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Studies of a larval herring (*Clupea harengus* L.) patch in the Buchan area. I. The distribution of larvae in relation to hydrographic features

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Abstract

The distribution of herring larvae (*Clupea harengus* L.) in relation to the hydrography of the Buchan region was recorded in September 1984. Larvae were found to be concentrated in the transition zone between thermally mixed and stratified water. This transition zone ran roughly north-south and was located between 0 and 1°W. Only weak horizontal temperature differences were observed in surface waters but these were more marked in bottom waters (east-west temperature difference ca. 2.5 °C). Patches of larvae moved south along this transition zone during the period of study. Review of existing literature suggests that the hydrographic conditions recorded were typical for this area and season. Although the association between the distribution of larvae and this thermal transition zone has not previously been noted, herring larvae survey data suggests that it is a recurring phenomenon.

Introduction

In 1982, Iles & Sinclair drew attention to the apparent association between the location of spawning grounds of Atlantic and North Sea herring and isothermal waters found near boundary zones or 'fronts' between well mixed and stratified waters as predicted by the Simpson-Hunter (1974) stratification parameter. From this observation, Iles & Sinclair went on to hypothesize the existence of 'larval retention areas' (geographic regions having specific oceanographic characteristics) and to discuss the possible significance of such regions in maintaining discrete herring stocks.

Since then, a number of studies have indicated that the distribution of larvae of a number of fish species may somehow be related to the occurrence of frontal zones (Grimm 1983, Bolz & Lough 1984, Boyle *et al.* 1984). However, it is still not clear how this association of fish larvae with frontal regions may affect the ecology of the larvae.

Phyto- and zooplankton distribution and activity in the vicinity of a number of thermal fronts have been extensively studied in recent years (for references, see discussions by Holligan *et al.* 1984, and Richardson *et al.* 1985). Although it is still not possible to describe exactly the biological and physical interactions which occur in frontal regions, it does seem that the apparent juxtaposition of spawning grounds and thermal fronts could have significance with respect to the ultimate distribution of larvae and/or to the food availability to first-feeding herring larvae.

The purpose of this study was to investigate a patch of newly hatched herring larvae with respect to the biology of the larvae and to their distribution in relation to local hydrographic features. In addition, the distribution and production of phyto- and zooplankton were also recorded in the vicinity of the herring larvae patch. The results of the study will be presented in four parts dealing, respectively, with

1. the distribution of the larvae in relation to hydrography (present paper)
2. a detailed account of the patch(es) of larvae including identification of discrete cohorts (Munk *et al.* 1986)
3. chlorophyll-*a* distribution and primary productivity in the study area (Richardson *et al.* 1986) and
4. zooplankton distribution and egg production in the study area (Kiørboe & Johansen 1986)

Hydrography of the study area

The study was conducted in the Buchan area, a region which is known as a herring spawning ground and where annual autumn surveys of herring larvae distribution have been carried out by these and other laboratories for a number of years (ICES: International Herring Larval Surveys). According to Pingree & Griffiths' (1978) model, which predicts the location of thermal fronts created by the interaction of heat input and tidal mixing around the British Isles, this region may be expected to experience thermally mixed near coast waters and stratified offshore waters during summer months. This stratification would be expected to become established during the spring, intensify during the summer months and erode in the autumn (Simpson & Bowers 1981). This pattern has been observed in the Buchan area by a number of workers.

The seasonal variations in North Sea water column characteristics were first reviewed by Smed (1954). He produced monthly charts showing the mean difference between surface and bottom temperature and salinity in 1° by 1° squares for the period 1904-1948.

Based on this analysis and subsequent analyses (see Lee 1980 and annual records of hydrographic data presented in Annales Biologiques), the seasonal changes occurring off the north-east coast of Scotland can be described in terms of 4 periods of different characteristics.

