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BIOLOGICAL INDICATIONS OF A CHANGE IN NORTH SEA CIRCULATION IN THE 1970's

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ABSTRACT

Abnormal distributions of 5 month-old herring larvae at the end of the 1970's have lead to the hypothesis of a changed North Sea circulation during this decade. The present paper reviews other biological data to see whether more support can be found for this theory.
Results from the ICES herring larvae surveys in the western North Sea show that transport of larvae from Shetland/Orkney towards Buchan was higher in the years 1979-84 than in the period 1972-78.
The large expansion of the sprat stock in the western North Sea in the 1970's may be explained by a reduced loss of larvae due to a decrease in residual currents. The collapse of the sprat stock in 1978-79 coincided with an increased south-easterly transport of juvenile sprat during the winter, and a southward shift of the adult stock.
Results from the Continuous Plankton Recorder Survey indicate that few warm-water oceanic species entered the North Sea around the north coast of Scotland in the years 1974-78, and that this trend was reversed in the following years.
These results support the hypothesis of a reduced inflow of Atlantic water into the North Sea by the Fair Isle Current during most of the 1970's, and a reversal of this trend at the end of the decade.

BIOLOGICAL INDICATIONS OF A CHANGE IN NORTH SEA CIRCULATION IN THE 1970s

A. Corten

1. Introduction

In an earlier paper by this author on recruitment in North Sea herring (Corten, 1984), the hypothesis was presented that the long period of recruitment failure in the mid-1970s was partly caused by a disruption of the transport of larvae, due to a change in residual circulation. Herring larvae are born mainly in the western and northwestern North Sea (Figure 1), and they are carried by the residual currents towards the main nursery areas in the eastern North Sea. This transport takes place between September and March.

During the period 1972-78 a steady series of abnormally low year-classes was produced on all herring spawning grounds in the western and northwestern North Sea (except for 1973 in the northwestern area). An annual sampling programme with Isaacs-Kidd midwater trawls (IKMT), which started in the winter of 1976/77, showed that year-classes 1976-78 were nearly absent from the eastern North Sea 5 months after they were born. Year-class 1979 and subsequent year-classes were all very abundant as 5 month-old larvae in the eastern North Sea. A sampling programme for large herring larvae in the Dutch Wadden Sea showed that the immigration of larvae coming from the western North Sea was minimal during the springs of 1973-79. This absence of herring larvae from the eastern North Sea, as recorded by both sampling programmes, could possibly be explained by a reduction of the normal anti-clockwise circulation in the North Sea.

The purpose of this paper is to consider further evidence for a change in North Sea circulation in the 1970s. Hydrographic data (mainly bottom salinities), reported by Martin, Dooley and Shearer (1984), show that the eastern North Sea in February 1978 was occupied by low salinity water from the central and southern North Sea. This was a very anomalous situation, which indicated a cessation of the eastward transport of the Fair Isle current. The Fair Isle current is the principle means of transportation for the herring larvae born in the Shetland Orkney area (Figure 2). The authors report that similar anomalous situations were encountered in February 1977 and 1979.

So there are hydrographic data to support the hypothesis that the absence of herring larvae from the eastern North Sea in some years of the period under consideration was due to a reduction of the normal anti-clockwise circulation in the North Sea. This applies specifically to the year-classes born in 1976-78. However, the herring recruitment failure in the 1970s started already in 1972, and the results from the monitoring programme for herring larvae in the Dutch Wadden Sea suggest that transport of the larvae had become blocked already by then.

There are no hydrographic data that suggest an unusual circulation pattern in the North Sea in the years 1972-76. Maybe the changes in this period were rather small, and could not be detected by the routine temperature and salinity measurements (which in an area of intensive mixing such as the North Sea often give imprecise information anyway). In this paper attention will therefore be focussed on fish and plankton species, which may serve as more sensitive indicators of hydrographic change.

2. Transport of herring larvae in the northwestern North Sea during September

From the early 1970s onwards, all herring spawning grounds in the western and northwestern North Sea have been extensively covered during the hatching period in September by ICES- coordinated herring larvae surveys. In the course of this month, the oldest larvae are seen to drift away from the spawning grounds, and gradually spread out in the direction of the residual current. A study of the distribution of the oldest larvae might therefore tell something about the strength and direction of the residual current.

