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The Propagation of Cod *Gadus morhua* L.

THE DISTRIBUTION OF YOUNG COD

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ABSTRACT

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The distribution of young cod in the North Sea is described, using catch data from national and international trawl surveys and experimental fishing. Information on seasonal movements and feeding related to the concentration in the winter of I- and II-group cod in shallow, low salinity water is presented.
The pelagic O-group cod in June move rapidly inshore by September-October and remain there as I-group fish until the spring. In the summer the majority move offshore returning again for the winter as II-group. Cod older than II-group generally avoid shallow, low salinity water. An analysis of food types of the age groups indicates that this behaviour reduces cannibalism.

INTRODUCTION

A study aimed at relating the distribution of juvenile cod *Gadus morhua* with the fisheries in the North Sea to which they recruit, has involved the use of inshore and offshore fish survey data, fish tagging and experimental fishing. The geographical distribution of the year classes at certain times of the year is now adequately known from the surveys and these have been related to environmental factors in order to define the distribution in physiological and behavioural terms. We thought the changes in the apparently preferred environment of cod with age may have a relevance to those involved in cod propagation either in fish farms or for the enhancement of natural recruitment. Firstly, the natural conditions of temperature, salinity, etc., where pelagic O-group occur, would be a guide to choice of hatchery conditions and secondly, any rearing-on fish-farm programme would benefit from a knowledge of the very different conditions in which later O-group and I- and II-group cod are found most abundantly in the sea.

In this analysis of young cod distribution, we have tried to demonstrate what may be the survival advantage to the species in the variation in distribution patterns with age and in particular the significance of the inshore habit of I-group and to a lesser degree II-group cod in winter.

MATERIALS AND METHODS

Catch data for the year classes 1974-80 from two International Council for the Exploration of the Sea (ICES) co-ordinated surveys were reworked to produce a summary of the distribution of O-, I- and II-group cod. The International O-group Gadoid Survey (IOGS) in June is carried out with an International Young Gadoid Pelagic trawl (Holden, 1981) in order to measure the distribution and abundance of pelagic O-group fish. The International Young Fish Survey (IYFS) in February is carried out now with a GOV trawl and formerly with a Dutch herring trawl and is aimed mainly at determining the abundance of I- and II-group fish when in demersal habit (Anon., 1981). For both surveys, sampling is on an ICES statistical rectangle basis (1° longitude x 0°30' latitude) and abundance indices initially expressed as mean catch in numbers per hour within each rectangle. In this analysis the mean catch per rectangle was expressed as a percentage of the total for each year class. Means of the percentages in each rectangle were obtained to provide a normalised abundance index for the seven year classes examined. The resulting distributions are shown in Fig. 1A-C and the mean bottom salinity in winter in Fig. 1D.

