Available online at www.sciencedirect.com
SCIENCE DIRECT®

Estuarine, Coastal and Shelf Science 63 (2005) 261–268

ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ECSS

The effect of eutrophication abatement on the bivalve *Scrobicularia plana*

T. Verdelhos*, J.M. Neto, J.C. Marques, M.A. Pardal

IMAR – Institute of Marine Research, Department of Zoology, University of Coimbra, 3004-517 Coimbra, Portugal

Received 2 August 2004; accepted 23 November 2004

Abstract

Over the last few decades, the excessive growth of macroalgae and decline of seagrass beds, associated with increased eutrophication, has become a worldwide problem. It is known that submersed aquatic vegetation (SAV) offers stable habitats, allowing the continuous availability of food and protection against predators and contributing to biodiversity, sediment stability and water transparency when compared to areas covered by macroalgae mats. In the Mondego estuary (Portugal), several mitigation measures (nutrient-load reduction, seagrass-bed protection and freshwater-circulation enhancement) were implemented in 1998 in order to promote the recovery of the seagrass beds and the entire surrounding environment following a long period of eutrophication. Here the success of this restoration project is evaluated by comparing the water nutrient concentrations, the extent of seagrass cover and the dynamics of the bivalve *Scrobicularia plana* before and after the implementation of the management measures. During the period in which environmental quality declined, *S. plana*'s adult abundance, total biomass and growth production also declined, parallel with the almost total disappearance of *Zostera noltii*. After the implementation of management measures, dissolved nutrients and green macroalgal blooms were much reduced, and seagrass beds started to recover. The *S. plana* population also responded positively, becoming more structured (including individuals of all age classes), with higher biomass and growth production.

Keywords: eutrophication; management; *Scrobicularia plana*; population dynamics; ecological restoration

1. Introduction

Eutrophication, or excessive organic carbon input associated with nutrient enrichment, of coastal waters is now widely recognized as a major worldwide threat (Raffaeli et al., 1998). As a response to global human disturbance, in recent years there has been an enormous increase in restoration as a technique for reversing habitat degradation worldwide (de Jonge et al., 2000). The general purpose of restoration projects is to help a habitat return from an altered or disturbed condition to a previously existing natural condition (Kennish, 2000). To evaluate the success of restoration plans, one must at least understand the processes which have driven the observed ecological changes. There is a need to monitor the restoration and to assess its success (Kennish, 2000; Pardal et al., 2004).

In the Mondego estuary (Portugal), eutrophication has triggered serious biological changes, which have led to a progressive replacement of seagrasses (*Zostera noltii*) by opportunistic macroalgae (Marques et al., 1997, 2003; Pardal et al., 2000, 2004; Martins et al., 2001; Cardoso et al., 2002, 2004; Dolbeth et al., 2003). Since the late 1980s, green macroalgal blooms have been

* Corresponding author.
E-mail address: tverdelhos@ci.uc.pt (T. Verdelhos).

0272-7714/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecss.2004.11.019

observed in the southern arm of the Mondego estuary as a major symptom of eutrophication, due to the high availability of nutrients (nitrogen and phosphorus), coupled with high water residence time (Marques et al., 1997, 2003; Pardal et al., 2000, 2004; Martins et al., 2001; Cardoso et al., 2002, 2004; Dolbeth et al., 2003). As a consequence, *Z. noltii* beds, considered the richest habitat in terms of biodiversity and productivity (Edgar, 1990; Marques et al., 1997; Cardoso et al., 2004), suffered a drastic reduction during the last two decades (Marques et al., 1997; Pardal et al., 2000, 2004; Martins et al., 2001). This led to a shift in primary producers, from *Z. noltii* towards faster growing green macroalgae (Raffaeli et al., 1998; Pardal et al., 2000; 2004; Cloern, 2001; Martins et al., 2001). Changes in the trophic structure and, ultimately, in the composition and productivity of entire macrobenthic assemblages have been reported (Dolbeth et al., 2003; Cardoso et al., 2004), leading to less structured and impoverished macrofaunal communities.

