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Potential export of soluble reactive phosphorus from a coastal wetland in a cold-temperate lagoon system: Buffer capacities of macrophytes and impact on phytoplankton

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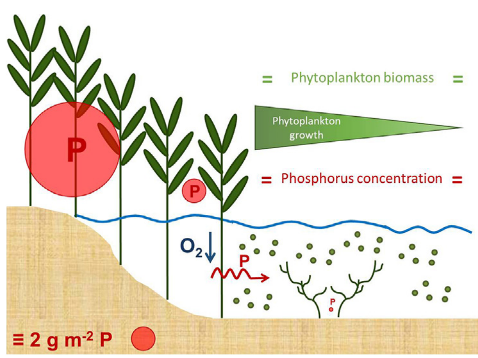
HIGHLIGHTS

- Coastal wetlands covered by emerged and submerged macrophytes are effective nutrient buffers during vegetation growth.
- Submerged macrophytes act as buffer only during late summer and *Phragmites* litter is prone to decomposition during winter.
- Concentration of PO_4 in the water is higher in the zones of emerged macrophytes than in the zones of submerged macrophytes.
- Increased phytoplankton growth close to the wetland edge indicates a nutrient leakage, without fluctuations in PO_4.

GRAPHICAL ABSTRACT



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ABSTRACT

The main pathways for phosphorus flux from land to sea are particle-associated (erosion) and dissolved runoff (rivers, groundwater, and agricultural drainage systems). These pathways can act as diffused sources for aquatic systems and support primary production, therefore, counteracting the efforts aimed at reducing phosphorus input from point sources such as sewage treatment plants. Phosphorus supports primary production in the water column and can elevate phytoplankton and macrophyte growth. Coastal wetlands with emerged (*Phragmites australis*) and submerged (*Stuckenia pectinata* and *Chara* sp.) macrophytes can affect phosphorus fluxes in the land-water transitional zone. The macrophytes have the potential to act as a buffer for phosphorus run-off. The aim of this study was to determine the phosphorus stocks in the transitional land-sea zone of a cold temperate lagoon at the southern Baltic Sea. Phosphorus in macrophytes, water samples, and phytoplankton growth were analyzed along a gradient moving away from the wetland. The phosphorus stocks in the above ground biomass of the *Phragmites* plants were the highest at the end of August and with more than 8000 mg P m^{-2} in the interior zone of the wetland, threefold the amount of P in *Phragmites* plant tissue at the wetland fringe. The submerged macrophytes stored only 300 mg P m^{-2}, close to the wetland. Concentrations of soluble reactive phosphorus in the water column were higher in the zones of emerged macrophytes than in the zones of submerged macrophytes and decreased along the land-sea transect. Phytoplankton could grow proximal to the wetland during all seasons, but not further away. This study indicates that macrophytes can act as phosphorus sinks. However, short-term releases of phosphate within the *Phragmites* wetland have the

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potential to lead to phytoplankton growth. Phytoplankton can use these nutrient pulses either immediately or later, and support high biomass and turbidity within the system.

1. Introduction

Coastal wetlands are ecotones that link terrestrial and aquatic ecosystems, some examples include salt marshes, mangroves, tidal flats, and seagrasses (Perillo et al., 2009). They are open systems that interact strongly with their environment (Andreu et al., 2016; Vazquez-Roig et al., 2011). The seaward edge of a coastal wetland reaches up to water depths where light penetration is still high enough to allow photosynthesis by benthic plants, while the landward edge of a coastal wetland is defined by the influence of salt water (Perillo et al., 2009). Lagoons and their adjacent wetlands make up more than 13% of the coastal shoreline worldwide (Kjerfve, 1994). These systems are dynamic and capable of providing various ecosystem services, such as nutrient regulation, nesting area for birds, and recreation areas (Duarte et al., 2013; Karstens and Lukas, 2014; Reddy et al., 1999). In particular, the impact on nutrient regulation constitutes an important ecosystem service. Many wetlands have undergone several decades of eutrophication fueled by anthropogenic nutrient inputs. Those nutrient inputs are primarily from agricultural lands and enter the wetlands via particle runoff, groundwater, drain tiles or rivers (e.g. Magnien et al., 1992; Lillebø et al., 2012; Lemley et al., 2014). In Europe, the nutrient inputs from rivers have been greatly reduced with the introduction of the European Water-Framework Directive (EU-WFD) in Europe. However, reduced nutrient inputs did not reduce the effects of eutrophication in most systems. The impact of nutrient export through wetlands in coastal waters needs to be investigated in order to include these systems in restoration strategies.

