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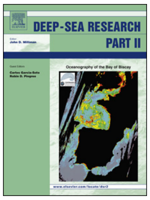

Phytoplankton and pigment studies in the Bay of Biscay and English Channel

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ABSTRACT

During the final year (2010) of the *MV Pride of Bilbao* (PoB) ferry operation between Portsmouth (UK) and Bilbao (Spain) a comprehensive phytoplankton data set was collected based on pigments and taxonomy measurements. The work was in support of the EU project ProTool (http://www.protool-project.eu) that aimed to develop an automated system for measuring primary productivity from ships of opportunity. Not unexpectedly, the biological patterns relate to the hydrographic conditions and in general, pigment distributions are indicative of the taxonomy. A predominately diatom bloom was observed in the Bay of Biscay in April, with a mixed population of diatoms, dinoflagellates and coccolithophores throughout the spring and summer, and a very distinctive bloom, which contained a large proportion of the dinoflagellate *Karenia Mikimotoi*, to the stratified side of the Ushant Front in mid-July.

1. Introduction

Marine phytoplankton are responsible for over half of our planet's primary production. Not only do they form the base of the marine food chain (Fenchel, 1988), but also they provide over 60% of our planet's oxygen (Roach, 2004), regulate the increasing manmade atmospheric carbon dioxide (Bates et al., 2012) and provide a route for its export from the atmosphere to the deep ocean (Yool et al., 2007). Phytoplankton uptake and export to the ocean's interior as organic matter is known as the 'biological pump'. The mechanism lowers the partial pressure of carbon dioxide in the upper waters and facilitates the diffusive drawdown of atmospheric carbon dioxide. Consequently phytoplanktons are fundamental to the health of our planet, but not necessarily *en mass*; species diversity is also important. For example, large chain forming diatoms are thought to contribute the most to carbon export because of their large size and the density of their opaline shells (Karl et al., 2012). On the other hand, the precipitation of calcium carbonate by calcifying organisms (e.g. coccolithophores) increases the partial pressure of carbon dioxide and promotes outgassing from the ocean to the atmosphere, a process known as the carbonate or alkalinity pump, that plays a vital role in maintaining equilibrium in ocean carbon chemistry (Elderfield, 2002). Furthermore, there are numerous species of micro-algae (e.g. dinoflagellates) that are toxic both to marine and human life (Moestrup et al., 2009).

Multiple phytoplankton species appear in marine waters throughout the spring and summer with their relative abundances at various stages of the seasonal cycle depending on localised distributions of the resources required for marine plant growth, in particular, light and the availability of inorganic nutrients. In general, throughout the oceans, diatoms are the first to bloom from March–May due to their tolerance of the turbulent, low-light, spring conditions which occur early in the season. They provide the food source for the many planktonic animals and fish that specifically time the laying of their eggs to match the onset of the bloom. Dinoflagellate blooms often follow diatom proliferations and this has been demonstrated in the western English Channel (Garcia-Soto and Pingree, 2009; Pingree et al., 1975; Pingree et al., 1977). The former mobile phytoplankton are able to "swim" small distances, with the aid of flagella, taking advantage of vertically segregated food sources. Some dinoflagellates provide a food source for planktonic animals during the summer, while others contribute to harmful algal blooms (HABs) that deter grazing and lead to mortality (Ayres and Cullum, 1978; Ayres et al., 1982; Turner et al., 1987; Davidson et al., 2009; Silke et al., 2005). Consequently, any changes in the balance between, for example, diatoms to dinoflagellates may have major effects on biodiversity at higher trophic levels. Furthermore, any alteration in the abundance of calcifying organisms e.g. coccolithophores, may impact the oceans ability to take up carbon dioxide.

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The sensitivity of phytoplankton growth to environmental factors (Behrenfeld et al., 2008) means that, within a particular geographic or climatic region, phytoplankton abundance varies at time scales ranging from a few days, to annual, decadal and millennial. This depends on local conditions such as storms and tides, year-to-year differences in prevailing conditions, climatic oscillations and climate change.

Climate prediction models tell us that phytoplankton communities are liable to change over the next century and could substantially decline (Sarmiento et al., 2004). There is some debate as to whether this is actually happening (Boyce et al., 2010; Mc Quatters-Gollop et al., 2011). Nevertheless, there is clear evidence that as northern waters warm, due to increasing sea surface temperature, there has been a $>10^\circ$ latitude northward shift in plankton blooms with increasing biomass over the past 50 years (Beaugrand and Reid, 2003; Beaugrand et al., 2008; MCCIP, 2010). In addition, the seasonal timing of plankton production has altered with some species appearing up to 4–6 weeks earlier than 20 years ago. The most pronounced effect of an abrupt ecosystem shift occurred in the later 1990s near the 9–10 °C sea surface temperature isotherm. This is a critical boundary between 'warm' and 'cold' water and as water is warming this boundary is moving northwards. The effects of such regime shifts are important for predators. In general, tropical species are small and do not provide a food source for higher trophic levels. They are also considered to be less important in the draw-down of carbon because their small size makes them less likely to sink to depth. In contrast, the release of large amounts of cold, low-salinity water into the North Atlantic from melting Arctic ice sheets and glaciers has introduced the Pacific Ocean diatom *Neodenticula seminae* into the North Atlantic for the first time in 800,000 years (Reid et al., 2007). Although it only crossed over the Arctic Ocean a little over a decade ago, it has already spread into the North Atlantic region.

