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Using bio-optical parameters as a tool for detecting changes in the phytoplankton community (SW Portugal)

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ABSTRACT

Upwelling events off the Southwest coast of Portugal can trigger phytoplankton blooms that are important for the fisheries and aquaculture sectors in this region. However, climate change scenarios forecast fluctuations in the intensity and frequency of upwelling events, thereby potentially impacting these sectors. Shifts in the phytoplankton community were analysed from the end of 2008 until the beginning of 2012 by examining the bio-optical properties of the water column, namely the absorption coefficients for phytoplankton, non-algal particles and coloured dissolved organic matter (CDOM). The phytoplankton community was assessed by microscopy, with counts from an inverted microscope, and by chemotaxonomic methodologies, using pigment concentrations determined by High-Performance Liquid Chromatography (HPLC). Results both from microscopy and from chemotaxonomic methods showed a shift from diatom dominance related to bloom conditions matching upwelling events, to small flagellate dominance related to no-bloom conditions matching relaxation of upwelling. During bloom conditions, light absorption from phytoplankton increased markedly, while non-algal particles and CDOM absorption remained relatively constant. The dynamics of CDOM in the study area was attributed to coastal influences rather than from phytoplankton origin. Changes in phytoplankton biomass and consequent alterations in phytoplankton absorption coefficients were attributed to upwelling regimes in the area. Bio-optical parameters can contribute to environmental monitoring of coastal and oceanic waters, which in the case of the European Union, involves the implementation of the Water Framework, Marine Strategy Framework and Marine Spatial Planning Directives.

1. Introduction

Phytoplankton is the basis of most of the marine food web, thus the knowledge of the dynamics of its communities is crucial for understanding shifts in the marine ecosystems. Temporary proliferations of phytoplankton, known as "blooms", are common and natural in coastal environments [Cullen (2008)] and are often due to the nutrient enrichment of the system, either by terrestrial runoff or by wind induced upwelling events. Indeed, areas where these events occur recurrently are known to be among the most productive areas of the world [Smith and Hollibaugh (1993), Loureiro et al. (2008)], and support economically important industries for fisheries and offshore aquaculture (e.g). [Kifani et al. (2008), Rueda-Roa and Muller-Karger (2013)]. However, some phytoplankton blooms can produce undesirable effects such as inducing high mortalities in fish and other marine species, contaminating seafood by algal toxins, and even directly damaging human health, thereby impacting human activities and welfare in the surrounding area [Hu et al. (2014)]. These events are referred to as Harmful Algal Blooms (HABs) and they can be caused either by an excessive proliferation of a specific phytoplankton species, or by those species that produce toxins. Thus, the need for an effective and global monitoring of phytoplankton algal blooms becomes

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evident for ocean management.

The classical studies and monitoring of phytoplankton blooms are based on discrete sampling schemes in limited areas, followed by intensive and laborious laboratory analysis such as identification and counts of phytoplankton by inverted microscopy. More recently, instrumental techniques such as High-Performance Liquid Chromatography (HPLC) and flow cytometry provide useful data to characterise the phytoplankton community in a more rapid and automated way, especially when combined with computational approaches [e.g. CHEMTAX, Mackey et al. (1996)]. The results of these techniques also allow the assessment of the functional diversity of small cell phytoplankton communities (nano- and picoplankton), that are normally classified as unidentified flagellates by the conventional light microscopy technique. This knowledge becomes more relevant since several climate change scenarios forecast a shift in domination from diatoms to smaller flagellates [e.g. Bopp et al. (2005), Leterme et al. (2008)], thereby modifying ecosystem function [Beaugrand (2005), David et al. (2012)]. This theme is relevant in the context of the implementation of the European Union's Water Framework Directive (WFD, [EC (2000)]), Marine Strategy Framework Directive (MSFD, [EC (2008)]), and the Marine Spatial Planning Directive (MSPD, [EU (2014)]), particularly, with regard to the choice of appropriate plankton indicators and metrics used to define the environmental status of the water masses. For example, Garmendia et al. (2013) recognize that the assessment of eutrophication for the WFD is based on only a limited number of indicators, particularly total chlorophyll *a* (TChl*a*) concentration, for which the data is readily available. However, Domingues et al. (2008) warn about using only TChl*a* for the implementation of WFD, especially in areas where nano and picoplankton are important components of the community. Even when composition-based indicators are used to evaluate the ecosystem function [Devlin et al. (2007, 2009)], these only include diatoms, dinoflagellates, and microflagellates (e.g *Phaeocystis* sp.). It is notable that the idea of a shift between diatom to flagellate dominated communities is explicitly considered by the MSFD, i.e. the relative proportions of diatoms and flagellates should be evaluated for Indicator 5.2.4 in Descriptor 5 for Eutrophication [EC (2008)]. In this context, the use of chemotaxonomic methods in combination with the classical methods would be useful to evaluate and characterise Descriptor 5.

