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The role of hydrographic parameters, measured from a ship of opportunity, in bloom formation of *Karenia mikimotoi* in the English Channel

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ABSTRACT

Unusually high chlorophyll values (~14 mg Chl m^{-3} at 5 m depth), recorded on a ship of opportunity (SOO) in July 2010, indicated the occurrence of a potential Harmful Algal Bloom (HAB) in the Western approaches of the English Channel. This bloom, located at 49.7°N, 3.2°W was observed *via* complementary datasets. These included data from samples collected for microscopic phytoplankton identification, information from satellite maps to follow geographical bloom development and *in situ* data to identify hydrographic factors related to bloom initiation. The relationships between chlorophyll-fluorescence, temperature, salinity and wind speed were examined. The intense summer bloom predominantly consisted of the dinoflagellate *Karenia mikimotoi* and followed an increase in sea surface temperature (to 18.5 °C). A mid-channel bloom of this magnitude along the SOO route was last seen in 2003. In both years the peak biomass was associated with *K. mikimotoi* blooms, which occurred at the same location and coincided with the least saline, warmest water and lowest wind speeds. This study demonstrates that ships of opportunity are a useful tool to identify and track HAB events through continuous *in situ* measurements and for the frequent sampling opportunities that they provide.

1. Introduction

Intense, spatially restricted summer phytoplankton blooms are common in the Western English Channel (Brand et al., 2012; Holligan et al., 1984; Irigoien et al., 2004; Jordan and Joint, 1984; Pingree et al., 1977). The bloom magnitude varies from year to year and can exceed 100 mg Chl a m^{-3} (Garcia-Soto and Pingree, 2009; Kelly-Gerreyn et al., 2006). They generally occur between 48°N and 50°N and are dominated by the 'red-tide' forming dinoflagellate *Karenia mikimotoi* (previously identified as *Gyrodinium aureolum*) in most years. This species is ecologically significant in the Western English Channel contributing up to 47% of the total annual primary production (Holligan et al., 1983). However, environmental concerns have been raised associating it with fish kills and water column anoxia (Gentien et al., 2007; Satake et al., 2005; Tangen, 1977); for example fish kills off the southern Irish coast (Raine et al., 2001; Silke et al., 2005). Consequently, *K. mikimotoi* can be considered a Harmful Algal Bloom (HAB) species; its many physiological and environmental characteristics have been reviewed (Brand et al., 2012; Dahl and Tangen, 1993; Gentien et al., 2007; Gowen et al., 2008).

In a simplified view of phytoplankton bloom development, bloom events are controlled by a combination of temperature, light and nutrients, which are in turn driven by physical processes (Behrenfield et al., 2006). Although summer blooms are studied extensively the controls on their timing and intensity are less well understood (Brand et al., 2012). Blooms of *K. mikimotoi* have been observed in the Bay of Brest (Morin et al., 1989) with the first appearance of cells in May and population increases in stratified stable conditions. In the Western English Channel *K. mikimotoi* blooms dominate in conditions of decreased wind and increased sea surface temperatures (Garcia-Soto and Pingree, 2009). Likewise Widdicombe et al. (2010) linked intense *K. mikimotoi* dominated blooms, of 2 to 5 week duration, to warm stratified conditions at the L4 site in the English Channel. The *K. mikimotoi* cells are fragile and slow growing, however they may have a competitive advantage over other species through diel migration and allelopathic effects (Brand et al., 2012). The development of large *K. mikimotoi* blooms is a function of both biological factors and physical factors such as mixing (Brand et al., 2012; Davidson et al., 2009). Presently, no single group of factors can account for the sporadic spatio-temporal distribution of these blooms and a predictive mechanistic model has not been developed (Brand et al., 2012).

The effects of climate change on the succession of phytoplankton functional groups are generally unknown, especially with respect to potential increases in temperature (Brand et al., 2012; Fu et al., 2012;

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Gollop et al., 2007). In the Irish Sea Harmful Algal Blooms are increasing in frequency (Gowen et al., 2008; Raine et al., 2001). Should species composition move towards more toxic or nuisance species there will be important implications for fisheries and public health (Widdicombe et al., 2010). It is thought that increasing temperature may influence the timing of summer blooms enhancing the growth of dinoflagellate species, such as *K. mikimotoi*; the mechanism of enhanced stratification favouring motile species (Falkowski and Oliver, 2007). In the Western English Channel there has been a 0.5 °C warming over the past 50 years (Smyth et al., 2010). This is seen at the L4 site in the English Channel where dinoflagellate blooms are now starting to occur later in the summer than has been previously reported (Widdicombe et al., 2010).

There is currently a gap in knowledge in tracking the mid channel HAB blooms (as distinct from coastal blooms), identifying the dominant species and seeing how they are influenced by the hydrography. In this study we investigate the summer dinoflagellate blooms in the Western English Channel in 2010. The extent of the bloom is mapped using satellite data while discrete samples, taken from a ferry platform, identified *K. mikimotoi* as the dominant species in the mid July bloom. We examine the spatial and temporal variability of chlorophyll-fluorescence in relation to hydrographic measurements made from a ship of opportunity (SOO) operation using a Ferry-box (Bargeron et al., 2006; Hartman et al., in press; Hydes et al., 2003; Kelly-Gerreyn et al., 2006). A 'time series' extracted from the Ferry-box dataset in the English Channel (49.7°N, 3.4°W) provides temporal coverage at the peak of the *K. mikimotoi* bloom while spatial context is provided by satellite data. *In situ* data includes cell counts, species identification and direct measurements of salinity and oxygen. We also consider the role of meteorological and tidal factors on the intensity of potentially harmful *K. mikimotoi* phytoplankton blooms in the Western English Channel.

