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The response of primary producer assemblages to mitigation measures to reduce eutrophication in a temperate estuary

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Abstract

The Mondego estuary is a well-described system located on the North Atlantic Ocean, where cultural eutrophication progressed over the last decades of the 20th century. Consequently, and due to a large productivity of *Ulva* spp., *Zostera noltii* meadows were severely reduced with a concomitant decrease in environmental quality. In 1998, experimental mitigation measures were implemented, via changes in hydrology to increase circulation and diversion of nutrient-rich freshwater inflow, to reverse the process in the most affected area of the estuary – its South arm.

The objective of this study was to assess the differences in response of primary producer assemblages to the implemented measures to reduce eutrophication.

Results show that the mean concentrations of DIN suffered a notorious decrease due to a significant reduction in the ammonium concentration in the water column, while DIP increased significantly. Primary producer assemblages showed different responses to these changes: phytoplankton, measured as concentration of chlorophyll *a*, did not show any significant changes; green macroalgae, mostly *Ulva* spp., suffered a large reduction in biomass, whereas *Gracilaria gracilis* and the macrophyte *Zostera noltii* biomasses increased greatly. Results show that phytoplankton biomass has remained constant and suggest that the reduction in ammonium could have been responsible for the changes in the green macroalgal biomass. Light was the most likely factor in the response of seagrass whereas red macroalgal reaction seemed to be dependent on both light and ammonium.

Keywords: *Zostera noltii*; *Ulva*; *Gracilaria*; nitrogen; phosphorus; eutrophication

1. Introduction

In estuarine systems, plant communities are constituted by complex assemblages of phytobenthos and phytoplankton, each with different access to nutrients and light (Taylor et al., 1995) that can constitute potentially limiting factors to the primary production of these aquatic autotrophs (Pedersen and Borum, 1992). Phytoplankton and fast-growing ephemeral macroalgae are often limited by nutrient availability, while slow-growing perennial macroalgae and rooted macrophytes seem less dependent on nutrient concentrations (Sand-Jensen and Borum, 1991).

In the last decades, anthropogenic activities have enhanced the enrichment of water bodies with nutrients, particularly nitrogen and phosphorus, named as "cultural eutrophication". Agricultural run-off, waste discharges from industries and fish farms amongst others are responsible for nutrient inputs into aquatic systems (Menéndez and Comín, 2000; Hernández et al., 2002; Nedwell et al., 2002).

Phytoplankton and macroalgae are capable of taking advantage of the available resources in transient environments (Viaroli et al., 1996; Raven and Taylor, 2003; Cohen and Fong, 2004). Their high surface area to volume ratio and high affinity for nutrients, especially N and P, favor a rapid

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nutrient uptake and high growth and production rates leading to very large biomass values (Rosenberg and Ramus, 1984; Hernández et al., 1997; Raffaelli et al., 1998; Raven and Taylor, 2003). Among the macroalgal species found in areas undergoing eutrophication are the genus *Chaetomorpha*, *Cladophora*, *Gracilaria* and *Ulva* (Raffaelli et al., 1998; Mistri et al., 2001; Fong et al., 2004). By influencing benthic nutrient processes through interception of light and water column nutrients (Boyer and Fong, 2005), they often out-compete other species, usually late-successional, long-lived species like perennial macroalgae (e.g. *Fucus*) and seagrass (e.g. *Zostera*) (Peckol and Rivers, 1996; Menéndez and Comín, 2000).

Seagrass are important primary producers in estuarine systems and their abundance and distribution are strongly correlated with light availability (Kraemer and Hanisak, 2000). Eutrophication effects on seagrass meadows are stronger in sheltered environments with frequent and high nutrient loadings, reduced tidal flushing and fluctuating temperatures (Maier and Pregnall, 1990). Increased nitrogen loading has been pointed out as an important cause of seagrass loss by stimulating competition for available light (e.g. van Katwijk et al., 1997; Brun et al., 2002; Valiela and Bowen, 2007).

