Automatic mapping of Seagrass beds in Alfacs Bay using Sentinel 2 imagery

Cartografía automática de praderas marinas en la Bahía dels Alfacs mediante imágenes Sentinel 2

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Abstract: Seagrass are marine flowering plants that form extensive meadows in shallow coastal waters. They play a critical role in coastal ecosystems by providing food and shelter for animals, recycling nutrients, and stabilizing sediments. Therefore, they are widely used as an ideal biological indicator for assessing the health status and quality of coastal ecosystems. In the Alfacs Bay (Ebro Delta), seagrasses are located in the shores, showing an annual variation with a peak in summer. The decreasing of averaged salinity and increasing of nutrients concentration and turbidity, has led to a notable reduction of the seagrass beds. Thus, a cartography to monitor spatiotemporal changes of meadows and to forecast the evolution of the environmental characteristics of the system, is needed. Nowadays, the standard methodology is a combination of photointerpretation and field prospection with significant workload resources. In contrast, an automatic methodology relying on multispectral moderate resolution Sentinel 2 (S2) satellite imagery is proposed. The methodology consists of: atmospheric correction of Level-1C images, application of Green Normalized Difference Vegetation Index, statistic thresholding to tell apart possible seagrass areas and a supervised learning method to refine this classification and to identify habitats. The methodology has been applied and calibrated using S2 satellite imagery and reference data comprising several patches distributed along the Alfacs Bay. In these patches, seagrass areas were identified (visually and location with GNSS). The results showed that seagrass meadows can be automatically delineated using S2 imagery.

Key words: Seagrass, Mapping, Remote Sensing, Sentinel 2

Resumen: *Las fanerógamas marinas son plantas acuáticas que forman praderas extensas en aguas costeras poco profundas. Desempeñan un papel fundamental en los ecosistemas costeros al proporcionar alimentos y refugio para los animales, reciclar los nutrientes y estabilizar los sedimentos. Por lo tanto, se utilizan ampliamente como un indicador biológico ideal para evaluar el estado de salud y la calidad de los ecosistemas costeros. En la Badia dels Alfacs (Delta del Ebro), las praderas marinas están ubicadas en las orillas, mostrando una variación anual con un pico en verano. La disminución de la salinidad promedio y el aumento de la concentración de nutrientes y la turbidez, ha llevado a una notable reducción de los lechos de pastos marinos. Por lo tanto, una cartografía para monitorizar los cambios espaciotemporales de praderas y para pronosticar la evolución de las características ambientales del sistema es necesaria. Hoy en día, la metodología estándar es una combinación de fotointerpretación y prospección de campo con una importante carga de trabajo. Por el contrario, se propone una metodología para llevar a cabo una cartografia automática basada en imágenes satelitales multiespectrales de resolución moderada proporcionadas por Sentinel 2 (S2). La metodología consiste en: corrección atmosférica de imágenes de Nivel 1C, aplicación del Índice de Vegetación de Diferencia Normalizada utilizando la banda Verde, un umbral estadístico para diferenciar entre posibles áreas de praderas marinas y agua y un método de aprendizaje supervisado para refinar esta clasificación e identificar hábitats. La metodología se ha aplicado y calibrado utilizando imágenes de satélite S2 y datos de referencia que comprenden varios parches distribuidos a lo largo de la Badia dels Alfacs. En estos parches, se identificaron las áreas de praderas marinas (visualmente y localización con GNSS). Los resultados muestran que se pueden delinear automáticamente praderas de pastos marinos mediante imágenes S2.*

Palabras clave: *Praderas marinas, Cartografía, Teledetección, Sentinel 2*

INTRODUCTION

The importance of seagrass in the functionality of the ecosystem is well known. From the point of view of geomorphology, they play a critical role in sediment stability (Pu et al., 2012) and trapping, also contributing to bioclastic sediment production (Gacia et.al, 2003). In addition, seagrass beds are directly related to the protection of the coast by dissipating the incoming energy (wave breaking, energy friction and reflection). There is a need to monitor spatiotemporal changes of meadows, even more in coastal areas supporting multiple uses and services (e.g. agriculture and aquaculture) where seagrass act as indicators of anthropogenic disturbance (Knudby & Nordlund, 2011). The standard methodology has been based on (aerial) photointerpretation and field prospection. Nowadays, space-borne remote sensing has emerged as an alternative by offering clear advantages over traditional seagrass mapping with limited temporal and spatial resolution (Lyons et al., 2013). From this perspective, the most used remote sensing data for seagrass monitoring is medium resolution multispectral data and the common methodology for seagrass mapping is based on the use of supervised or unsupervised classification techniques together with fieldwork data from all kind of environments (Hossain et al., 2015). Most of the approaches used green red and NIR spectral bands and their combinations.