In many cases, however, the sampling area doesnot extent far beyond the immediate vicinity of the spawning area. The older larvae therefore cannot be tracked once they leave the sampling area. In other instances, older larvae from adjacent spawning grounds drift into the study area, and cannot be distinguished from local larvae. In this case, the drift of the local larvae cannot be followed either.

There is one area where the method may be used succesfully, and this is the Buchan area off Aberdeen (Figure 3). This area had very little indigenous production of herring larvae until 1983, but older larvae originating from the Shetland/Orkney area were seen to drift into this area in certain years. The ratio between the abundance of older larvae in the Buchan area in the last half of September and the abundance of small larve in the Shetland/Orkney area in the 1st half of September, might serve as an indicator of the residual southward flowing current in the area. The ratio between old larvae at Buchan and small larvae at Shetland/Orkney, however, may be influenced also by the mortality rate of the larvae.

Table 1 presents abundance indices of larvae < 10 mm at Shetland/Orkney and Buchan in the first half of September, together with the abundance of larvae > 15 mm in both areas in the second half of September. Also given are the ratios between big larvae in both areas in the second half of September and small larvae at Shetland/Orkney in the first half of September. Data have been derived from the data base of ICES herring larvae surveys, a copy of which was kindly supplied by the Marine Institute in Aberdeen. The series starts in 1972, and results were available until 1984.

Looking at the abundance of larvae >15mm in the Buchan area, it is seen that the abundance was very low until 1979, when it suddenly increased and remained high for the rest of the period. In the years 1979-81, the older larvae at Buchan must have drifted in from the north; there was very little local production of small larvae in that period. Also in 1982, production of small larvae at Buchan was still relatively low. Starting from 1983 the production of small larvae in this area increased dramatically, and from this year onward the older larvae at Buchan may be either from local or Shetland/Orkney origin.

The increased abundance of older larvae at Buchan in the years 1979 - 82 was not just the result of a higher production of small larvae at Shetland/Orkney. Table 1 shows that the production of small larvae at Shetland/Orkney increased already in 1978, without resulting in an increased abundance of older larvae at Buchan. For the period starting in 1979, the ratio between older larvae at Buchan and small larvae at Shetland/Orkney increased strongly (from an avergae of 0.009 in the years 1972-78 to an average of 0.061 in 1979-84). This can only be explained by an increased southerly transport of larvae, or by an increased survival of larvae born at Shetland/Orkney.

To investigate the possibility of an increased survival, the combined abundance of older larvae at Shetland/Orkney plus Buchan has been compared with the production of small larvae at Shetland/Orkney (Table 1, last column). It is assumed that all small larvae born at Buchan drift out of the area before reaching a length of 15 mm, and that no immigration of big larvae occurs into the Shetland/Orkney region from spawning grounds west of Scotland. The mean survival rate increases from 0.113 in 1972-78 to 0.243 in 1979-84. So, although there was some increase in survival rate between the first and second period, this increase is not sufficiently large to account for the 6-fold increase in the ratio between large Buchan larvae and small Shetland/Orkney larvae. An increased southerly transport of larvae born at Shetland/Orkney therefore remains the most likely explanation.

3. Distribution of plankton indicator species

A change in residual North Sea circulation in the 1970s must have had its effect on the distribution and abundance of a number of plankton species in the North Sea. For the last 3 decades, the most important source of information on plankton distributions in the North Sea is the British programme of Continous Plankton Recorder surveys. A summary of the results of this programme is published each year in the ICES Annales Biologiques (Robinson 1975-1979, Robinson and Budd 1980, Robinson and Jonas 1981-83, Robinson and Hunt 1984, 1985, Roskell 1982, 1983). A review of these summary articles shows that long term changes in circulation were occurring in the 1970s, both in the North Sea and in the adjacent part of the North Atlantic. A summary of relevant quotations from the papers by Robinson is listed below:

1973 - ... but there were few other instances of oceanic plankton in the North Sea.
The distributions of other oceanic plankton (..........) were more restricted than usual, being common only from August to October in areas D5 and C5 (for area divisions see Figure 4).

