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Impacts of urban wastewater discharge on seagrass meadows (*Zostera noltii*)

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Abstract

The abiotic disturbance of urban wastewater discharge and its effects in the population structure, plant morphology, leaf nutrient content, epiphyte load and macroalgae abundance of *Zostera noltii* meadows were investigated in Ria Formosa coastal lagoon, southern Portugal using both univariate and multivariate analysis. Four sites were assessed, on a seasonal basis, along a gradient from a major Waste Water Treatment Works (WWTW) discharge to a main navigation channel. The wastewater discharge caused an evident environmental disturbance through the nutrient enrichment of the water and sediment, particularly of ammonium. *Zostera noltii* of the sites closest to the nutrient source showed higher leaf N content, clearly reflecting the nitrogen load. The anthropogenic nutrient enrichment resulted in higher biomass, and higher leaf and internode length, except for the meadow closest to the wastewater discharge (270 m). The high ammonium concentration (158–663 μM) in the water at this site resulted in the decrease of biomass, and both the leaf and internode length, suggesting a toxic effect on *Z. noltii*. The higher abundance of macroalgae and epiphytes found in the meadow closest to the nutrient source may also affect the species negatively. Shoot density was higher at the nutrient-undisturbed site. Two of the three abiotic processes revealed by Principal Component Analysis were clearly related to the WWTW discharge, a contrast between water column salinity and nutrient concentration and a sediment contrast between both porewater nutrients and temperature and redox potential. A multiple regression analysis showed that these abiotic processes had a significant effect on the biomass-density dynamics of meadows and on the overall size of *Z. noltii* plants, respectively. Results show that the wastewater discharge is an important source of environmental disturbance and nutrients availability in Ria Formosa lagoon affecting the population structure, morphology and N content of *Z. noltii*. This impact is spatially restricted to areas up to 600 m distant from the WWTW discharge, probably due to the high water renewal of the lagoon.

Keywords: wastewater; urban effluents; nutrient enrichment; disturbance; seagrass; *Zostera noltii*; Ria Formosa

1. Introduction

Seagrass declines have been reported worldwide, whether natural or human-induced. Most of these declines are attributed to anthropogenic disturbances, such as eutrophication, toxic pollutants and mechanical damages (Short and Wyllie-Echeverria, 1996). Urban and industrial development, as well as intensive agriculture, in proximity of coastal areas have resulted in the increase of nutrient inputs to the near shore and estuarine ecosystems all over the world. Eutrophication of coastal waters may follow the increased nutrient loads, promoting the deterioration of water quality (Short and Wyllie-Echeverria, 1996). The reduction of water transparency limits the light penetration into the water column generating an important threat to seagrasses by reducing the light availability for photosynthesis. Although direct toxic effects of nutrients have been demonstrated (Burkholder et al., 1992; Van Katwijk et al., 1997; Brun et al., 2002), seagrass declines seem to be primarily related to the indirect effects associated with eutrophication, namely the responses of other primary producers to the nutrient loads

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(Hemminga and Duarte, 2000). Macroalgae, phytoplankton and epiphytes proliferate as nutrient inputs increase (Borum, 1985; Tomasko and Lapointe, 1991; Frankovich and Fourqurean, 1997; Wear et al., 1999; Hauxwell et al., 2003), because they can rapidly assimilate the nutrients from the water column (Duarte, 1995). The overgrowth of macroalgae and epiphytes leads to the shading and suffocation of seagrass meadows, contributing to seagrass declines (Duarte, 1995; Hughes et al., 2004; Lapointe et al., 2004). Moreover, other indirect effects associated with eutrophication, such as sediment anoxia may also be detrimental for seagrasses (Terrados et al., 1999).

As the other primary producers, seagrasses also respond to the increase of nutrients. However, the lower rates of nutrients uptake under abundant nutrient supply makes seagrasses inferior competitors compared with macroalgae (Duarte, 1995). In a meta-analysis approaching the nutrient effects on seagrasses, Hughes et al. (2004) identified the biomass as one of the seagrass parameters that respond positively to the *in situ* nutrient enrichment of the sediment (particularly the aboveground biomass). The water column nutrient additions had strong negative effects on seagrass biomass, because it also results in increased epiphyte biomass (Hughes et al., 2004). On the other hand, the seagrass nutrient content reflects to a certain extent the nutrient availability in marine ecosystems. Higher nutrient concentrations have been related with higher nutrient contents in plant tissues (Borum et al., 1989; Duarte, 1990; Fourqurean et al., 1992; Udy and Dennison, 1997b; Lee et al., 2004). Even though the effects of increased nutrients on seagrasses have been extensively documented by experimental and field studies, the direct impact of an urban wastewater effluent on seagrass meadows was never assessed.

