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COCCOLITHOPHORES AND THE CONTINUOUS PLANKTON RECORDER SURVEY

G.C. HAYS*, A.J. WARNER*, A.W.G. JOHN*, D.S. HARBOUR+ AND P.M. HOLLIGAN†

*The Sir Alister Hardy Foundation for Ocean Science, The Laboratory, Citadel Hill, Plymouth, PL1 2PB.
†Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH. ‡Present address: School of Ocean Sciences, University of Wales Bangor, Menai Bridge, Gwynedd, LL59 5EY.

Samples historically collected and analysed by the Continuous Plankton Recorder (CPR) survey were used to describe the distribution of coccolithophores (class Prymnesiophyceae) in the north-east Atlantic and the North Sea. In the routine CPR analysis, members of this group are simply identified as 'coccolithophores' and not to any further taxonomic level. From this analysis, the 200-m depth contour marked a point of distinct transition between high coccolithophore occurrence (off the shelf) and low coccolithophore occurrence (on the shelf). Thirty-three CPR samples that had been collected between 1979–1992, were re-examined and the coccolithophores identified to a more detailed taxonomic level. Among the species identified was the bloom-forming coccolithophore, Emiliania huxleyi. Thus archived CPR samples could potentially be re-analysed to assess regional, seasonal and decadal changes in the occurrence of this species.

There has been considerable recent interest in the biology of coccolithophores (class Prymnesiophyceae), particularly the species Emiliania huxleyi (Lohmann) Hay & Mohler, due to the potential importance of this group in marine biogeochemical cycles (cf. Holligan et al., 1993a). In the oceanic North Atlantic there is a relatively diverse coccolithophore flora which tends to be dominated by Coccolithus pelagicus (Wallich) Schiller and E. huxleyi (Okada & McIntyre, 1979), compared with the North Sea where E. huxleyi alone tends to dominate (Braarud et al., 1953; Holligan et al., 1993b). While these two species have a similar external morphology, they differ markedly in size. Coccolithus pelagicus is the larger species, being up to 32 µm in diameter (Heimdal, 1993), while E. huxleyi is smaller, typically being only 5–8 µm in diameter (Jahnke, 1992; Heimdal, 1993).

Since the advent of satellite imagery the extensive size of coccolithophore blooms, usually consisting of E. huxleyi, has been revealed, with blooms extending over thousands of square kilometres (cf. Holligan et al., 1983). While clearly of great value in providing synoptic views of the overall extent of blooms, there are, however, problems with the interpretation of satellite images. First, the high surface reflectance seen in images is caused not by intact coccolithophores, which tend to absorb light, but by detached coccoliths, with both the ratio of coccolithophores to coccoliths and their absolute abundances influencing the surface reflectance (Groom & Holligan, 1987; Balch et al., 1991; Brown & Yoder, 1993). Coccoliths tend to be shed predominantly in the older, senescent stages of a bloom (Groom & Holligan, 1987) and thus the ability to detect blooms on satellite images may be heavily dependent on the bloom's physiological state. Second, satellite imagery of the sea surface is impaired at visible wavelengths by cloud cover, and so in areas such as the North Sea and north-east Atlantic, where extensive cloud cover dominates, images of the sea-surface may be obtained only sporadically. Third, satellite imagery of blooms has been available only since the launch of the Coastal Zone Color Scanner (CZCS) in 1978, and so there is
only a limited time-series of images with which to examine long-term changes in coccolithophore occurrence. Alternative techniques which could provide multi-decadal data on the basin-wide spatio-temporal occurrence of *E. huxleyi* would therefore be of great value. Such extensive coverage has been achieved by the Continuous Plankton Recorder (CPR) survey. In this paper we examine the potential value of this data-set in describing the spatio-temporal occurrence of *E. huxleyi*.

From 1948 to the present day CPRs have been towed regularly from ships of opportunity in the North Sea and the north-east Atlantic. The CPR survey is currently under the auspices of the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), Plymouth. Continuous plankton recorders are towed in near-surface waters (Hays & Warner, 1993) with plankton being retained on a continually moving band of silk mesh of nominal aperture 270 \( \mu \text{m} \) (Hays, 1994). On return of the recorder to the laboratory, the silk band is cut into sections corresponding to 10 nautical miles (~18.5 km) of tow and then these samples are analysed using standard methods (Colebrook, 1960). Continuous plankton recorder samples are stored in buffered formalin and all the samples collected from 1959 to the present day have been archived and are available for re-examination.

