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PLANKTONIC EVIDENCE FOR IRREGULAR FLOW THROUGH THE IRISH SEA AND NORTH CHANNEL IN THE AUTUMN OF 1954

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(Text-fig. 1)

During the autumn of 1954 plankton samples were taken in the northern Irish Sea and the North Channel from R.V. *Clupea* (Scottish Home Department) as part of a larger survey of the distribution of herring larvae. At the same period similar samples were taken in the central Irish Sea from R.V. *William Herdman* (Marine Biological Station, Port Erin). The present paper concerns the distribution, as shown by both sets of samples, of a few selected species.

I am indebted to all those on both vessels who assisted in taking the samples and to the Marine Laboratory, Aberdeen, for lending me for analysis the samples taken from R.V. *Clupea*.

Methods

In each vessel oblique hauls were taken with a 1 m diameter silk net of 60 meshes to the inch (24 meshes per cm), weighted with a 56 lb (25 kg) iron weight. The relationship between towing depth and length of warp was determined by previous experiment with 'Sealax' sounding tubes. Each haul was taken with the vessel travelling at about 2 knots (3·5 km/h); the net was lowered rapidly to within a few fathoms of the bottom, then hauled steadily at about 9 fathoms (16 m) of warp per minute.

The dates of sampling are shown in Fig. 1 (top left). Within each sub-area shown no pair of neighbouring samples was separated by more than 24 h. Excluding the area to the south of the Isle of Man, all samples were taken within 9 days, and no pair of neighbouring samples was separated by more than 5 days. The stations to the south of the Isle of Man were added after a considerable time lag, so that the samples taken on 14 October were separated by an interval of 17 days from those immediately to the north of them, and the most southerly samples were added another 8 days later. Intervals of more than 7 days between neighbouring samples are signified by broken lines in the three distribution charts (Fig. 1).

The distributions of *Biddulphia sinensis* (Greville), *Sagitta setosa* J. Müller and *Isias clavipes* Boeck are indicated by contouring (Fig. 1). In each chart each contour level is set at 10 times that below it. With the contour levels set at such extremely wide intervals (cf. Cushing, 1953) sampling errors are likely to have little effect on the apparent distributions.

