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Limited impact of beach nourishment on macrofaunal recruitment/settlement in a site of community interest in coastal area of the Adriatic Sea (Mediterranean Sea)

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A R T I C L E I N F O

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A B S T R A C T

Beach nourishment is a widely utilized solution to counteract the erosion of shorelines, and there is an active discussion on its possible consequences on coastal marine assemblages. We investigated the impact caused by a small-scale beach nourishment carried out in the Western Adriatic Sea on macrofaunal recruitment and post-settlement events. Artificial substrates were deployed in proximity of nourished and non-manipulated beaches and turbidity and sedimentation rates were measured. Our results indicate that sedimentation rates in the impacted site showed a different temporal change compared to the control sites, suggesting potential modifications due to the beach nourishment. The impact site was characterized by subtle changes in terms of polychaete abundance and community structure when compared to controls, possibly due to beach nourishment, although the role of other factors cannot be ruled out. We conclude that small-scale beach nourishments appear to be an eco-sustainable approach to contrast coastal erosion.

1. Introduction

Coastal environments are under increasing pressures related to multiple stressors and impacts of anthropogenic origin, including overfishing, contamination, coastal construction and consequent habitat destruction. These local-scale impacts are superimposed on the impact of global climate change, regional climate anomalies, and episodic events (Barange et al., 2010), often including synergistic effects (Rossi, 2013). Thus, the provision of essential goods and services of coastal ecosystems is significantly reduced, with implications for local eco-sustainable development (Barbier et al., 2011).

Human activities can have both direct and indirect effects on marine ecosystems, as a consequence of the increased exploitation of biotic and abiotic resources and alterations of nutrient and sediment loads entering in the marine ecosystems (Rossi, 2013). Modifications of natural sedimentation regimes can be ascribed to a variety of factors, but they are primarily associated with human interventions on coastlines, such as coastal constructions, sediment dredging and trawling activities, breakwaters and beach nourishments, among others (Tinley, 1985; Colosio et al., 2007).

Increased sedimentation rates can be harmful for a number of marine food-web components, including photosynthetic organisms due to the reduction of light penetration (Ruiz and Romero, 2003), and filter-feeder organisms due to the higher ingestion of mineral particles (Nepote et al., 2017). Another observed food-web effect is that increased sediment can suppress fish herbivory (Goatley and Bellwood, 2013). In addition, major alterations of the sedimentation rates can affect the habitat morphology (Nepote et al., 2017), with implications for the achievement of the targets of good environmental status defined by the Marine Strategy Framework Directive of the European Union (MSFD2008/56/EC).

The Western sector of the Adriatic Sea is a region characterized by an extremely intense human intervention on the coastline, with a huge number of coastal defense structures, extending for hundreds of km,

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which were built in the last 40–50 years to protect the sandy beach from progressive erosion (Colosio et al., 2007).

In order to mitigate beach erosion, the main alternative to the artificial structures for coastal defense is represented by the "soft" approach of beach replenishment/nourishment based on the use of natural material deriving from relict sand deposits or from terrestrial caves (Charlier, 2003; Colosio et al., 2007). Although, this approach is considered one of the most ecologically sustainable among those available so far (Speybroeck et al., 2006), the possible consequences of this approach on coastal sedimentation rates, coastal assemblages (Colosio et al., 2007; Wooldridge et al., 2016), and ecosystem functioning (Valdemarsen et al., 2015; Kristensen et al., 2012; Wooldridge et al., 2016 and references therein) are still debated and depend on different factors such as the quantity and typology of the materials used, the location of the intervention, the hydrodynamic regime and the season when the replenishment is carried out.

In the present study, we compared the effect of beach nourishment to natural conditions with respect to macrofaunal colonization, recruitment, and settlement processes using artificial substrates deployed in the North Western Adriatic Sea.

2. Material and methods

2.1. Study area and sampling strategy

The study area is located in the "Portonovo Bay" along the Italian Adriatic coast (Fig. 1). The beach nourishment was done in June 2013 (the exact point is indicated in Fig. 1a). A classic profile nourishment technique was used, which involves the deposition of the material across the entire intertidal zone (Speybroeck et al., 2006). In particular, in order to reach the position of the coast line of 2010, the works on the submerged beach were conducted as far as 18 m from the present coast line. Before nourishment, the material was accurately washed to avoid any additional effect on water transparency and sedimentation rates. The nourishment has been performed with 2500 m^3 of pebble gravel (with diameter between 4 and 64 mm; Wenthworth-Krumbein classification) calcareous materials, derived from a terrestrial cave with grain sizes and mineralogy similar to those present on the receiving beach. It has been deployed on a surface of about 5000 m^2 with an extension of 400 linear meter. The works were subdivided in two phases (for a total of 6 days of works): the first consisted in a redistribution of the already present materials, while during second phase the grave was added. Both phases were done with the use of wheel loaders. Although gravel material was used, a certain quantity of fine sediment is always present, moreover it is created during the abrasion due to human material distribution along the beach and wave/current motion.

