Influence of artificial reefs on the surrounding infauna: analysis of meiofauna

R. Danovaro, C. Gambi, A. Mazzola, and S. Mirto


We adopted a bottom-up approach in studying the effect of two artificial reefs in contrasting environmental conditions (sandy-mud and meso-eutrophic in the Adriatic Sea versus coarse sands and oligotrophic in the Tyrrhenian Sea) on the surrounding environment by assessing changes in the meiofauna. The spatial distribution of meiofaunal assemblages was established along a transect running from within each reef to well outside its direct sphere of influence, along with information on the trophic conditions of sediments (chloropigments, proteins, carbohydrates, and total organic matter). Although total densities were significantly higher in the Adriatic than in the Tyrrhenian, the meiofauna displayed a similar spatial distribution at the two sites, with highest densities being reached between 2 and 20 m away from the reef area and lowest densities among the reef blocks. This pattern corresponded largely with variations in grain size and oxygen penetration in the sediment. Total densities inside the reef areas were significantly lower than at the control station 50 m from the reef, suggesting that processes influencing meiofaunal assemblages largely reflect the interaction between reef and surrounding soft sediments, independently of differences in latitude, sediment texture, and trophic conditions. The results indicate that the proximity of artificial structures altered the composition of meiofaunal assemblages significantly, with potentially important implications for their role in secondary production and energy transfer to higher trophic levels.

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Introduction

Thirty years have passed since the first artificial reef was installed in the Mediterranean. Since then, a large number of studies have been carried out to assess their ecological role on coastal marine ecosystems (Bombace, 1989; Jensen et al., 2000). Despite such efforts, scientific investigations have failed to cover exhaustively and systematically the different ecological compartments. Artificial reefs have been investigated almost exclusively in relation to their effects on fish populations and nearshore fisheries (even as a tool for protecting areas from trawling, with important consequences on coastal management), but whether the effects observed are the result of fish attraction or new biomass production is still an open question (Fabi and Fiorentini, 1994; Lindquist et al., 1994; Relini and Relini, 1996; Badalamenti and D’Anna, 1996).

The presence of hard substratum might allow the settlement of a wide range of benthic invertebrates that otherwise could not find suitable habitats for their crucial post-recruitment survival (Jensen and Collins, 1996). Macrofaunal settlement, in turn, might represent an important food source for several benthic-nektonic fish species (Relini et al., 1994). Man-made structures might also have a strong impact on benthic communities living in adjacent soft-bottom sediments by changing current speed and direction, sediment erosion, sedimentation rates, grain-size distribution and sorting, and organic matter content (Turner et al., 1969; Davis et al., 1982), but information on effects on soft sediments around the reef is limited (Ambrose and Anderson, 1990).

Most investigations on foodwebs associated with artificial reefs have utilized a top-down approach (i.e. looking at the fish biomass and relative stomach...
content. However, an increased biomass in higher trophic levels might result from a higher efficiency of material and energy transfer through trophic levels, or from an increased primary production. Both aspects have been almost completely neglected so far (Bohnsack, 1989; Bombace, 1989; Jensen et al., 1994; Relini and Relini, 1996). A possible alternative to assessing the ecological implications is the use of a bottom-up approach (i.e. assessing the actual role of the artificial reef in enhancing primary production and its transfer to the lower trophic levels of the benthic foodwebs). Knowledge about these aspects is crucial in evaluating the possible role of artificial reefs in influencing microphytobenthic biomass, bacterial production, and meiofaunal abundance.

Meiofauna is thought to respond rapidly to environmental changes such as grain size, redox potential, and food availability (Soyer, 1985; Danovaro, 1996). Moreover, meiofauna is the main link between primary producers and higher trophic levels (i.e. macrobenthos and juveniles of several nekto-benthic species, Lindquist et al., 1994). However, literature dealing with meio-benthic responses to the presence of artificial reefs is, to our knowledge, practically non-existent (Fricke et al., 1986).

This study was designed to investigate the effects of artificial reefs on nearby bottom sediments and associated meiofaunal assemblages. Two reefs located in areas characterized by different environmental and trophic conditions (Northern Adriatic and Southern Tyrrhenian Seas) were compared: (a) to assess effects on soft-sediment grain size, microphytobenthic biomass, and organic matter quality and quantity; (b) to assess differences in meiofaunal assemblages in relation to different trophic conditions; and (c) to identify seasonal changes in meiofaunal community structure along gradients of increasing distance from the reefs.