1974 - Other oceanic plankton (........) were widespread in areas C5 and D5 from April to November, but only a few of these were carried as far north as areas B4 and B5. None of these was found in the samples from the North Sea.

1975 - Such evidence as there is suggests a relatively weak penetration of oceanic water around Scotland: most warm water oceanic species (........) were restricted to areas C5 and D5 from May onwards.

1976 - Most warm-water oceanic species (..........) were widespread in the northeastern Atlantic from May onwards; only P. robusta and Clausocalanus spp.penetrated into the Norwegian Sea and none was found in the North Sea. The evidence from the plankton suggests a weak flow of oceanic water around Scotland.

1977 - Most warm-water oceanic species were scarce in the northeastern Atlantic and restricted to the southern oceanic areas D5 and C5 until October.

1978 - ... and high numbers of Euphausiacea were found in the east-central North Sea (C1) for the sixth year in succession.
Most warm-water oceanic species were restricted to the more southerly Atlantic areas D5 and C5 until August.

1979 - ... although Calanus finmarchicus was present in average numbers in the northwestern North Sea (B2) for the first time in 15 years.
Euphausiids, which had increased in abundance in area C2 over the past five years, returned to average numbers there in 1979.

1980 - A large number of species usually associated with warm Atlantic water was found as far north as area C5 from March onwards, much earlier than usual.
Salpa fusiformes was more abundant and occurred earlier around the British Isles than in any year since 1970.

1981 - Salpa fusiformis was abundant in the oceanic Atlantic and penetrated into the northwestern North Sea in July, and into the west-central North Sea (C2) in August; that is earlier than they have ever been found in this area by the CPR survey. A few species characteristic of warm Atlantic water were present in the southern oceanic area D5 from February onwards (...); in July most of these were present in the northern oceanic area B5, and one of them (Eucalanus elongatus) penetrated into the northwestern North Sea.

1982 - Plankton more typical of warmer waters to the south of the survey area was widespread in the oceanic areas 14 and 5 (corresponding to the former areas D/E5 and B/C5) from March onwards and some penetrated into the northern and central North Sea.

1983 - A large number of species, usually associated with warm water were found in the oceanic areas 14 and 5 from April onwards and exhibited more than usual penetration into the northwestern North Sea.

From this brief review of CPR-data, one can draw 3 conclusions:

a). Warm water oceanic plankton species were restricted to more southerly areas during the period 1973-78.

b). There was evidence of a reduced inflow of oceanic water around the north coast of Scotland at least in 1975 and 1976.

c). After 1979-80 there was a reversal of the long-term trend in distributions that existed throughout the 1970s, with warm-water oceanic species penetrating into the North Sea in increasing numbers.

Plankton data thus seem to support the hypothesis of a long term disturbance of the normal circulation pattern in the North Sea and adjacent waters in the 1970's. During the period 1971-78 the transport of oceanic warm-water plankton species northward along the shelf, and then around the north coast of Scotland into the North Sea was significantly reduced.

The high abundance of Euphausids in the eastern Central North Sea in the period 1973-78 could be related to an increased penetration of Atlantic waters via the Norwegian Deep. In section 5 we shall return to this subject.

4. Sprat in the western North Sea

An abrupt increase in sprat stocks in the western North Sea took place in the early 1970s, and the stocks declined with equal abruptness at the end of the decade. The peak period were the years 1973-78 when more than 100 000 tons of sprat was taken each year from the western central North Sea. The rise and decline of the sprat stocks in the western North Sea have been described by various authors (e.g. McKay 1984, Johnson 1982) but no causal explanation has been given of these developments. The herring/sprat interaction theory has been critically reviewed by this author (Corten, in press), and no evidence was found of a causal relationship between the fluctuations in both stocks during the 1970's.