Remote sensing of ocean colour is also a powerful tool for monitoring phytoplankton communities, because of its extensive spatial and temporal coverage, and is considered as the best option for observing extensive coastal and oceanic blooms, especially, when the observations are supplemented by direct sampling [Johnsen et al. (1997), Tangen (1997), Cullen (2008)]. Remote sensors estimate chlorophyll biomass by using reflectance ratio algorithms, which strongly indicate that chlorophyll biomass is related to oceanic absorption bio-optical properties [Gordon et al. (1983), O'Reilly et al. (1998), Lyon et al. (2004)]. These algorithms are based on the radiative transfer model [Preisendorfer (1971)], which relates the sea surface reflectance with the absorption and scattering processes in the water column. In addition to the absorption properties of pure water, the total amount of light absorbed in the seawater column is affected by the combined contribution of particulate matter, both from phytoplankton and non-algal suspended particles, and of coloured dissolved organic matter (CDOM) present in this medium [Bricaud et al. (1998)]. In order to improve the accuracy of existing algorithms for ocean colour remote sensing, and for the development of new ones, it is essential to understand the individual contribution of each of these components in different productivity scenarios [Ferreira et al. (2009)].

Remote sensing of ocean colour has been a particularly useful tool to monitor climate change impacts at a global scale [Brewin et al. (2015)]. Climate change scenarios for the western Iberian Peninsula coast present contradictory forecasts for climate alteration: some predict an enhancement of upwelling events [Bakun (1990), Lorenzo et al. (2005), Ramos et al. (2013), Casabella et al. (2014)], and others predict a decrease in the intensity and the number of upwelling events [Lemos and Pires (2004), Lemos and Sansó (2006), Alvarez et al. (2008), Álvarez-Salgado et al. (2008), Alves and Miranda (2012)]. In an area where fisheries, offshore aquaculture, and marine related tourism are the main economic activities, it is important to develop the most appropriate tools to monitor how climatic change could impact the area. In this context, this study has been conducted to test the overall hypothesis that the determination of the absorption properties of the water column could be used to identify upwelling induced changes in the phytoplankton community. In order to test this hypothesis, this article is structured according to the following research questions:

1) Can bio-optical absorption properties be used to monitor phytoplankton blooms?
2) Are the changes in phytoplankton community and bio-optical parameters of the water column related to the upwelling regimes in the area?

2. Methods

2.1. Study area

The Sagres area is located at the southwest of the Iberian Peninsula (Fig. 1). Seasonal upwelling is induced by northerly winds, mainly occurring from late spring to early autumn [Fiúza et al. (1982), Sousa and Bricaud (1992), Cravo et al. (2010)]. Small upwelling events can also be stimulated by local westerly winds [Relvas and Barton (2002), Loureiro et al. (2008)]. Phytoplankton blooms, especially diatoms, have been reported as a consequence of upwelling events in the area [e.g. Goela et al. (2013)], and dinoflagellate presence has been associated with the relaxation of upwelling conditions [Loureiro et al. (2008)]. The anthropogenic pressures in this coastal area are considered to be low, due to limited agriculture, industry, and population, and no major freshwater inputs [Peliz and Fiúza (1999), Edwards et al. (2005)]. Thus, the contrasting primary productivity scenarios shown in Fig. 1, where TChl*a* concentration attains 5 $\mu g\ l^{-1}$ for bloom conditions (Fig. 1a) and lower than 0.5 $\mu g\ l^{-1}$ for no-bloom conditions (Fig. 1b), can be attributed to differences in upwelling conditions rather than to anthropogenic pressure [Loureiro et al. (2005), Goela et al. (2014)]. The main economic activities in the area are related to the utilisation of coastal resources, dominated by the fisheries industry, although in recent years offshore bivalve aquaculture has assumed an increasingly important role [Edwards et al. (2005)].

2.2. Sampling

Three sampling stations were selected at 2, 10 and 18 Km off the coast of Sagres as validation sites for the MEdium-Resolution Imaging Spectrometer (MERIS), the ocean colour sensor onboard of the ENVISAT European Space Agency (ESA) satellite. A total of 31 sampling campaigns were conducted from autumn 2008 until the spring of 2012 when ENVISAT terminated its mission. They were designed to meet the conditions for MERIS data validation [Doerffer (2002), Barker (2011)], by selecting sampling dates with relatively calm sea and clear sky conditions that matched the ENVISAT overpass (Table 1, Fig. 2).

This paper focuses mainly on the data from the coastal Station A (at approximately 37°00′39″N and 8°53′58″W, see A in Fig. 1) as this