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Long-term analysis of *Zostera noltei:* A retrospective approach for understanding seagrasses' dynamics

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ABSTRACT

Long-term studies are necessary to establish trends and to understand seagrasses' spatial and temporal dynamic. Nevertheless, this type of research is scarce, as the required databases are often unavailable. The objectives of this study are to create a method for mapping the seagrass *Zostera noltei* using remote sensing techniques, and to apply it to the characterization of the meadows' extension trend and the potential drivers of change. A time series was created using a novel method based on remote sensing techniques that proved to be adequate for mapping the seagrass in the emerged intertidal. The meadows seem to have a decreasing trend between 1984 and the early 2000s, followed by an increasing tendency that represents a recovery in the extension area of the species. This 30-year analysis demonstrated the *Z. noltei*'s recovery in the study site, similar to that in other estuaries nearby and contrary to the worldwide decreasing behavior of seagrasses.

1. Introduction

Despite the economic and ecological value of seagrasses (Costanza et al., 1997; Grech et al., 2012), anthropic derived pressures have generated a global decreasing trend in their distribution area (Orth et al., 2006). Physical disturbances and water quality deterioration are two factors that have been associated with the seagrasses decline (Duarte, 2002), which is also related to the indirect effects of eutrophication, with the overgrowth of macroalgae and epiphytes causing shading and suffocation of seagrasses (Cabaço et al., 2008).

Long-term analysis is necessary for identifying trends and establishing the baselines for natural variability (Hedley et al., 2016), and can also improve studies related to the resilience of populations and recovery after a perturbation. Historic satellite imagery and environmental databases can reduce the economic and temporal resources needed for this type of analysis, facilitating its application in research and management projects. Nevertheless, using historic satellite imagery can entail a considerable limitation: the ability of mapping the seagrasses using past images that lack reference data (i.e. field information or "ground truth"). This is a major challenge in large scale mapping and retrospective time series analysis (Hedley et al., 2016), as many supervised algorithms require the definition of training areas based on reference information (e.g. Artigas and Pechmann, 2010; Fornes et al., 2006; Phinn et al., 2008; Pu et al., 2012). In addition, other mapping approaches require extensive field work incompatible with using past images (Byrd et al., 2014; Yang and Yang, 2009).

Variables that affect the seagrasses' health have been studied experimentally, mostly addressing the short-term effect of perturbations (less than months), but setting aside the analysis of long-term effects on the seagrasses' health. Examples include, among others, the relation of light and biomass partitioning on the growth of the vegetation (Olivé et al., 2007), the toxic effect of increased sediment nutrient and organic matter loading (Govers et al., 2014), and the physical perturbations and recovery in contrasting wave regimes and nutrient stress levels (Cabaço and Santos, 2007; Soissons et al., 2014).

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There are relatively few examples of retrospective analysis of seagrass dynamics and their relation to environmental changes. Some researchers focus on the temporal analysis of the meadows and infer possible relations with environmental variables (Barillé et al., 2010; Dekker et al., 2005; Gullström et al., 2006; Lyons et al., 2013), without directly analyzing the relationship between the variables and the meadow. There are also examples focused on the analysis of the vegetation dynamic and its relation to environmental changes (Frederiksen et al., 2004a, 2004b; Hossain et al., 2015; Plus et al., 2010), but this type of publication is scarce, as long-term records of environmental variables are generally not available.

In the Bay of Santander, an estuary located in the north of Spain (Bay of Biscay), there has been an apparent recovery of the seagrasses *Zostera noltei* (Hornem.) and *Zostera marina* (Linnaeus) in recent years. The increase in the extension area of these meadows appears to coincide with the initiation of Santander's water treatment system, so it has been hypothesized that the physical and chemical changes that came with the removal of urban discharges from the Bay might be the cause for the seagrasses' recovery. A long-term analysis of *Z. noltei's* dynamic using historic satellite images would allow for the confirmation of this apparent recuperation. In addition, physical and chemical variables measured *in situ* can establish the change in the quality of the water body, and may identify the drivers responsible for the changes in this species' distribution area.