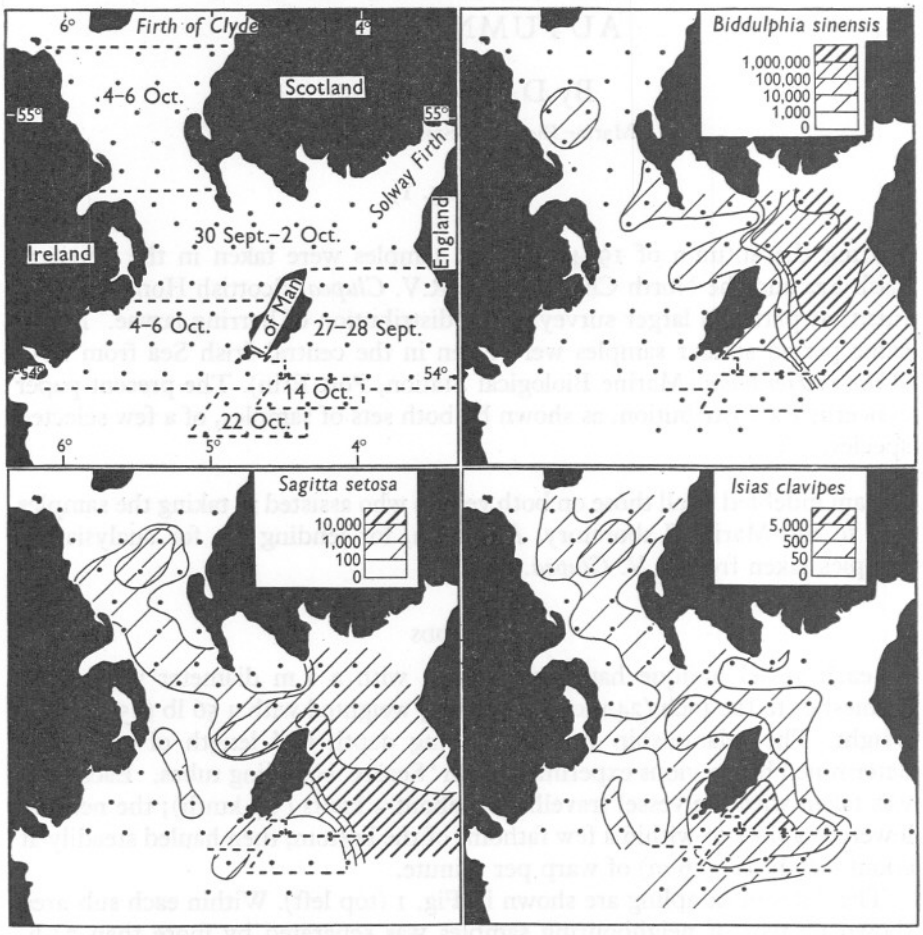

Fig. 1. Top left: North Channel and part of Irish Sea, showing positions and dates of samples. Top right: distribution of *Biddulphia sinensis*. Bottom left: distribution of *Sagitta setosa*. Bottom right: distribution of *Isias clavipes*. Keys relate to numbers of specimens per haul.

Results and Discussion

Results of the present and earlier plankton surveys (Williamson, 1952, 1956) are all consistent with the following generalized picture of conditions in the Irish Sea in the autumn. Water enters the southern Irish Sea from St George's

Channel and carries with it *Sagitta elegans*, large numbers of *Isias clavipes* and smaller numbers of other species including *Centropages typicus* and the late larvae of *Nyctiphanes couchii*. The main flow passes to the east of the Isle of Man, where it comes into contact with water very rich in *Sagitta setosa* and *Biddulphia sinensis*. There is considerable mixing in this region, and the north-flowing water itself becomes rich in *Sagitta setosa* and *Biddulphia sinensis*. Beyond the north of the Isle of Man the flow continues westward and northward into the North Channel. Previous surveys have not extended into the North Channel.

The present results (Fig. 1) show that at the time of sampling in the autumn of 1954 there was an area of water containing relatively high concentrations of *Biddulphia sinensis*, *Sagitta setosa* and *Isias clavipes* near the north end of the North Channel. The regions of maximum local concentration of *Sagitta setosa* and *Isias clavipes* coincided almost exactly; that of *Biddulphia sinensis* was about 10 miles to the south-west, but the patch of this species overlapped with those of the other two. Altogether the distributions of fifteen species were analysed, but only the three mentioned showed local concentrations in the northern North Channel; as other species were not affected, it is unlikely that the concentrations were formed in the region where they were recorded. These same three species also showed considerable similarity of distribution in a lobe extending westward from the north of the Isle of Man, and their concentrations in this area were similar to those in the patch in the North Channel. From the distributions shown in Fig. 1 it appears that the lobe off the north of the Isle of Man consisted of mixed water from the east of the Island, and it seems probable that the patch in the North Channel was of the same origin. The distributions of *Sagitta setosa* and *Isias clavipes* appear to indicate the path that this body of water had followed from the north of the Isle of Man to the northern North Channel.

The fact that the patch of *Biddulphia sinensis* did not quite coincide with the patches of *Sagitta setosa* and *Isias clavipes* may have been the result of uneven horizontal distribution of the three species in the detached body of water, or it may be related to differences in vertical distribution and indicate some shearing of the body of water.

The results also show a distinct patch of *Isias clavipes* off the south-east of the Isle of Man, but the time intervals in the samples make it impossible to estimate accurately its size and shape. Small numbers of *Centropages typicus* and of cyrtopia larvae of *Nyctiphanes couchii* were also present in this patch but otherwise absent from the Isle of Man area. From previous results (Williamson, 1956) the main source of these three species appearing in this region at this season is likely to be in St George's Channel or farther south.