The Darss-Zingst Bodden Chain (DZBC) at the southern Baltic Sea (Fig. 1A) is a highly eutrophic lagoon system (Schiewer, 1997). This system has undergone decade-long nutrient inputs with the rivers as main source. Even though, these inputs were reduced in the mid-1980s, there has been no reduction in the phytoplankton biomass(chlorophyll *a* – Chl *a* concentration), or turbidity. Phytoplankton in the DZBC tends to be limited by phosphorus, if light and temperature conditions are optimal (Berthold et al., in press). Similarly, other potential nutrient pathways need to be predicted and quantified. The entire length of the lagoon is lined by coastal wetlands, which serve as a potential nutrient buffer between land and water. For a holistic understanding of the eutrophication problems within lagoon systems, we need to understand the phosphorus (P) cycle across the wetland, from its landward edge to the seaward edge and beyond. With this study, we provide a link between the nutrient dynamics inside and outside the wetlands. Karstens et al. (2015) presented evidence that hypoxic conditions are possible during all seasons in the basin zone of the coastal wetland covered by emerged macrophytes (*Phragmites australis)*, which could lead to a release of P from the sediment to the water. Berthold et al. (in press) showed that strong precipitation events could elevate nutrient concentrations in coastal water bodies of the southern Baltic Sea. These short-term events could support the continuity in phytoplankton biomass at low ambient nutrient levels. These two studies together posed the question whether a nutrient export from the wetland basin zone to the fringe zone is possible, and if this supports phytoplankton growth at the edge of the *Phragmites* area. One of the main questions was whether submerged and emerged macrophyte stands can act as a sufficient

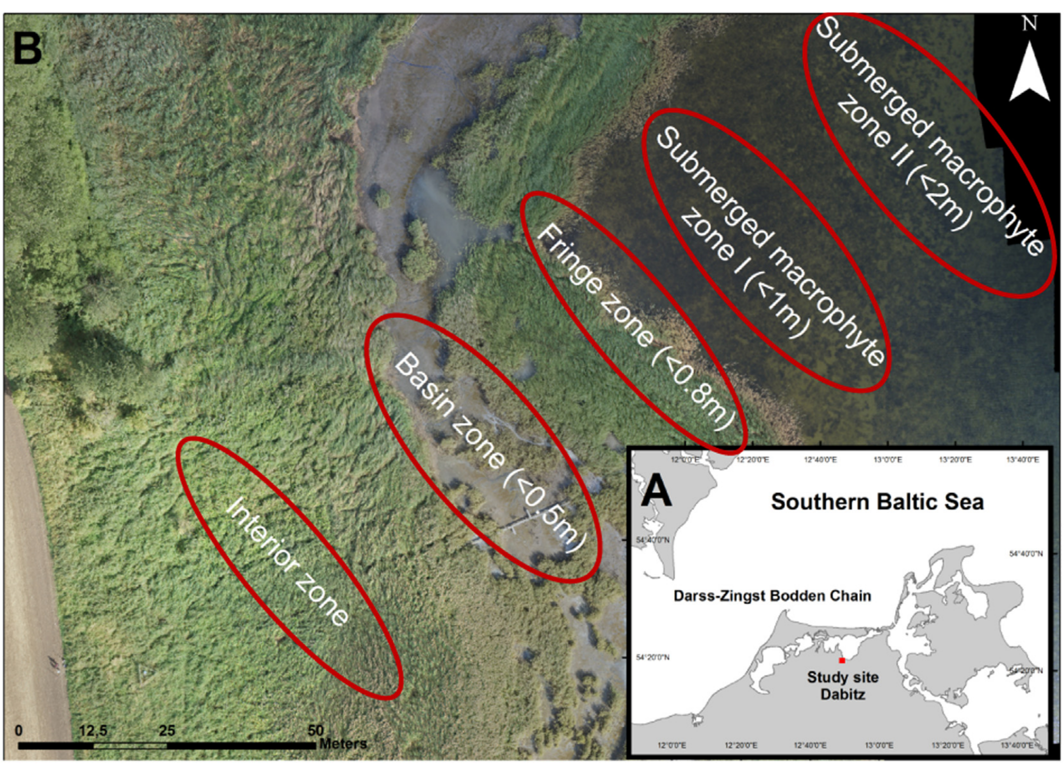

Fig. 1. (A) The Darss-Zingst Bodden Chain is a lagoon system at the southern Baltic Sea. The shallow coastline of the Bodden is, in most cases lined by emerged and submerged macrophytes such as *Phragmites* or *Stuckenia pectinata* and *Chara* spp. in deeper water depths. (B) Aerial image (August 2015) of the study site Dabitz. Water and vegetation samples were analyzed separately for the different zones. Red circles indicate the proximate sampling area per zone. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)