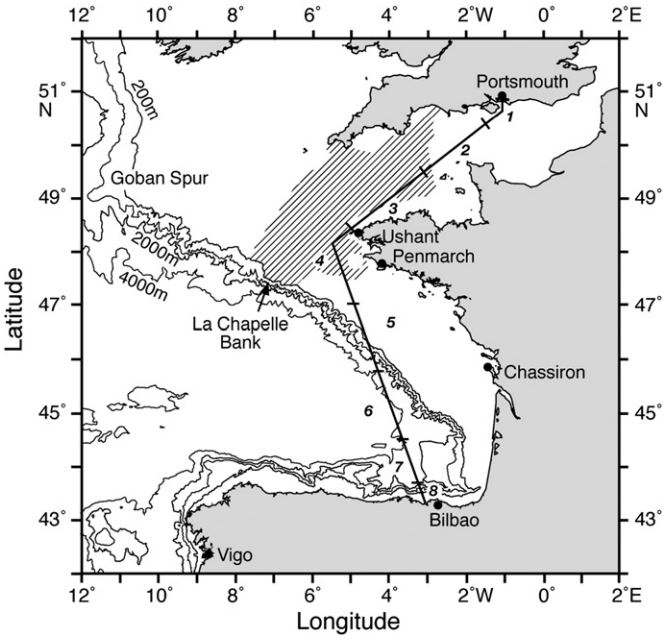

Fig. 1. Idealised ferry route divided topographically into regions 1–8 following Bargeron et al. (2006). Of relevance are regions 2 (shallow, mixed 30–60 m central channel, S < 1); 3 (shallow, summer stratified western channel) and 4 (the western approaches near the French coast at Ushant (30–130 m). The hatched area shows the extent of transitional values (2 > S > 1) for the stratification parameter, S (Pingree and Griffiths, 1978).

2. Materials and methods

2.1. Area of study

Fig. 1 shows the idealised route of the Pride of Bilbao (PoB) ferry (P & O European Ferries Ltd) operating between Portsmouth (UK, 50.8°N, 1.1°W) and Bilbao (Spain, 43.4°N, 3.0°W). The ship made approximately two crossings each week (except for January when the ship was in refit). The northbound tracks are almost identical from month to month and provide consistent data for inter-comparison. In Fig. 1 the route is divided topographically into regions 1–8 following Bargeron et al. (2006). In this paper we focus on complementary datasets from the Western English Channel (48°N to 50°N), particularly in the summer stratified region 3. The stratification parameter (S) was used to distinguish regions 2 to 4 in the Western English Channel (after Pingree and Griffiths, 1978).

2.2. Bloom identification

The location of the summer bloom was identified using a MODIS ocean colour map of chlorophyll in the Western English Channel during July 2010; provided by Plymouth Marine Laboratory. Further maps were used to show the progression of the bloom; chlorophyll for these maps was derived from a merged MERIS/MODIS OC5 product from Ifremer. Sea surface temperature, from OSTIA UK Met Office products, was also extracted and mapped for three successive dates.

The ferry was used as a platform for sample collection, with discrete water samples being collected along the route by scientific personnel at approximately monthly intervals. Sampling was maintained around the clock in both north and southbound transects. Water samples collected for phytoplankton identification and counting by light microscopy were preserved in 100 ml darkened bottles with 2% Lugol's solution. Sub-samples settled in 100 ml settling chambers for 24 h and were examined using an inverted microscope. Large and numerically rare taxa were counted during full examination of the settling chamber (at ×100), while small and numerically dominant taxa were counted on 1 to 2 transects of the chamber (×400) or from cumulative counts of 5 to 10 fields of view. Diatoms and dinoflagellates were identified to genera or species levels. The identification of the species *K. mikimotoi* was confirmed using a molecular biology method similar to a polymerase chain reaction (PCR), nucleic acid sequence based amplification (Ulrich et al., 2010).

Water samples from the ferry were also filtered and analysed ashore using High Performance Liquid Chromatography (HPLC) for phytoplankton pigments (reported in Smythe-Wright et al., in press). Additionally on day 203 (July 22nd), two samples of water were collected by the Environmental Health and Pollution Regulation Unit seven miles to the west of Guernsey; these were sent to CEFAS Lowestoft for species identification using microscopy and cell counts, using a similar method to the one used for samples collected from the ferry.

2.3. Data from the Ferry-box

The ferry was instrumented with a Ferry-box system from April 2002 until the closure of the route in 2010. Each transect measured ~1000 km with a journey time of about 35 h each way, giving a repeat sampling frequency varying from 4 h to 3 days depending on the location. The design and operation of the PoB Ferry-box system was detailed in Hydes et al. (2003) and in Kelly-Gerreyn et al. (2006). In brief the instrument was connected to the ship's cooling water supply which takes water from a depth of 5 m and the flow rate through the system was 15 to 20 l min^{-1}. Chlorophyll-fluorescence (precision 0.01 ± 0.01 mg Chl m^{-3}) was measured using a Turner C3 sensor. The Turner C3 was calibrated by directly comparing its fluorescence values to samples of High Performance Liquid Chromatography (HPLC) measured chlorophyll-a. During the *K. mikimotoi* bloom, in the middle of July