The present study evaluates the success of a restoration project implemented in the Mondego estuary, focussing on the dynamics of *Scrobicularia plana*, a long-lived deposit-feeding bivalve species, living in muddy to sandy sediments (Hughes, 1969, 1970a,b; Guelorget and Mazoyer-Mayére, 1983; Essink et al., 1991; Sola, 1997; Guerreiro, 1998). Long-term data sets (8 years) are required in order to capture slow ecological processes (e.g. population dynamics of long-lived organisms), rare events (e.g. floods) and complex phenomena, in which a long span of time is required to detect changes or trends (Franklin, 1989).

2. Materials and methods

2.1. Study site

The Mondego estuary, located on the Atlantic coast of Portugal (40° 08′ N, 8° 50′ W) comprises a northern and a southern arm, separated by the alluvial Murraceira Island (Fig. 1). The northern arm is deeper (4–8 m during high tide, tidal range about 1–3 m) and constitutes the main navigation channel and the location of the Figueira da Foz harbour. The southern arm is shallower (2–4 m during high tide, tidal range 1–3 m) and is almost silted up in the upper zones, constituting a kind of coastal lagoon in which the water circulation is mostly dependant on the tides and on the freshwater input from the Pranto River, a small tributary (Marques et al., 1997; Lillebø et al., 1999; Pardal et al., 2000, 2004). The discharge from this tributary is controlled by a sluice (Pardal et al., 2000, 2004; Cardoso et al., 2004) and is regulated according to the irrigation needs in rice fields in the Mondego Valley (Martins et al., 2001).

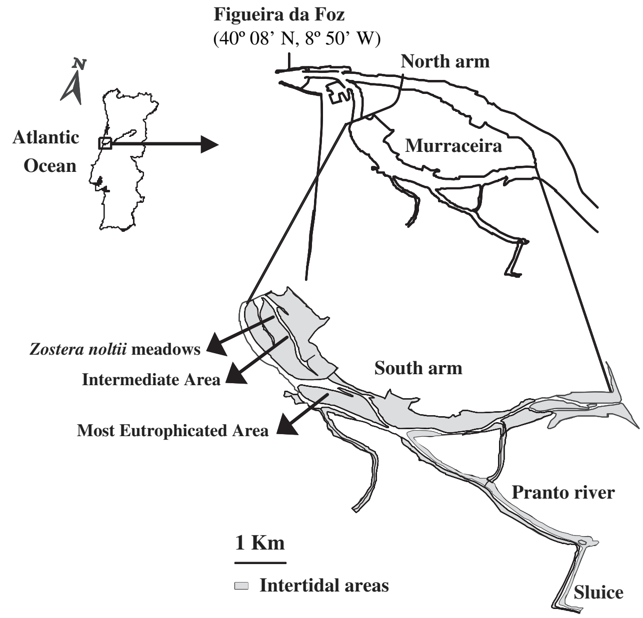

Fig. 1. Location of the sampling areas on the Mondego estuary (40° 08′ N, 8° 50′ W).

Since the 1980s, *Zostera noltii* beds have been drastically reduced in area extent and biomass in the southern arm (Cardoso et al., 2004; Pardal et al., 2004). For instance, an area of 15 ha was progressively reduced to 1.6 ha in 1993 and to less than 300 m^2 in 1997. In 1998, several mitigation measures were applied. The hydraulic regime in the southern arm was improved by enlarging the connection between the two arms. The Pranto sluice-opening regime was minimized in such a way that most of the nutrient enriched freshwater from the Pranto River is diverted to the northern arm (by another sluice located more upstream), reducing the nutrient loading in the southern arm. In addition, the remaining seagrass patches were protected with wooden stakes to prevent further disturbance of that area (by fishermen digging in the sediment and looking for bait), and several forums were run to inform local people of the ecological and economic importance of the seagrass beds.

Three study areas were established in the southern arm (Fig. 1):

(a) *Zostera noltii* beds, a non-eutrophic area located downstream, characterized by muddy sediments with high organic matter content (6.3 ± 1.5%), higher salinity values (20–30), lower total inorganic nitrogen concentrations (15–30 μmol N l^{-1}), and higher water-flow velocity (1.2–1.4 m s^{-1});
(b) an intermediate eutrophic area, located just upstream of the previous study area, has no seagrass cover, although some rhizomes remain in the sediment. The physical–chemical conditions are otherwise similar to those of the *Z. noltii* beds but with lower sediment organic matter content (5.8 ± 1.3%);