Materials and methods

Study areas
Two reefs were selected: Senigallia artificial reef (SAR) in the Adriatic Sea and the Palermo artificial reef (PAR) in the Tyrrhenian Sea (Figure 1). SAR, deployed in 1987 in 11 m of water, is situated 25 km NW of Ancona, 1 km offshore on a sand-muddy seabed, remote from natural hard substratum (Bombace et al., 2000). The reef has 29 pyramids arranged in a rectangle at intervals of 15 m, each pyramid consisting of 5 blocks (2 × 2 × 2 m). PAR was deployed in 1992 in 20 m of water. The six reef pyramids are also arranged in a rectangle and have been deployed on a sandy seabed within a seagrass bed (Posidonia oceanica), 300 m from shore (Toccaceli et al., 1996; Riggio et al., 2000). In this case, the pyramids are about 100 m apart.

Environmental parameters

Redox potential discontinuity depth (RPD in cm) was visually estimated as the depth at which sediment colour
Table 1. Mean (standard deviation in parentheses) parameter values for redox potential discontinuity depth (RPD; cm), percentage sand (S%), total organic matter (TOM; %), Chl a (µg g⁻¹), chloroplastic pigment equivalents (CPE; µg g⁻¹), carbohydrates (GE: glucose equivalents; µg g⁻¹), and proteins (AE: albumin equivalents; µg g⁻¹) by reef area (SAR, PAR) and station (St).

<table>
<thead>
<tr>
<th>St</th>
<th>RPD</th>
<th>SAR</th>
<th>PAR</th>
<th>S%</th>
<th>SAR</th>
<th>PAR</th>
<th>% TOM</th>
<th>SAR</th>
<th>PAR</th>
<th>Chl a</th>
<th>SAR</th>
<th>PAR</th>
<th>CPE</th>
<th>SAR</th>
<th>PAR</th>
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<td>5.2</td>
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<td>4.7</td>
<td>3.9</td>
<td>7.7</td>
<td>3.2</td>
<td>21.5</td>
<td>4.9</td>
<td>1025</td>
<td>602</td>
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<td>3731</td>
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<td>6.0</td>
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<td>14.5</td>
<td>5.9</td>
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<td>1744</td>
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<td>2.8</td>
<td>40.4</td>
<td>91.0</td>
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</table>

Environmental parameters

Generally, RPD values at SAR in the Adriatic were lower than at PAR in the Tyrrhenian (Table 1). Sediment grain size in the two areas displayed evident differences. SAR stations were dominated by muddy sediment, except at the 20 m station, whereas PAR stations were strongly dominated by sands. Total organic matter (TOM) content at PAR decreased over the same trajectory (from 4.9% to 2.9%).

All biochemical parameters differed significantly between Adriatic and Tyrrhenian sediments (Table 2). Chl a and CPE displayed similar spatial patterns in the two areas with highest values generally reported at 20 m outside the reef (Table 1). At SAR, the lowest values were encountered outside the reef at the 2 m station, whereas at PAR the lowest values were reported at the 50-m station. Carbohydrates displayed a similar spatial pattern in the two areas, with highest concentrations at the −3 m station between the pyramids and lowest values within the pyramids. In the Adriatic, protein concentrations reached highest values at the −3 m and 50-m stations, whereas in the Tyrrhenian, proteins showed higher values at the −3 m and 2 m stations.

In the Tyrrhenian, differences between the control (50 m) station and the reef (−3 m) station were significant (t-test, p<0.05) for all biochemical parameters, whereas in the Adriatic differences were statistically
significant only for chloroplastic pigment equivalents and carbohydrates.

Meiofauna

Average total meiofauna density was significantly higher in the Adriatic than in the Tyrrhenian (Table 2; Figure 2). However, density in the Adriatic was much higher during summer than in winter, whereas in the Tyrrhenian meiofauna density did not display significant seasonal changes. In both areas, meiofauna reached highest densities just outside the reef area (between 2 and 20 m) and the lowest densities at the 0-m stations. Total meiofauna density inside a reef area was always significantly different from the control station (t-test, p<0.05).

Nematodes were the dominant taxon in both areas and their relative importance was higher in winter than in summer (Figures 3 and 4). In winter in the Adriatic, nematode percentage was over 90 at all stations, whereas in the Tyrrhenian it ranged from 55 to 95, increasing from the artificial reef to the control station. In summer, relative contribution was reduced to 56–74% and 50–80% in the Adriatic and Tyrrhenian, respectively, and presented a less consistent spatial pattern (Figure 4). At least in the Adriatic, the reduction in relative contribution of nematodes was caused by the greatly increased number of harpacticoid copepods and nauplii at all stations (Figure 3). Polychaetes, kinorhynchs and gastrotrichs represented less abundant groups and their contribution to the total density was mostly low in both areas (0–10%; Figure 4).