During the winter period (December-February), large areas of the north and central North Sea are characterized by warmer water at the bottom than at the surface. However, by March, the water column over the whole area is generally isothermal. During summer (April-August) thermal stratification develops over the entire region. This stratification can extend nearly up to the Scottish coast during periods of calm weather in July. Throughout this summer period, the bottom water below the thermocline remains relatively cold – rarely rising above 9 °C which is only slightly higher than typical winter temperatures of 6-7 °C (Craig 1959).

By September, heat input is sufficiently reduced to allow mixing in the inshore region presumably through tidal stirring and the area of isothermal water adjacent to the coast becomes extended offshore causing a rise in bottom temperature of 3-4 °C. As a consequence, a sharp thermal boundary or front develops although this feature manifests itself primarily in subsurface waters (Filarski 1972, Koltermann 1973, Huber & Becker 1975). This front moves progressively further offshore as stratification is eroded by autumn storms until, by about November, only a small core of deep water in the middle of the North Sea remains thermally stratified.

Another feature apparent from Smed's analysis is that the contribution by salinity difference to the density structure of the water column is most pronounced in the eastern North Sea and is of little significance in the west except in the immediate vicinity of major sources of land runoff. Although horizontal salinity gradients are frequently observed in the north-western North Sea, the water column is generally isohaline in this region and temperature structure is the overriding source of water column stability. This situation is particularly prevalent in the vicinity of Aberdeen and Turbot Banks, off the northeast coast of Scotland (56°30′-57°30′N; 00′30°E-01°30′W).

In this region, surface to bottom salinity differences rarely exceed 0.05 ‰ whilst horizontal salinity gradients are generally less than 0.1 ‰ per nautical mile. Under these conditions, the surface to bottom temperature difference gives a good indication of water column stability.

The Aberdeen Bank area lies south of the area most strongly affected by the inflow of mixed coastal Atlantic waters into the North Sea (which during summer months approx. follows the 100 m depth contour). The distribution in the North Sea of Caesium-137 (Kautzy 1973) derived from effluents discharged into the Irish Sea, and data from JONSDAP 76 (Davies 1983) indicate that the major current flow is south until 57°30′N and then east towards Norway.

Although current streams along the eastern Scottish coast are dominated by the tidal component, occasional strong non-tidal residual currents have been observed which are apparently generated by significant meteorological events (Dooley 1971, 1974a, 1983). The investigations of Dooley & Furnes (1981) indicate that south of approximately 57°30′N, the surface residual circulation is predominantly wind driven; winds containing a westerly component induce a south or southeasternly residual whilst easterly winds tend to generate northerly current. Under conditions of northerly winds, the residual flow is very weak and ill defined.

Additional local variability in residual currents may be a consequence of topographic features (Dooley 1974b) and the seasonally controlled position of the boundary between thermally stratified and mixed waters may also affect current patterns in this region.

Materials and methods

The study was conducted from September 16-29, 1984 aboard the RV *Dana* (Danish Fisheries Ministry).

Temperature and salinity were recorded using a Niel Brown Mark III CTD. From these values, the stratification parameter, Φ, which gives a measure of the mechanical work required to mix the water column, was calculated according to Simpson (1981).

$$\Phi = gh \int_{-h}^{0} (p - p_0)\, z \cdot dz$$

where g = acceleration due to gravity
h = total depth of water column
p = density
p_0 = average density of the water column
z = depth

Herring larvae were collected using a GULF III sampler after the method described by Christensen *et al.* (1983). The GULF III was fitted with an ELEKTRO LLOYD (CTPS) CTD and data received via a cored towing cable.

The study area was surveyed 3 times during the cruise in order to record larval distributions in relation to hydrographic features. In addition, 2 east-west transects were conducted through a patch of larvae. These transect studies were made from 57°19′; 00°18′E to 57°10′N; 01°10°W on 17 September and from 56°55′N; 01° 20′W to 56°55′N; 00°20′E on 24 September. The purpose of these studies was to examine distribution and activity of phyto- and zooplankton as well as fish larvae in relation to the hydrography of the area.