Zostera noltii is a small seagrass species distributed along the intertidal and subtidal areas of the Northern and Western Europe, Mediterranean Sea and North-West Africa (Den Hartog, 1970). The decline of *Z. noltii* meadows has been reported in the Wadden Sea (Philippart and Dijkema, 1995), the southern coasts of Spain (e.g. Palmones River estuary; Niell et al., 1996; Hernández et al., 1997) and in the Portuguese coast (e.g. Mondego estuary; Oliveira and Cabeçadas, 1996; Cardoso et al., 2004), mostly as a consequence of eutrophication. In Ria Formosa lagoon, southern Portugal, *Z. noltii* is the most abundant seagrass, covering large areas of the lower intertidal. This species plays an important role in the lagoon productivity (Santos et al., 2004). Even though this system constitutes a natural park, the conservation status of this species in the lagoon is unknown, due to the lack of long-term monitoring studies. Thus, the assessment of the effects caused by the increasing anthropogenic nutrient load assumes a major importance in order to prevent potential seagrass declines.

The main objective of this study was to determine the relationships among the urban wastewater discharge and the population structure, plant morphology, nutrient content, epiphyte load and macroalgae abundance of *Zostera noltii* meadows of Ria Formosa lagoon, along a gradient from a major urban wastewater discharge to the main navigation channel of the lagoon.

2. Materials and methods

2.1. Study sites

Ria Formosa lagoon is a mesotidal system located in the southern coast of Portugal (Fig. 1). The lagoon has a high spring tide surface area of 84 Km^2, with an exposed intertidal area of approximately 80%. The lagoon is separated from the Atlantic Ocean by a system of five sand barrier islands and six inlets. In each tidal cycle about 50–75% of the water in the lagoon is renovated. The tidal amplitude ranges from 3.50 m on spring tides to 1.30 m on neap tides, and salinity ranges from 35.5 to 36 along the year. Four continuous *Zostera noltii* meadows of similar bathymetry, located in the lower intertidal, were selected along a tidal creek from a Waste Water Treatment Works (WWTW) effluent to a main navigation channel of Ria Formosa (Fig. 1). The period of meadow emersion during low tide is small (less than one hour), and after that period, the flooding water rapidly covers the meadows. Site 1 was the *Z. noltii* meadow closest to the WWTW discharge (270 m), while site 4 was located in the main channel where there

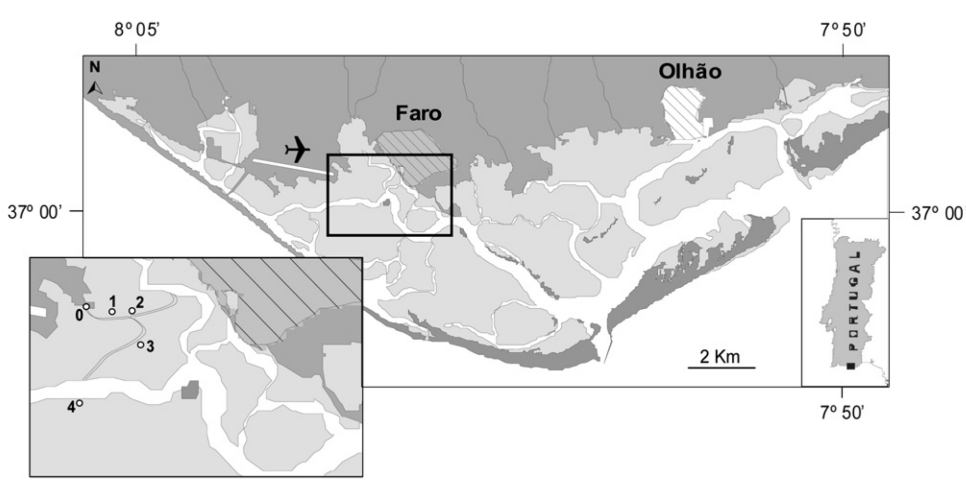

Fig. 1. Map of Ria Formosa, southern Portugal, with the location of the sampling sites from the wastewater effluent (site 0) to the main navigation channel (site 4).