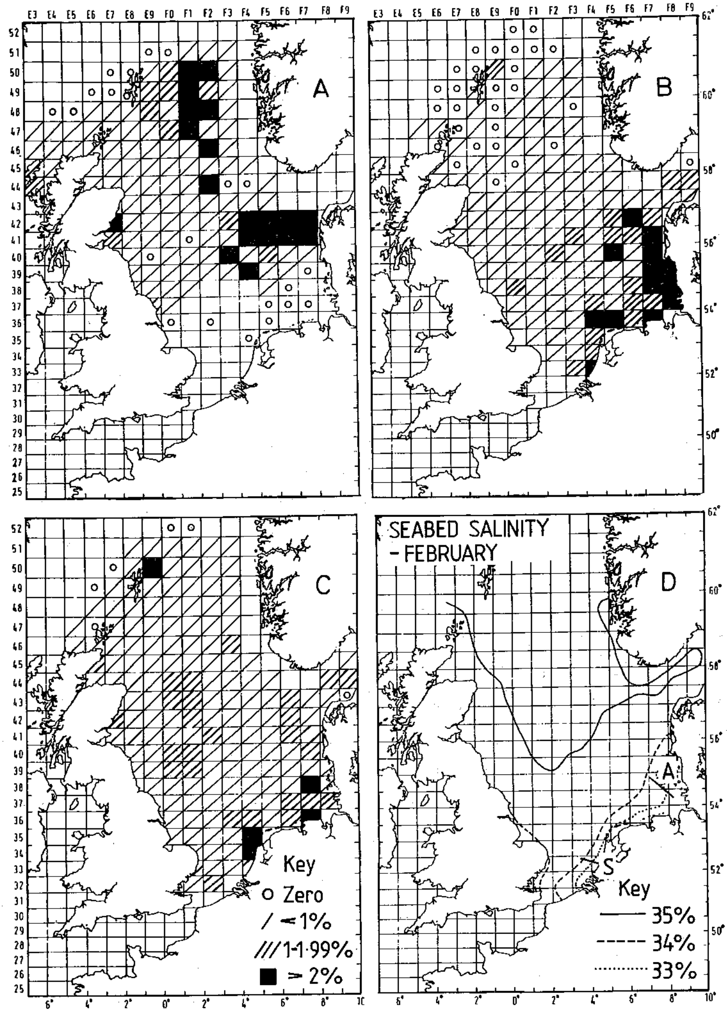

Fig. 1. The distribution of young cod (1974-80 year classes) in the North Sea in relation to salinity: A - distribution of pelagic O-group cod in June (IOGS); B - distribution of demersal I-group cod in winter (IYFS); C - distribution of demersal II-group cod in winter (IYFS); D - mean bottom salinity in winter (modified from Lee and Ramster, 1981); experimental trawling positions marked A - Amrum, S - Scheveningen.

For the February survey abundance indices were also calculated for the <34, 34 and 35°/oo salinity bands.

Details of the coastal distribution of the 'early' demersal O-group phase in September-October were obtained from surveys using a standard 2m beam trawl, as described by Riley et al. (1981) on the English and Welsh coasts. Mean abundance indices have been calculated and compared witn those of whiting *Merlangius merlangus* and the poor cod *Trisopterus minutus* in relation to depth and salinity. Details of the horizontal distribution were studied in a similar beam trawl survey in the Thames Estuary.

A study of the distribution of cod in February, particularly in relation to salinity was made in 1983. The relative abundances of the different age groups was estimated along two salinity gradients, one in the German Bight off Amrum and the other off Scheveningen, the Netherlands. Seven replicate hauls of 1 h duration were made at each of four stations on each transect using a Portuguese high headline trawl. The catch of gadoids at each haul was separated into year classes by examination of the otoliths, and expressed as a percentage of the total catch of a species/age group on the transect. Depth, surface and bottom salinity and temperature were recorded at each station. Variations in temperature and depth were kept to a minimum. Sampling positions on the German Bight transect had a mean temperature range of 3.01 to 3.88°C and mean depth range 19.1 to 24.5 m. Equivalent values for the Dutch transect were 3.27 to 4.45°C and 17.9 to 28.3 m.

Cod feeding on these transects were measured by the estimation of stomach fullness on a 0 to 4 index, (0 = empty, 1 = <25%, 2 = 25-49%, 3 = 50 to 74% and 4 = 75 to 100% full). Stomach contents were grouped into four types of fish, two types of crustacea, molluscs and polychaetes and the relative importance of each food type estimated.

The seasonal movements of young cod were assessed by tagging the 1981 year class of I-group, using small plastic flag tags. Fish were caught and released in ICES Rectangle 33 F4, off Scheveningen, in February 1982. Recaptures up to 31 March 1983 have been analysed.

RESULTS

The mean normalised distribution of the 1974-80 year classes of pelagic O-group cod in the North Sea in June is shown in Fig. 1A. The fish had a range of mean lengths of from 3 to 5 cm.

Similar presentations of the distribution of the same year classes in the demersal phase in February at I- and II-group are illustrated in Fig. 1B and 1C respectively.

The same February catch data were used to calculate the mean normalised abundances of the I- and II-group cod and additionally older fish, in seawater depth bands of 10-20, 20-30, 30-50, 50-100 and 100-200 m and the values are shown in Fig. 2.

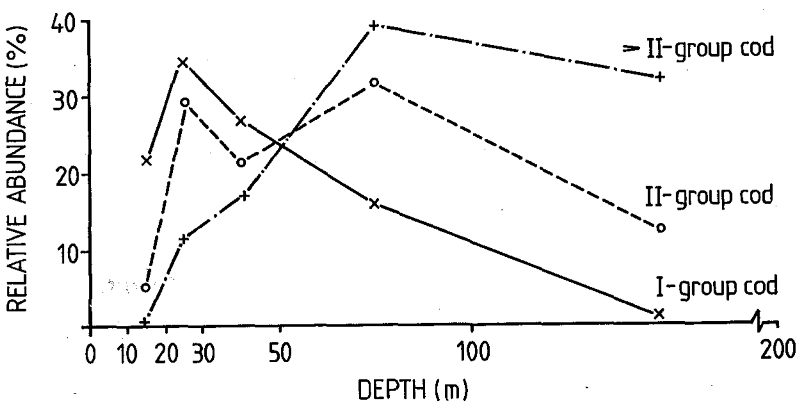

Fig. 2. The distribution of cod by age group, in the North Sea in relation to depth, 1974-80 year classes.