Discussion

The results indicate clear influences of artificial reefs on the adjacent sediments. Changes in grain size and other benthic parameters are presumably caused by the modified hydrodynamic conditions and micro-scale bottom topography. In the Adriatic, the reduced sand fraction within the reef suggests reduced turbulence as a direct consequence of the blocks, but such an effect was not evident in the Tyrrhenian. Fricke et al. (1986), studying a scuttled ship on a sandy seabed, calculated that the hydrodynamic energy resulting from its presence could easily re-suspend detrital particles and meiofauna even in calm weather conditions, leading to micro-habitat differentiation. Information on hydrodynamic changes induced by concrete blocks is limited (Ambrose and Anderson, 1990; Badalamenti and D’Anna, 1996), but similar changes at the sediment–water interface have also been reported for disused oil platforms (Davis et al., 1982).

The reef influence on sediments was evident also in terms of redox potential discontinuity depth, which is often reduced in areas characterized by higher deposition rates (such as between blocks; Ambrose and Anderson, 1990). At SAR, RPD effects were less evident within the reef compared to the control site, but the sediments at this reef were generally characterized by low RPD values, indicating low oxygen penetration
rates. However, in both areas, effects were strongest between blocks, where the silt-clay fraction was also largest.

Both Chl $a$ concentration and chloroplastic pigment equivalents inside the SAR area were slightly lower than at the control station, but phytopigments were significantly depressed between the blocks and immediately outside both reef areas. This effect may be related to the modified soft-bottom structure and light regime between blocks, but patterns can be further complicated by the current system. Nonetheless, accumulation of fine sediments and debris inside the reef area may be responsible also for accumulation of labile organic compounds in both reef areas. In other words, organic matter deposited may not have been produced in situ, but rather have been imported from outside the reef area. While carbohydrates reached significantly higher concentrations within the reefs than at the controls (comparing stations $-3$ and $50$ m) in both areas, proteins were not enhanced. This indicates a different quality of the organic matter load inside and outside the reef, even though total organic matter remained fairly constant along the transects.

Artificial reefs might affect the infaunal assemblages in various ways: (a) by altering the hydrodynamic regime and the physical characteristics of the substrate; (b) by modifying the distribution and/or composition of the available food sources; and (c) by altering the biological interactions between different parts of the foodweb. One of these factors might prevail over the others or the different forcing functions might act simultaneously resulting in complex responses of the infaunal assemblages.

The limited number of studies conducted so far on infaunal communities from soft bottoms close to artificial reefs has provided contrasting results. Some authors have reported changes in community structure as a result of altered sediment texture. Ambrose and Anderson (1990) found a reduced density of some taxa near the reef, and Nelson et al. (1994) observed a strong reduction in the zone less than 1 m from the edge of the man-made structure. Conversely, Davis et al. (1982) did not find any decrease in density at a distance of at least 4 m from the edge of two artificial reefs off California (i.e. outside the most affected area). Their results might have two possible explanations: predation effects were
observed in the close, downstream vicinity of the reef (2 m station). The lower density inside the reef areas seems best explained by the higher silt/clay fraction and possibly the slightly reduced oxygen penetration.

Fricke et al. (1986) reported enhanced meiofaunal densities in coastal sediments close to a scuttled ship which were closely associated with increases in the fine sediment fraction. Unfortunately, the lack of information on OM availability from this South African study does not allow clarification of potential effects of modified trophic conditions.

Meiofaunal densities were significantly higher in the meso-eutrophic Adriatic than in the oligotrophic Tyrrhenian. The difference in trophic conditions between the two areas is clearly emphasized by the larger amounts of organic compounds in the SAR sediments. Also seasonal changes in density were much larger in the Adriatic, pointing to a strong effect of seasonal changes in food availability. Climatological effects related to the different latitudes of the two areas may also be involved, and appear to be related to the much wider seasonal changes in food input reported at SAR compared to the lack of clear changes reported at PAR. In this regard, Manini et al. (2000) reported protein and carbohydrate concentrations in the northern Adriatic (close to SAR) to be two to four times higher in June than in February. Nevertheless, the similarity of some spatial patterns observed in the two areas suggest that processes influencing meiofaunal assemblages largely reflect the interaction between reef and surrounding sediments, independent of latitude, sediment texture, and trophic conditions.

The reduction in total meiofaunal density inside the reef area largely reflected the reduced abundance of nematodes, the predominant taxon. Other taxa did not decrease or even increase in the proximity of the reef, resulting in spatial differences in meiofaunal composition. Crustacean nauplii, harpacticoid copepods, and polychaetes displayed highest densities inside the reef, particularly at SAR during summer. Even though these differences were not always significant (Table 2), the spatial patterns displayed by these taxa might suggest a preference for different trophic sources (such as carbohydrates accumulating inside the reef). Fricke et al. (1986) also reported changes in assemblage composition, with nematodes and oligochaetes showing the clearest response (even to small changes in grain size), but also turbellarians and polychaetes differed significantly from the control. The conclusion that the proximity of artificial reefs significantly alters the composition of meiofaunal assemblages, with potentially important implications for their secondary production and energy transfer to higher trophic levels, seems justified.

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References