Results

Hydrography: During the period of survey, a marked horizontal temperature discontinuity was observed in bottom waters at about 01°W. The temperature difference at 60 m across this discontinuity on the first survey (September 17-18) was ca. 2.5 °C (Fig. 1a). A less marked discontinuity was also observed in surface waters of this region where the horizontal temperature difference across the study area was only ca. 1-1.5 °C (Fig. 1b). 60 m and surface salinities measured during the study are presented in Fig. 2a & b. The water column was almost completely isohaline over the whole area. Thus salinity has little influence on the vertical density structure over the area and the calculated stratification parameter is almost entirely a reflection of the temperature differences recorded during the survey (Fig. 3). Figs 4a & b show ΔT (surface to 60 m temperature difference) on the first and last surveys of the study area (September 17-18 and September 27-28).

These figures indicate the presence of a thermal front running roughly parallel to the northeast Scottish coast between 00°00′ and 01°00′W. During the course of the study, the boundary between thermally mixed and stratified waters moved eastwards.

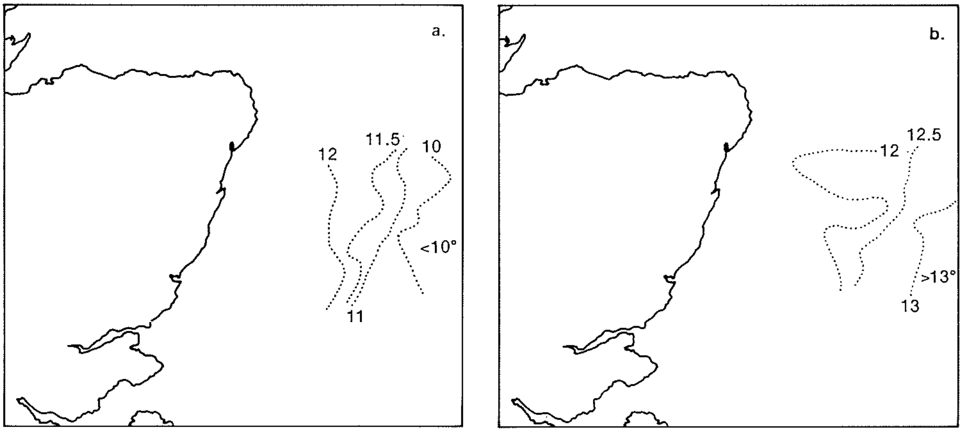


Fig. 1. Distribution of temperature, 17-19 September. a, 60 m; b, 0 m.

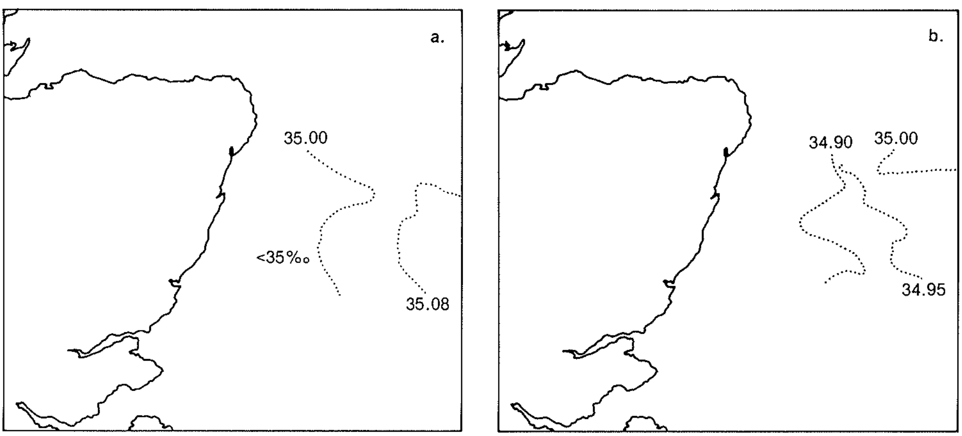


Fig. 2. Distribution of salinity, 17-19 September. a, 60 m; b, 0 m.