The residual current hypothesis discussed in this paper offers a very attractive explanation for the above developments in the sprat stocks. To understand the effect of residual currents upon the sprat stocks, a few words have to be said about the biology of the species. Sprat is mainly a coastal species; in winter the adult fish aggregate in coastal areas along the western and eastern boards of the North Sea, where they are subject to various fisheries. The main spawning takes places in the western and northwestern parts of the North Sea, where the sprat spawning areas and season partly overlap with those of the herring. However, despite some overlap in spawning between herring and sprat, the subsequent migrations of the larvae are very different in both species. Herring larvae are going to drift with the southeastern residual current all the way accros the North Sea, to end up in the shallow coastal areas in the eastern North Sea. From here the juvenile herring in their second and third year gradually migrate back to the northwestern North Sea to join the adult stocks in this area.

Juvenile sprat normally lead a less adventurous life. Sprat larvae born in the northwestern North Sea probably grow up in that area and recruit directly to the adult stock in the area at the age of 2 years. If they are carried away as larvae towards the eastern North Sea, they probably cannot make their way back to their place of origin. The hypothesis that sprat larvae may be carried away by residual currents, and thereby get lost for their parent stock was first put forward by Veley (1951) in a study of the effect of wind on sprat recruitment. He supposed that the further the sprat were carried away from the east coast of England during the fry stage, the less they might be subject to the east coast fishery 1.5 years later.

The sprat populations in the western North Sea are probably sustained by the fraction of larvae that is retained in the coastal area, and that grows up along the western side of the North Sea. A reduction in the southeasterly residual current in this area would thus reduce the number of larvae that is disappearing towards the eastern North Sea, and hence increase recruitment to local stocks. Conversely, an increase in southeasterly drift would have a negative effect on sprat stocks in the western North Sea.

An indication that the decline in western sprat stocks at the end of the 1970s was indeed due to an increased southeasterly water transport is provided by the results of Norwegian acoustic surveys in the winter of 1979/80. Aglen and Iversen (1980) describe how the main sprat concentrations in the open North Sea (fish of 0.5 years old and about 5 cm length) shifted unusually far to the southeast between November 1979 and January 1980. They ascribe that to an influx of Atlantic water from the north: both the 35 per mille isohaline and the main sprat concentrations moved southeastward during the same period. A similar shift occurred in the Norwegian sprat fishery.

What Aglen and Iversen considered as an unusually southeastern distribution of 0-group sprat in January 1980 became the normal pattern in the following winters (Iversen, Aglen and Bakken 1981, Johnson, Edwards and McKay 1983). Presumably this was also the normal pattern in the winters before 1971, when sprat stocks in the western North Sea were also at a relatively low level. The really unusual pattern may have been the high abundance of 0-group sprat in the northwestern North Sea, found during the first Norwegian acoustic survey for sprat in November 1979.

Another indication that the decline in the western sprat stocks may have been due to an increase in southeasterly water transport is the chronological order in which the various sprat stocks declined. The stock at Shetland declined from 1978 onwards; this was followed by a decline along the English northeast coast in 1979 and 1980. During this period there seemed to be a southward shift of the inshore concentrations of adult sprat (Johnson 1982). Sprat catches in the southern North Sea temporarily increased, and some catches in this area were taken from grounds not usually fished before (Anon 1981). So the supposed increase in southeasterly water transport at the end of the 1970s could not only have been responsible for a the loss of recruits to the western stocks, but also for the southward shift of the remaining populations.

5. Discussion

If the existence of an abnormal circulation pattern in the North Sea during most of the 1970s is accepted, the question remains as to what caused this anomaly. This author (Corten, 1984) earlier suggested that the cause of the anomaly should not be sought in local meteorological conditions in the North Sea area, which do not show enough persistence over time. A more likely place for the origin of persistent anomalies is the North Atlantic Ocean; with the much higher inertia of its large water masses. Attention was drawn to the fact that the eastern North Atlantic in the 1970s was the scene of a pronounced hydrographic anomaly, which was first noticed from a sharp drop in salinity in the Shetland/Far-Oer Channel (Martin, Dooley, and Shearer 1984).

Admittedly, meteorological conditions over the North Sea were rather abnormal during the 1970s (very mild winters), but it is unlikely that the anomalies in local wind stress could have caused a persistent disturbance of residual currents over a period of 7 years. It is more likely that the abnormal. meteorological conditions over the North Sea were another symptom of the major oceanographic anomaly that occurred over the entire eastern Atlantic (Dooley, pers. comm).

