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A Bayesian spatial approach for predicting seagrass occurrence

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ABSTRACT

We implement a Bayesian spatial approach to predict and map the probability of occurrence of seagrass *Posidonia oceanica* at high spatial resolution based environmental variables. We found that depth, near-bottom orbital velocities and a spectral pattern of Landsat imagery were relevant environmental variables, although there was no effect of slope or water residence time. We generated a data inventory of *P. oceanica* samples at Palma Bay, NW Mediterranean, from three main sources: side scan sonar, aerial imagery and a customized drop-camera system. A hierarchical Bayesian spatial model for non-Gaussian data was used to relate presence-absence data of *P. oceanica* with environmental variables in the presence of spatial autocorrelation (SA). A spatial dimension reduction method, the predictive process approach, was implemented to overcome computational constraints for moderately large datasets. Our results suggest that incorporating spatial random effects removes SA from the residuals and improves model fit compared to non-spatial regression models. The main products of this work were probability and uncertainty model maps, which could benefit seagrass management and the assessment of the ecological status of seagrass meadows.

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1. Introduction

Seagrass meadows provide important ecosystem services including carbon sequestration, nutrient cycling, protection from erosion, and enhanced biodiversity (Hemminga and Duarte, 2000). In the Mediterranean Sea, the dominant seagrass species is the endemic *Posidonia oceanica* (L.) Delile, which forms extensive meadows on both soft and hard bottoms, from sea level down to 40 m (Duarte, 1991; Boudouresque et al., 2009). *P. oceanica* is a long-lived marine clonal angiosperm characterized by very slow growing rhizomes (Marbà and Duarte, 1998) and is sensitive to natural and anthropogenic disturbances (Boudouresque et al., 2009; Grech et al., 2012; Jorda et al., 2012). Monitoring seagrass is particularly important because the European Water Framework Directive (Foden and Brazier, 2007; López y Royo et al., 2009; Montefalcone, 2009) and the Marine Strategy Framework Directive use seagrass as an indicator of ecosystem health and disturbance (Marbà et al., 2013).

Species distribution models (SDM) have been extensively used in conservation planning and management (Peterson et al., 2002). Such models relate species distribution data (e.g., presence–absence) to environmental characteristics in order to improve our understanding of the effects of environment on species distribution (inference) and our ability to predict species distributions (Crase et al., 2012). However, achieving these objectives has proved challenging. One of the most important drawbacks of species distribution data is spatial autocorrelation (SA), that is, observations that are not only related to environmental conditions, but also to one another because of the geographic distance between them. SA may lead to (1) incorrect assessment of the ecological processes causing the observed distribution, and (2) poor predictive capabilities. These two errors are especially relevant to modeling *Posidonia oceanica* because the biology of the species (i.e., clonal reproduction and low growth rate) suggests that SA may be high.

Despite the fact that SA is usually ignored, spatial models are a useful tool for relating seagrass presence with environmental variables and human threats (Bekkby et al., 2008; Leriche et al., 2011; Downie et al., 2013). Bayesian hierarchical models have recently been applied in seagrass research (March et al., 2013). However, it is not feasible to fit large datasets with such models using Markov chain Monte Carlo methods (MCMC) as it results in a problem known as the “big-n problem”. This consideration is important when working with large areas and a large number of sampling locations. One solution is the proposed *predictive process approach* (Banerjee et al., 2008; Banerjee and Fuentes, 2012). The *predictive process approach* allows a balance between model richness and computational feasibility, and it has been successfully employed in previous studies (Finley et al., 2009; Latimer et al., 2009; Eidsvik et al., 2012).

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In this work we implement a *predictive process approach* to analyze the spatial distribution of seagrass occurrence from point-based data and a set of environmental variables. This modeling approach allows testing the effects of environmental variables on seagrass occurrence while considering SA, and generates maps of probability of occurrence and its uncertainty. We demonstrate such approach using data of *Posidonia oceanica* at Palma Bay (NW Mediterranean) to assess and map its spatial distribution.

2. Materials and methods

2.1. Study area

The study was conducted in Palma Bay (Mallorca, NW Mediterranean), a large (31 km, 50 m maximum depth) oligotrophic bay (Fig. 1). This area is under ecological pressure from humans because the surrounding municipalities have 44.8% of the population, and are the main targets of tourism in Balearic Islands. Palma Bay contains extensive seagrass meadows of *Posidonia oceanica* (Diaz Del Rio, 1993). Conservation measures in this area include two marine protected areas (Fig. 1), which were declared largely to protect the seagrass meadows from human pressures. The first is a marine area called “Cap de Cala Figuera”, located in the western area of Palma Bay, which was declared as a Site of Community Importance (SCI, Natura 2000) in 2006. The other, Palma Bay Marine Reserve, in the eastern area of Palma Bay, was declared a marine reserve in 1982 by the local government, although human activities were not regulated until 1999. In addition, since 1990 several artificial reefs have been deployed in order to deter illegal trawling in the area (Moreno et al., 1994).

