitable for early life. Examples of differences in the degree of estuarine-dependence were recently provided by two closely related species in south-western Australia (Chubb et al. 1981; Lenanton, Robertson & Hansen, 1982). Thus, small juvenile sea mullet, Mugil cephalus L., were found extensively in the Swan–Avon Estuary but never in local coastal waters or the nearby marine embayment of Cockburn Sound, whereas $0+$ yellow-eye mullet, Aldrichetta forsteri (Valenciennes), were common in all these areas. In contrast to species such as whiting and poor cod, the gadoids which enter the estuary in only very small numbers can be regarded as ‘marine stragglers’.

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