The calculation of cod abundance in relation to salinity was complicated by the variation in the salinity pattern from year to year. However, the mean percentage of the seven years, of each year class I, II and >II occurring in three salinity strata were calculated. The mean percentage of the survey area occupied by the near seabed salinities of <34, 34 and >34°/oo was also calculated. In Fig. 3 the index of catch per unit

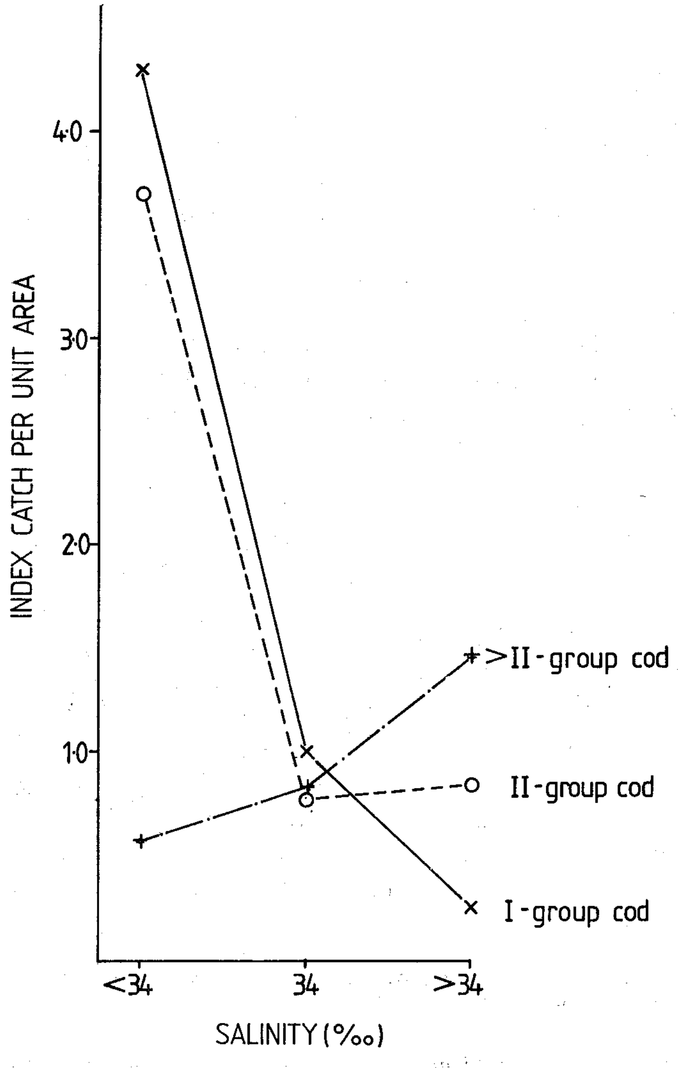

Fig. 3. The distribution of cod, by age group in the North Sea in relation to salinity, 1974-80 year classes. The index of catch/unit area is the ratio of the mean percentage catch in each salinity band to the mean percentage area of each salinity band.

area, the ratio of the catch to the area, is shown for each age group in the three salinity strata.

The catch data of O-group gadoids in the coastal areas of England and Wales in September-October, was analysed in a way identical to that used by Riley et al. (1981) for flatfish. The relative abundances of cod, whiting (*M. merlangus*) and poor cod (*T. minutus*) in relation to water depth and to salinity are shown in Figs. 4 and 5 respectively. A species association