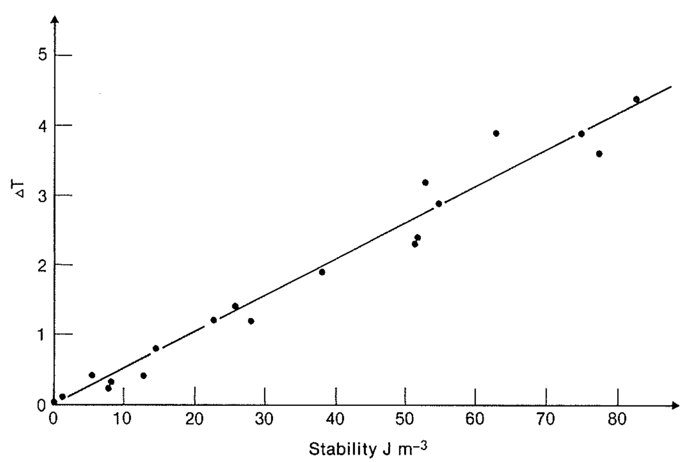


Fig. 3. Surface to bottom temperature difference (ΔT) plotted as a function of the stability parameter, Data taken from transect stations.

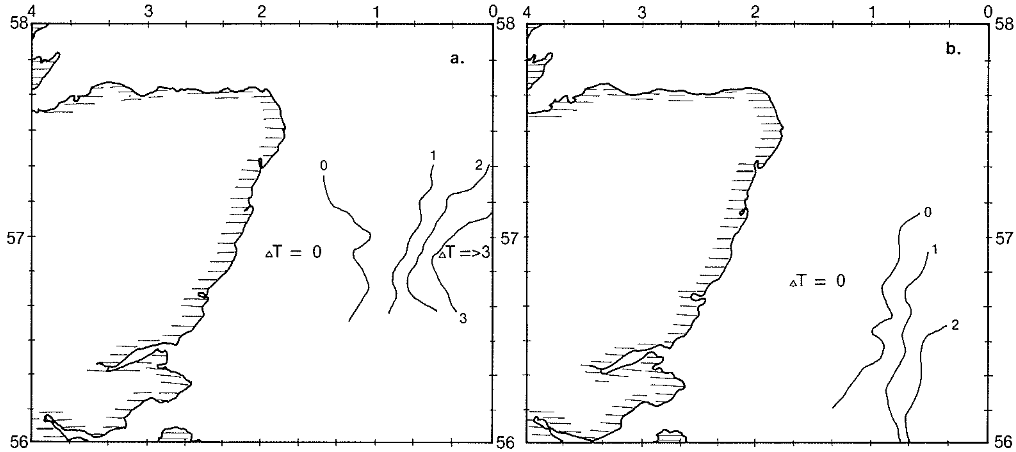
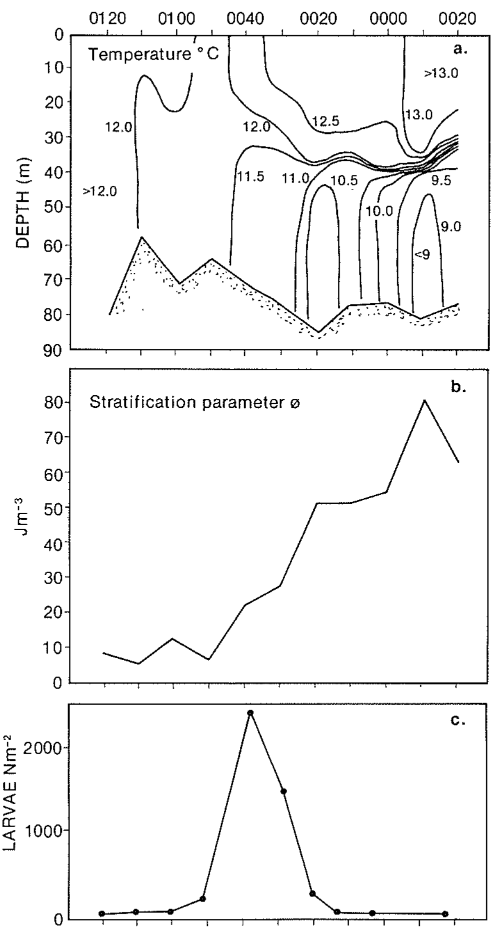


Fig. 4. ΔT distribution over study area. a, 17-19 September. b, 27-29 September.