METHODOLOGY

In this paper, an automatic methodology relying on multispectral moderate resolution Sentinel 2 (S2) satellite imagery is proposed to map Seagrass areas of the Alfacs Bay, based on the use of corrected Sentinel 2A multispectral imagery (S2/MSI). Data processing includes an atmospherically correction step accounting also for the sun glint effects, performed using ACOLITE processor (Vanhellemont & Ruddick, 2016) to get the surface water reflectance's for each pixel (at 20 m^2 resolution) and for each spectral band image. The Green Normalized Difference Vegetation Index (GNDVI) (eq. 1), using the green and the red edge reflectance instead of the common NIR reflectance, is applied for each date. This allow to mask apart areas with the possibility to harbour seagrass from areas where their development is not probable. Then, the combined image of three bands (Band 3: 560 nm, Band 4: 665 nm and Band 7: 783 nm) can be used for training a model using Support Vector Machine technique, if ground truth data is available, or as input for the classification step using the pre-trained model.

Equation 1: $$GNDVI_{red\_edge} = (R704 - R560) / (R704 + R560)$$
where R = reflectance

The ground truth data consists of *N* sampling points, located with Global Navigation Satellite System (GNSS) receiver, that are used to define class polygons for their training. Each sampling point includes the typology of seabed accounting for five different categories (seagrass at high and low densities, sparse environment, algae and 'open' water).

STUDY AREA

Located on the southern side of the Ebro Delta (NW Mediterranean), Alfacs (fig. 1) is a shallow (maximum depth of 7 m), small (56 km2), semi-enclosed (renewal time ≥ 15 days) bay characterized by a large annual variability of salinity (26 – 37 PSU) and temperature (8 – 32 ˚C). The shallowest areas (0 – 2 m), confined to the inner margins of the bay, are colonized by seagrass (mainly Cymodocea nodosa), forming monospecific stands or mixed meadows (Mascaró et al., 2014) which abundance depends on the nutrient availability. The northern shore is influenced by freshwater inputs from rice fields (high nutrient load), while the southern margin has an oligotrophic regime similar to nearby Mediterranean Sea waters.

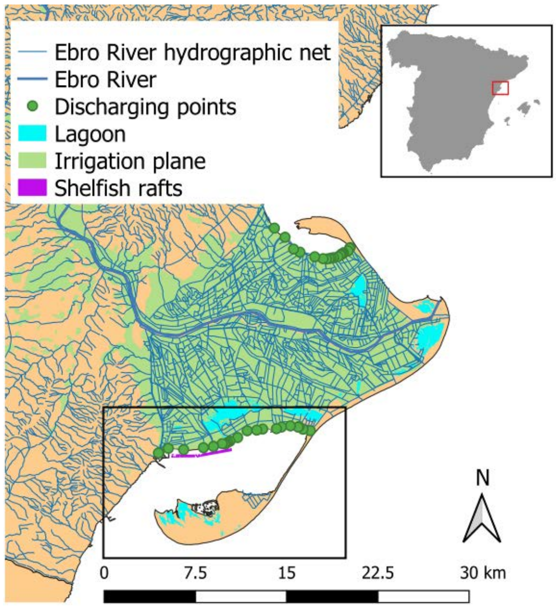

FIGURE 1. *Location of the Alfacs Bay, Ebro River, hydrographic network, mussel rafts, main lagoons, rice fields and the discharging channels in the Ebro Delta.*

RESULTS

A field sampling was carried out on 23.05.19 to generate the ground truth data, consisting in the identification of the five different categories (seagrass at high, and low densities, sparse environment, algae and 'open' water) at 26 sampling points, covering northern and southern margin of the bay. The coordinates of the sampling points were measured with a GNSS receiver.

Sentinel 2 L1C (top of atmosphere) imagery covering the study area and corresponding to two different dates (19.08.18 and 26.05.19), including spring and summer seasons, were downloaded from the

Copernicus Open Access hub and processed with the presented methodology (https://scihub.copernicus.eu).

The $GNDVI_{red\_edge}$ worked fine in the two dates. Independently of the date, a threshold of 0.3 proved to be a good differentiation method to mask areas with (shallower water) and without (deeper water) probability of harbouring seagrass meadows (Fig. 2) in Alfacs Bay.

