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Estimation of available seagrass meadow area in Portugal for transplanting purposes.

A. H. Cunha, J. Assis, E. A. Serrão
Centro de Ciências do Mar, CIMAR-L.A.
Universidade do Algarve, Campus de Gambelas
8005-139 Faro – Portugal
acunha@ualg.pt

ABSTRACT

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Seagrasses are marine flowering plants found in shallow coastal habitats around the world. These plants create a habitat of substantial importance from an ecological, economic and biodiversity point of view. Unfortunately, there have been considerable losses of seagrass habitat worldwide, leading to increasing interest on the development of seagrass restoration and rehabilitation projects. These projects, often developed as a mitigation tool, deeply benefit from the spatially explicit information included in Geographic Information Systems (GIS). Thus, to have seagrass area estimates for transplanting purposes and, to be able to monitor transplanting impacts, a large-scale GIS map was build for Sado and Mira River Estuaries, Portinho da Arrábida Bay and Ria Formosa regions using: (1) aerial photography analysis, (2) photo-interpretation, (3) on-site groundtruthing surveys and (4) statistical analysis. Habitat boundaries were evaluated through aerial photography, and a complete set of selected sites were visited for groundtruth validation, using 4 types of transect methods (along the shore-line, free-diving, scuba diving and boat transects). Twelve thousand, six hundred and fifty two hectares (12652.17 ha) were assessed, 3944 groundtruth points were recorded and 3 seagrass species were identified and mapped (*Zostera marina*, *Zostera noltii* and *Cymodocea nodosa*). Ria Formosa had the largest distribution area of seagrass species (241.04 ha), followed by Sado Estuary (32.68 ha). Mira Estuary had only one seagrass meadow and in Portinho da Arrábida Bay no seagrass meadows were registered. *Zostera noltii* was the most abundant species in both regions, followed by *Cymodocea nodosa* and *Zostera marina*. The error assessment for species distribution area and diversity, estimated through kappa statistics based on error matrices, gave a perfect agreement value (K=0.912) to the methodology used.

ADDITIONAL INDEX WORDS: *GIS, Mapping, Seagrass, Restoration*

INTRODUCTION

Seagrass meadows provide a wide array of ecological functions that are important in maintaining healthy estuarine and coastal ecosystems (ORTH *et al.*, 1984, THAYER *et al.*, 1984, HECK *et al.*, 1995). They increase the stability of the seafloor through the growth of extensive rhizome mats (FONSECA and FISHER, 1986), play a critical role in primary production, including the harnessing and cycling of nutrients (HILLMAN *et al.*, 1989), and provide valuable habitat for a diverse array of marine organisms (SHORT and WYLLIE-ECHEVERRIA, 1996, DUARTE, 2002, ORTH *et al.* 2006). Unfortunately, over the last years, Atlantic seagrass populations have declined due to pollution associated with increased human populations (KEMP *et al.*, 1983, VALIELA *et al.*, 1992) and episodic occurrences of the wasting disease (SHORT *et al.* 1986, DEN HARTOG, 1994), as well as other human-induced and natural disturbances (SHORT and WYLLIE-ECHEVERRIA, 1996, ORTH *et al*,. 2006).

Major efforts have been developed to implement seagrass restoration and rehabilitation projects (Palling *et al.,* 2009). The approaches that involve the collection of mature seagrass from donor populations for transplanting purposes, to areas of seagrass loss (e.g. SEDDON, 2004), deeply benefit from the spatially explicit information included in benthic habitat maps. With this type of baseline information, planning managers and researchers are allowed to better choose population donor sites and to monitor spatial and temporal changes in species distribution at a landscape level. The use of applications such as Geographic Information System (GIS) and fieldbased measurements using Geographic Positioning System (GPS) have become common place methods to achieve precise habitat mapping and spatial resource management decision-making (BRETZ *et al.*, 1998).

The present paper describes the approach used in the Biomares restoration project to build a large-scale benthic habitat map to assess the potential donor seagrass meadows area coverage available in Portugal for transplanting purposes. It is also the first attempt to estimate total seagrass cover in the regions studied. Biomares, a European Union Life project (LIFE06 NAT/P/192), aims to restore and manage the biodiversity of the Marine Park Site Arrábida-Espichel.