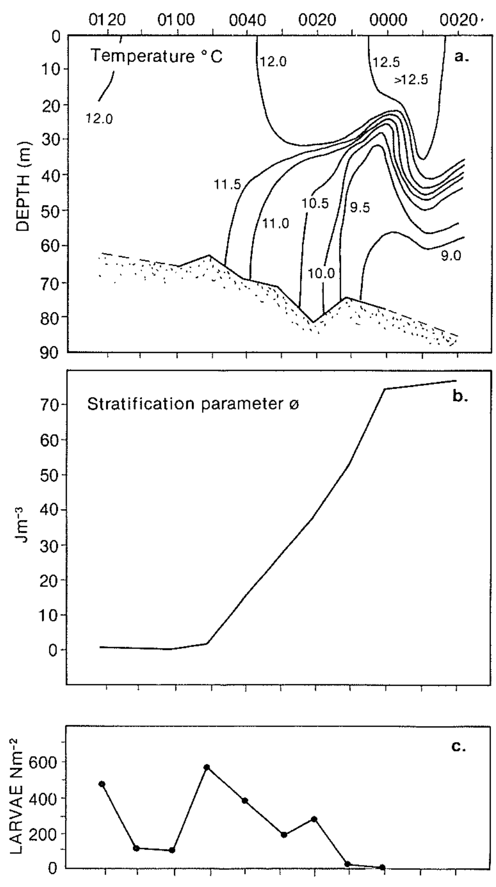


Fig. 5. Transect 1

Fig. 6. Transect 2

a, temperature profile. b, distribution of the stability parameter, Φ. c, occurrence of larvae.

Transect studies: Vertical sections of temperature made along the two transect lines are presented in Figs 5a and 6a. These emphasize the relatively weak surface horizontal temperature gradient evident in Fig. 1. On September 17, the waters to the west of the front exhibited weak thermal stratification but the distribution of the stratification parameter (Figs 5b and 6b) shows a similar pattern for both transects; i.e. weakly stratified water west of 00°40′W and a transitional zone with steadily increasing stratification to the east. These transects suggest that the thermocline became more shallow at the eastern edge of the study area.

On both occasions, numbers of larvae · m^{-2} exhibited a marked peak at stations at the edge of this transition zone (Figs 5c and 6c). However, on the September 23 transect study, an additional peak in numbers of larvae was recorded at the most westerly station surveyed and well into the region of thermally homogeneous water. On the basis of length analyses, these two peaks appear to represent distinct cohorts of larvae; the peak in the isothermal water corresponding to larvae of 7-8 mm in length and that in the frontal region to larvae of 8-9 mm (see Munk *et al.* 1986).

Movement of the larvae patch(es): During the course of the study, the northern border of the region in which herring larvae were recorded moved southwards from about 57°20′ to 56°40′ (Munk *et al.* 1986). The larvae remained in the transitional zone between isothermal and stratified waters throughout the study (Fig. 7). The mechanism of the transport of these larvae is unknown.

