Ecological Indicators 36 (2014) 169–177

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Review

The application of remote sensing for marine protected area management

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ARTICLE INFO

Article history:
Received 20 July 2012
Received in revised form 8 July 2013
Accepted 10 July 2013

Keywords:
Space borne observations
Satellite data
Biodiversity surrogates
Conservation
Coastal habitats
Pelagic habitats
Habitat mapping
Fisheries remote sensing
Monitoring systems

ABSTRACT

Marine protected areas (MPAs) are important tools for the conservation of marine biodiversity but their designation and effective monitoring require frequent, comprehensive, reliable data. We aim to show that remote sensing (RS), as demonstrated for terrestrial protected areas, has the potential to provide key information to support MPA management. We review existing literature on the use of RS to monitor biodiversity surrogates, e.g. ecological (e.g., primary productivity) and oceanographic (e.g., Sea Surface Temperature) parameters that have been shown to structure marine biodiversity. We then highlight the potential for RS to inform marine habitat mapping and monitoring, and discuss how RS can be used to track anthropogenic activities and its impacts on biodiversity in MPAs. Reasons for low integration of RS in MPA management and current limitations are also presented. This work concludes that RS shows great promise to support wildlife managers in their efforts to protect marine biodiversity around the world, in particular when such information is used in conjunction with data from field surveys.

Contents

1. Introduction

Marine biodiversity is under serious threat from anthropogenic stressors, such as fisheries (Worm et al., 2009), pollution from land-sources (Klemas, 2011a) and increasingly from climate change (Greene et al., 2010; IPCC, 2011; Valdes et al., 2009) and ocean acidification (Hoegh-Guldberg et al., 2007). Yet marine biodiversity is key to the provision of many ecosystem services: marine resources were recently estimated to contribute 16.9% of the animal protein for nutrition worldwide (FAO, 2012). Apart from the intrinsic biodiversity value, there are economic arguments for the protection of marine biodiversity (Balmford et al., 2002; Costanza et al., 1997). Habitats such as mangroves are key for coastal protection against extreme flooding events (Costanza et al., 1997; Dahdouh-Guebas, 2006). High marine biodiversity moreover increases the resilience of marine ecosystems against climate change and ocean acidification (Hughes et al., 2007; Wilson et al., 2009). This makes

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1470-160X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ecolind.2013.07.003

the maintenance of marine biodiversity a significant environmental management objective.

Marine protected areas (MPAs) are important tools in the conservation of marine biodiversity (Worm et al., 2009). They can be broadly defined as spatial protection measures associated with varying access and resource use limitations, ranging from gear restrictions to no-take zones (Roberts, 2005). The IUCN defines a MPA as "*any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment*" (Kelleher, 1999). While 13.9% of the terrestrial environment is under protection (Chape et al., 2008), recent calculations by the Marine Reserve Coalition show that only 3.2% of the marine environment is (Marine Reserves Coalition, 2012) – the proportion of this that is effectively protected, is likely to be much lower. This figure falls short of the 10% coverage target to be achieved by 2012 that was internationally agreed under the Convention on Biological Diversity (CBD) in 2006 (Annex IV, Target 1.1, CBD, 2006). It should be noted, that in 2010 the time-frame was revised to 10% coverage by 2020 (Strategic Goal C, Target 11 CBD, 2010), although up to 30% have been called for (Sheppard et al., 2012). Most existing MPAs are located in the coastal zone and in order to realistically reach the 10% target it will be necessary to extend the designation of MPAs to the pelagic realm. Within national Exclusive Economic Zones (EEZs) there are a few recently established MPAs that incorporate the pelagic realm, such as the no-take marine reserve in the British Indian Ocean Territories (Sheppard et al., 2012). Outside of EEZs, however, the status of the High Seas under the United Nations Convention on the Law of the Seas as areas beyond national jurisdiction makes it complicated to establish, manage and enforce MPAs (Druel et al., 2011), with the notable exception of some initiatives by regional organisations, e.g. the multinational conservation organisation responsible for the North East Atlantic (OSPAR) (O'Leary et al., 2012). Meanwhile political progress is being made (Chiarolla et al., 2012); the recent Rio + 20 outcome document specifically requests an international framework for the designation of MPAs outside national jurisdiction to be developed before 2014 (Doran et al., 2012). MPAs have been the subject of intense scientific discussions and improvement of current practices has been suggested by taking into consideration issues including, but not limited to: difficulty of enforcement (Mora and Costello, 2006); indirect trophic effects on species (Fenberg et al., 2012); limited effect on highly migratory species (Hyrenbach et al., 2000; Roberts, 2000); representativeness (Boersma and Parrish, 1999; Fraschetti et al., 2008; Stevens, 2002); capacity for self-recruitment/larvae retention (Bell, 2012; Mora and Costello, 2006); vulnerability to land-based pollution (Boersma and Parrish, 1999); and being inadequate to address detrimental effects of climate-change (Selig et al., 2012). Scientific guidelines for MPA designation are not yet routinely implemented (Rabaut et al., 2009), nor is there an agreed set of criteria for site selection. The ecological criteria reviewed by Salm and Price (1995) are similar to the ones adopted by OSPAR in 2003 (O'Leary et al., 2012) and the indicators for Ecologically and Biologically Significant Areas (EBSAs) (Dunn, 2011; Gregr et al., 2012) adopted by CBD in 2009 (see Appendix, Table 1A). Balancing ecological criteria with social, economic and political considerations is an important aspect of decision making, resulting in a bias towards well studied sites, where strong pro-conservation arguments can be provided (O'Leary et al., 2012) with low opposition by stakeholders (Roberts, 2000). Once designated, being able to monitor a given MPA using scientifically sound criteria and protocols is key in demonstrating MPA effectiveness (Fenberg et al., 2012). While terrestrial and marine ecosystems are obviously different, some of the challenges faced by managers are of a similar nature, e.g. the difficulties associated with the monitoring of large, remote areas without high field data coverage. In particular, as MPAs are being more frequently established in the pelagic realm to increase global representativeness, the issue of designating and monitoring large areas using scattered, selective in situ datasets will become more frequent (O'Leary et al., 2012). It is therefore important to explore whether lessons can be learnt from terrestrial protected area management to inform MPA management.