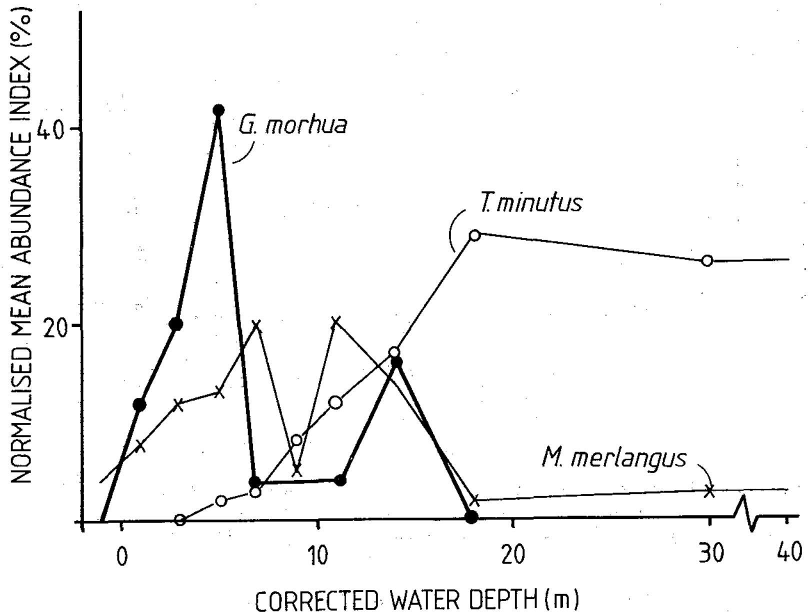

Fig. 4. The variation in abundance of O-group cod, *G. morhua* poor cod, *T. minutus* and whiting, *M. merlangus* with water depth, English and Welsh coasts, September-October 1970-75.

dendrogram based on the determination of similarity coefficients (Sneath and Sokal, 1973), similar to that of Riley et al., 1981, placed O-group cod which at this time had a length range of 6-13 cm, in closest association with O-, I- and II-group flounder (*Platichthys flesus*), O-group herring (*Clupea harengus*), smelt (*Osmerus eperlanus*) and the viviparous blenny (*Zoarces viviparus*). All of these fish can be found inshore in regions of lowered salinity and some, for example the flounder, are characteristically found in brackish, even fresh water.

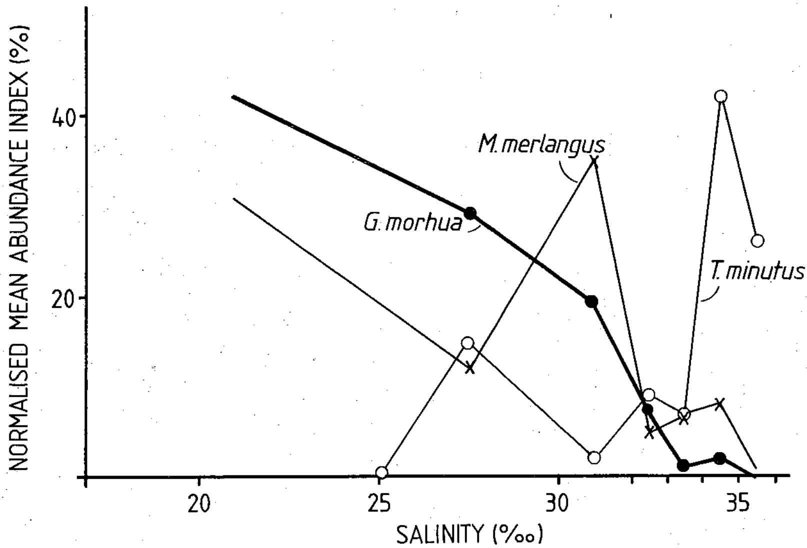

Fig. 5. The variation in abundance of O-group cod, *G. morhua* poor cod, *T. minutus* and whiting, *M. merlangus* with salinity, English and Welsh coasts, September-October 1970-75.

This group of fish have been called the 'estuarine association'. O-group whiting and poor cod were associated together and with others in an association found in sheltered bays in water deeper than 6 m, over sand.

The details of catches of O-group cod in a survey of the Thames shown in Fig. 6, can be considered as typical of most of those carried out during the six years of the programme. The highest catch rates of the O-group were made in the tidal reaches of the rivers. The remainder was taken in areas including sand and mudbanks often exposed at low water. Catches in open water were nil.