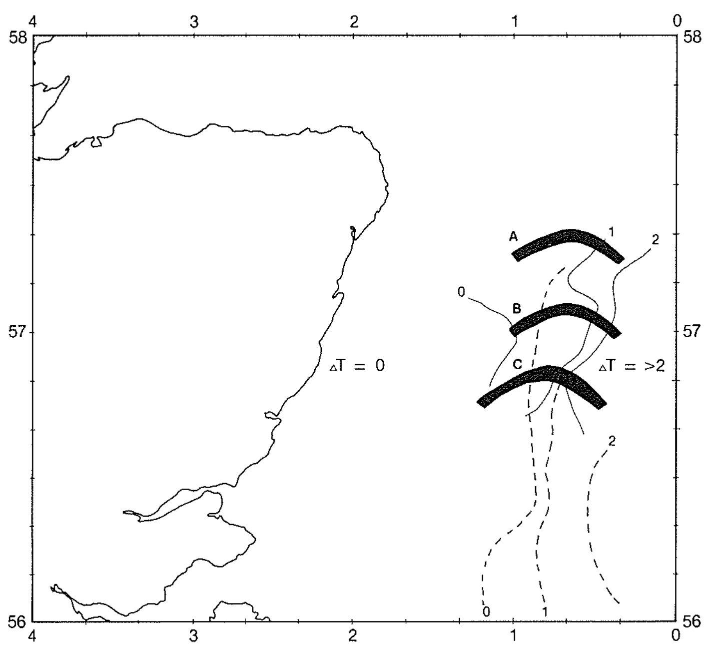


Fig. 7. Northern boundary of >250 larvae · m^{-2} on various sampling dates.

Discussion

In this study, patches of young herring larvae were observed moving south and in direct association with a thermal front or discontinuity in the Buchan area. Before discussing in the following papers the possible significance, if any, of this association between the distribution of larvae and local hydrographic features, it is important to address the question of whether this pattern is unique to 1984 or can be expected to occur regularly in this area.

There seems to be no reason to believe that the gross hydrographic features observed during this study were atypical for this region during September. Smed (1954) reported that the average surface to bottom temperature difference in a quadrat roughly corresponding to our study area in September 1902-1948 was 0.6°C. In addition, a roughly north-south thermal front characterized by small horizontal temperature differences in surface waters compared to those occurring along the bottom has been reported between 00°00′ and 01°00′W during September 1964 (Payne & Craig 1966), 1965 (Payne & Craig 1966), 1970 (Filarski 1972), 1971 (Payne 1973, Heise 1973), 1975 (Hahlbeck 1976) and 1977 (Pastuszak & Wysocki 1978).

This same region was well known as a herring spawning ground for many years prior to the decline of the Buchan herring stock in the late 1960's. Since 1981, there has been an apparent return to this area by spawning herring (see Saville 1952, Anon. 1985, and reports from ICES International Herring Larvae Surveys).

The southerly movement of larvae as observed in this study has also been recorded previously (Saville 1952, Munk & Christensen 1984). Saville's description of larval transport is particularly interesting:

'Drift of the larvae (in 1951) from the spawning centres shows a general tendency to radiate outwards to the south and east. As regards the eastern drift, however, there is no indication of a shift of the centres of density in this direction but merely a dispersion of the fringe of the distribution', pp. 141. The failure of the centres of larval concentration to move eastward in our study is remiscent of Saville's observations and may suggest that the larvae in 1951 were contained in frontal waters. Thus, although no direct connection between the distribution of herring larvae and the thermal discontinuity occurring in this region has previously been made, the indication from the literature is that this may be a regularly occurring association.

The mechanism by which the larvae get into the frontal region has not been considered in this study. The exact position(s) of spawning site(s) near the Aberdeen Bank have never been located so it is not possible to speculate as to whether the 1984 larvae hatched in the frontal area or were transported into it. Future studies should include consideration of local currents in relation to larval drift from spawning grounds and hydrographic features.

The southern movement of larvae along the front during the entire period of this study and Saville's (1952) observation that larvae drifted southwards to the Firth of Forth or further indicate that the larvae remain associated with the front for some time. During our study, the area covered by stratified water apparently decreased as observed by the eastward movement of the transition zone between isothermally mixed and stratified waters. This seasonal degeneration of the front will vary in timing from year to year depending on local weather conditions but we expect total dissolution of the front by about November. In future studies, it will be important to consider what happens to the larvae as the front dissolves and whether the timing of the autumnal breakup of the front is important to subsequent drift and survival of larvae.

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