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Using remote sensing as a support to the implementation of the European Marine Strategy Framework Directive in SW Portugal

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ABSTRACT

The exclusive economic zones (EEZ) of coastal countries are coming under increasing pressure from various economic sectors such as fishing, aquaculture, shipping and energy production. In Europe, there is a policy to expand the maritime economic sector without damaging the environment by ensuring that these activities comply with legally binding Directives, such as the Marine Strategy Framework Directive (MSFD). However, monitoring an extensive maritime area is a logistical and economic challenge. Remote sensing is considered one of the most cost effective methods for providing the spatial and temporal environmental data that will be necessary for the effective implementation of the MSFD. However, there is still a concern about the uncertainties associated with remote sensed products. This study has tested how a specific satellite product can contribute to the monitoring of a MSFD Descriptor for "good environmental status" (GES). The results show that the quality of the remote sensing product Algal Pigment Index 1 (API 1) from the MEdium Resolution Imaging Spectrometer (MERIS) sensor of the European Space Agency for ocean colour products can be effectively validated with *in situ* data from three stations off the SW Iberian Peninsula. The validation results show good agreement between the MERIS API 1 and the *in situ* data for the two more offshore stations, with a higher coefficient of determination (R^2) of 0.79, and with lower uncertainties for the average relative percentage difference (RPD) of 24.6% and 27.9% and a root mean square error (RMSE) of 0.40 and 0.38 for Stations B and C, respectively. Near to the coast, Station A has the lowest R^2 of 0.63 and the highest uncertainties with an RPD of 112.9% and a RMSE of 1.00. It is also the station most affected by adjacency effects from the land: when the Improved Contrast between Ocean and Land processor (ICOL) is applied the R^2 increases to 0.77 and there is a 30% reduction in the uncertainties estimated by RPD. The MERIS API 1 product decreases from inshore to offshore, with higher values occurring mainly between early spring and the end of the summer, and with lower values during winter. By using the satellite images for API 1, it is possible to detect and track the development of algal blooms in coastal and marine waters, demonstrating the usefulness of remote sensing for supporting the implementation of the MSFD with respect to Descriptor 5: Eutrophication. It is probable that remote sensing will also prove to be useful for monitoring other Descriptors of the MSFD.

1. Introduction

Maritime and coastal activities are expanding rapidly in the world increasing the pressures on the marine and coastal ecosystems (Bertram et al., 2014; Bertram and Rehdanz, 2013). Economic sectors such as fishing, aquaculture, maritime transport, energy production of oil and gas, intensive agriculture together with high population density in the coastal areas are the major economic drivers (Bellas, 2014; O´Higgins and Gilbert, 2014). In

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Table 1
(a) The qualitative descriptors for determining good environmental status for the Marine Strategy Framework Directive (MSFD). The descriptors highlighted in grey could potentially be monitored by remote sensing. (b) List of the indicators for the Descriptor 5: Eutrophication. The indicators highlighted in grey could potentially be monitored by remote sensing and in bold are the indicators that are assessed in this paper.

MSFD Descriptors
Descriptor 1: Biological diversity
Descriptor 2: Non-indigenous species
Descriptor 3: Commercial fish
Descriptor 4: Foof webs
Descriptor 5: Eutrophication
Descriptor 6: Sea-floor integrity
Descriptor 7: Hydrographical conditions
Descriptor 8: Contaminants and pollution effects
Descriptor 9: Contaminants in fish and other seafood
Descriptor 10: Marine litter
Descriptor 11: Underwater noise/energy

Descriptor	Criteria	Indicator
Descriptor 5: Eutrophication	5.1. Nutrients levels	5.1.1 Nutrients concentration in the water column
		5.1.2 Nutrient ratios
	5.2. Direct effects of nutrient enrichment	**5.2.1 Chlorophyll concentration in the water column**
		5.2.2 Water transparency related to increase in suspended algae, where relevant
		5.2.3 Abundance of opportunistic macroalgae
		5.2.4 Species shift in floristic composition such as diatom to flagellate ratio, benthic to pelagic shifts, as well as bloom events of nuisance/toxic algal blooms (*e.g.* cyanobacteria) caused by human activities
	5.3. Indirect effects of nutrient enrichment	5.3.1 Abundance of perennial seaweeds and seagrasses adversely impacted by decrease in water transparency
		5.3.2 Dissolved oxygen, *i.e.* changes due to increased organic matter decomposition and size of the area concerned

recent years, these economic activities provide a number of goods and services that are used directly or indirectly by humans. The sectoral drivers increase the competing usages and pressures on the marine and coastal ecosystems (Borja et al., 2013; Bertram and Rehdanz, 2013).

