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THE LONG TERM TRANSPORT OF DIURNALLY MIGRATING PLANKTON

by

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Summary

A simple mathematical model is used to demonstrate how transport of plankton in the western North Sea can arise from the interaction of a progressive tidal wave and diel vertical migration. During spring tides high water always occurs at about mid-day and mid-night off north eastern Scotland and low water occurs off eastern England at about the same time. As a result, southerly transports exceeding 100km/month are possible off Scotland between March and July and off England between September and February. At other times small northerly transports occur, against the direction of drift induced by Stokes' correction.

These results suggest that, in the western North Sea at least, plankton will make very poor indicators of water mass distribution.

Introduction

Rae and Rees (1947) among others, have demonstrated how certain species of plankton, eg Metridia lucens, penetrate south down the entire east coast of Britain between July and December. It might seem reasonable to suggest from this that these plankters are responding to a fairly strong southerly transport of water. There is not however any hydrographic evidence to support this interpretation and lagrangian components of tidal flow such as Stokes' drift cannot even approximate the rate of transport implied by the plankton. This suggests two possibilities. Either (i) the plankton is not being transported but is merely reflecting a geographical shift in the season at which conditions allow them to become abundant or (ii) that they are not acting as lagrangian tracers. This paper will deal only with the latter suggestion.

Plankters that vertically migrate cannot of course act as lagrangian tracers. Because of this Hardy (1953) suggests that where there are also vertical variations in currents, plankton distributions may have added complexity. In particular it enables plankton to move on from any particular patch as if 'each tiny creature is given ten league boots to get it striding through the sea'. Recently Riley (1976) developed this topic in a model in which diurnally migrating plankton were drifting in a tidal current which varies with depth. He demonstrated that such an interaction provides a mechanism for the inception of phytoplankton patchiness.

The purpose of this paper is to develop further the ideas of Hardy and Riley, with particular reference to the plankton of the western North Sea. It will be shown that the interaction of vertical migration with the North Sea tide fulfils Hardy's picture of plankton with 'ten league boots' since, at times, horizontal migration exceeding 100 kilometres per month can be demonstrated.

The results of the model presented here rely on the unique character of the tide conditions in the western North Sea and do not in general apply elsewhere. In particular they rely on the fact that during spring tides the maximum flood current (south flowing) always occurs at mid-day and midnight near the latitude of Wick, in northern Scotland and the maximum spring ebb current occurs at the same time off the east coast of England near Hornsea. Because spring tidal currents are at least twice as strong as those at neaps considerable horizontal migration can occur depending on the phase of the tide relative to that of a diurnally migrating plankter.

The Model

As in most models, many simplifying assumptions have been made. As a result the model will only approximate the real world, assuming it has been properly tuned to observed behaviour. The necessary conditions for this model are as follows:-

a. Plankton migrate to the surface layer at sunset, and sink to the bottom layer at sunrise.

b. Sunrise and sunset have been approximated to the nearest hour for each month of the year, using data for Edinburgh which is about half way down the North Sea.

c. The M2 (semidiurnal lunar tide) has an amplitude in the bottom layer of 50 cm/s. The S2 (semidiurnal solar tide) has an amplitude of 20 cm/s.

d. The tide propagates south at about 50 knots (0.3 degrees/kilometre)

e. The surface tide current is 1.8 times stronger than the bottom tide current. This ratio was estimated from unpublished data and is in fairly good agreement with Defant (1961 - Fig. 13/9) at maximum tidal streams.

The assumptions made concerning the tides are reasonably valid for the area within about 100 km of the Scottish East Coast but break down increasingly south of 55°N. A more accurate tidal distribution could be incorporated within the model but the uncertainty in the behaviour of plankton renders this worthless at this stage.

The model was run in the lagrangian frame of reference form making increments every hour. Hence the effect of Stokes' drift is included in the plankton drift. Cumulative monthly displacements were generated and these were plotted for a period of 1 year (Figs 1 and 2).

Because the life cycle of many plankters is limited to a period of say 2-3 months the displacements in Figs 1a and 2 cannot be attributable to one individual, but rather at least during spring and summer, to several generations.

Results

The results presented here are those for runs starting in alternate months. Four cases are considered, for plankton initially off Lerwick (Fig. 1a), Wick (Fig. 1b), Edinburgh (Fig. 2a) and Hornsea (Fig. 2b). The horizontal migration of the modelled plankton all show southerly directed transport averaged over a year but on time scales of a month there is considerable variability from place to place. The migration of the modelled plankton can be described as follows:-

Plankton starting at Lerwick (Fig. 1a) remain relatively static between September and March but by April southerly transport is commenced (spring inflow) and reaching as far south as Aberdeen by September. Plankton present off Lerwick later than July do not penetrate beyond the Fair Isle until the following spring and in fact move northwards during the winter months.