Remote sensing (RS) has been advocated as being key in supporting the designation, mapping, and monitoring of terrestrial protected areas (Gross et al., 2009; Pettorelli et al., 2012). RS offers repeatable, standardised and verifiable information on long-term trends in ecosystem structure and processes at the global scale (Muller-Karger et al., 2005). RS has been applied successfully to address a variety of questions relevant to environmental management, including, but not limited to: landscape change monitoring (Townsend et al., 2009); habitat indicator derivation (Bommel et al., 2005), representativeness assessment (Armenteras et al., 2003); connectivity monitoring (DeFries et al., 2005); and climate change impact analysis (Pettorelli et al., 2012). There have been numerous notable recent reviews and books on the applications of RS for coastal managers (Klemas, 2011a; Miller et al., 2005; Weng, 2010), coastal biodiversity indicators (Strand et al., 2007), mangrove ecosystems (Kuenzer et al., 2011), seagrass meadows (Dekker et al., 2006; Kirkman, 1996), reef fish management (Hamel and Andréfouët, 2010) and fisheries science (Klemas, 2012). To date, however, there has been no review on the merits and pitfalls of using RS to inform the designation, mapping, monitoring and management of MPAs for biodiversity protection, especially in regions with low in situ data availability. With this review, we aim to fill this gap in knowledge, by providing an overview of the opportunities associated with the use of RS to inform the management of MPAs. This review will start by providing a brief presentation of the physical and biological parameters structuring marine environments and relevant to marine biodiversity assessments that can be derived from RS. The use of RS information to map marine habitats will then be explored, followed by a discussion on the monitoring capabilities of RS to detect and map anthropogenic threats and their potential impacts on biodiversity in MPAs. The review will end by listing existing limitations and highlighting new RS developments relevant to MPA management.

2. Remote sensing to monitor environmental correlates of biodiversity in MPAs

Biological diversity, or biodiversity, refers to the "*diversity within species, between species and of ecosystems*" (CBD, 1992). RS is the derivation of information by analysing radiation received by a sensor. For an explanation of RS terms, see Text 1A in the appendix. The direct observation of individual species is usually not possible using RS information, but biological and physical parameters that are reported to structure biodiversity patterns can be derived from RS data. Table 1 provides an overview of the most important parameters discussed below, as well as examples of satellite sources.

The monitoring of primary productivity to support terrestrial protected area management has been highlighted as a key tool by many (see e.g., Pettorelli et al., 2009, 2012; Pfeifer et al., 2011). In pelagic environments, primary productivity refers to the productivity of phytoplankton, which has a specific spectral signature due to its chlorophyll a content. The concentration can be inferred from ocean colour, i.e., from the radiation reflected back from the ocean in the visible wavelengths (Muller-Karger et al., 2005). The lessons from terrestrial PA management in this context, however, need to be interpreted with caution, as major differences exist in the importance of primary producers in the terrestrial and marine environments. Primary producers represent the basis of the food