How this anomaly may have affected the North Sea is still obscure. The circulation in the northern North Sea is governed by two major inflows, the Fair Isle Current and the Norwegian Trench Current, and one major outflow, the Norwegian Coastal Current (Figure 2). The Fair Isle Current is essentially a summer, non-wind driven current (Dooley, pers. comm.). This means it cannot be predicted by wind-driven models. The same applies, to an even greater degree, to the Norwegian Trench Current (Dooley, 1984). In the absence of adequate current measurements in the northern North Sea in the 1970s, it is difficult to reconstruct the events that have happened there. Yet there is some hope that more sophisticated models, using wind and density gradients over the entire shelf area, may provide a description of the currents in the 1970s (Backhaus, in press).

An interesting observation in respect of the origin of water masses in the North Sea in the 1970s is the unusually high abundance of Euphausids in the eastern central North Sea in the years 1973-78 (section 3). Euphausids are normally very abundant in the Norwegian Deep area, and an increased abundance in the eastern central North Sea could point to an increased southward transport of these plankton organisms, and the type of water they thrive in.

Going from a description of facts into the area of speculation, one could imagine that an increased influx of water by the Norwegian Trench current would reduce the normal anti-clockwise circulation in the North Sea. Under normal circumstances, the Atlantic water drawn into the North Sea by the

Fair Isle current, after having gone round the North Sea in an anti-clockwise direction, is expelled from the North Sea by the Norwegian Coastal Current. This current is also the route by which water from the Norwegian Trench Current leaves the North Sea. If an increased influx of Atlantic water by the Norwegian Trench Current occurs, all this water has to be transported out of the North Sea again by the Norwegian Coastal Current. This may somehow reduce the capacity of the Norwegian Coastal Current to take on board water from the Fair Isle Current, and in that case, a blocking of the North Sea circulation would occur. Speculative as this hypothesis may be, it does offer a mechanisme by which events in the North Atlantic could affect North Sea circulation in a direct way.

It would be very interesting to further investigate existing plankton and hydrograhic data to see wether more evidence can be found for an increase in the Norwegian Trench Current in the 1970s.

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Table 1. Abundance of herring larvae <10 mm in first half September and >15 mm in second half September at Shetland/Orkney and at Buchan. Numbers in thousand millions.

year	Shetland/Orkney		Buchan			
	a	b	c	d		
	< 10 mm	> 15 mm	< 10 mm	> 15 mm	d/a	(b+d)/a
1972	1054	24	32	3	.003	0.026
1973	1648	74	4	7	.004	0.049
1974	764	148	60	25	.033	0.226
1975	355	36	271	NS*	-	0.112
1976	737	5	0	4	.005	0.012
1977	1544	535	108	12	.008	0.354
1978	4016	47	NS*	2	.000	0.012
1979	3811	611	173	173	.045	0.206
1980	3354	641	18	104	.031	0.222
1981	3845	527	3	304	.079	0.216
1982	2597	623	347	235	.090	0.330
1983	3332	375	3674	187	.056	0.169
1984	1758	471	2328	87	.049	0.317

