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Distribution and ecological relevance of fine sediments in organic-enriched lagoons: The case study of the Cabras lagoon (Sardinia, Italy)

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Abstract

In organic-enriched sedimentary systems, like many Mediterranean coastal lagoons, a detailed analysis of sediment grain size composition and partitioning within the muds is crucial to investigate sedimentological trends related to both hydrodynamic energy and basin morphology. In these systems, sediment dynamics are particularly important because the partitioning and transport of fine sediments can strongly influence the redistribution and accumulation of large amounts of organic matter, and consequently the distribution of benthic assemblages and the trophic status and functioning of a lagoon. Nevertheless, studies on benthic–sediment relationships have been based mainly on a rather coarse analysis of sediment grain size features. In muddy systems, however, this approach may impede a proper evaluation of the relationships and effects of the distribution of fine sediment and organic matter on the biotic benthic components. Here we show that the distribution of sedimentary organic matter (OM) and total organic carbon (TOC) in the Cabras lagoon (Sardinia, Italy) can be explained (i.e., predicted) as a function of a nonlinear increase in the amount of the cohesive fraction of sediments ($\leqslant$8 μm grain size particles) and that this fraction strongly influences the structure, composition and distribution of macrobenthic assemblages. Even in such a homogeneously muddy system, characterized by "naturally" occurring impoverished communities, impaired benthic assemblages were found at $\leqslant$8 μm, OM, TOC contents of about 77%, 11% and 3.5%, respectively. A review of studies conducted in Mediterranean coastal lagoons highlighted a lack of direct integrated analysis of sediment features and the biotic components. We suggest that, especially in organic-enriched coastal lagoons, monitoring programs should primarily investigate and consider the cohesive fraction of sediments in order to allow a better assessment of benthic–sediment relationships and ecological quality of the system.

Keywords: Fine sediments; Mud; Organic matter (OM); Macrofauna; Ecological quality; Coastal lagoons

1. Introduction

Transitional waters such as estuaries and coastal lagoons are classified by the European Water Framework Directive (WFD; 2000/60/EC) as one of the five categories of "surface water", which also include coastal waters, rivers, lakes, and artificial and heavily modified bodies of water. Due to their partly saline character "substantially

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influenced by freshwater flows" and their usually high sediment-surface-area to water-volume ratio, transitional waters can be considered a very sensitive aquatic system where benthic components and processes play an important regulatory function for the whole ecosystem (Viaroli et al., 2004). Accordingly, there has been a major development of biotic benthic indices in Europe in recent years, with special attention paid to the use of macroinvertebrate communities, in assessing the ecological quality status of coastal and estuarine waters (Borja et al., 2000; Simboura and Zenetos, 2002; Rosenberg et al., 2004; Dauvin and Ruellet, 2007; Muxika et al., 2007), as well as coastal lagoons (Reizopoulou et al., 1996; Fano et al., 2003; Basset et al., 2004; Ponti and Abbiati, 2004; Reizopoulou and Nicolaidou, 2007; Mistri and Marchini, in press). Comparisons of different biotic indices and assessments of their applicability in different geographical areas of the world are now also on the rise (Díaz et al., 2004; Arvanitidis et al., 2005; Magni et al., 2005a; Quintino et al., 2006; Fleischer et al., 2007; Pranovi et al., 2007; Zettler et al., 2007; Blanchet et al., in press; Borja et al., in press). In contrast, the physical and chemical characteristics of sediments appear to be less explored and more controversial in terms both of their integration in the biological elements and their relevance in assessments of environmental quality (Crane, 2003; Borja et al., 2004; Borja and Heinrich, 2005; Marín-Guirao et al., 2005). This is particularly true in non-tidal (*sensu* McLusky and Elliott, 2007) transitional systems, such as Mediterranean coastal lagoons. Here, only recently quality/vulnerability biogeochemical tools and integrated measurements of status variables and system metabolism are being proposed (Viaroli and Christian, 2003; Viaroli et al., 2004; Giordani et al., in press).