Thus, our research aims to: i) develop a method based on remote sensing techniques for mapping *Z. noltei* over time, and ii) to characterize the *Z. noltei* meadows' extension trends in the Bay of Santander, and to try to identify potential drivers which may be related to significant changes in the distribution of the meadows. This represents an important contribution to this specie's knowledge base, as it will create one of the few long-term analyses of its

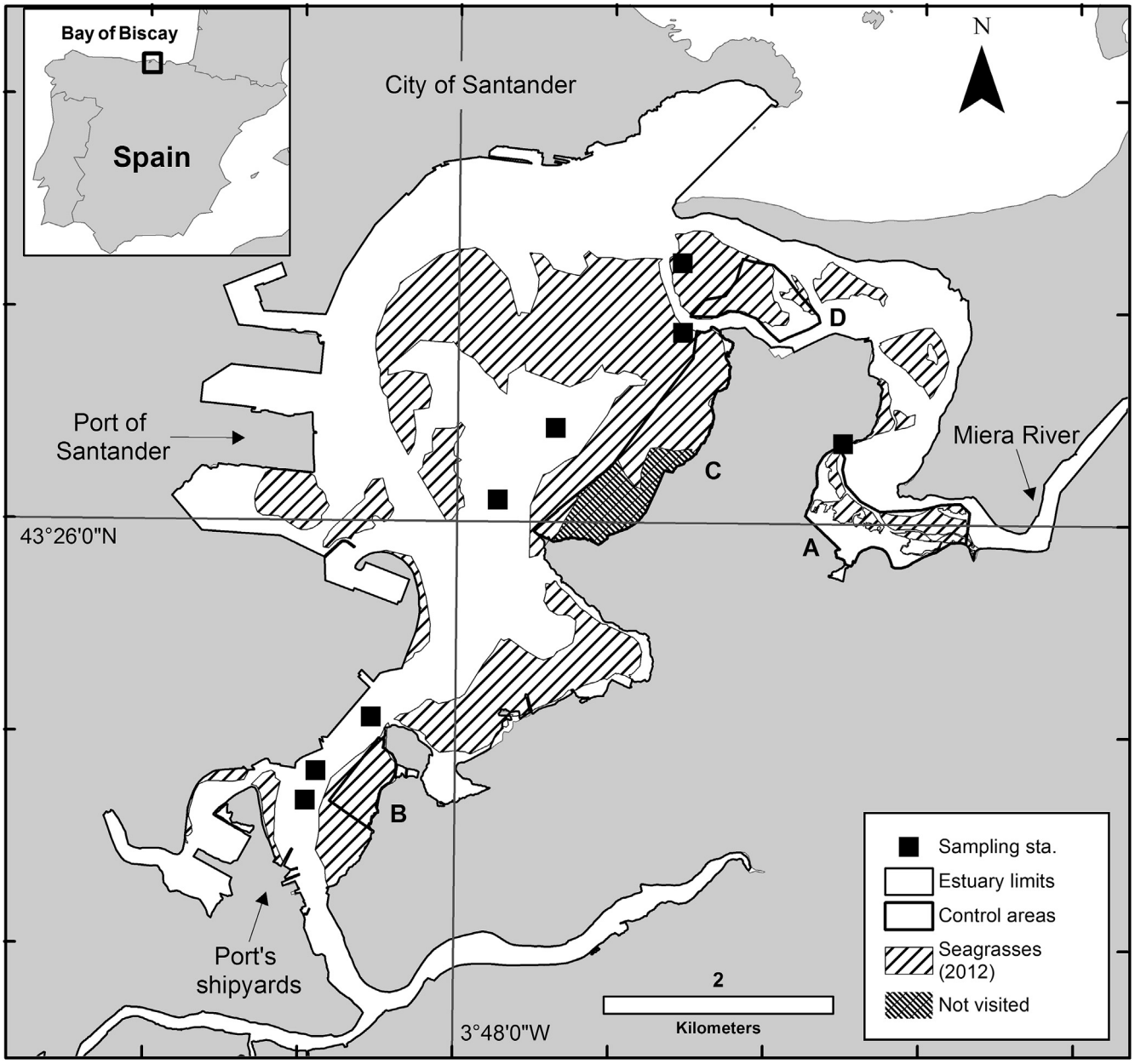

Fig. 1. Bay of Santander. Official limits, seagrass presence according to field cartography (including not visited), and control areas with the environmental variable's sampling stations (total extension and mean depth ± std in brackets): A (65.34 Ha, 0.91 ± 0.85 m), B (21.60 Ha, 0.25 ± 0.49 m), C (100.80 Ha, 0.42 ± 1.34 m), D (36.45 Ha, −0.71 ± 0.44 m).