Although the CPR mesh aperture of 270 \( \mu \text{m} \) is much larger than the diameter of coccolithophores, coccolithophores along with other phytoplankton are nevertheless retained, possibly being caught on the finer threads of silk that make up the mesh weave (Gieskes & Kraay, 1977), or as a result of plankton clogging up the meshes and thus reducing the effective filtering apertures. The routine CPR analysis of phytoplankton is conducted under a light microscope at x450 magnification (Colebrook, 1960) with 'coccolithophores' being identified as spherical cells \( \geq 10 \mu \text{m} \) in diameter covered with plate-like coccoliths. Members of this group are not routinely identified by the CPR survey to any more detailed taxonomic level. As a consequence of this analytical protocol, larger species such as *C. pelagicus*, are more likely to be recorded than smaller species, such as *E. huxleyi*. In addition, larger cells may be retained on the filtering mesh with greater efficiency. Thus in areas where *E. huxleyi* is the dominant species, such as in the North Sea, we would expect comparatively few records of coccolithophores in the CPR database. Conversely, in areas where larger species, such as *C. pelagicus*, occur in high abundance, such as the oceanic Atlantic, we would predict comparatively more records of coccolithophores in the CPR database.

To examine these predictions, from the archived CPR database the probability of coccolithophores occurring in different regions was estimated as:

\[
P_{\text{occ}} = \frac{x}{N}
\]

where \( x \) = the number of samples (sections of silk mesh corresponding to 10 nautical miles of tow) on which coccolithophores were found and \( N \) = the total number of samples examined, with the variance of this probability (SD\(^2\)) given by:

\[
SD^2 = \frac{1 - P_{\text{occ}}}{N}
\]

We calculated the distance of each sample from the closest point on the 200-m depth contour of either the European continental shelf or the Icelandic shelf and hence calculated the probability of coccolithophore occurrence in relation to this feature. A very distinct pattern was evident (Figure 1). As predicted from the manner in which the CPR samples are collected and analysed, coccolithophores were recorded relatively rarely on the continental shelf and relatively frequently off the shelf, with the 200-m depth contour marking the inshore limit of their high occurrence.

To examine if *E. huxleyi* could be identified on the archived CPR samples, 33 samples collected between August 1979 and October 1992 in the North Sea and north-east Atlantic on which coccolithophores were identified in the original CPR analysis, were re-examined. The sections of silk were cut into strips, placed in a test tube with buffered formalin, and then shaken in a commercial test-tube shaker (Rotamixer). Material shaken off the silks was then viewed through...
a phase-contrast microscope at x720 magnification. Coccolithophores were identified on 32 out of these 33 samples. The species present were *E. huxleyi*, *C. pelagicus*, *Gephyrocapsa mullerae* Bréheret, *Syracosphaera pulchra* Lohmann, *Caneosphaera molischii* (Schiller) Gaarder, *Calcidiscus leptoporus* (Murray & Blackman) Loeblich & Tappan, *Coronosphaera mediterranea* (Lohmann) Gaarder and *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre, plus holococcolithophorids which were not identified to species.

The ability of the CPR to give quantitative information about organisms that are considerably smaller than the mesh size (270 μm) remains equivocal. For example, the abundance of *E. huxleyi* in the CPR samples may reflect its true abundance in the water, or alternatively may simply reflect the abundance of other net-clogging organisms that dictate the capture efficiency of small species. For *E. huxleyi* this question could be resolved, at least partly, by comparing the occurrence of intact cells and detached liths on CPR samples with the presence/absence of *E. huxleyi* blooms on satellite images.

In summary, both the method of routine CPR sample analysis and the spatial distribution of coccolithophores in the CPR records suggest that the historical CPR analysis has been weighted towards recording larger oceanic species such as *C. pelagicus* rather than smaller species such as *E. huxleyi*. However, *E. huxleyi* occurs in the archived samples. Archived samples may potentially, therefore, be re-examined to quantify seasonal, spatial and decadal changes in the occurrence of this species.

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REFERENCES