This study investigates four different sites characterized by a mix of sandy and rock substrate, where the prevalent habitats depend on site (Table 1; Fig. 1b). Two different precious habitats of particular interest at European community level (European Union Habitat Directive 92/43/EEC; site of community importance IT5320005 and IT5320006) were investigated: "Sandbanks slightly covered by sea water" (Habitat type 1110), which hosts the typical "*Biocoenosis of fine sands*" (SFBC, identification code RAC/SPA III.2.2) and "Reef" (Habitat type 1170) hosting the "*Biocoenosis of infralittoral algae*" (identification code RAC/SPA III.6.1). In the studied area, the habitat type 1170 includes calcareous rocky reefs and biogenic reefs. The Conero Promontory represents the main hard bottom habitat of the Adriatic coast, and hosts *facies* dominated by important habitat forming species as the mollusk bivalve *Mytilus galloprovincialis*, from 0 to 4 m depth and the polychaete worm *Sabellaria spinulosa*. Light-exposed reefs have assemblages dominated by algae and other photophilous organisms as the sea anemone *Anemonia viridis,* hosting a rich associated fauna. In dim-light conditions sponges and cnidarians dominate the benthic assemblages (Di Camillo et al., 2012, 2014). Calcareous reefs host also an abundant infauna as the boring sponge *Cliona adriatica* and the date-mussels *Lithophaga lithophaga* and *Pholas dactylus*. Four sites at ca. 7 m water depth were identified, one facing the beach subjected to material redistribution and the sediment displacement due to replenishment/nourishment activity (Fortino, hereafter defined impact site), and 3 sites without additional sources of sediments and thus putatively not impacted (Trave, Mezzavalle and La Vela, hereafter defined control sites) (Fig. 1). The depth of 7 m was selected because it is at the margin of the "active submerged beach" which represents the target to monitor the impact of beach nourishment. Except for the system of Mezzavalle, all the experimental systems were deployed on sandy bottoms with a similar distance from rocky habitats, considered as the main possible source of larval supply. Due to the time necessary for larval settlement on the panels, the use of a BACI design was impractical.

2.2. Biotic sample collection and treatment

Within each the four sampling sites, 6 PVC panels (15 × 15 cm) were deployed at the beginning of the nourishment activity. Three panels were placed horizontally and 3 panels were placed vertically with respect to the bottom substrate. The panels had one side exposed to waves (i.e., exposed surface), and one side non-exposed (i.e., sheltered surface). All panels were recovered one month after their deployments. The panels were left in the area also after the conclusion of the nourishment activity to potentially detect also the effects related to the redistribution of the material used for beach nourishment due to wave actions. To avoid the loss of fauna from the panels during the recovery by scuba divers, all panels were carefully enveloped using plastic bags. After recovery, all of the panels were fixed in 95% alcohol, and organisms of the inner and outer surface were separately analyzed in the laboratory (Denitto et al., 2007). Moreover, each panel was maintained in stove at 60 °C for one day, subsequently the organisms covered each side were removed and weighed. This approach was preferred to the analysis of infaunal community because hard substrates are the most common habitats in the study area (see Fig. 1b), and because the infaunal community is characterized by a high heterogeneous distribution in terms of abundance and biodiversity. Consequently, the analysis of the biodiversity and canopy of hard substrates is expected to better reflect the effects of human impact from the natural variation. In addition, artificial substrates are usually utilized to mimic hard bottom habitats and to provide standardized microhabitats (Ransome et al., 2017), so that any difference they detect cannot be attributed to the differences in biotope characteristics, allowing ecological impacts to be more easily identified (Mirto and Danovaro, 2004; Bishop, 2005; Costa et al., 2016 and references therein).

2.3. Environmental variables

To assess changes of sedimentation rates potentially induced by the beach nourishment, 3 small sediment traps with the same configuration of those previously utilized at shallow depths (Danovaro et al., 2004) were deployed at each site. The traps were deployed for 18 days subdivided in two periods (6 days covering the entire nourishment period plus 12 additional days after the completion of the beach replenishment). This approach was successfully tested in previously monitoring studies (Storlazzi et al., 2011). After collection, sediments contained in each trap was dried at 60 °C for 48 h, weighed (Stubler et al., 2015), and total mass flux was standardized on the basis of the trap collection area and the number of days and expressed as $g\,m^{-2}\,d^{-1}$.

The main physical–chemical variables (temperature, salinity, pH, dissolved oxygen, chlorophyll-a) of the water column (from the surface down to the bottom) of the study area were determined before (T_0) and after the beach nourishment (T_1) using a CTD multi-parameter probe (accuracy temperature: ± 0.003 °C, pH ± 0.01, dissolved oxygen: ± 0.1 ppm, chlorophyll-a: ± 0.003 $\mu g\,L^{-1}$, salinity: ± 0.003 mS/cm). The turbidity was determined using a Seapoint Turbidity Meter, which detects light scattered by particles suspended in water, generating an