Seasonal and other long-term variations in the rate of the north-going current through the Irish Sea have been previously suggested, but apart from these the flow has been assumed to be fairly regular (see Bowden, 1955;

Williamson, 1956). The distributions recorded in the present paper would, however, be almost impossible to explain in terms of a steady flow. Reasons have already been given for believing that the body of water distinguished in the North Channel was produced by mixing of waters to the east of the Isle of Man and transport of the mixed water so produced. A steady rate of mixing and a steady flow would have produced a tongue of water whose planktonic character changed gradually through further mixing with increasing distance from the north of the Isle of Man. A temporary increase in the rate of mixing would have produced a corresponding increase in the concentrations of *Biddulphia sinensis* and *Sagitta setosa* and a decrease in *Isias clavipes* in the north-going water, because the former two species are introduced into the north-going water by mixing, while the concentration of *Isias clavipes* is reduced by the same process. Similarly, a temporary decrease in the rate of mixing would have produced a corresponding decrease in the numbers of *Biddulphia sinensis* and *Sagitta setosa* and an increase in the numbers of *Isias clavipes* in the north-going water. Only a sudden and temporary increase in the rate of flow from the Isle of Man area could have produced a marked and simultaneous increase in the numbers of all three species in the north-going water by producing a faster moving body of water which would mix less with surrounding water in a given distance and so maintain its planktonic character for a greater distance. It is suggested that such a 'puff' of water was responsible for the local concentrations of *Biddulphia sinensis*, *Sagitta setosa* and *Isias clavipes* recorded in the North Channel.

The patch off the south-east of the Isle of Man containing *I. clavipes* and smaller numbers of *Centropages typicus* and the larvae of *Nyctiphanes couchii* suggests that the flow into the Isle of Man area from the south may also have been irregular.

Salinity measurements are available for all stations except those sampled on 14 and 22 October (Smed, 1955). These show high salinity water off the south-east of the Isle of Man corresponding with the area of greatest abundance of *Isias clavipes*, but they show no patches of high salinity water in the North Channel. As the north-flowing water undergoes sufficient mixing off the Isle of Man to alter drastically its planktonic character, it is not surprising that it should also lose its characteristically high salinity in this region.

On existing information it is not possible to say whether the flow through either the Irish Sea or the North Channel is commonly intermittent. Previous plankton surveys in the Irish Sea (Williamson, 1952, 1956) have given no indication of intermittent flow, but the coverage of the area has never been sufficiently complete to rule out the possibility. Also the sampling area has not previously included the North Channel, and it seems possible that the flow through the North Channel may be intermittent at times even when the flow into the Irish Sea from the south is regular. This could result from a period of south-westerly winds causing an accumulation of water in the Solway Firth

region, followed by the release of the water on a reduction in strength or a change in direction of the wind. (Winds were generally south-westerly throughout September 1954; Smed, 1955.) It may also be relevant that the region off the north-east of the Isle of Man consists of shallow water (much of it less than 10 fathoms, 18 m) and is the meeting place of flood tides from both north and south. These two factors, however, are probably more important in promoting mixing than as temporary barriers to the non-tidal flow.

It is not known how common the occurrence may be, but it is improbable that conditions at the time of the 1954 autumn survey were unique. It seems probable, therefore, that the northward flow through the North Channel may at times consist of comparatively fast-moving pulses of water separated by periods of reduced flow. Under these conditions, each pulse of Irish Sea water seems likely to penetrate much farther north before losing its identity through mixing than the slow average rate of flow would suggest. Bowden (1955) has estimated the mean flow across a section at the southern end of the North Channel to be about $\frac{1}{4}$ mile (400 m) per day, although this figure is likely to be exceeded in parts of the section.

The Irish Sea has been suggested as the source of populations of *Sagitta setosa* recorded in upper Loch Fyne in the Clyde Sea area (Barnes, 1950) and off the Scottish west coast as far north as the Minches (Fraser, 1952). The first of these examples implies the transport of Irish Sea water through about 120 miles (145 km), of which the last 30 miles (48 km) are a narrow cul-de-sac; the second implies the transport of the water through more than 200 miles (320 km). In both cases the Irish Sea origin of the water seems highly improbable if the rate of transport were only of the order of Bowden's figure (see above), but much more probable if the water were transported in pulses travelling at many times this rate.

Summary

The distributions of *Biddulphia sinensis*, *Sagitta setosa* and *Isias clavipes* in late September and early October 1954 suggest that the flow through the Irish Sea and North Channel was intermittent at that period.

Some effects of intermittent flow on the transport of Irish Sea water are discussed.

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