METHODS

A large-scale seagrass habitat map was built during the year 2007, for Sado and Mira Rivers Estuary, Portinho da Arrábida

Bay and Ria Formosa regions (Figure 1). Intertidal and subtidal areas were surveyed for all regions except for Ria Formosa, where data from intertidal zone was available from a previous work (Guimarães, 2007). Aerial photography, on-site groundtruthing surveys, photo-interpretation and statistical analysis was used following the methods by Israel and Fyfe, 1996, Wyllie *et al.*, 1997, Kendrick *et al.*, 1999, 2002.

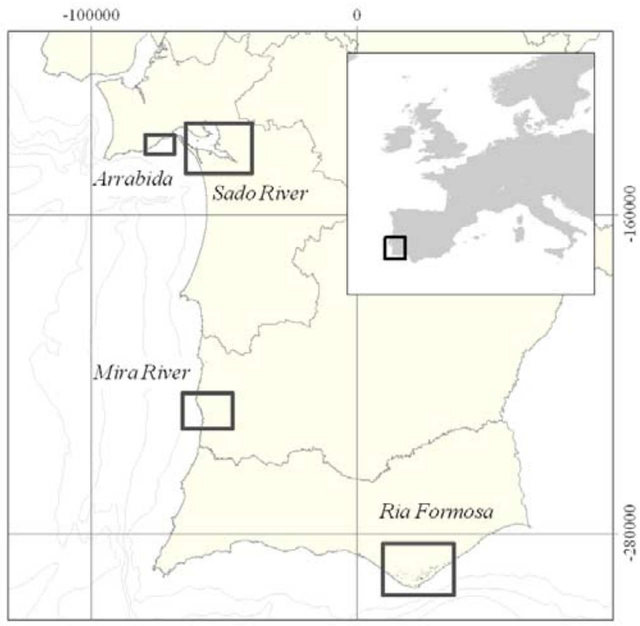

Figure 1. Studied regions (Arrábida, Sado Estuary, Mira Estuary and Ria Formosa).

One essential concern to conduct a marine habitat map is the use of an appropriate classification scheme. General consensus of the seagrass habitat mapping community is that the simpler the system, the greater the chance of consistency and improved accuracy in the mapping results and the greater the opportunity for replication of the mapping over several time periods (Davison and Hughes, 1998). In order to describe the habitat a GIS classification scheme was developed under a simple hierarchical system. From a landscape perspective, the spatial structure of the habitats was conceptualized at 4 simple different levels: (1) Sandy or Muddy bottom, (2) Rocky bottom, (3) algal bed, and (4) seagrass meadow.

Aerial photography remote sensing

A set of the latest rectified orthophotographs of the studied regions were selected within the archives of the Instituto Geográfico Português and loaded into ArcGis 9.1 software, to generate a first draft habitat map. Interpretation and drawing of the extension and boundaries of the habitats, was realized by on-screen digitizing techniques (Galdies and Borg, 2006). For each identified area assigned according to the classification scheme, a polygon was constructed. Brightness, contrast, and occasionally color balance of the mosaics were manipulated to enhance the interpretability of some subtle field features and boundaries.

Groundtruth validation

Selected field sites were visited, exploring all study regions for groundtruth validation to achieve a better agreement of the draft maps polygon boundaries and to assign the correspondent seagrass species to the constructed polygons. Accurate GPS positions with field features following the classification scheme, were gathered in low tide periods, using 4 types of transect methods (transects along the shore line, free diving transects, scuba diving transects and boat transects) with systematically unaligned orientations (Aronoff, 1985), diagonally to the shore line from shallow to deeper water, and reverse. For supratidal field sites, groundtruthing was made by walking along the shore line, accurately registering GPS points with the observed field features. For shallow subtidal sites, inaccessible by boat, groundtruthing was made by means of free diving (snorkeling) in clear water conditions. Deep water or low visibility subtidal sites were visually evaluated by means of scuba diving, placing the GPS unit to float on the water's surface, in a housing attached to a buoy, vertically positioned over the scuba diver. For large open sites with clear water, long distance boat/canoe transects were made, using a crystal glass tube to better visually groundtruth the underwater field features. The habitat signatures and transitions, intercepted by the transects, were evaluated, and a georeferenced text table was compiled and loaded to ArcGis 9.1 software in order to better place the drafts map polygon boundaries and to assign the seagrass species information to the drawn polygons.