The objective of the EU Marine Strategy Framework Directive (MSFD) is to enable the sustainable use of marine goods and services and to ensure that the marine environment is safeguarded for the use of future generations (European Commission, 2008). The MSFD establishes a comprehensive structure within which Member States are required to develop and implement cost effective measures to protect and preserve the marine environment necessary to achieve or maintain "good environmental status" (GES) according to 11 key Descriptors by the year 2020 (European Commission, 2008). However, monitoring an extensive maritime area is a logistical and economic challenge, (European Commission, 2008), particularly, for a small country like Portugal with limited resources but, also, with an extensive exclusive economic zone (EEZ). Remote sensing offers the opportunity to assess a large amount of data with both a high spatial and temporal resolution (Pieralice et al., 2014). Table 1a shows which of the 11 Descriptors of the MSFD might be assessed from remote sensing data. For each Descriptor, there are series of Criteria and Indicators that enable assessment of GES. As these Criteria and Indicators are numerous, Table 1b lists only those for Descriptor 5: eutrophication. There is a range of earth observation satellites with different sensors (Johannessen et al., 2000) and it is necessary to identify which satellite products could contribute data to a MSFD Descriptor, by focusing on Indicator(s) for specific Criteria. For example, the key Descriptor 5: Eutrophication could be monitored by remote sensing of the "chlorophyll concentration in the water column" (Indicator 5.2.1) which responds to fluctuations in "nutrients level" (Criterion 5.1). Chlorophyll is considered a proxy for phytoplankton biomass (Boyce et al., 2010) and can be estimated by satellite sensors for ocean colour by measuring light coming from the sea and subsequently retrieving the chlorophyll concentrations with ocean colour algorithms (IOCCG et al., 2008).The objective of this paper is to test how a specific satellite product can contribute to the assessment of GES for a MSFD Descriptor.

The site selected for this demonstration is located off Sagres in SW Iberia (Fig. 1a and b) where there has been a project for the European Space Agency (ESA) to validate the ocean colour products of the MEdium Resolution Imaging Spectrometer (MERIS) located on the ENVISAT satellite with *in situ* measurements (Cristina et al., 2009, 2014; Goela et al., 2013, 2014). The product is Algal Pigment Index 1 (API 1) that corresponds to the total concentration of chlorophyll *a* and its degradation products, and should be useful for assessing Descriptor 5: Eutrophication. API 1 has been selected for this study as it is similar to the standard algorithms used in other satellite missions *e.g.* the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard NASA's Aqua and Terra satellites. The OC4Me is the semi-analytical algorithm developed for MERIS for estimating the API 1 (Morel and Antoine, 2007). The algorithm includes four wavelengths at 443, 490, 510 and 560 nm providing three ratios of spectral reflectances that are used to construct the Maximum Band Ratio (MBR) for the OC4Me algorithm (Morel et al., 2007). Thus, API 1 data is more readily comparable between different ocean colour satellite missions than Algal Pigment Index 2 (API 2), where the latter is specific to the MERIS sensor and the algorithm includes the optical properties of phytoplankton pigments, total suspended matter and yellow substances (Doerffer and Schiller, 2007).

Earlier studies (Goela et al., 2013; Loureiro et al., 2005) in this region have suggested that these waters are essentially dominated by phytoplankton as there are no significant terrestrial inputs supplying suspended matter. Although the potential advantages of remote sensing data for monitoring GES are evident, uncertainties associated with this data have to be understood (Hooker and McClain, 2000). Thus, the validation or "sea truthing" of API 1 with *in situ* data is essential to understand and quantify the quality and accuracy of this data product, including verification of models and derived parameters (Bailey and Werdell, 2006; Cui et al., 2014; Mélin et al., 2007; Smith et al., 2013; Sørensen et al., 2007).

In summary, this paper presents how MERIS API 1 can be