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Seasonal modification of tidal flat sediment dynamics by seagrass meadows of *Zostera noltii* (Bassin d'Arcachon, France)

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ABSTRACT

The Arcachon lagoon (Atlantic coast, SW France) is a mesotidal embayment where seagrass beds colonize the majority of intertidal areas. In recent years, the surface area of *Zostera noltii* meadows has considerably decreased, with possible consequences for the sediment balance of the lagoon. However, such interactions are poorly understood, and knowledge of the relationship between hydro-sedimentary processes and small intertidal meadows, such as *Z. noltii*, is limited.

An intertidal mudflat, with variable meadow coverage, was studied during an annual survey. The study consisted in continuous high-frequency monitoring of bed altimetry, tidal elevation and waves. Sediment parameters and meadow characteristics were analyzed using samples collected monthly. Acoustic altimetry was validated as an efficient method to measure bed elevation in a vegetated environment, despite the presence of leaves under the transducer. The acoustic altimeter was also shown to have the potential to accurately estimate canopy height in a submerged environment.

Our survey data showed centimetric bed accretion at all vegetated stations. Accretion was positively correlated with seasonal growth of the meadows. During seasonal degeneration, the meadow prevented erosion of the sea bed. These results highlight the important role of seagrasses as ecosystem engineers.

1. Introduction

In coastal shallow waters, seagrass meadows dampen the hydrodynamic energy of tidal currents (Fonseca and Fisher, 1986; Gambi et al., 1990; Hendriks et al., 2008, 2010; Verduin and Backhaus, 2000) and waves (Koch, 1999; Koch and Gust, 1999). Consequently, seagrass meadows are also believed to enhance sediment deposition (Gacia and Duarte, 2001; Gacia et al., 1999, 2003; Hendriks et al., 2008) and to protect the sediment bed from erosion (Amos et al., 2004; Bos et al., 2007; Gacia and Duarte, 2001), with direct consequences for the long-term sediment balance. Seagrass meadows comprise a wide variety of species, and many studies have been undertaken to assess their role in ecosystem engineering by modifying hydro- and sediment dynamics. However, most of these studies focused on tall subtidal species, like *Posidonia oceanica* (Gacia et al., 1999; Granata et al., 2001; Hendriks et al., 2008), *Zostera marina* (Fonseca and Fisher, 1986; Fonseca and Koehl, 2006; Gambi et al., 1990) or *Thalassia testudinum* (Fonseca and Fisher, 1986; Koch, 1999; Koch and Gust, 1999). Much less attention has been paid to intertidal short-leaf species, such as *Z. noltii* (Widdows et al., 2008). Because of their seasonal growth cycle, these species cause strong time-dependent variability of the interactions between the seagrasses, tidal flows and sediments. Their presence in the intertidal zone may also affect the morphodynamics of wide tidal flat areas through significant seasonal and long-term modifications. Knowledge of the interactions between hydro-sedimentary processes and seasonal variations of *Z. noltii* is still limited (Bos et al., 2007; Widdows et al., 2008). Additionally, in many European coastal areas, a major decline in the surface area of seagrasses has been reported during the last century (Bernard et al., 2005, 2007; Giesen et al., 1990; Orth et al., 2006; Waycott et al., 2009) and the consequences of this decline remain to be determined.

With a total surface area of 174 km^2, the Arcachon lagoon is a triangular-shaped mesotidal embayment located along the Aquitaine Atlantic coast (South-West France, Fig. 1). The tidal range varies from 0.8 m at neap tides to 4.6 m at spring tide. Wide intertidal areas (117 km^2) are extensively colonized by perennial seagrass meadows of *Z. noltii*, and are the largest seagrass meadows in Europe (Auby and Labourg, 1996). Comparison of maps made in 1989 and 2007 showed that the surface area of these meadows has decreased by 33% from 68.5 km^2 to 45.7 km^2 (Plus et al., 2010). This decline has consequences not only for the ecology of the lagoon, but also for its management. At the same time as the reduction in area, the inner lagoon's channels are tending to fill in, increasing the need for dredging. Such events suggest that the decline in meadows will have significant consequences for the sediment balance. For this reason, *in situ*