Error assessment

Map users should be able to evaluate whether the accuracy of the map suits their objectives or not (Congalton, 1991). Error matrices, also known as confusion matrices, have become a widely accepted method to report the error of mapped data (Smits *et al.*, 1999). Following Carletta (1996), the habitat map error assessment was based on the concordance agreement scale (Landis and Koch, 1977) of the Kappa coefficient statistical method (Cohen, 1960). This coefficient, calculated from error matrices, was introduced to the remote sensing community in the early 1980s (Congalton *et al.*, 1991) and has become a widely used measure for classification accuracy.

The study sites error matrices data were recorded for 100 points in 2 haphazardly chosen locations, following the classification scheme. Furthermore, the accuracy measured at these 2 regions was assumed to be representative of the overall maps accuracy, elsewhere in the study area (Congalton, 1991).

Seagrass habitat map analysis

In order to have measures of technical effort dispended in the groundtruth process, the number of groundtruth points and surveyed area were reported and calculated. Seagrass habitat map, number of seagrass meadows, estimated seagrass species area per region (TESSD) and total estimated seagrass area per region were calculated and reported. Moreover, seagrass habitat maps were generated for each studied region to visually evaluate the most diverse localities in terms of seagrass species, number and area of seagrass meadows.

RESULTS

The identified seagrass meadows boundaries in the orthophotographs were delineated around signatures (e.g. areas with a specific and similar color and texture patterns). A total of 412 seagrass meadows were identified and polygons constructed. For Ria Formosa, 342 seagrass meadows were identified, while Sado Estuary registered 64. During 31 days of field work, a total area of 12652.17 hectares was assessed and 3944 groundtruth points (GP) were recorded. Free-diving and scuba diving transects along the shore-line and boat transects were applied in all regions, except in the Mira Estuary, where only boat transects were used. Ria Formosa had the largest number of groundtruth points (GP), followed by the Sado Estuary, the Mira Estuary and Arrábida. The classification scheme followed was: sandy and muddy bottoms, rocky bottoms, algae meadows and the 3 seagrass species (*Zostera marina*, *Zostera noltii* and *Cymodocea nodosa*). The groundtruth records were used to correct the polygon boundaries of the draft habitat map, which led to the final seagrass distribution map. Ria Formosa and Sado Estuary had 3 seagrass species, while in Mira Estuary only 1 species was recorded (*Z. noltii*). No seagrass meadows were found in Portinho da Arrábida Bay (Table 1).

Table 1. Seagrass species meadows and total estimated seagrass species distribution area (TESSD) for Portinho da Arrábida Bay, Sado and Mira Rivers Estuaries and Ria Formosa (ZM for *Zostera marina*, ZN for *Zostera noltii* and CN for *Cymodocea nodosa*). The values for *Z. noltii* areas from Ria Formosa only includes the subtidal areas.

Region	Species	Meadows	TESSD (ha)
Port. Arrábida	–	0	0
Sado Estuary	*ZM*	93	1.16
	ZN	203	28.38
	CN	46	3.14
Mira Estuary	*ZN**	1	0.006
Ria Formosa	*ZM*	42	5.01
	ZN	7	144.78
	CN	15	91.26

*The seagrass meadow found in Rio Mira had very sparse plant shoots and hard to find in the area.