The abundance estimates of I-group cod on the salinity

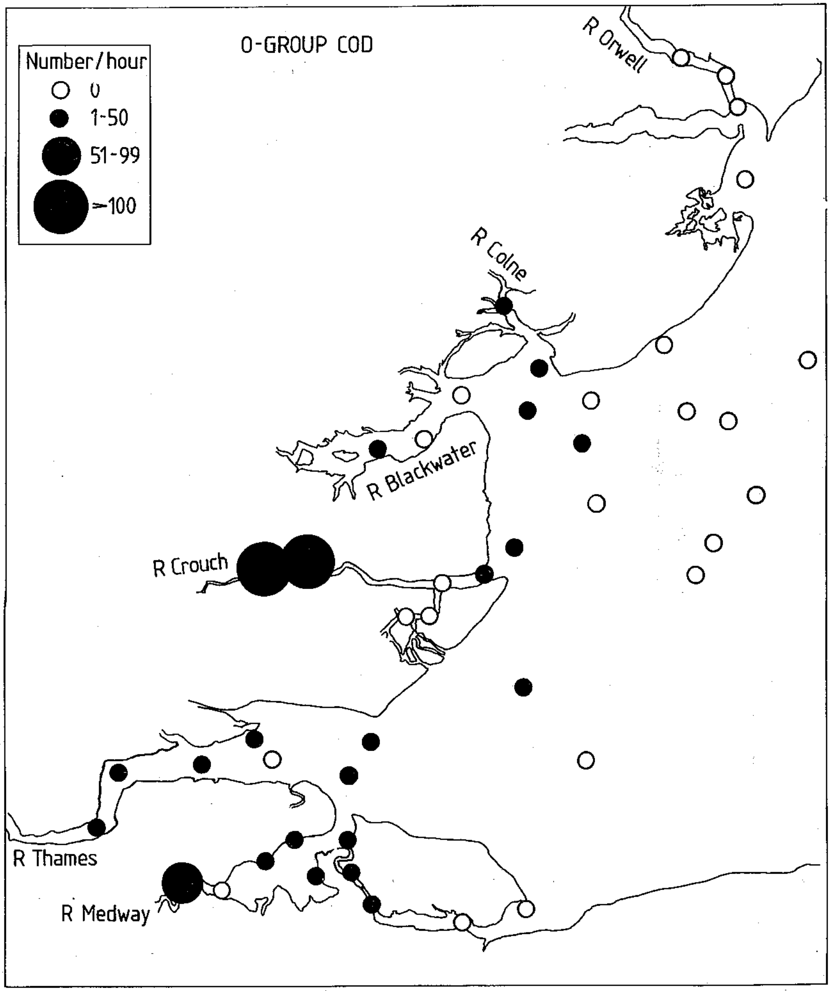

Fig. 6. The distribution of O-group cod in the Thames, October 1976.

gradients in the German Bight and off the Dutch coast, are plotted against the near sea-bed salinity value, in Fig. 7. The estimate is a normalised mean catch per unit of effort at each fishing position and is shown with the standard error of the mean.

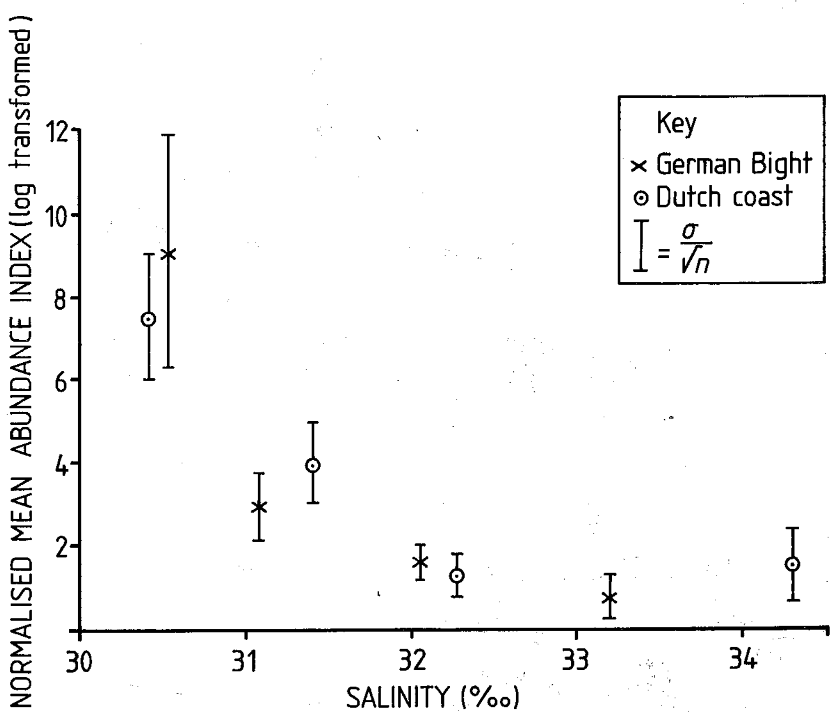

Fig. 7. The abundance of I-group cod along salinity gradients in the German Bight and off the Dutch coast, February 1983.