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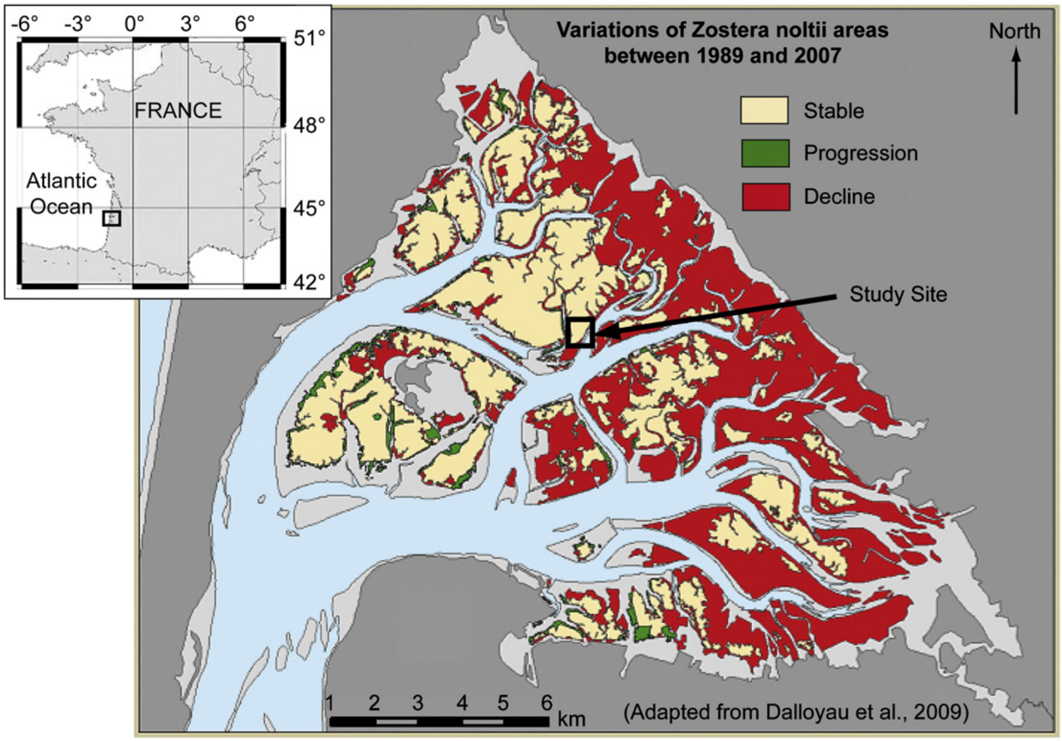

Fig. 1. General location of the Arcachon lagoon and the study site. Channels and subtidal areas are in sky blue. The interannual variation of *Zostera noltii* on intertidal flats highlights the decline of meadows in the inner parts of the lagoon.

continuous monitoring of the bed altimetry, coupled with monthly determination of seagrass development and surficial sediment characteristics, was performed over a period of one year. Using this dataset, the aim of the present study was to understand how seasonal changes in the meadows are linked to the sediment dynamics of tidal flats. In addition, this is the first demonstration of the use of acoustic altimetry in a vegetated environment. When evaluating the data, we focused on observed seasonal trends, with emphasis on the interaction between the seasonal growth of *Z. noltii* meadows and sediment dynamics. Finally, the possible long term consequences for the lagoon are discussed.

2. Materials and methods

2.1. Site description

Field research was conducted from February 2009 to March 2010 on an intertidal flat located in the central part of the Arcachon lagoon (Fig. 1). The site was selected based upon the relative stability of the meadows throughout the year (Plus et al., 2010). The experimental site consists of three vegetated stations comprising meadows with different densities of *Z. noltii*. The leaf cover was estimated visually before the beginning of the survey, and stations were identified as "high-density" (HD), "medium-density" (MD) and "low-density" (LD) meadows. The stations were located 60 m apart. Bathymetry (nautical chart datum) for the three stations ranged from 1.78 m (LD) to 1.82 m (HD), and the average emersion time ranged from 3 h 45 min (LD) to 3 h 50 min (HD). A fourth station was located in a bare mud area closest to the HD station. This bare mud station was denoted the "unvegetated mud" (UM) station. Because of the natural heterogeneity in meadow morphology and distribution in the field, this station had a slightly lower bathymetry (1.69 m) than did the vegetated stations, and it was located closest to the channel edge (40 m). However, the average emersion time (3 h 38 min) was only 12 min less than that of the highest station (HD).

Current velocity measurements were recorded simultaneously at the stations with the highest and lowest bathymetry (respectively, the HD and UM stations). These measurements were made from August 18, 2009 to September 2, 2009 and from January 28, 2010 to February 12, 2010 using ADCPs (Acoustic Doppler Current Profiler, RD Instruments). Computed depth-averaged current velocities under fair weather conditions (U, Fig. 2a) were of the same order of magnitude at both stations. During the first 40 min of inundation, slightly higher velocities were recorded at the unvegetated mud station (UM), but they decreased rapidly to reach the values recorded at the vegetated HD station. Moreover, under windy conditions (Fig. 2b), wind-induced waves of significant wave height (H_s), measured with an ALTUS pressure sensor (see below), exhibited comparable growth and decay at both the UM and HD stations. We can thus safely assume that each station was subject to similar hydrodynamic forcing.

2.2. Eelgrass sampling

A biometric analysis was performed at each vegetated station (HD, MD and LD) following a protocol adapted and calibrated for the European Water Framework Directive (Hily et al., 2007). Mini-core samples (98 mm in diameter and 70 mm in length) of eelgrass were collected monthly. Nine samples were collected at each station. Samples were washed with fresh water on a sieve (mesh size 1.25 mm) to separate seagrasses from sediments and shell fragments. The seagrasses were frozen until analysis. For biometric analysis, the seagrasses were first separated into individual plants, and then divided manually into above- and below-ground biomass. When the rhizomes and roots were soft and dark brown in color, they were considered to be dead and removed. The number of shoots per mini-core was recorded, providing the shoot density (D_{shoot}, in shoot.m^{-2}). Using digital photography, the length and width of a leaf from ten randomly selected shoots were measured. Using these measurements, the mean leaf length (L_{leaf}, in mm) and the leaf area index (LAI, total leaf area per ground area unit in m^2.m^{-2}) were calculated. For each of the three