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Spatial and temporal variations in aboveground and belowground biomass of *Spartina maritima* (small cordgrass) in created and natural marshes

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Spartina species are commonly used for salt marsh manipulative projects, where aboveground and belowground biomasses are functional traits that play important roles, showing high spatial and temporal variations. This work analyses variations in AGB and BGB of *Spartina maritima* and abiotic environmental parameters along a chronosequence of six marshes created from 1997 to 2003 with disparate sediment dynamics, and adjacent natural marshes and unvegetated tidal flats. *S. maritima* behaved as an autogenic engineer, as its colonization of bare sediments yielded abiotic environmental changes: specifically, bed level rise accompanied by higher oxygenation and salinity. These modifications of the environment were site-specific, depending mainly on sedimentary dynamics. At the same time, abiotic environmental changes determined biomass production rates of *S. maritima* that were higher in more-accreting marshes; however, AGB was kept constant from early in its development (2 years). The increase in BGB with elevation seemed to be related to the inhibition of subsurface tissue development in anoxic sediments. Biomass accumulation and production varied markedly, depending on the spatial scale, indicating the relevance of the plot size chosen for the analysis of biomass of cordgrasses. Our results show that managers of salt marshes should consider sedimentary dynamics carefully when setting realistic expectations for success criteria of created and restored wetlands.

1. Introduction

Salt marshes fulfill many functions, such as biodiversity support, water quality improvement, or carbon sequestration. However, they have been affected by anthropogenic degradation worldwide, so today there is a need for salt marsh ecological restoration and improvement (Zedler and Kercher, 2005). In this context, *Spartina* species are commonly used for salt marsh creation, restoration, protection (Fang et al., 2004), or phytoremediation (Czako et al., 2006). Belowground and aboveground biomasses are functional traits that play important roles in successfully developing these ecological services, since they affect the role of *Spartina* in fighting against erosion or in promoting accretion (Neumeier and Amos, 2006), developing the habitat structure (Craft et al., 2003), extracting or stabilizing pollutants (Weiss and Weiss, 2004), and facilitating succession development (Castellanos et al., 1994; Egerova et al., 2003).

At the same time, salt marshes are highly heterogeneous environments, showing many different habitats with disparate abiotic conditions promoting *Spartina* ecophenes (Trnka and Zedler, 2000; Proffitt et al., 2003; Castillo et al., 2005). Small-scale changes in physical factors, such as elevation or hydrology, are likely to have substantial effects on the development of ecosystem function in restored salt marshes (Callaway, 2005). Moreover, *Spartina* biomass varies throughout its ontogenic development from expanding seedlings to mature tussocks suffering die-back (Turner et al., 2004). Therefore, understanding spatial and temporal variations in *Spartina* biomasses is an important step towards improving their applications in salt marsh bioengineering. Some opportunities for improving restoration have been identified, such as increasing our understanding of the development of restored salt marshes over time, especially in comparison to natural marsh development, identifying the limiting factors that restrict the development of restored marshes, and evaluating the link between physical heterogeneity and ecosystem function.

Although many studies have been carried out on salt marsh restoration on the Atlantic coast of the USA with *Spartina alterniflora* Loisel. (smooth cordgrass), little is known about the restoration of European salt marshes using *Spartina maritima* (Curtis) Fernald (small cordgrass). *S. maritima* is a European cordgrass typically found in low salt marshes with anoxic sediment exposed to high inundation periods (Castillo et al., 2000). In these habitats, *S. maritima* shows important differences in survivorship, shoot density and height, and biomass (Castellanos et al., 1994, 1998; Castillo et al., 2000, 2005).

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This work analyses temporal and spatial variations in above- and belowground biomass of *Spartina maritima* and abiotic environmental parameters (sediment texture and elevation, accretion rate, redox potential, interstitial water conductivity, and organic matter content) along a chronosequence of six 9–2-year-old created marshes, adjacent natural marshes, and unvegetated tidal flats with contrasted sediment dynamics.

2. Materials and methods

2.1. Study area

Work was carried out in the Odiel Marshes, on the Atlantic coast of the SW Iberian Peninsula (37°08′–37°20′N, 6°45′–7°02′W). These salt marshes are among the largest of the Iberian Peninsula, and they are protected as a 'Natural Reserve of the Biosphere'. The semidiurnal tides have a mean range of 2.10 m and a mean spring tidal range of 2.97 m, representing 0.40–3.37 m above Spanish Hydrographic Zero (SHZ). Mean sea level is +1.85 m relative to SHZ. The physiography, climate, and vegetation have been described by Castellanos et al. (1994) (Fig. 1).