Due to the unique importance of seagrass meadows in the ecosystems, it is necessary to take measures to minimize and revert the effects of eutrophication, bringing the systems into the previous stable state (e.g. Webster and Harris, 2004). However, to guarantee that the restoration programmes are successful, it is important to understand the mechanisms that have led to the ecological changes (Zhang et al., 2003). In the case of macroalgal blooms, the knowledge of their responses to changes in their driving variables (e.g. nutrient loadings, hydrodynamics) is essential to understand the way the system will react and thus assuring its recovery (e.g. Webster and Harris, 2004).

The Mondego estuary is a temperate, intertidal ecosystem that has been for the last decades under ecological stress caused mainly by eutrophication. Overall the system presented itself with a severe decrease in environmental quality (Lillebø et al., 2007; Teixeira et al., 2007), and to revert this condition, in 1998, a management plan was implemented with measures that included the reduction of nutrient load to the system South arm, the increase in hydrodynamics in order to reduce the water residence time and the physical protection of the seagrass meadows (for further information see Lillebø et al., 2005).

The aim of the present study was to assess the response of phytoplankton (accessed as concentration of chlorophyll *a*), the macroalgae *Ulva* spp. and *Gracilaria gracilis* and the seagrass *Zostera noltii* (Hornem) to the mitigation measures implemented in the Mondego estuary to reduce the eutrophication symptoms.

2. Material and methods

2.1. Study area

The Mondego estuary is located on the Western Coast of Portugal (40°08′N; 8°50′W), with an approximate area of 1072 ha and 7 km long, characterized by a temperate coastal climate with Mediterranean and Atlantic influences. It comprises two arms, North and South, separated by an alluvium-formed island (Murraceira Island) that joins again near the mouth. The North arm of the sea is deeper (4–8 m during high tide, tidal range 1–3 m), while the South arm is shallower (2–4 m during high tide, tidal range 1–3 m) and until 1998 it was largely silted up in the upstream areas, which caused freshwater to flow mainly through the North arm. As a consequence, water circulation was dependent on tides and freshwater discharges (which constituted an important input of nutrients) from a small tributary, the Pranto River (Fig. 1).

In 1998, a restoration program was implemented to reverse the process of eutrophication in the most affected area of the estuary – the South arm (Fig. 1), comprising several measures. To reduce the loadings of nutrients into the South arm from the Pranto River the sluice aperture was reduced and most of the freshwater flow from this tributary was diverted to the North arm by another sluice located upstream. To improve water circulation the connection between both arms was enlarged allowing water to flow from the North arms during high tide. The remainder of the seagrass patches was delimited by wooden stakes to prevent physical disturbance and awareness meetings were held to inform the population about the importance of these areas (for more detailed description see Lillebø et al., 2005, 2007).

The summary of the main characteristics of the South arm of the estuary is presented in Table 1.

2.2. Field program and laboratory procedures

The study was conducted between February 1993 and December 2004 in the South arm of the Mondego estuary, as a part of a long-term monitoring program. Three sites (*a*, *b* and *c* – Fig. 1A) were selected based on macroalgal abundance following a preoperational gradient increasing from downstream to upstream. The distance between sites *a* and *b* is 0.25 km and between *b* and *c* is 0.5 km. Originally the three sites were covered by rooted macrophytes but as eutrophication increased, together with human disturbance, *Zostera noltii* declined progressively, being currently restricted to site *a* (Fig. 1B).

Sampling was carried out almost each 2 months from February 1993 until December 2000 and monthly thereafter. From January 1997 to December 1998 no sampling was performed. On each sampling occasion, water temperature and salinity were recorded *in situ*. The water samples collected (approximately 250 ml) were stored, filtered through pre-combusted (3 h at 500 °C) GF/C filters (Whatman) in acid-washed polythene bottles at −18 °C until further analysis. Nitrate (NO_3-N) and nitrite (NO_2-N) were analysed according to standard methods described in Strickland and Parsons (1972) and ammonium (NH_4-N) and phosphate (PO_4-P) analysis followed the Limnologisk Metodik (1992) methodology. The phytoplankton chlorophyll *a* (Chl *a*) determinations were performed by filtering 0.5–1.0 L of water through Whatman GF/C glass-fibre filters followed by extraction according to Parsons et al.