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Spatio-temporal pattern of community development in dredged material used for habitat enhancement: A study case in a brackish lagoon

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ABSTRACT

Dredged material is a potential resource for beneficial use for create/improve subtidal habitats. In a northwestern Adriatic lagoon, dredged sand was placed in inner areas with the management objective of improving the characteristics of the muddy areas being recharged. With this study we investigated the recolonization dynamics of benthic communities following the placement of dredged sand in a microtidal lagoon. The disposal of dredged sand had an immediate and negative effect on resident fauna. After an initial reduction, benthic communities followed different recovery pathways. One year after disposal, we recorded an almost complete recovery of the benthic invertebrates in terms of univariate parameters. Despite multivariate analyses still showed significantly different community structures, the trajectories of recovery for disposal areas converged towards the same basin of attraction of control areas. The ecological quality of sites, assessed with benthic indices, did not improve, thus no new beneficial habitat was created for macrobenthos.

1. Introduction

Dredging and disposal of dredged material constitute one of the most important problems in coastal zone management (Bolam et al., 2006). In the marine environment, a number of studies examined the spatial and temporal impacts of dredged material disposal on benthic communities (Harvey et al., 1998; Bolam and Whomersley, 2003, 2005; Fredette and French, 2004; Bolam et al., 2006; Powilleit et al., 2006; Bolam, 2012). In fact, while benthic organisms are adapted to the natural processes of sediment erosion and deposition, sedimentation exceeding natural thresholds of a certain area may involve harmful effects on the benthos, and even total loss of the community (Miller et al., 2002). Impacts to the benthos include direct burial by dredged material, reductions in community diversity, and a shift in the dominance patterns within the benthic community (Harvey et al., 1998; Bolam, 2011). Impacts from dredged material placement on the benthic community are influenced by a number of factors including attributes of the dredged material, the receiving habitat, and the community composition of the disposal site (Bolam, 2012).

In the shallow lagoons of the Po River Delta (Northern Adriatic Sea), dredging is necessary to maintain the safety and accessibility of navigation channels. Here, in recent times, attention has arisen on the relocation of dredged material in such a way as to derive environmental benefits (Bolam and Whomersley, 2003), including the creation of new sandbanks and saltmarshes for bird nesting, and the improvement of the sediment characteristics of muddy areas subjected to recurrent hypoxic/anoxic events. One of the key issues in understanding the ecological significance of dredged sediment placement is determining the rate of recovery of the macrobenthic community. While recent studies investigating benthic infaunal recovery following sediment reworking have indicated that, in the Sacca di Goro (a lagoon in the Po River Delta) invertebrate recolonization of subtidal habitats can be relatively rapid (Mistri et al., 2004; Munari et al., 2006), there are no studies that explicitly investigate the invertebrate recovery pattern from dredged sediment placement in shallow lagoons. When dredged sediments are placed on a subtidal bottom, the resident fauna is smothered and recovery occurs through lateral/vertical migration and adult/juvenile settlement (Bolam and Whomersley, 2005). Recolonization of some species can be rapid, although this depends on the spatial scale and depth of the recharge, on changes in the properties of the sediment itself together with the life history characteristics of the recolonising fauna (Bolam et al., 2004; Lewis et al., 2003).

In the Sacca di Goro, a microtidal shallow lagoon in the Po River Delta, the principal marine channel was dredged in summer 2008. During this project, the channel was deepened to 5 m, which entailed placement of about 42,000 m^3 of sand into several

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disposal sites in inner parts of the Sacca. The management objective, together with the deepening of navigation channel, was to improve the characteristics of the muddy areas being recharged. Disposal of dredged sand involved use of a hydraulic cutterhead dredge that pumped a sediment slurry through a pipeline, extended several hundreds meters from the dredge site. At the discharge sites, the sediment slurry was jetted aerially outward before falling to the water's surface with a baffle plate affixed to the end of the pipeline to dissipate the energy of the jetted sediment mixture. Disposal was carried out to intentionally distribute sediments at a maximum thickness of 30–40 cm to alleviate impacts to the benthos that occur with thicker overburdens.

In order to evaluate the impact of dredged sediment deposition on lagoonal benthic communities, two experimental areas, in different parts of the lagoon, were chosen and recharged with sand in summer 2008. We used a BACI (Before and After, Control and Impact) design (Underwood, 1992), and multivariate analysis to evaluate the impact of the disposed sediment on the macrobenthic community. This paper aims (i) at testing the hypothesis that deposition of dredged material does affect the composition and abundance of the macrobenthic community, and (ii) at investigating the spatio-temporal dynamics of the macrobenthic community re-colonization. Only a few papers analyzed the effects of dredged sediment deposition on macrobenthic communities of the Mediterranean Sea (Toumasiz, 1995; Simonini et al., 2005). To our knowledge, this is the first investigation on the effect of sediment recharge on the benthic community of dynamic ecosystems like lagoons.

2. Materials and methods

The experimental treatment was sand deposition at two different sites (C: 44°49.603N, 12°17.411E; G: 44°47.775N, 12°20.830E) in the Sacca di Goro (Fig. 1) and was carried out at the end of July 2008. Both sites had silty-clayey bottoms, but at site G there was some more sand (see Section 3) than at C. Hydrodynamics was slightly more accentuated at site G than at C (Provincia di Ferrara, 2006). We assessed the ecological effects of sand deposition using a BACI design (Underwood, 1992), contrasting data from the sediment recharge sites with control areas. Control areas were sited about 300 m apart of the disposal sites. Sampling was conducted once before the beginning of recharge operations (June 2008, time A) and five times after it (on a grossly × 3 geometric scale), i.e., at 3 (time B), and 10 (time C) days, and then after one (time D), three (time E), and twelve months (time F) from the recharge operations. At each control and recharge areas, benthic fauna was collected in triplicate with a Van Veen grab (area: 0.027 m^2; volume: 4 l) and sieved through a 0.5 mm mesh. In the laboratory, macroinvertebrates were identified at the species level. The taxa were also classified into trophic groups following current literature. Sediment cores (4.5 cm i.d.) were taken at three dates (times A, B and F) for particle size analysis, and characteristics of the surface sediment were determined in the laboratory by wet sieving and pipette analysis (Folk, 1980).

Data from the BACI design were analyzed, according to the three-factor hierarchical experimental design, using permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001; McArdle and Anderson, 2001). This approach partitions the variability in the original dissimilarity matrix according to the full multifactorial design, with tests of individual terms obtained using permutations. The analysis included the following factors: (i) treatment (Tr), fixed, two levels (recharged, control); (ii) site (Si), fixed, two levels (C and G); (iii) time (Ti), fixed, six levels (A–F). *P*-values were provided using unrestricted (9999) permutation of fourth root transformed abundance data. When low unique values in the permutation distribution were available, asymptotical Monte Carlo *P*-values were used instead of permutational *P*-values. Macroinvertebrate assemblage was also investigated by means of non-metric multidimensional scaling ordination (nMDS) based on the Bray–Curtis similarity index of fourth root transformed abundance data. The contribution of individual species to overall dissimilarity in assemblage structure between treatments and times was determined by the similarity percentage routine, SIMPER. All the analyses were done using PRIMER software (Clarke and Gorley, 2006).

The following univariate measures were also determined: the total number of species (*S*), the total number of individuals (*N*), and diversity (as Shannon–Wiener's H'). A three-way ANOVA (with

Fig. 1. Sacca di Goro with study sites.

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