Specifically, the experiment was carried out on three extensive, flat, and unvegetated tidal flats bordering the main channel of the estuary, close to the scarce natural populations of *Spartina maritima* (NM), and with similar topographical positions ($+2.10 \pm 0.03$ m SHZ). Locations 1 and 2 (L-1 and L-2) were situated on opposite banks, just at the point where the Odiel River joins the Tinto River. Location 3 (L-3) was close to the mouth of the estuary. L-1 and L-3 each counted with one natural population of *S. maritima* (Fig. 1; Table 1). The banks of this channel are sporadically used for bait catching of *Nereis diversicolor* Müller (Annelida, Polychaeta). Vertical and undermined banks have been recorded in some stretches where high horizontal erosion rates of high salt marshes have been recorded associated to the influence of waves generated by the boat traffic of the Port of Huelva city (Castillo et al., 2002).

2.2. *Transplants of* Spartina maritima

Six created marshes (CM) of *Spartina maritima* with an area between 247 and 810 m^2 were set up at the three locations described above, which showed an appropriate environment for small cordgrass development (Castillo et al., 2000). Clumps were extracted from different tussocks in the adjacent natural populations with similar amounts of underground reserves as rhizomes and roots, 15–20 shoots and a horizontal diameter between 7–10 cm. No attempt was made to remove local sediment adhering to the clumps. Individual clumps were planted to a depth of 10–15 cm at a density of one clump per square meter. Three created marshes were established at L-1 in May 2000 (CM-1.1), July 2001 (CM-1.2), and June 2002 (CM-1.3), with plant material coming from the adjacent natural population (NM-1). Another created marsh was established at L-2 in February 2001 (CM-2.1) with plant

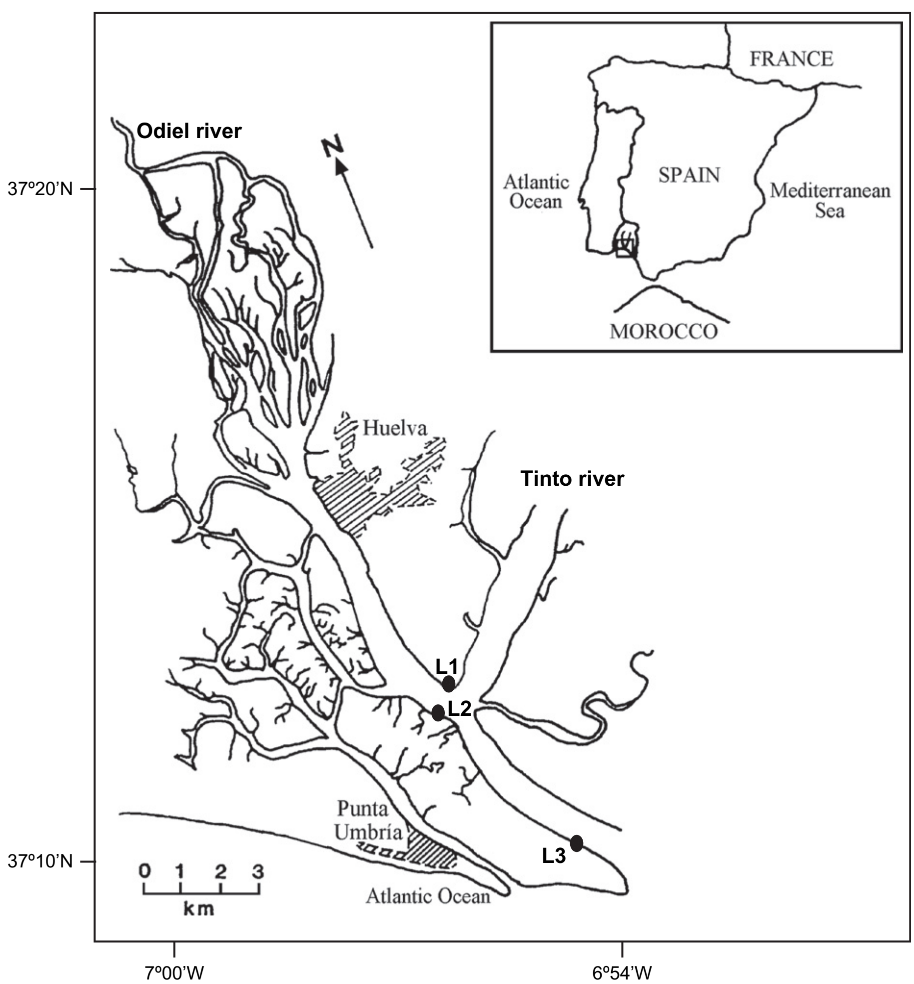

Fig. 1. Location of the Odiel Marshes on the Atlantic coast of south-west Spain showing the three sites on the banks of the main channel within the Odiel Marshes where the study was carried out (L1, L2, and L3).