To understand long-term changes over and above the natural inter-annual variability it is vital to make, on a regular basis, comprehensive measurements that provide a firm footing for extrapolation and prediction. In addition, it is vital to have good, continuously updated, baseline knowledge of phytoplankton communities in shelf and coastal areas so that the effects of human pressures over and above environmental change can be teased out.

Since 2002, the National Oceanography Centre, in the UK has operated a Ferrybox system on the P&O ferry *MV Pride of Bilbao* from Portsmouth (UK) – Bilbao (Spain) taking standard temperature, salinity, oxygen and fluorometer measurements. In 2010, this was augmented with the collection of samples for plant pigment analysis, backed up by samples for microscope counting of phytoplankton species and nutrient concentrations. This comprehensive set of measurements has enabled us to study phytoplankton distributions in the surface waters of the Bay of Biscay and the western English Channel and to compare them with other measurements made at a similar temporal and spatial resolution from the P&O ferry in 2003 and 2004. A companion paper Hartman et al. (2013) provides an analysis of the nutrient supply in relation to the mixing in the Bay of Biscay. Measurements of Sea Surface Temperature, PAR irradiance, wind speed and turbulence and phytoplankton concentration for the years 1997–2007 along the same FerryBox line can found in Garcia-Soto and Pingree (2009).

2. Area of study

The Bay of Biscay (see Fig. 1) positioned on the edge of the NW European continental shelf is open to the Northeast Atlantic on its western edge and bounded by the land masses of Spain to the south and France to the east. To the north lies the shallow Celtic Sea (<200 m), whereas the central part of the Bay reaches depths in excess of 4000 m. To the northeast lies the narrow English Channel that provides a route from the North Atlantic to the North Sea. The hydrography of the two regions and the parameters that influence them has been comprehensively discussed with wind and tide playing an important role. The large tidal currents and shallow water depth (30–70 m) of the central part of the English Channel and along the French coast, maintain a well-mixed water column throughout the year (Pingree and Griffiths, 1978). By comparison, much of the western English Channel and Celtic Sea has weaker tides and greater depth allowing a strong seasonal thermocline to develop during the summer months (Pingree, 1980) with a distinct frontal zone, the Ushant Front, at approximately 3.5°W–4.5°W. To the south along the wide (150–180 km) shelf area south of the island of Ushant (48.46°N, 5.1°W) the waters offshore are highly stratified in summer (Pingree and Griffiths, 1978). In addition, there are tidal frontal regions running along the coast from the Gironde to the Ras de Seine (Pingree et al., 1982) and the central part of the Bay of Biscay also becomes thermally stratified and oligotrophic in summer. Further south the narrow continental shelf ($\sim$12 km) off northern Spain is often eutrophic (González et al., 2003). Both the Channel and the Bay of Biscay are subjected to fresh water input in the summer after the spring bloom in March/April (Garcia-Soto and Pingree, 2009), with the Seine being the main source to the English Channel (primarily the eastern Channel) and the combined estuaries of the Loire and Gironde spreading onto the Armorican Shelf. High discharges, particularly in spring, are known to cause salinity anomalies with distinct low salinity lenses (<35.0) off the Brittany coast (Puillat et al., 2004) which have been further studied and modelled in Laiz et al. (2014).

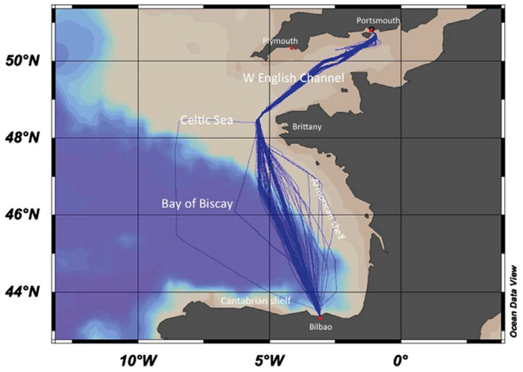

Fig. 1. The route of the P&O *MV Pride of Bilbao* in 2010. The results presented in this manuscript do not include the track to the extreme west of the area, which was necessary due to foul weather conditions.

The P&O ferry route from the UK to Spain passed through both the English Channel and Bay of Biscay and so provided information across a number of hydrographic and biological areas over a variety of temporal and spatial conditions. The route was particularly advantageous in that it was operational all year round and had a repeat rate of 4 times per week on its twice weekly return journey between Portsmouth and Bilbao, thus enabling events such as storms, plankton blooms, salinity anomalies and the effects of stratification to be measured. However, the linear nature of the ferry track constrains the spatial resolution, which is a disadvantage for capturing the variable spatial distribution of summer phytoplankton blooms.

3. Methodology

Personnel travelled on the *MV Pride of Bilbao* at approximately monthly intervals between February and May and then at