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Impact of adjacent land use on coastal wetland sediments

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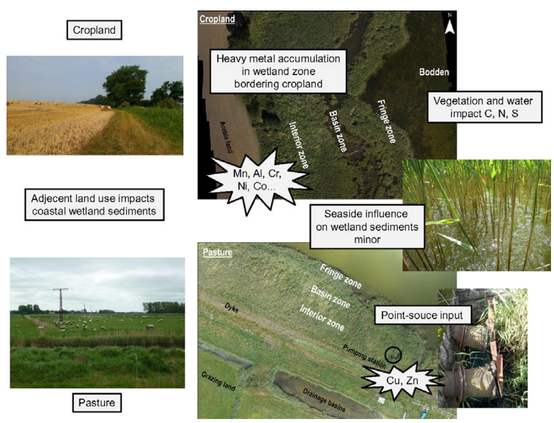
HIGHLIGHTS

- The adjacent land use (cropland/pasture) impacts wetland sediment composition.
- Fertilizer application led to heavy metal accumulation in the zone bordering cropland.
- Seaside influences on sediments were minor compared to influences from land.

GRAPHICAL ABSTRACT



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ABSTRACT

Coastal wetlands link terrestrial with marine ecosystems and are influenced from both land and sea. Therefore, they are ecotones with strong biogeochemical gradients. We analyzed sediment characteristics including macronutrients (C, N, P, K, Mg, Ca, S) and heavy metals (Mn, Fe, Cu, Zn, Al, Co, Cr, Ni) of two coastal wetlands dominated by *Phragmites australis* at the Darss-Zingst Bodden Chain, a lagoon system at the Southern Baltic Sea, to identify the impact of adjacent land use and to distinguish between influences from land or sea. In the wetland directly adjacent to cropland (study site Dabitz) heavy metal concentrations were significantly elevated. Fertilizer application led to heavy metal accumulation in the sediments of the adjacent wetland zones. In contrast, at the other study site (Michaelsdorf), where the hinterland has been used as pasture, heavy metal concentrations were low. While the amount of macronutrients was also influenced by vegetation characteristics (e.g. carbon) or water chemistry (e.g. sulfate), the accumulation of heavy metals is regarded as purely anthropogenic influence. A principal component analysis (PCA) based on the sediment data showed that the wetland fringes of the two study sites are not distinguishable, neither in their macronutrient status nor in their concentrations of heavy metals, whereas the interior zones exhibit large differences in terms of heavy metal concentrations. This suggests that seaside influences are minor compared to influences from land. Altogether, heavy metal concentrations were still below national precautionary and action values. However, if we regard the macronutrient and heavy metal concentrations in the wetland fringes as the natural background values, an accumulation of trace elements from agricultural production in the hinterland is apparent. Thus, coastal wetlands bordering croplands may function as

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effective pollutant buffers today, but the future development has to be monitored closely to avoid breakthroughs due to exceeded carrying capacities.

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1. Introduction

Coastal wetlands are open structures with strong interactions along the land-water interface, linking terrestrial with marine ecosystems (Andreu et al., 2016), and represent ecotones in the core sense of the term. Coastal wetlands can provide a variety of ecosystem services that are fundamental for physical processes and biogeochemical cycling including sediment retention and protection against coastal erosion, habitats for fish or birds, raw material provisioning, pollutant buffering and nutrient regulation (Duarte et al., 2013; Karstens and Lukas, 2014; Perillo et al., 2009; Reddy et al., 1999). The relative importance of these services for humans often depends on management decisions and the specific location of a coastal wetland.

Coastal wetland sediments are a mixture of material from various sources including terrestrial input via surface or groundwater flows, erosion of near-by coastal sites or adjacent land, atmospheric depositions or sedimentation of marine particles (Abi-Ghanem et al., 2009; Bao et al., 2015). Macronutrients may have natural origins (wetland vegetation or sea influence), whereas the accumulation of heavy metals in sediments can be regarded as a 'finger print of human activity' (Andreu et al., 2016). Heavy metal concentrations in the landward zones of wetlands may be largely driven by input from adjacent parts of land, especially when these are croplands because erosion tends to be stronger compared to permanent grasslands or forests (Pimentel and Kounang, 1998). In aquatic environments, heavy metals can be a major threat due to their persistence, prevalence, potential toxicity and bioavailability (Boyd, 2010; Marchand et al., 2011). Identifying the sources of heavy metals and evaluating of the influence of anthropogenic activities is difficult (Bayen, 2012; Wang et al., 2014). Agriculture is often mentioned as an important input source and fertilizers applied in agroecosystems can be a major source of heavy metals (Jiao et al., 2012). Some heavy metals included in fertilizers are essential for plant growth but toxic above critical concentrations (e.g. copper, zinc, manganese, iron), whereas others are always contaminants with no benefits for plant growth (e.g. chromium) (He et al., 2005). Contamination assessments and monitoring of heavy metal concentrations in coastal wetland sediments are essential, especially when anthropogenic pressures are on the rise (Andreu et al., 2016; Pascual-Aguilar et al., 2015), and coastal wetlands are 'the last line of defense' before pollutants reach adjacent waters.

