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Primary production enhancement in a shallow seamount (Gorringe — Northeast Atlantic)

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ABSTRACT

Gorringe bank is a shallow seamount having its summit within the euphotic layer. The purpose of this study was to test the hypothesis that the interaction of ocean currents with shallow water seamounts, as the Gorringe, has a significant effect on local upwelling and primary production. Three hydrographic surveys were carried out: one in autumn (October 2011) and two in summer (June and July 2012). Physical (salinity, temperature), chemical (nutrients, dissolved oxygen, pH, total alkalinity and suspended particulate matter) and biological (chlorophyll, pelagic primary production and phytoplankton composition and abundance) variables were measured and/or determined in the area of Gorringe Bank, in particular over and around the Ormonde and Gettysburg peaks. Multivariate analyses (PCA and MDS) were applied to environmental and phytoplankton data. Statistical analysis of historical satellite and model data was also carried out in order to analyze local hydrographic conditions and to compare sea surface temperature and chlorophyll concentrations over the peaks and off the peaks in different seasons. Pelagic primary production, measured by Dissolved Oxygen methodology, reached values up to 24.10 mg C m^{-3} h^{-1} in the vicinity of the peaks. Phytoplankton abundance ranged from 2.2 × 10^3 to 14 × 10^3 cells L^{-1}, being the community composed mainly of chain-forming Diatoms like *Chaetoceros* sp., *Dactyliosolen* spp., *Hemiaulus hauckii* and *Pseudonitzschia* spp., in summer months, in zones of high hydrodynamics of the peaks. By contrast, at locations away of the seamount summits and in autumn, Coccolithophores species reached the same or higher percentage in total abundance than Diatoms, being *Discosphaera tubifer* and *Calcidiscus leptoporus* cf. the most abundant species. The combined results indicate the presence of a seasonal effect of Gorringe summits on local upwelling and enhancement of primary production reflected in higher abundance of phytoplankton in the vicinity of the peaks, with emphasis on the Gettysburg, and higher surface chlorophyll concentrations. Therefore, obtained results support the hypothesis of production enhancement.

1. Introduction

Following the definition of seamounts given by Pitcher et al. (2007) as any topographically distinct seafloor feature with, at least, 100 m height, without breaking the sea surface, there may be nearly one million of seamounts worldwide. Seamount research started over 100 years ago (Brewin et al., 2007). Since then, several key questions about seamount ecology were put forward, some of which are still to be answered, such as "what physico-chemical or biotic factors drive the apparent high abundance of life over seamounts?" (Hubbs, 1959). These ecosystems became areas of intensive commercial fishing pressure since the mid-1950s (Brewin et al., 2007) and many of them have been overfished (Fulton et al., 2007). Therefore, there is a need for their management and conservation (World Wild Fund, WWF, 2003; Santos et al., 2009). For example, the Gorringe seamount has been recommended by the World Wild Fund to be included in the OSPAR network of marine protected areas (http://www.ngo.grida.no/wwfneap/Projects/MPAmap.htm).

Traditionally, seamounts have been reported as places of high biological diversity and large abundance of fish and invertebrates.

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Some authors refer to seamounts as "larders" or oases of food (e.g. Pitcher and Bulman, 2007), attracting many species important for fisheries and conservation.

Physical oceanography of seamounts has been extensively studied over the last decades through measurements and modeling. Therefore, their effect upon oceanic currents is relatively well understood (White et al., 2007) through phenomena such as Taylor columns, upwelling and water recirculation processes nearby seamounts (e.g. Mohn et al., 2009). Whereas these processes were initially hypothesized to increase primary production over these ecosystems, obtained data did not support such hypothesis consistently (Genin and Dower, 2007; Rowden et al., 2010). Therefore, other hypothesis were put forward to explain relatively high biomass concentration over seamounts, such as bottom trapping of vertically migrating zooplankton and enhanced horizontal fluxes of suspended food (Genin and Dower, 2007; Hirch et al., 2009; Morato et al., 2009).

According to the last hypothesis, seamount ecosystems depend mostly on organic matter produced elsewhere. Surprisingly, none of the works done so far assessed benthic primary production of very shallow seamounts, such as the Gorringe Bank, in spite of the large amounts of seaweeds, including kelps, known to cover the upper areas of many shallow seamounts worldwide (Graham et al., 2007). Thus, it is yet to establish its potential contribution to support life on these ecosystems. Also, no studies on the composition and abundance of phytoplankton exist so far in the Gorringe Bank.

Recent studies around the Gorringe Bank show some of the effects of its seamounts on water movement. A hydrodynamic model (Coelho and Santos, 2003) applied to circulation and primary production around the ridge, points to the development of upwelling of deep nutrient rich water. Also, according to Bower et al. (1995) and Serra and Ambar (2002), the ridge is a topographic barrier to the flow of Meddies (eddies of Mediterranean water) and tends to deflect them to the west.

