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Seagrass mapping in Greek territorial waters using Landsat-8 satellite images

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ABSTRACT

Seagrass meadows are among the most valuable coastal ecosystems on earth due to their structural and functional roles in the coastal environment. This study demonstrates remote sensing's capacity to produce seagrass distribution maps on a regional scale. The seagrass coverage maps provided here describe and quantify for the first time the extent and the spatial distribution of seagrass meadows in Greek waters. This information is needed for identifying priority conservation sites and to help coastal ecosystem managers and stakeholders to develop conservation strategies and design a resilient network of protected marine areas. The results were based on an object-based image analysis of 50 Landsat-8 satellite images. The time window of image acquisition was between June 2013 and July 2015. In total, the seagrass coverage in Greek waters was estimated at 2619 km^2. The largest coverages of individual seagrass meadows were found around Lemnos Island (124 km^2), Corfu Island (46 km^2), and East Peloponnese (47 km^2). The accuracy assessment of the detected areas was based on 62 Natura 2000 sites, for which habitat maps were available. The mean total accuracy for all 62 sites was estimated at 76.3%.

1. Introduction

Seagrass meadows are among the most valuable coastal ecosystems due to their structural and functional roles in the coastal environment. In recent years, seagrass meadows have become among the main targets of conservation efforts in European waters. *Posidonia oceanica* is an important endemic species in the Mediterranean Sea, which can form meadows extending from 0 to 40–45 m depth (Telesca et al., 2015). *P. oceanica* is one of the priority habitats of the European Union's (EU's) Habitats Directive (92/43/EEC) and it is protected by the Barcelona Convention. Furthermore, the EU Mediterranean Fisheries Regulation (EC No. 1967/2006) requires mapping highly important habitats for fish production, (such as seagrass meadows), in all EU member states, and imposes restrictions to fishing activities in such habitats.

The *World Atlas of Seagrasses* (Green and Short, 2003), a publication developed in collaboration with the United Nations Environmental Program-World Conservation Monitoring Center (UNEP-WCMC), tried to synthesize seagrass distribution on a global scale. Greece is almost absent in that report due to lack of information.

The most recent study on seagrass meadows in the Mediterranean Sea (Telesca et al., 2015) presented the historical distribution of *P. oceanica* and the total area of seagrass meadows. According to Telesca et al. (2015), only 8% of the Greek coastline was surveyed, and the known *P. oceanica* cover in Greek territorial waters totaled 44,939 ha (449.39 km^2). Taking into account the total coastal length of Mediterranean Sea without sea grass data (21,471 km) and the unmapped coastal length of the Greek coastline (≈14,000 km), almost 65% of the unmapped potential seagrass areas of Mediterranean Sea are in Greek waters. Previous studies on seagrass mapping in the Mediterranean Sea had either a limited spatial extent (Boudouresque et al., 2009) or provided maps at a low spatial resolution (Giakoumi et al., 2013).

The only areas in Greek territorial waters for which detailed habitat maps are available are 62 marine sites of the Natura 2000 network. These sites, with a large coverage of seagrass meadows, were extensively mapped between 1998 and 2001. For each area, a dedicated map was produced using a combination of *in situ* measurements, including phytobenthic sample analysis, hydroacoustic sensors for seabed classification (RoxAnn), underwater photography/video and aerial imagery (Panayiotidis et al., 2002). Although the Hellenic Centre for Marine Research (HCMR) systematically monitors the health status of seagrass meadows in Greece, their geographic distribution has rarely been mapped. The statistics on the lower limits and the meadow densities of *P. oceanica* in the Greek seas were reported (Gerakaris et al., 2014), however, the produced datasets are not available in the geographic information systems (GIS) format. Finally, the marine part of Samaria National Park on Crete Island was mapped using mainly

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echosounder data (Poursanidis et al., 2014).

Remote sensing permits the study of extensive coastal areas for assessment of the spatial patterns of seagrass meadows, and simultaneously can be used to reveal temporal patterns due to the high frequency of the observation (Green et al., 2000). Mapping seagrass meadows from space on a large scale cannot provide the levels of accuracy and detail of a field survey. However, the complete area coverage of satellite images provides benefits by revealing large-scale patterns (Hedley et al., 2016). Remote sensing covers a variety of technologies from satellite images, aerial systems, boat systems, and underwater remotely operated vehicles (ROVs). The power of remote sensing techniques has been highlighted by the estimation of the statistical power of mapping coastal areas. Mumby et al. (2004) implied that 20 s of airborne acquisition time would equal 6 days of a field survey. Hossain et al. (2015) presented an overview of the extent of the remote sensing of seagrass ecosystems. Four parameters were mapped from remote sensing data: presence/absence, percentage coverage, species, and biomass. The selection of the most relevant parameter in the scientific literature depended on the area mapped, the availability of ground truth data, and the specific target of each study (e.g., ecology, change detection).

Although seagrass mapping with high-resolution satellite images is common in relatively small areas, only a few studies (Monaco et al., 2012; Torres-Pulliza et al., 2013; Wabnitz et al., 2008) have focused on a regional-scale mapping with low-resolution data. The feasibility of achieving large-scale seagrass mapping from Landsat images with acceptable accuracies was first presented by Wabnitz et al. (2008) for the Wider Caribbean region. Later, the Lesser Sunda Ecoregion (LSE) in the Coral Triangle (tropical marine waters of Indonesia, Papua New Guinea, Philippines, Solomon Islands and Timor-Leste) was mapped to support the design and implementation of protected marine areas using 18 Landsat scenes (Torres-Pulliza et al., 2013). A recent publication by the National Oceanic and Atmospheric Administration (NOAA) reported on the long-term mapping of the shallow-water coral reef ecosystems across the US (Monaco et al., 2012). Although this report was dedicated to US territory, it detailed the methodologies used, the results of habitat mapping (including the exceptional study on Puerto Rico and the US Virgin Islands), and the national statistics.