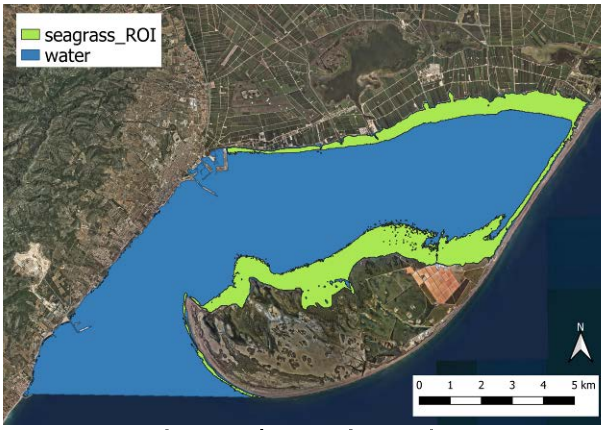

FIGURE 2. *Delineation of water and potential seagrass areas*

For the classification step, the image of 26.05.19, dated closest to the field campaign (23.05.19), was used together with the ground truth data to train the model. The resulting model was applied to the image of summer (19.08.18). The supervised classification using a combination of green, red and NIR channels was consistent with the input benthic-class polygons (Fig. 3), but the results obtained for August 2018 (Fig. 4) were not validated (not available field data).

Broadly, in spring (May 2019), excluding the sparse environment, the most representative category, in terms of coverage, was 'low density meadows'. 'Dense seagrass' was more represented at the northern margin, especially at the eastern half of the bay. It is highlighted the low presence of 'algae', mostly confined to the southern margin.

In summer (August 2018), the 'sparse environment' category practically disappeared and the most representative classes were 'high density seagrass' at the southern shore and 'algae' within the northern one. The 'low density seagrass' class, with very low coverage, was reduced to the shallower areas of each shore (Fig 4.).

Considering that our results may explain, roughly, the change between spring and summer, two different dynamics were observed in the northern and southern shores. While in the northern shore, 'sparse environment' and 'low density seagrass' were replaced by algae, displacing the 'high density seagrass' to the deeper area of the 'seagrass_ROI' (Fig. 3), in the southern margin, 'sparse environment' and 'low density seagrass' were superseded by 'high density seagrass'.

DISCUSSION AND FURTHER RESEARCH

The proposed methodology could not be fully validated because field data were only available one day (26.05.19). However, the results obtained in summer (19.08.18) of the prior year, and the evolution between seasons, can be explained by the dynamics described in the literature (Pérez et al. 2001, Mascaró et al., 2014). These authors found that during late summer (August) in the northern margin, seagrass showed maximum mortality, which, together with the overgrowing of opportunistic macroalgae, displaced the seagrass meadows to deeper areas. This fact might explain the reduction of the coverage of this class from spring to summer. They concluded that the combination of light limitation within the seagrass canopy (shadowing due to high densities of seagrass enhanced by high nutrient loads from the runoff of paddy fields), warmer summer temperatures and the presence of macroalgae (severely limits the light availability) are the main factors controlling shoot mortality. Contrarily, in the southern shore, the similar conditions to the general oligotrophic regime of nearby Mediterranean (not external nutrient availability), are associated with a lower recruitment rate and hence lower shoot density, so competition for light between shoots is reduced, thus resulting in lower mortality rates. Moreover, no effects of light deprivation by macroalgae are expected as no overgrowing macroalgae were found at this site, in agreement with the results obtained in this study.

To conclude, S2 MSI imagery has been used successfully to differentiate seabed coverage within 0-2 m deep. The methodology should be improved, but the first results allow confirming that S2/MSI may become a new tool to identify seagrass meadows and monitor its dynamics in relation to the surrounding environment. This may contribute also to understand the interaction between meadows dynamics and the geomorphological processes of the bay (*e.g.* changes in nearshore sandbars and shoreline stability).

In order to improve the methodology and the results, further research should include more calibration scenarios (location, environmental forcing, season, cover type) with a refined classification, also taking into account the variance of reflectance due to different depths. Moreover, further research must be directed towards long term monitoring (time series) which may help to differentiate between seagrass types (differentiated growing), and to analyse the relation of freshwater discharge from paddies, sediment deposition areas and the dynamics of seagrass.

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REFERENCES

Gacia E, Duarte CM, Marba N, Terrados J, Kennedy H, FortesMD, Tri NH (2003): Sediment deposition and production in SE-Asia seagrass meadows. Estuar Coast Shelf Sci. 2003, 56:909– 919.