NS= no sampling

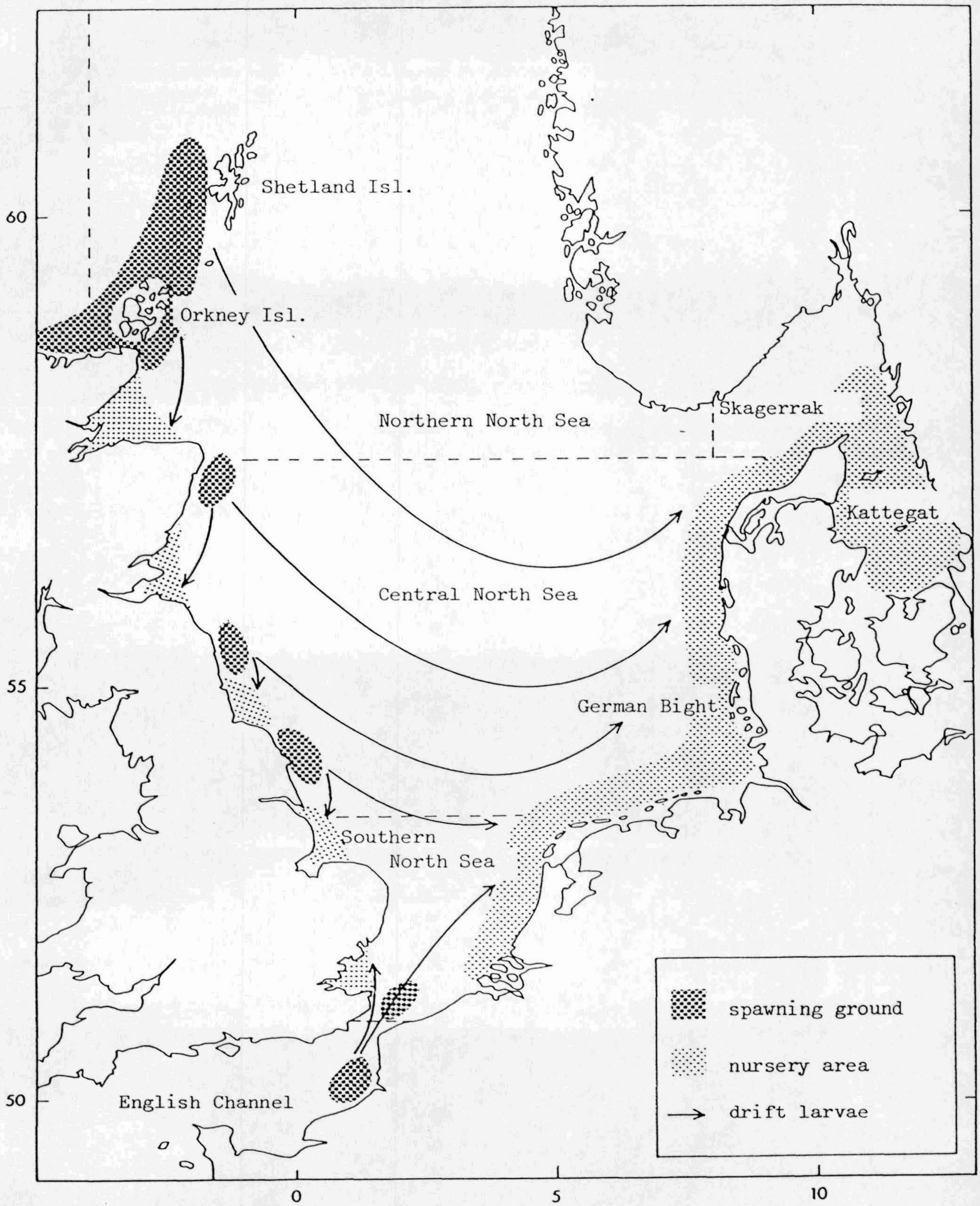

Figure 1. - Herring spawning grounds, nursery areas, and drift routes larvae