The 30-m resolution of Landsat images was previously used successfully for regional mapping. This paper reports for the first time on the seagrass beds' distribution in Greek waters by using a consistent method. Despite the increasing number of studies on seagrass mapping with satellite data, relevant data in GIS formats are still difficult to access. This study explains the production of country-scale seagrass GIS vectors, derived from Landsat-8 imagery. The results are compared with the data from national reference maps, provided for protected areas. Finally, the products' relevance for future biodiversity research on conservation and management at the country level is discussed.

2. Materials and methods

2.1. Area of study

The area of study (Fig. 1) spans the national marine territorial borders of Greece, covering 13,676 km of coastline, in the Aegean Sea, the eastern Ionian Sea, and the northern Libyan Sea. The study area can be divided into three major regions regarding the deep-limit of seagrass (Gerakaris, 2017; Gerakaris et al., 2014): the Northern Aegean Sea, the Southern Aegean Sea, and the Ionian Sea with depth limits 26.3 m (± 6.44 m), 30 m (± 5.75 m), and 35.4 m (± 4.95 m) respectively. The northern Aegean Sea consists of shallow platforms, resulting from the offshore continuation of the alluvial plains of northern Greece. These plains are fed with terrigenous clastic material because of river drainage (Sakellariou et al., 2005). The North Aegean Sea is also a dilution basin, as the water balance is positive; fresh light waters come from the Black Sea through the Dardanelles Strait. The South Aegean Sea is a concentration basin, as the water balance is negative, and evaporation exceeds freshwater input. The Aegean Sea is characterized by a complex geomorphological status as a result of geological and geodynamic processes (Sakellariou and Alexandri, 2007). The Aegean Archipelago comprises a group of islands, including Cyclades southeast of mainland Greece, Sporades along the east coast, Dodecanese on the eastern limit of the Cretan Sea, and the northeastern Aegean Islands (the major ones are Ikaria, Samos, Chios, Lesvos, Limnos, and Samothrace). The Ionian Sea is located on the western part of Greece, south of the Adriatic Sea, and covers the Ionian Islands (the main ones are Corfu, Zakynthos, Kefalonia, Ithaca, and Lefkada) and the west coast of Peloponnese. On the southern part of the study area, the sea floor morphology and sedimentation are controlled by the seismicity of the region. Normal active faults can cause the formation of deep bays, such as the Messiniakos and the Lakonikos Gulfs (Sakellariou et al., 2005). Finally, the Cretan Sea is located between Santorini Island and Crete Island. The sea area around Crete can also be divided into the northern part toward the Aegean Archipelago and the southern part toward the Libyan coast (*i.e.*, the Libyan Sea). In Crete, a deep basin called Heraklion Basin can be found, with a depth of about 1800 m.

2.2. Image dataset

The present study is based on Landsat-8 satellite images (Operational Land Imager; OLI). Landsat-8 was launched in February 2013 and has a repeat cycle of 16 days, with an approximate scene size of 170 km (north-south) to 183 km (east-west). The OLI sensor operates on seven bands, from coastal blue (0.43–0.45 μm) to SWIR2 (2.11–2.29 μm), with a 30-m spatial resolution and a 12-bit radiometric resolution. The data are available free of charge via an HTTP download within 24 h of acquisition. As opposed to previous Landsat sensors, the Landsat-8 series included the coastal blue band, which is dedicated to images of shallow waters (https://lta.cr.usgs.gov/L8).

Landsat-8 collects images with a standard world reference system (WRS-2). Greece is covered in 33 frames (row/path), of which 25 cover all the Greek coastal or marine areas (Fig. 2). During the time window from June 2013 to July 2015, in total, 50 Landsat-8 images were downloaded for further processing (Table 1). The images were chosen manually based on three basic quality criteria: i) cloud-free images, ii) calm seas as possible (or low and stable wind speed), and iii) the absence of major oceanographic phenomena (e.g., fronts, eddies). However, due to the large swath of Landsat-8 images and the complexity of the Aegean Sea, in many cases, the criteria were not fulfilled. Some of the images were ideal for further processing, while others depicted oceanic phenomena that prevented accurate seagrass mapping. Therefore, each Landsat-8 frame (path and row) was covered by two images. At the classification stage, the first image was processed for seagrass mapping; for all subareas where the water clarity was insufficient, the second image was taken instead. During the image-selection phase, a strong preference was given for the period between months of August and December or close to them due to better water stratification (*i.e.* thermocline reaches maximum). The images were explored and downloaded from the United States Geological Survey (USGS) Earth Explorer web service (http://earthexplorer.usgs.gov).

2.3. Image analysis

The methodological framework was based on four main pillars (Fig. 3), as follows: (i) the data selection contained Landsat-8′s frame identification as described in the previous paragraph; (ii) the preprocessing phase included all the necessary steps for the main analysis (*i.e.*, radiometric calibration, atmospheric correction, land mask, and image cropping); (iii) the object-based image processing, the images segmented into objects, classified, and manually edited where necessary; (iv) finally, in the accuracy assessment, the quality of the product was assessed.