Plankton starting off Wick (Fig. 1b) also demonstrate northerly movements during the winter (specifically between November and March)but once again, by April significant southerly transports are observed, the plankton penetrating the North Sea to beyond Edinburgh by August and Hornsea by November. Indeed plankton off Wick in May shows a continuous southerly drift and has penetrated beyond Harwich by the following May. This is of course completely unrealistic because of the distorting effects of the continental coast at this southerly latitude.

Off Edinburgh (Fig. 2a) southerly transport persists throughout the year and has a maximum in the summer months. In the period June to December plankton can penetrate to as far as the Wash. For plankton off Hornsea (Fig. 2b) southerly transport is limited entirely to the winter months November to January with practically no movement between March and September.

Discussion

Seasonal and spatial variation of plankton migration in the western North Sea can arise from an interaction of tidal currents with vertical migration. As a result the distribution of plankton will not be related directly to the water mass distribution. In the real world this pattern will be more complex than that demonstrated here because the distribution of tides and the vertical migration patterns of the zooplankton is a good deal more complicated than that assumed here. Nevertheless well defined features are apparent which may probably be reflected in the real environment. For example the apparent late summer and autumn "penetration" of mixed water plankton down the east coast is predicted by the model. On the other hand certain features eg the significant "spring inflow" is not so readily related to observed distribution. Is this because of the relative scarcity in the spring of species such as Metridia lucens and Centropages typicus which are normally used by planktologists to trace the "movement" of mixed water towards the central and southern North Sea?

Whilst this paper has restricted discussion to the distribution of plankton its findings are equally applicable to other species, including fish and fish larvae which vertically migrate.

Acknowledgement

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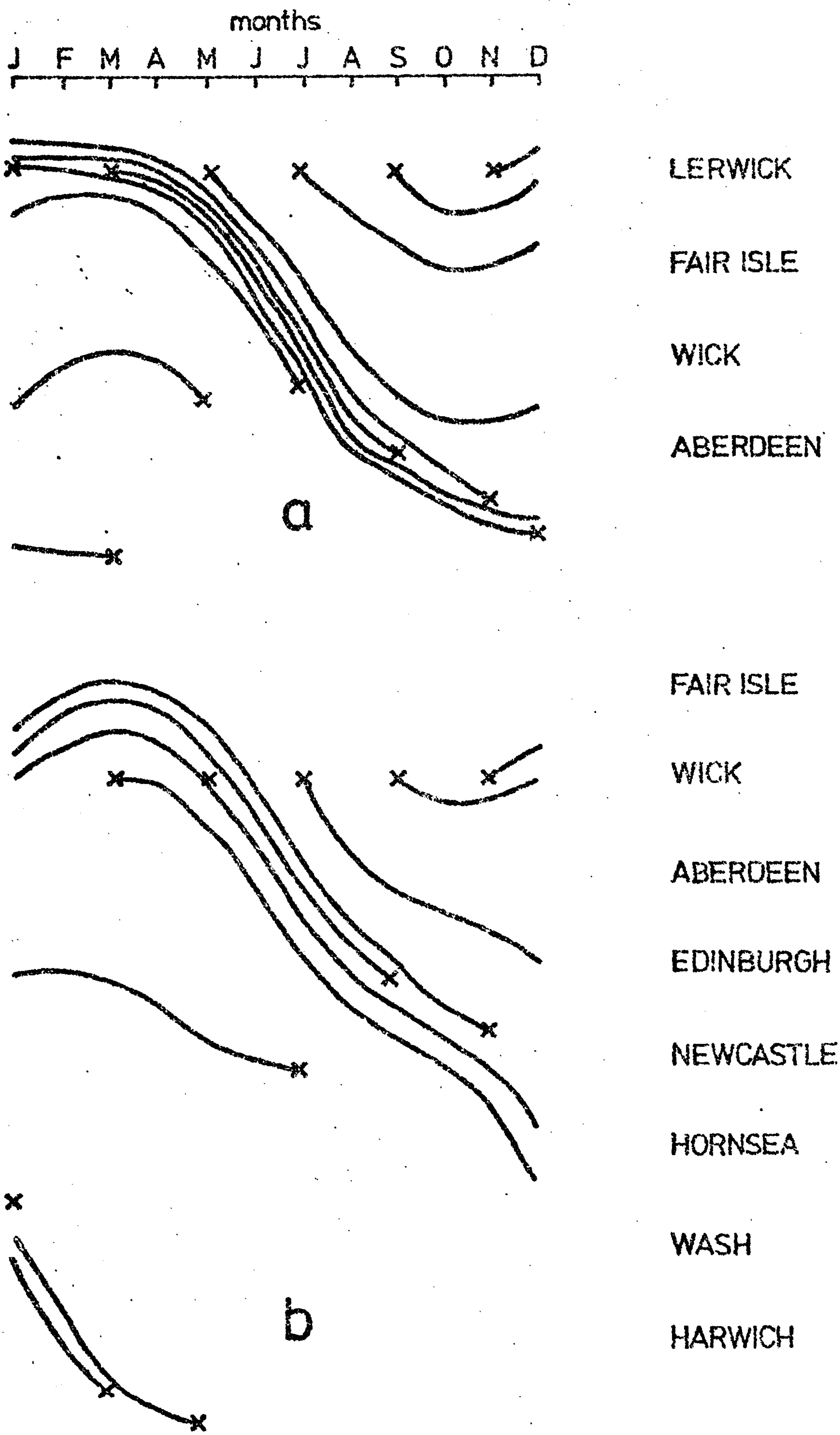