2.2. Data collection

Within a study area of ~100 km^2 (Fig. 1), we determined the presence-absence of *Posidonia oceanica* at Palma Bay using three different methods through a random sampling design (mean distance to the nearest neighbor location was 247 m, $n = 857$ locations). Firstly, we used aerial photography imagery (Instituto Geográfico Nacional) to determine seagrass absence in shallow waters ($n = 19$ locations). Secondly, we used a recent survey conducted at Palma Bay Marine Reserve by side scan sonar (Government of Balearic Islands, http://lifeposidonia.caib.es) to determine the presence-absence of seagrass in the reserve ($n = 153$ locations). Finally, we used an underwater drop-camera system (March et al., 2013) to collect standardized vertical geo-referenced images at 685 locations during expeditions between January 2008 and June 2009. At each location, three images were captured at random sampling positions separated by 2–10 m. Image classification was based on the Braun-Blanquet Cover Abundance (BBCA) scale. The BBCA assesses the cover of *P. oceanica* according to a qualitative scale

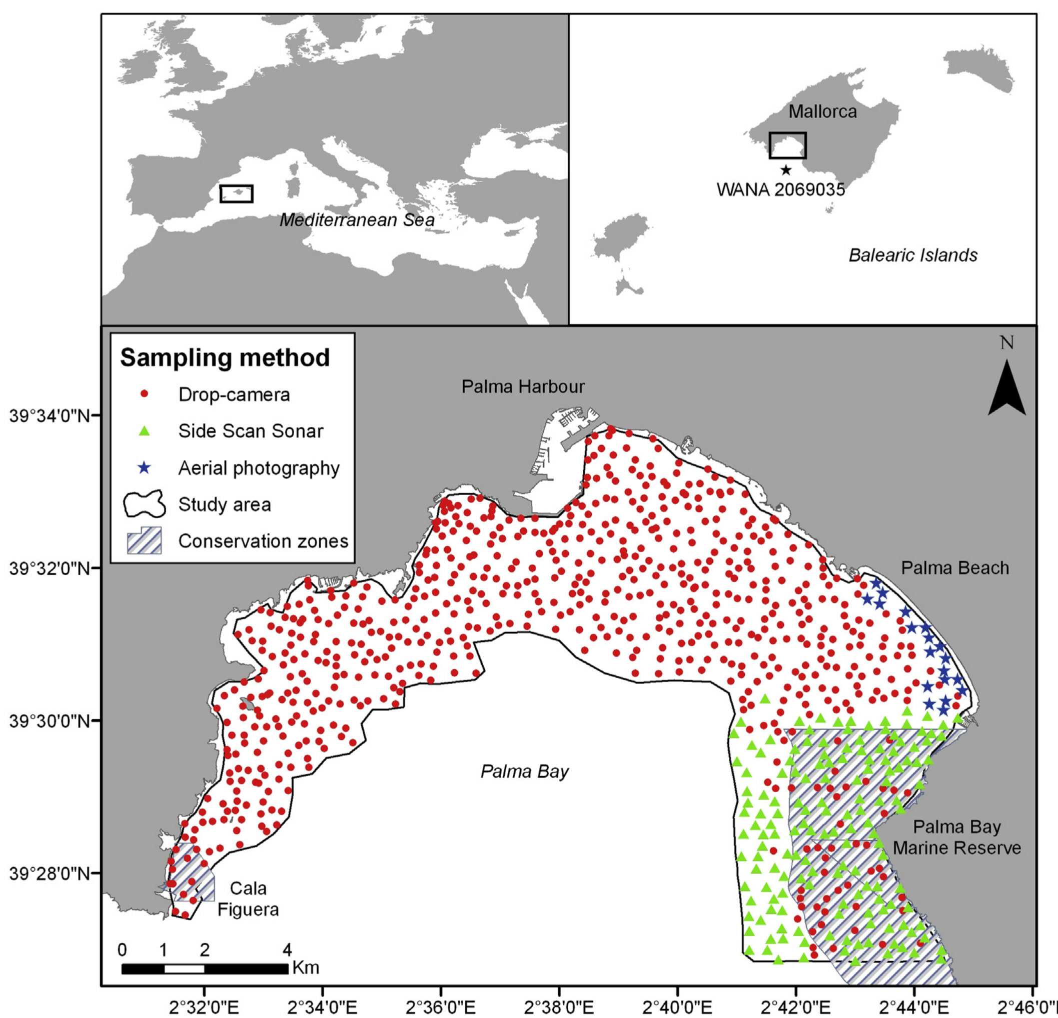

Fig. 1. Palma Bay. Sampling locations classified by observation method: aerial photography, side scan sonar and drop camera.

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