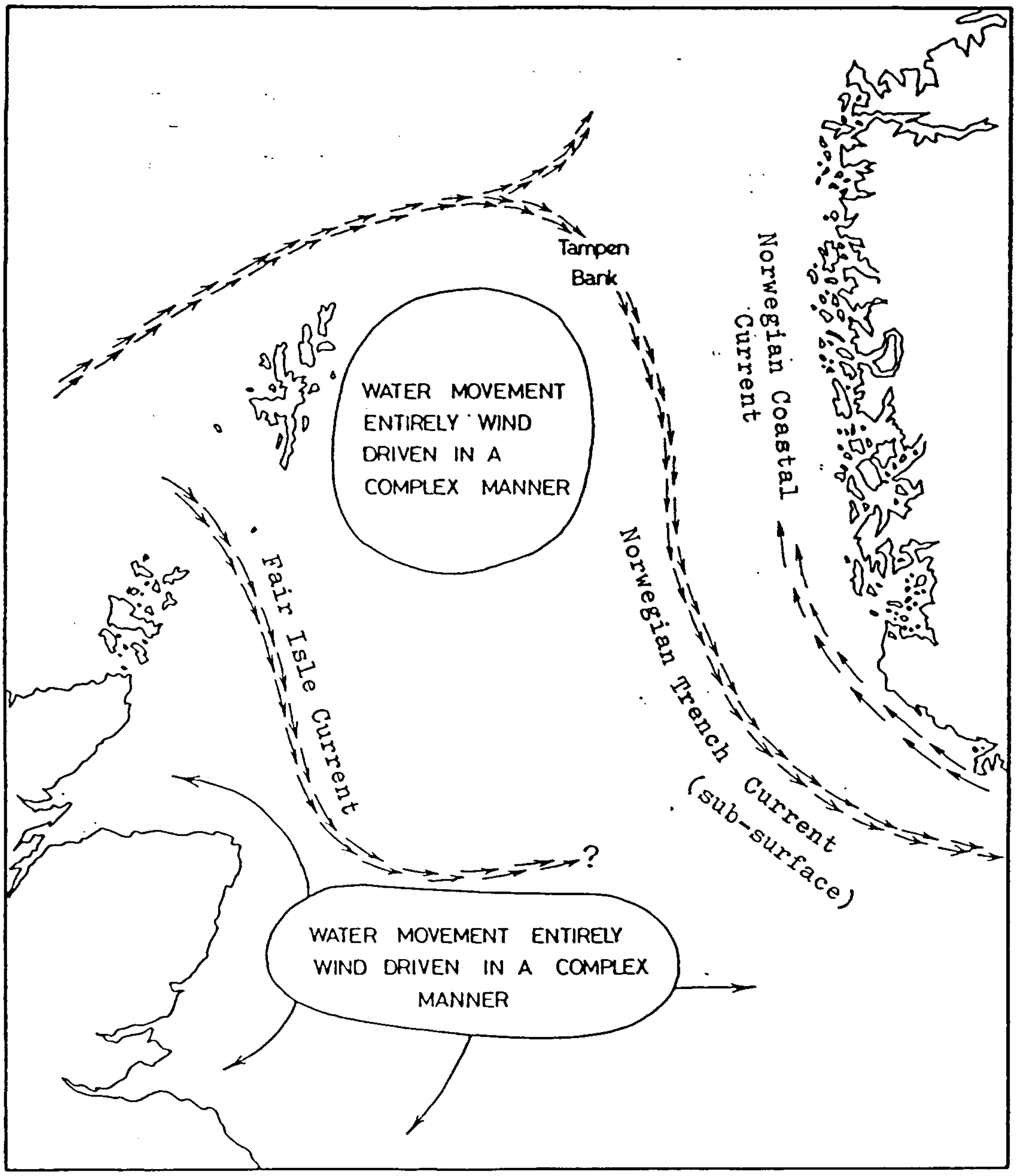

Figure 2. - Residual currents in the northern North Sea (after Dooley, 1974)