A one-way analysis of variance of the log transformed values showed significantly higher abundances at salinities <31°/oo at both localities.

The analysis of the food items in the stomachs of the cod caught on the salinity gradients is shown in summary, in Table 1. There was no correlation between either stomach fullness or food items with position on the transects and so the data for each locality has been shown separated only into age groups of the cod. The progressive decline in importance of *Crangon* as a food with the age of the cod is matched by the increase in the importance of fish. Gadoids however were absent in the stomachs of I-group fish and a minor constituent of the diet of II-group cod at <1%. On the Dutch coast 11% of the food of >II-group cod was identified as gadoid.

TABLE 1

Cod stomach contents, North Sea, February 1983. Values are means of percentages of food type at the four fishing positions in the German Bight and off the Dutch coast.

Locality	Age group	No. of observations	Food type (%)				
			Gadoid	Clupeoid	Other fish	Crangonids	Other crustacea
German Bight	I	241	0	1.2	11.7	73.1	4.7
	II	226	0.4	19.0	31.5	33.0	7.0
	>II	23	1.6	10.2	50.2	31.4	5.1
Dutch coast	I	106	0	2.6	21.9	67.6	1.0
	II	78	0.5	12.3	35.0	39.4	5.7
	>II	25	11.1	18.3	35.5	11.0	18.8

Recaptures of cod, tagged and released as I-group fish (defined as <28 cm length), off Scheveningen in February 1982 (ICES Rectangle 33 F4) are shown in Fig. 8. Recaptures during the first few weeks after tagging, up to 31 March 1982, have not been used. Those for the next year up to the end of March 1983 have been presented in three-monthly periods, April-June, July-September, October-December and January-March.

In the figure, rectangles which had more than 10% of the returns are shaded. A separation of the recaptures into those occurring in Dutch coastal rectangles and those not, gave a percentage 'coastal' in the periods above, of 77, 12, 67 and 71