It is a classical, general assumption that sedimentary organic matter (OM) influences the composition and distribution of macrobenthos (Rhoads, 1974; Pearson and Rosenberg, 1978; Gray, 1979). It is also well known that the level of OM is related to the grain size composition of sediments. In particular, a higher content of OM tends to occur at an increasing mud (clay) content due to a greater surface area and higher number of complexing sites of the sediments (Buchanan and Longbottom, 1970; Mayer, 1994a,b; Tyson, 1995). A high mud content together with excessive OM may then result in a lower permeation of oxygen, an increased microbial oxygen uptake/demand and a subsequent buildup of toxic byproducts (e.g., ammonia, dissolved sulphide) (Florek and Rowe, 1983; Santschi et al., 1990; Fenchel et al., 1998). This can lead to impoverished benthic communities, dominated by few resistant *r*-selected opportunistic species (Díaz and Rosenberg, 1995; Como et al., 2007). Notwithstanding combined and confounding effects of other major environmental factors such as bathymetry and salinity (e.g., Jones et al., 1986; Schlacher and Wooldridge, 1996; Teske and Wooldridge, 2003), clear patterns of macrobenthos change have been demonstrated for some time along marked gradients of mud and/or organic matter enrichment (e.g., Ishikawa, 1989; Quintino and Rodrigues, 1989). In fact, it appears that works on benthos–sediment relationships in marine and estuarine waters have been mainly based on a rather coarse analysis of sediment grain size features, e.g., on the sand vs. mud fractions, generally restricted to the few uppermost integrated centimeters (e.g., see Table 1 in Snelgrove and Butman, 1994). Several benthic studies on animal–sediment associations have also been conducted in lagoon systems. Especially in muddy systems, however, like many of the coastal lagoons in the Mediterranean Sea, this approach may be of little use. In contrast, a detailed analysis of sediment grain size composition within the muds may reveal sedimentological trends related to both hydrodynamic energy and lagoon morphology which are not detectable otherwise (De Falco et al., 2004). In these often eutrophic and organic-enriched systems, such analysis is important also because the partitioning and transport of fine sediment particles may strongly influence the redistribution and accumulation of large amounts of organic matter, and consequently the distribution of macrozoobenthos and the overall trophic status and functioning of a lagoon. However, there is a lack of studies linking the distribution and dynamics of fine sediments to the distribution of benthic macroinvertebrate communities in coastal lagoons.

In the present study, we aimed at assessing the relationships between the distribution of fine sediments, the levels of organic matter in the sediments and the structure and composition of macrobenthic assemblages in a Mediterranean lagoon system, as well as evaluating the overall ecological relevance of such relationships. For these purposes, we used the Cabras lagoon (Sardinia, Italy) as a case study, where we had previously conducted extended surveys on both sediment characteristics (De Falco et al., 2004) and macrozoobenthic assemblages (Magni et al., 2004b, 2005b). For the present study, we made a detailed analysis of sediment particle distribution within the muds, with specific analytical size intervals of 0.5 μm, and focused on the $\leqslant$8 μm grain size fraction of sediments (hereafter "fine sediments"). This was based on the fact that the 8 μm boundary is known to separate non-cohesive from cohesive sediments (McCave et al., 1995) and because this fraction was found to be most correlated with the total organic carbon (TOC) content of sediments in the Cabras lagoon (De Falco et al., 2004). As for the macrozoobenthos, the biomass of individual taxa as well as species' richness and diversity, not used in our previous study (Magni et al., 2004b), were analyzed together with the total abundances. A review of studies reporting OM and/or TOC content of sediments, as well as grain size and biological benthic features, in Mediterranean coastal lagoons was also made. This was to provide a general assessment of benthic–sediment studies and monitoring schemes in these systems on a regional scale, as well as an operational framework for both lagoon ecology and management issues.