The total estimated seagrass distribution area of Ria Formosa and Sado Estuary was 241.05 ha and 32.68 ha. The most well represented species in Ria Formosa and Sado Estuary was *Z. noltii*, followed by *C. nodosa* and *Z. marina*. For the Ria Formosa region, Faro, Olhão, Culatra and Fuzeta were the localities with the highest species richness (3 species), with a total seagrass cover area of 15.75 ha (58 meadows) for Faro, 39.58 ha (46 meadows) for Olhão, 62.65 ha (47 meadows) for Culatra and 44.52 ha (88 meadows) for the Fuzeta sites. In the Sado Estuary region, Tróia had the highest species richness (3 species), whereas Cabeços do Rio, Comporta and Pé de Cavalo had the largest *Z. noltii* meadows present, with 7.78 ha (7 meadows), 7.03 ha (8 meadows) and 17.98 ha (3 meadows), respectively. In Caldeira, Moitinha, and Águas de Moura, no seagrass meadows were detected. Ria Formosa (Figure 2) had the larger distribution for the 3 identified seagrass species followed by the Sado Estuary (Figure 3).

An error matrix was built using 100 GPS points recorded in the Ria Formosa and Sado Estuary regions (Table 2). Sandy and muddy bottoms, *Z. marina Z. noltii* and *C. nodosa* meadows were registered. No rocky bottoms or algal mats were registered in this process. Using the Kappa coefficient equation, the concordance agreement scale estimated was 0.91.

Table 2. Error matrix. Based on 100 GPS records for Sado Estuary and Ria Formosa regions. Sandy and muddy bottoms (SMB) Rocky bottom (RB) Algae meadow (AM) *Zostera marina* (*ZM*) *Zostera noltii* (*ZN*) *Cymodocea nodosa* (*CN*).

	SMB	RB	AM	*ZM*	*ZN*	*CN*
SMB	29	0	0	1	3	2
RB	0	0	0	0	0	0
AM	0	0	0	0	0	0
ZM	2	0	0	16	0	2
ZN	2	0	0	1	18	0
CN	1	0	0	1	1	21

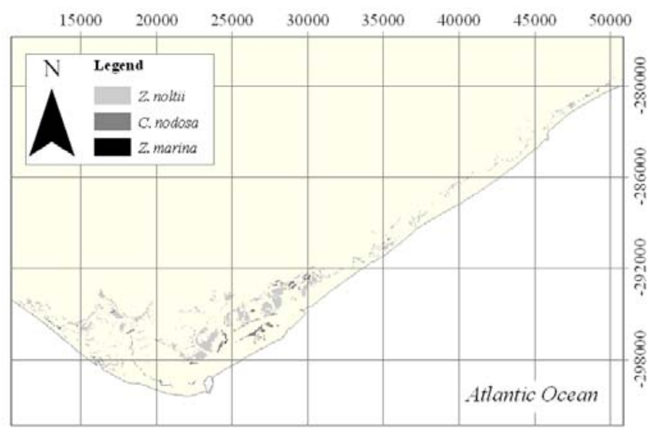

Figure 2. Seagrass distribution in Ria Formosa.

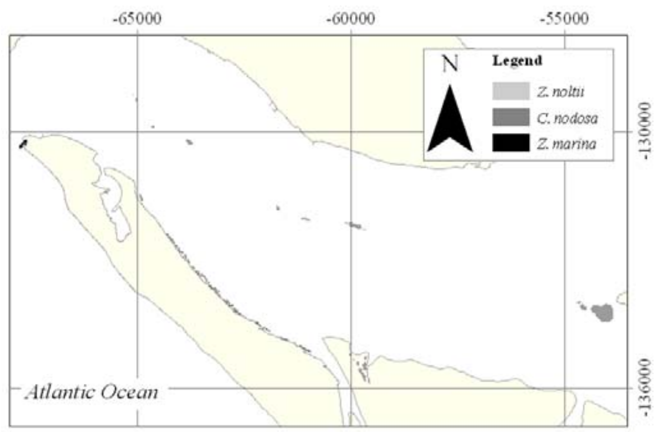

Figure 3. Seagrass distribution in Sado Estuary.

DISCUSSION

The use of aerial photography methods is a valuable tool for natural resource managers and researchers to document the location and extent of seagrass meadows (VALTA-HULKKONEN *et al.*, 2003). Aquatic vegetation yields spectrally distinct signals governed by the density of the vegetation, the openness of the canopy and the amounts, forms and orientations of the leaves, thus facilitating the visual identification of the different patches.