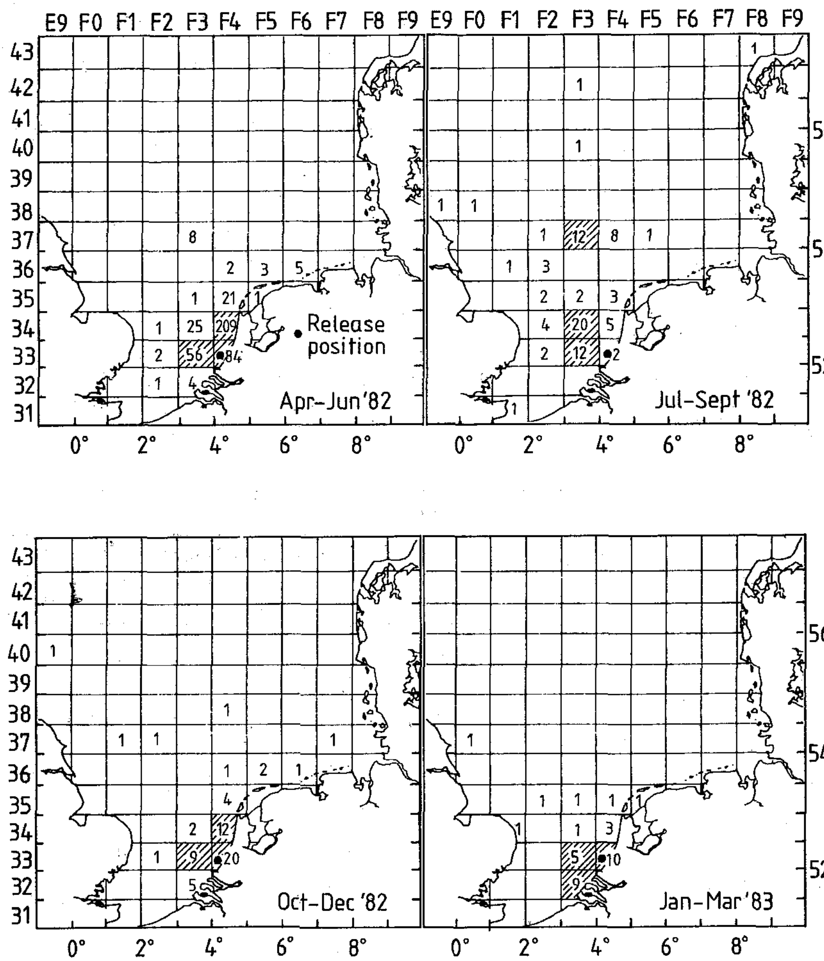

Fig. 8. Tagged I-group cod returns from a release in ICES rectangle 33 F4, in February 1982, by three-monthly periods. Additional returns but without adequate recapture positions numbered in time sequence, 16, 26, 40 and 10 respectively.

respectively. A fully statistical interpretation of these returns is frustrated by fishing effort data not being available. Of the 2856 I-group cod released in rectangle 33 F4, the number returned up to the end of March 1983 was 731 or 26%. This includes fish caught before 31 March 1982 and those for which no adequate recapture position was given.

DISCUSSION

Cod spawn mainly in the period February to April and in the North Sea generally away from the coasts in sea areas with surface salinities of 34 to 35^{o}/oo (Lee and Ramster, 1981).

The most appropriate place to begin a discussion of the progress of cod towards the fishery is the O-group in the pelagic phase following metamorphosis from the planktonic larvae. The survey in June shows two major centres of abundance (Fig. 1A), one in the northern North Sea in surface salinities of 34-35^{o}/oo and the other in the eastern middle North Sea in salinities of 33-35^{o}/oo. In the studies reported here, the fish are likely to have come mostly from the latter area and the fate of the northern patch will not be discussed further. An additional area of O-group abundance in the Southern Bight is not sampled adequately in the June survey but its presence may be appreciated from the distribution of the O-group in the south-eastern North Sea in the third quarter of 1980-82 shown by Heessen (1983). That the movements into inshore areas of low salinity are rapid, certainly well underway by September, is shown by the distribution of O-group catches for the Thames area at that time (Fig. 6.).

It was a national study aimed at the description of the distribution of all O- and I-group fish inshore, which first measured the association of young cod and low salinity water, although workers reported young demersal cod inshore many years ago (e.g. Patterson, 1905; Graham, 1948).

The plots of the abundances of O-group cod on the English and Welsh coasts show a distribution mainly in water shallower than 20 m (Fig. 4) and that there is an inverse relationship between salinity and abundance (Fig. 5). The distribution of cod contrasts with that of the poor cod which is not found in salinities of <25^{o}/oo and is usually caught in water depths of >15 m. The whiting is more ubiquitous, being taken infrequently only in salinities of <33^{o}/oo.

The distribution of the O-group for the fourth quarter of the year, given by Heessen (1983) illustrates the progress inshore which gives rise to that shown in the winter (Fig. 1B) when most occur at or below seabed salinities of 34^{o}/oo (cf Fig. 1D).

This directed movement must be an active one as it occurs against the general residual water movements in the German Bight indicated by numerical models (Davies, 1980) although Lee (1980) showed that residuals are dependent in part on the meteorological conditions and can consequently vary from year to year.

The North Sea winter horizontal distribution of the II-group cod (Fig. 1C) has some similarities with that of the I-group. The differences are due to a shift in the depth distribution towards slightly deeper water by the II-group cod (shown in Fig. 2).

The seasonal movements between the winter distribution of the I- and II-group fish were demonstrated by the tagging of the I-group in February. The recapture returns (Fig. 8) indicate that in the period April to June these cod are moving away from the release position near the Dutch coast, generally north and west. Between July and September 88% of returns were from rectangles away from the Dutch coast although the median distance between release and recapture positions was only 80 km. These tagged fish returns give a similar picture to that of the trawl survey data of Heessen (1983) covering the same period, which showed lower abundances of I-group cod near the coasts in the period July-September.

The autumn recapture pattern indicates a return south and east and by the January-March period 71% are again made in rectangles on the Dutch coast which again reflects the survey data of Heessen (1983). The seasonal movements indicated in Figure 8 and by Heessen (1983) for I-II group cod are generally similar to those deduced from tagging experiments recorded in the Report by the North Sea Roundfish Working Group (Anon. 1971). This movement into overwintering grounds in shallow, low salinity areas clearly seen in the first winter and repeated in the second, invites the questions, 'what do cod use as cues in the location and maintenance of their winter distribution' and 'what is the survival advantage gained in congregating in nursery areas over winter'? Could it be similar behaviour to that of plaice and some other flatfish that enter inshore nursery areas but stay there irrespective of season until they are late II-group?

