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Distribution modeling of seagrasses in brackish waters of Grado-Marano lagoon (Northern Adriatic Sea)

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ABSTRACT

Seagrasses play an important role in coastal lagoons both as primary producers and ecosystem engineers, thus sustaining biodiversity and ecosystem services. In recent decades, their populations have shown a rapid decrease, mainly due to their vulnerability to environmental degradation. Their ecology was widely investigated in the marine domain whereas the knowledge of their distribution patterns in lagoon waters is still not exhaustive. This study aimed at improving the knowledge of seagrass ecology in such ecosystem. Three seagrass species (i.e. *Zostera marina*, *Zostera noltii* and *Cymodocea nodosa*) occurring in Grado-Marano lagoon (Northern Adriatic Sea -Italy) were studied by examining: (i) the distribution of each *taxon*, (ii) the main water, and (iii) geomorphological variables, gathered in 466 sample points during field surveys and from literature, respectively. Logistic-Generalized Linear Models (GLMs) were used to develop species distribution models (SDM) of seagrass meadows and single species. The seagrass presence was mainly explained by two clear ecological gradients: (i) sea-inner shoreline and (ii) channel-tidal flats. In particular, seagrasses thrive in areas mostly subjected to marine influence, in both terms of proximity to lagoon inlets and main channels, avoiding areas near major rivers mouths. Species distribution models highlighted the crucial role of water salinity and distance from fresh water sources (positively and negatively related, respectively). *Zostera marina* and *Zostera noltii* showed similar comparable effects for most of the ecological predictors, with the exception of water depth (ecological vicariance). *Cymodocea nodosa* showed a wider ecological variability, with lower goodness of model selection.

1. Introduction

Seagrasses are rhizomatous marine angiosperms widespread in both marine and brackish shallow waters from temperate to tropical regions (Short et al., 2007). In these regions, they often act as ecological engineers (Wright and Jones, 2006), forming extensive meadows that are among the most productive ecosystems on Earth (McRoy and McMillan, 1997; Duarte and Chiscano, 1999). Seagrass meadows provide key ecosystem services, including organic carbon production and export, nutrient cycling, sediment stabilization, biodiversity, and trophic transfers to adjacent habitats (Duarte et al., 2005; Duffy, 2006; Orth et al., 2006; Cullen-Unsworth and Unsworth, 2013; Marco-Méndez et al., 2015). Although widely distributed, seagrasses have experienced a large-scale decrease in the last decades in most of worldwide populations (Borum et al., 2004; Waycott et al., 2009). These reductions were mainly due to multiple environmental stressors, often attributable to human activities (e.g. water eutrophication, coastal salinity changes, water turbidity in relationship to sediment management, alien species) (Orth et al., 2006).

Seagrass meadows are a pivotal habitat also for transitional water bodies (Aliaume et al., 2007). On the other hand, among transitional water bodies, lagoons are ephemeral and fragile ecosystems, which constitute an important harbor for life (e.g. algae, invertebrates and fish nurseries, migratory birds) (De Wit, 2011; Garrido et al., 2011). Lagoons are shallow aquatic environments

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located in transitional zones between terrestrial and marine systems, characterized by considerable gradient of water salinity, spanning from freshwater to hypersaline conditions (Kjerfve, 1994). Their permanence is strictly related to depositional and erosion balance, sea level fluctuation, and human activities (Kjerfve, 1994; De Wit, 2011). As such, studies on seagrass distribution in brackish water systems are of the utmost importance for conservation of both biotic and abiotic features of such a fragile ecosystem.

Seagrass ecology has been described in several reviews, with particular reference to marine systems (Duarte, 1999; Hemminga and Duarte, 2000; Larkum et al., 2006). In particular, species distribution modeling was commonly used as a powerful tool to depict species and taxa niches (van der Heide et al., 2009; Valle et al., 2011; Valle at al., 2013) and distribution (Lathrop et al., 2001). Kelly et al. (2001) produced seagrass predicting maps, indicating the role of hydrodynamic features, whereas Bekkby et al. (2008), in northern marine waters, were able to model the distribution of eelgrass (*Zostera marina*), underlining the role of depth, slope and wave exposure. Other authors were able to model eelgrass niche, using other environmental predictors, highlighting that the species prefers shallow and moderately exposed locations, near sandy shores (Downie et al., 2013). Many other papers examined diverse ecological parameters and their effects on various seagrass species distribution and vitality, such as (i) salinity (Torquemada et al., 2005; Fernández Torquemada and Sánchez Lizaso, 2006; Pagès et al., 2010), (ii) water depth (Orth and Moore, 1988; Gallegos and Kenworthy, 1996; Duarte et al., 2007), (iii) water and sediment nutrients availability (Perez et al., 1991; Burkholder et al., 2007), and (iv) temperature (Nejrup and Pedersen, 2008).