Concerning nutrient water status and pelagic production, few studies have been conducted in the Gorringe seamount region. Nutrient data were obtained in the region in 1983 and later on, in 2000 and 2005 (Cavaco and Nogueira, 2005; Cavaco and Pissarra, 2007; Cabeçadas et al., 2010). The respective data revealed a well-developed deep chlorophyll maximum (DCM), normally close to the nitracline, and a euphotic zone of 50–60 m deep. Not far away from the Gorringe seamount and towards southwest Portugal, primary production was measured as well (Cavaco and Cabecadas, 2003).

The Gorringe seamount is placed in a particular situation from an oceanographic point of view, on the northeastern limit of the North Atlantic subtropical gyre (NASG). The main flow in this part of the NASG is the Azores current (AC). Recent studies suggest that the AC formation may be the result of water masses transformation associated with the Mediterranean outflow in the Gulf of Cadiz (Volkov and Fu, 2010). The AC shows an eastward flow and gives rise to several southward branches (Stramma and Siedler, 1988; Klein and Siedler, 1989), being the easternmost feeding the eastern part of the NASG, the Canary current (CC) (New et al., 2001, Pérez-Hernández et al., 2013). Also, the presence of the Portugal Current (PC) can affect the Gorringe area. The PC is a southward flow west of Portugal (Perez et al., 2001; Martins et al., 2002) that interacts in its southern limit with the AC (Perez et al., 2001; Pérez-Hernández et al., 2013). Upwelling filaments off the Portuguese coast may reach a length of 200–250 km within the reach of the Gorringe seamount (Haynes et al., 1993). Cravo et al. (2010) and Rossi et al. (2013) also suggest the potential regional importance of nutrients and chlorophyll exported by upwelling filaments from the Portuguese coast. The last authors emphasized the presence of microphytoplankton in open ocean communities, possibly transported offshore within the upwelling filaments.

Considering the lack of a generally accepted theory relative to the oasis effect of seamounts, it may be speculated that different explanations are more or less appropriate according to the interactions between oceanographic circulation and seamount features. Among these features, summit height is probably of great importance, since it determines to a great extent the presence of benthic primary producers and, possibly, the depth range of upwelling processes. As shallow seamounts have their summit within the euphotic layer (Genin and Dower, 2007) it may be hypothesized that upwelled water may have a stronger effect on the enhancement of local phytoplankton production than in deeper seamounts. Accordingly, the main objective of this work was to test the hypothesis that the interaction of ocean currents with the Gorringe seamount has a significant effect on local upwelling and phytoplankton production as a first step towards a possible generalization across shallow water seamounts. As a way to complement the main objective, this study also provides information on: (i) the magnitude and distribution of physical and chemical variables in the vicinity of the Gorringe Bank, in particular over the Ormonde and Gettysburg peaks; (ii) the pigment component and phytoplankton community composition; and (iii) the pelagic primary production.

The methodology implemented to fulfill the objective mentioned in the previous paragraph combined a limited number of sampling campaigns and an analysis of historical satellite and model data. The current work was part of a larger study to estimate benthic and pelagic primary production over the Gorringe peaks.

2. Methodology

2.1. Study site

The Gorringe seamount is located in the Portuguese exclusive economic zone (EEZ) and it has been visited several times by various scientific expeditions (Fig. 1). It is a shallow volcanic seamount off the southwest coast of Portugal situated between, c.a., 35°46′ and 37°29′ N and 10°14′ and 12°23′ W, that arises from abyssal plains at almost 4200 m depth with two peaks approaching the surface — the Gettysburg and the Ormonde — at, approximately, 20–28 m and 33–46 m depths, respectively. It is enclosed northern and southern by the Tagus and Horseshoe Abyssal plains, respectively. This seamount is composed of recent conglomerates and lava flows with some areas of exposed carbonate rock (Girardeau et al., 1998). It has a large volcanic elliptic shape with a NE–SW orientation, 250 km long and 80 km width (Fig. 1), and is approximately, 270 km off Cape São Vicente, at the eastern tip of the Azores–Gibraltar plate boundary separating Eurasia and Africa (Girardeau et al., 1998). While the Gettysburg has an almost perfectly circular summit, resulting from the blanket of bioclastic sediments over an igneous "core", Ormonde is an elongated summit mainly composed of gabbros and alkaline basalts (Auzende et al., 1982, 1984; Lagabrielle and Auzende, 1982). Several water masses from different origins meet in the study area, being Gorringe an important constraint for Mediterranean Water trajectory and located close to a site of meddy formation (Bower et al., 1995). Some taxonomic data were collected since, at least, 1967 from the Gorringe (http://seamounts.sdsc.edu).

2.2. CTD profiles and water sampling

The results presented in this work were obtained in three sampling surveys carried out in the following periods: 9–11 October 2011, 3–10 June 2012 and 25–27 July 2012. The first and the last surveys were undertaken with the vessel Xunauta, while the second was with the vessel NTM Creoula.

Water samples were collected with Niskin bottles at the surface (s) and at c.a. 40 m depth (d) simultaneously with some of the CTD profiles. In October 2011, four CTD profiles were taken over the Ormonde peak and water samples collected in two of these profiles. In June 2012 three CTD profiles were taken; one over Ormonde and two over Gettysburg. Water samples were collected in Ormonde and in one of the Gettysburg profiles. During the July campaign a total of six CTD profiles were taken as well as water samples — 2 stations at