Defining the edges of the seagrass meadows, through on-screen analysis of the orthophotographs, was a critical step to determine the total habitat area coverage of the studied regions. The photographs had considerable good quality and were already georeferenced, making the digitizing technique much simpler. Although automated techniques exists (KENDRICK *et al.*, 2002), it was decided to analyze the photographs manually, since brightness levels varied significantly within and between photographs, causing variation in the gray tones corresponding to the signatures of the classification scheme. The extension and boundaries of the seagrass meadows were correctly percepted and corresponding polygons were constructed within the GIS. All remote sensing technologies require groundtruthing to accurately interpret the mapped data in order to relate the aerial image data to real field features on the ground (LILLESAND and KIEFER, 1987). This procedure was successfully accomplished by registering field features using 4 transect methodologies. These were differently used according to the underwater depth and visibility at the time. Transects along shore and by boat were most used since they cover larger areas with less field effort. For deeper waters, free-dive transects were preferentially used rather than scuba diving transects for the same reason. An unaligned systematic sampling design was used in transects to eliminate a possible source of bias that may happen if periodical patterns coincide with the systematic design (BERRY and BAKER, 1986). Systematic sampling ensures that sample points are recorded from an entire area, which is adequate when the field features are randomly distributed over the area. Yet, most features show some form of clustered distribution, or regular distribution (ARONOFF, 1985), therefore if the distribution of the draft map polygons tended in a particular direction (e.g. parallel to transects), with a systematic sampling a significant bias could be introduced to the groundtruth process. The systematic unaligned sampling used in this work, combined the advantage of randomization and stratification with the useful coverage achieved with systematic sampling, while avoiding potential systematic bias sources.

Three seagrass species were identified (*Z. marina*, *Z. noltii* and *C. nodosa*) and accurately mapped for two sites, Ria Formosa and Sado Estuary. In Portinho da Arrábida Bay no seagrass species were found at the time of this survey, although this site had segrasses in the recent past (pers. obs. in 2006). When analyzing a species distribution habitat map, it is important to remember that it is not a perfect representation of reality. There are always errors in maps and before we can evaluate the utility of a particular map we need to have an idea of how accurate it really is and how accurate it should be to sufficiently meet the requirements for the intended application. In order to check the exactness between the spatial data produced and the reality, an accuracy assessment was made in 2 haphazardly chosen locations. The assessment provided an overall Kappa statistics value – 0.91 – considered by the LANDIS and KOCH (1977) concordance agreement scale as a perfect match (the 0.91 calculated value is between the range of 0.81 - 1.00). This accuracy could then be assumed to the rest of the spatial distribution and field cover data of the 3 found seagrass species (*Z. marina*, *Z. noltii* and *C. nodosa*). From the results of the GIS analysis, Ria Formosa showed the greater area of seagrass cover. In this region, Faro, Olhão, Culatra and Fuzeta were the locations with higher species diversity and total area of distribution. The largest meadows found were *Z. noltii* and *C. nodosa* in Olhão, Culatra and Fuzeta. These localities were recommended to the Biomares planning managers and researchers as suitable as donor sites for *Z. noltii* and *C. nodosa*. In Sado River Estuary region, the Tróia locality had higher species richness (3 species), while Cabeços do Rio, Comporta and Pé de Cavalo had the largest *Z. noltii* meadows. This last locality was also recommended as a suitable *Z. noltii* donor site. For *Z. marina*, Culatra site in Ria Formosa and the Tróia site in the Sado Estuary were recommended as suitable donor sites. Nevertheless, the area covered by this species is very small in both regions. For this reason, the use of only a very small proportion of the total area and precaution in removing plants were recommended.

CONCLUSIONS

The method provided the necessary information for the seagrass restoration task implementation of the Biomares project. Information on location, size and structure of seagrass communities of Ria Formosa and Sado River Estuary were obtained. In Mira River Estuary only a residual area of seagrasses was found and that no seagrasses were found in Portinho da Arrábida Bay. The aerial photography method used in this work proved to be an appropriated technique to carry such an environmental survey. Indeed it proved to be reliable, and the numeric nature of the data in the GIS enables the generation of maps on various scales and at different levels of complexity.

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