In coastal lagoons, seagrasses have also been largely studied, but focusing mainly on their distribution, biomass, reproduction and population dynamics (Ward et al., 1997; Sfriso and Ghetti, 1998; Sfriso and Facca, 2007; Rivera-Guzmán et al., 2014). In particular, modeling of biomass was undertaken on diverse species in other nearby sites (Zharova et al., 2001, 2008). Conversely, few works dealt with ecological modeling of species distribution, most of them concerning only specific environmental predictors (e.g. Callaghan et al., 2015). Nonetheless, it is possible to hypothesize that the distribution of seagrass species in lagoon waters is strongly related to the macro-ecological gradients characterizing transitional water systems. Some comprehensive studies, considering an overview of principal environmental predictors (i.e. chemical features of water, hydromorphological features of the lagoon and sediment parameters of sea bed) are, hence, needed. More specifically, the study of the effects of environmental predictors on species distribution produces new knowledge on species distribution modeling in such peculiar ecosystems. The achievement of a better understanding of species ecology in brackish water can produce important implication for the environmental management of the transient waters. For these reasons, this study aimed at increasing the ecological knowledge of seagrasses in lagoons. In the Mediterranean bioregion, the lagoon systems include six aquatic angiosperm species (Short et al., 2007). Three of them were considered in this research, due to their widespread across the lagoon (Falace et al., 2009), viz. *Zostera marina* (hereafter *Z. marina*), *Zostera noltii* (hereafter *Z. noltii*) and *Cymodocea nodosa* (hereafter *C. nodosa*). *Z. marina* (eelgrass) is a temperate-boreal species (range between 25° and 75°N) (Green and Short, 2003), which, in the Mediterranean Sea, is considered as a relict species (McRoy and Helfferich, 1977; Nejrup and Pedersen, 2008). *Z. noltii* (dwarf eelgrass) and *C. nodosa* show smaller ranges, covering European (Mediterranean, Black, Azov, Caspian, Aral, Baltic and North) and northern African waters, and from Mediterranean to northern African waters, respectively (Green and Short, 2003; Larkum et al., 2006).

The study relies on a large dataset of both presence/absence data and a wide pattern of environmental predictors encompassing the most important ecological drivers for seagrasses. Analyses of such wide pattern of predictors can provide solid insights in species and seagrass distribution understanding in a typical brackish water system such as the study leaky lagoon.

We used generalized linear models (GLMs) coupled with multimodel inference (MMI), as one of the most known Species Distribution Modeling (SDM) methods. The aim was to test the following hypotheses: (i) are there strong relations between seagrass distribution and environmental predictors (i.e. water and geomorphological features of the lagoon)? (ii) are there diverse ecological patterns of the considered species, in terms of both species distribution and environmental predictor sensitivity?

2. Materials and methods

2.1. Study area

The study area was the lagoon of Grado and Marano (Fig. 1) (45°40′40″ N 13°03′50″ E to 45°46′30″ N 13°27′20″ E), included in the delta system of Northern Adriatic Sea. With a surface of approx. 160 km^2, it is the second major transitional water body of the Italian coast lines. It is separated from the Adriatic Sea by six sandbars spaced by inlets. The average distance between sandbars and inner coast line is approx. 5 km, whereas the costal length is approx. 35 km. The lagoon is morphologically classified as a leaky lagoon (Kjerfve, 1994), with strong tidal influence (Ferrarin et al., 2010). It is divided into two basins (Marocco, 1995; Gatto and Marocco, 1993): the first, named the Marano basin, is characterized by (i) shallow water body, (ii) few areas above sea level, (iii) conspicuous inputs of fresh waters, due to rivers flowing into the lagoon across the principal channels, and (iv) a diffusive water tidal cycle; the latter, named the Grado basin, with (i) several islands, (ii) salt marshes, (iii) shallower waters, (iv) a complex channel network and (v) an advective water tidal cycle. Tides are semidiurnal with an average range of 65 cm (Gatto and Marocco, 1993*)*. The amount of fresh water flowing by principal rivers is approx. 2200 − 2500 10^6 m^3 year, whereas inlets input of marine water is 125 10^6 m^3 year. The average water salinity ranges from 28.5, for the basin of Grado, to 22.2, for the basin of Marano (Falace et al., 2009). Water temperature shows a positive gradient form the river mouths to the inlets, having an average of 15.8 °C and 14.8 °C for Marano and Grado basins, respectively. The lagoon encompasses a complex of ecosystems with high nature value, sustaining biodiversity and several ecological functions (Falace et al., 2009). Moreover, it is included in the Natura 2000 network as both Special Area of Conservation (SAC) and Special Protection Area (SPA).

2.2. Species data

A preliminary map of patches of the putative presence/absence of seagrass meadows was digitalized in a GIS environment by photo interpretation on two series of digital orthophotos in low tide (20 cm × 20 cm pixel, year 2003) and high tide (50 cm × 50 cm pixel, year 2007), respectively. Main channels were *a priori* discarded due to periodic disturbance of dredging. On this preliminary map (scale 1:5.000), a geographic grid with operative geographic units (OGU) of 11.25″ latitude x 18.75″ longitude amplitude (approx. 350 m × 400 m) was overlaid. The grid reference follows the Central European MTB (Ehrendorfer and Hamann, 1965); used for the Flora Atlas of the region (Poldini, 2002), cell size was defined to maximize map detail information. The four hundred and sixty-six points were placed in all OGU intersecting a putative patch. Field surveys were conducted during the summer season of 2010.