Figure 1. Transport of modelled vertically migrating plankton starting in alternate months at latitude of (a) Lerwick and (b) Wick.

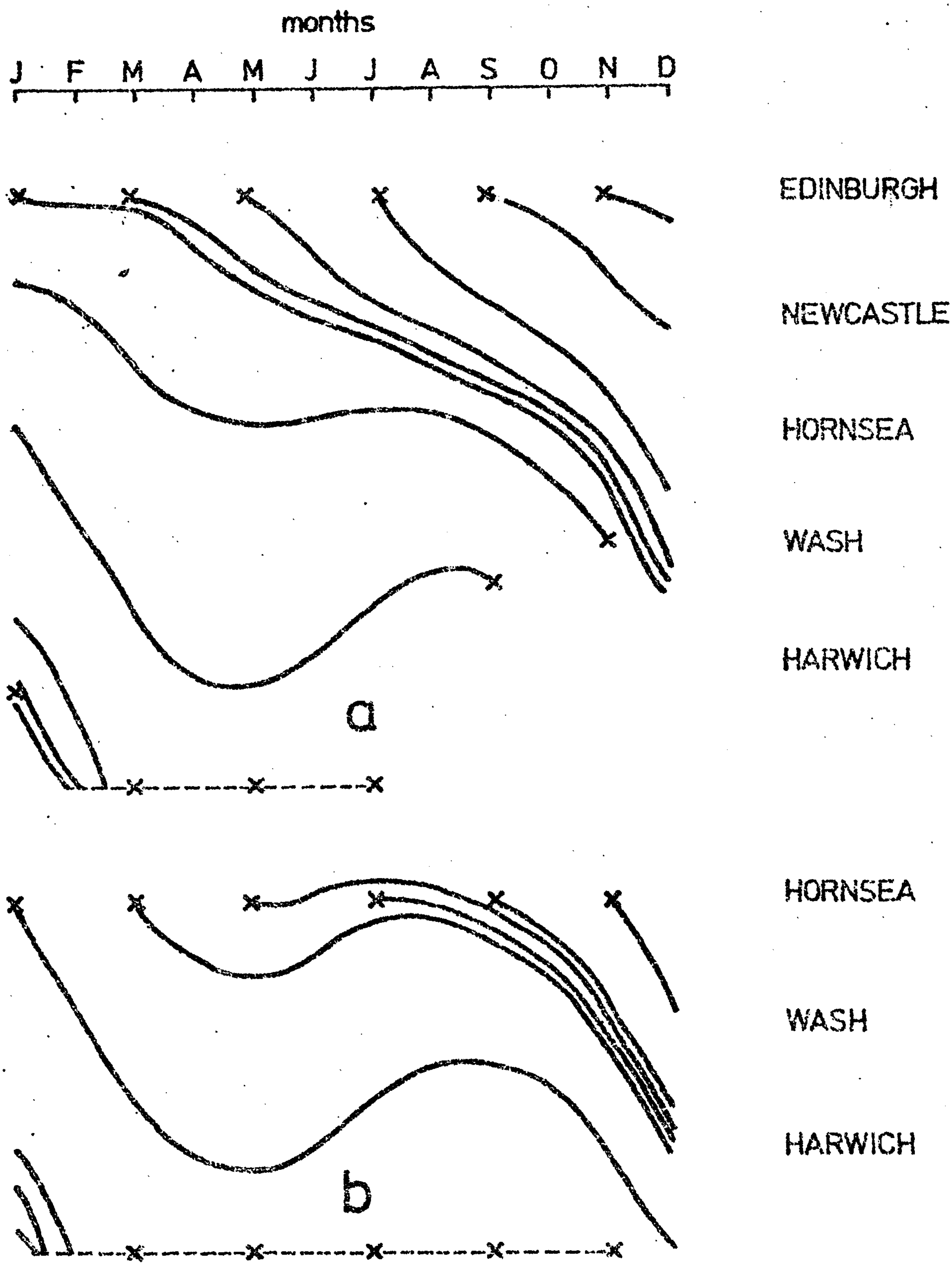

Figure 2. Transport of modelled vertically migrating plankton starting in alternate months at latitude of (a) Edinburgh and (b) Hornsea.