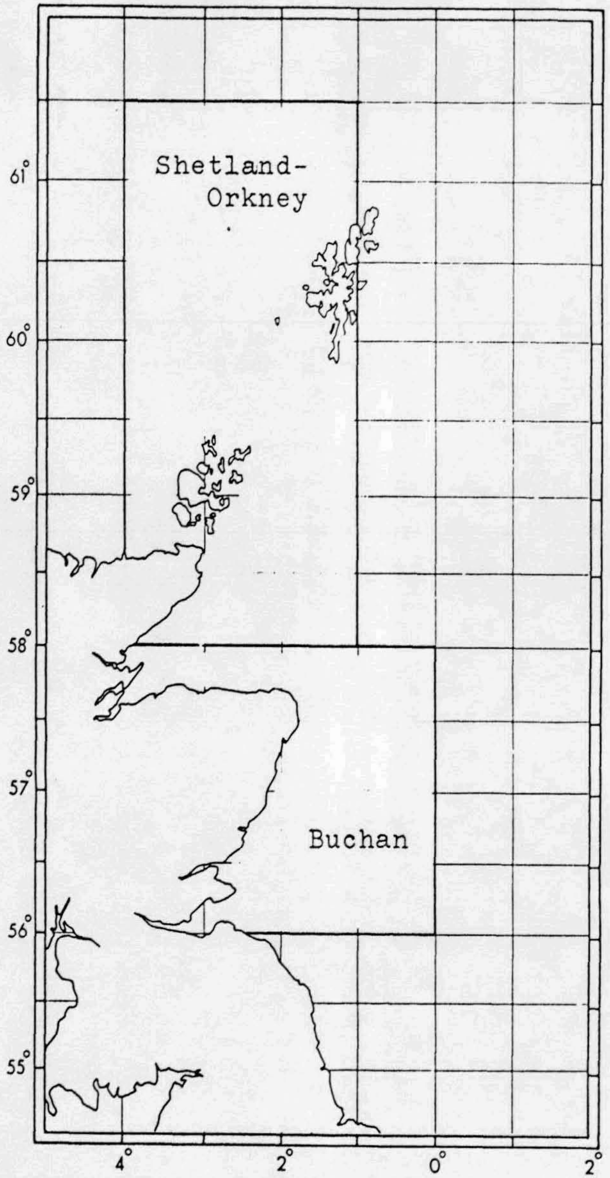

Figure 3. - Sampling areas for herring larvae during ICES Surveys

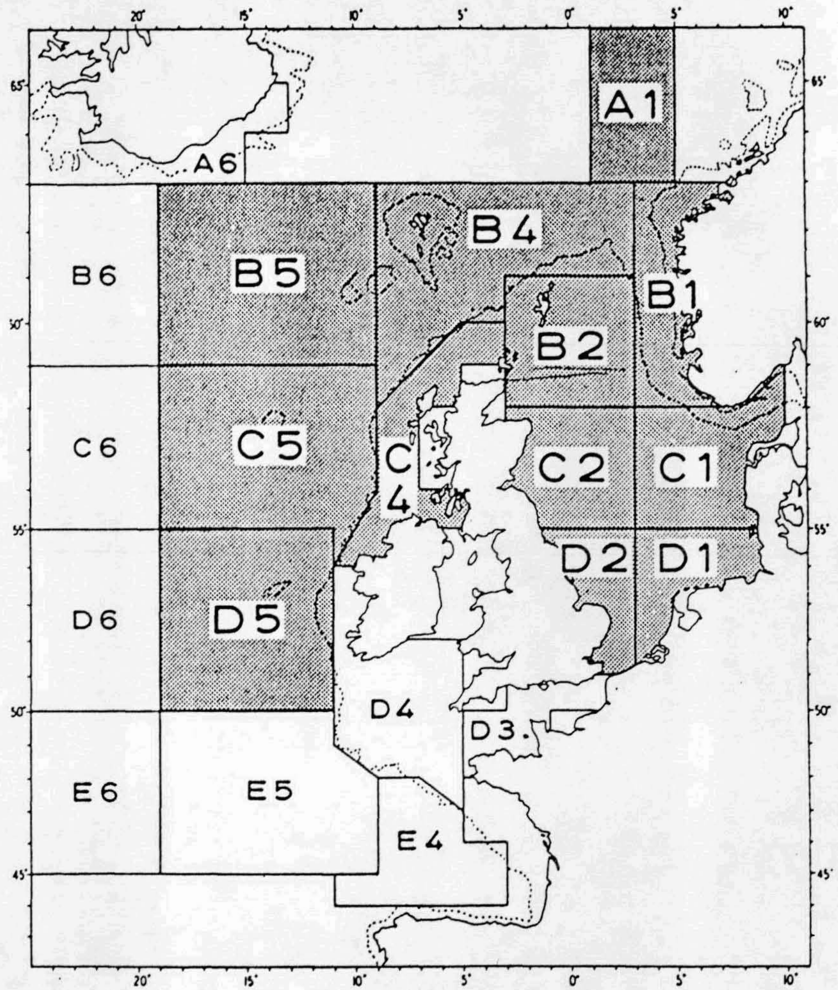

Figure 4. - Sampling areas for the Continuous Plankton Recorder Survey