Hossain, M. S., Bujang, J. S., Zakaria, M. H., Hashim, M. (2015): The Application of Remote Sensing to Seagrass Ecosystems: An Overview and Future Research Prospects. Int. J. Remote Sens. 2015, 36 (1), 61–114.

Knudby, A., Nordlund, L. (2011): Remote Sensing of Seagrasses in a Patchy Multi-Species Environment. Int. J. Remote Sens. 2011, 32 (8), 2227–2244.

Lyons, M. B., Roelfsema, C. M., Phinn, S. R. (2013): Towards Understanding Temporal and Spatial Dynamics of Seagrass Landscapes Using Time-Series Remote Sensing. Estuar. Coast. Shelf Sci. 2013, 120, 42–53.

Mascaró, O., Romero, J., Pérez, M. (2014): Seasonal Uncoupling of Demographic Processes in a Marine Clonal Plant. Estuar. Coast. Shelf Sci. 2014, 142, 23–31.

Pérez, M., Mateo, M. A., Alcoverro, T., Romero, J. (2001): Variability in Detritus Stocks in Beds of the Seagrass Cymodocea Nodosa : Botanica Marina. 2001, 44, 523–531.

Pu, R., Bell, S., Meyer, C., Baggett, L., Zhao, Y. (2012): Mapping and Assessing Seagrass along the Western Coast of Florida Using Landsat TM and EO-1 ALI/Hyperion Imagery. Estuar. Coast. Shelf Sci. 2012, 115, 234–245.

Vanhellemont, Q. and Ruddick, K. (2016): Acolite for Sentinel-2: Aquatic Applications of MSI Imagery. Eur. Sp. Agency, (Special Publ. ESA SP 2016, SP-740 (May), 9–13.

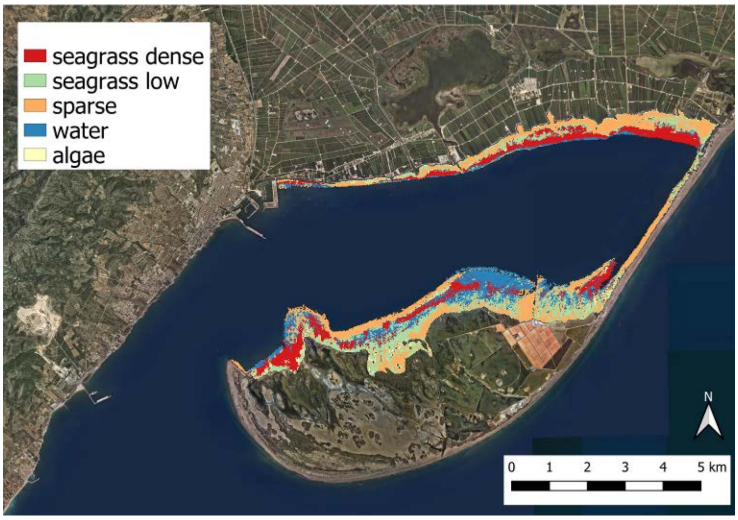

FIGURE 3. *Seabed cover classification 26.05.19*

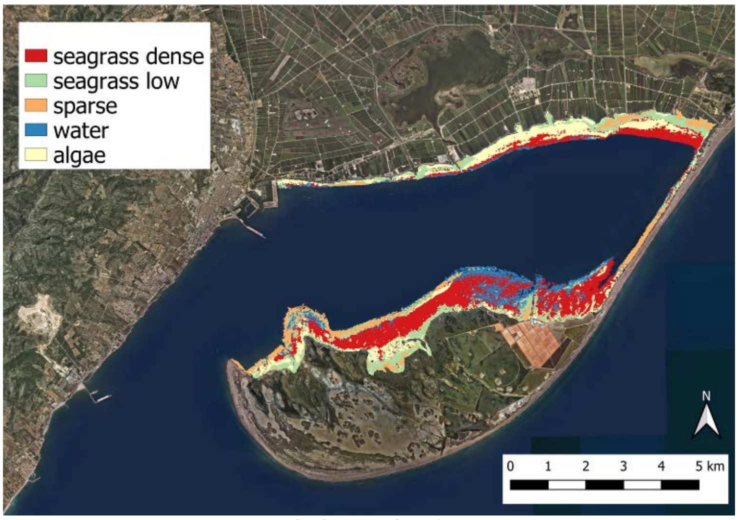

FIGURE 4. *Seabed cover classification 19.08.18*