In the search for environmental factors likely to cue appropriate migration and the maintenance of a winter distribution of O/I and I/II group cod, we looked first at those which were relatively stable. Both depth and salinity have this stability. Temperature on the other hand shows extreme variation, particularly during the period of movement inshore of the O-group, which extends from June to November. In the German Bight for example, the June seabed isotherms show an increasing thermal gradient coastwards which intensifies during July and August. In September this breaks down and there is no thermal gradation in relation to the coast with the whole area having a temperature of about 15°C. During October and November inshore temperatures decline relatively, resulting in a thermal gradient in the reverse direction to the summer one. We found it difficult to visualise how behaviour could be initiated by a cue of such complexity.

The survey data presented here for late O-group and overwintering I- and II-group cod show a clear relationship between low salinity and higher abundances. The significantly higher abundances found at salinities of <31°/oo on the salinity gradients in the German Bight and near the Dutch coast could be a measure of the value of lowered salinity as a cue to the location of the nursery or overwintering areas.

The survival advantage of this distribution to cod could be that it tends to provide better feeding conditions or a direct physiological gain from the lower salinity environment or the lowering of predatory pressure on cod or a combination of them all.

The analysis of the cod stomach contents in February on the salinity transects over the salinity range of 30.5-34.3^{o}/oo showed no trend in the degree of stomach fullness, the feeding indices averaging 1.6, equivalent to 40% full in the I-group, and 2.13, equivalent to 53% full in the II-goup. This indicates that there was no apparent improved feeding conditions in lower salinities over the range sampled.

Our studies could not explore the second possible survival advantage being the direct physiological advantage resulting from reduced energy used on the osmotic control of body tissues.

The distribution analysis and the feeding studies presented here combine to support the third option, that of the reduction of predation on young cod by their congregation in shallow, low salinity areas. The distribution of the age groups of cod in relation to depth (Fig. 2) shows some separation of the ages between I- and II-group but a clearer separation between I- and >II-group. This separation becomes even clearer when the cod distribution is related to salinity (Fig. 3). The stomach analysis (Table 1) shows no gadoids taken in either area by I-group cod and only very low percentages of gadoids taken by II-group cod (0.4 and 0.5%). It is only in the older (>II-group) cod that gadoids form a significant part of the diet, rising to 11% on the Dutch coast. Any reduction in the numbers of these older cod which is effected by a behavioural response to shallow water or more likely low salinity would directly reduce the mortality of small gadoids there. Of the gadoids studied, cod would be distributed such that it would benefit most.

The studies have shown that a major factor influencing the distribution of young cod after metamorphosis is salinity; in this the cod differs from the plaice mentioned earlier. Surveys have shown (Riley et al., 1981) and tagging studies have confirmed (Riley, 1973) that O-group plaice distribution is depth-dependent and is not related to salinity. Young plaice are present in the nursery areas all the year round and the differences in the depth distribution of the age groups are generated by a continuous and progressive spreading into deeper water. The separation of the year classes in the plaice is therefore never as well developed as in the cod. For example, <50% of the II-group plaice are found in the 0-15 m depth zone, which is the depth zone used by almost all the O-group plaice. In cod, however, the salinity-dependent winter distribution effects much greater separation of the fish older than II-group from the I- and II-groups (Fig. 3).

The cod stomach content analysis described here shows practically no cannibalism between the two younger age groups in winter. In the plaice, in contrast, some workers have shown I-group plaice to be important predators of O-group plaice in the six months following recruitment to the nursery areas (Riley and Corlett, 1965; Macer, 1967). Any survival advantage to be gained from the inshore depth-related distribution of young plaice seems therefore not to be in the reduction of cannibalism in particular but may be in the reduction of predation generally. It may also be associated with the exploitation of a better food supply generated by wave-induced seabed turbulence in shallow water or a combination of the two and other factors.

Although the reasons behind the distribution of young plaice and cod may differ, cod are found most abundantly in a sequence of water depths, temperatures and salinities during their progress to maturity. These differing conditions when applied to the appropriate age of cod should provide a basis for propagation techniques.

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