In this study we analyze the sediment composition of different coastal wetlands including all macronutrients (C, N, P, K, Mg, Ca, S) as well as eight heavy metals (Mn, Fe, Cu, Zn, Al, Co, Cr, Ni) to answer the question, whether sediment characteristics of coastal wetlands dominated by *Phragmites australis* differ depending on adjacent land use. Two typical and representative sites with respect to land use, topography and hydraulic conditions in the Southern Baltic Sea region were chosen. The wetlands were further subdivided into three zones in order to distinguish between influences from land or sea. We address how adjacent land use (pasture vs. cropland) impacts sediment composition and how influences from the land or sea dominate across the wetland zones. By doing this, we aim to differentiate between 'natural' and 'anthropogenic' influences. While the amount of macronutrients in sediments might be either influenced by vegetation characteristics (e.g. carbon) or water chemistry (e.g. sulfur), the accumulation of heavy metals in sediments is regarded as anthropogenic influence.

2. Research approach and methods

2.1. Study sites

The Darss-Zingst Bodden Chain is a lagoon system with four subbasins at the Southern Baltic Sea in Germany (Fig. 1). It is a shallow water body with a mean water depth of 2 m. The only connection to the open Baltic Sea is a narrow outlet called Gellenstrom in the northeast (Schumann et al., 2006). Tides do not exist and water exchange with the Baltic Sea is induced meteorologically with inflow situations under strong and persistent northeasterly winds (Selig et al., 2007).

The southern hinterland of the Darss-Zingst Bodden Chain is predominantly used for agriculture (Fig. 1). Lowland areas are dyked and used as grassland, whereas areas with a more pronounced topography are usually not dyked and used as cropland. Consequently two different types of coastal wetlands can be differentiated: coastal wetlands bordering arable fields and coastal wetlands confined by a dyke landwards with pastures in the hinterland. At the coasts of the Darss-Zingst Bodden chain both wetland types are dominated by *Pahragmites australis* (Cav) Trin. Ex Streudel (common reed).

In this study, one site of each type was investigated: the *Phragmites* wetland at Dabitz borders directly cropland, whereas the wetland at Michaelsdorf is 'squeezed' behind a dyke and the hinterland used as pasture for sheep (Fig. 1). The distance between the study sites is about 15 km and consequently climatic conditions do not differ. Both sites are situated at the southern coast of the Bodden system. The sediment textures of the adjacent Bodden sediments are fine to medium sands (Bitschofsky et al., 2015). A detailed description of vegetation, water and sediment characteristics of the wetlands follows in the Results Section 3.1.

Tidal salt marshes are often divided into low, mid- and high marsh according to the influence of the tidal range (Packham and Willis, 1997). Since there are no tides in the Darss-Zingst Bodden Chain the wetlands are subdivided into interior, basin and fringe zone, based on water level and hydraulic energy (Fig. 1). This classification was already proposed in the 1970s for mangrove forests (Lugo and Snedaker, 1974), and proved to be functional. Water level and hydraulic energy are higher in the fringe than in the basin zone, whereas the interior zone is rarely flooded (see Brinson, 1993; Karstens et al., 2015a; Lugo et al., 1988).

2.2. Analysis of land use

Aerial images (1953–2013) provided by the government office for geoinformation, surveying and cadaster MV were used to analyze land use changes at the two study sites since the 1950s. Semi-structured, face-to-face interviews were conducted with the farming company that manages the cropland at Dabitz and with the shepherds responsible for sheep grazing at Michaelsdorf to improve our understanding of past and present land use activities. Questions were grouped into categories, but the order of questions was not pre-defined, and further questions could be added during the interviews to enhance flexibility and allow in-depth information (Hollway and Jefferson, 2000; Helfferich, 2009).

2.3. Sampling and analysis of sediment, water and vegetation

A total of 60 sediment samples at Dabitz and 48 samples at Michaelsdorf were collected between March 2014 and January

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