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Effects of an artificial reef on the surrounding soft-bottom community (central Adriatic Sea)

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The benthic communities of the soft seabed inside and outside the Cesano–Senigallia artificial reef (central Adriatic Sea) were investigated seasonally for 2 years (spring 1997 to winter 1999) to evaluate the effects of the reef on the surrounding bottom. The community living close to the reef is typical for the coastal area. Mean species richness and densities over the entire sampling period were comparable inside and outside the reef, while higher values were recorded at the control site. However, the Shannon–Wiener diversity index was higher close to the reef than at the control. Physical factors associated with the presence of the artificial structures appear to affect composition and abundance of the infauna community more than biological factors do (predation). The area inside the reef was characterized by fine mud favouring the settlement of deposit and suspension feeders, mainly polychaetes. Outside the reef, molluscs were numerically dominant, with an increasing proportion of sandy-bottom species with increasing distance from the structures. These differences were more marked in spring and autumn, while in the other seasons the reef effect appeared to be reduced to a narrow area close to the structures.

Keywords: Adriatic Sea, artificial reefs, benthic community.

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Introduction

Artificial reefs are commonly used around the world as fishery-management tools and to replace habitat losses caused by human impacts. These structures are generally placed on soft seabed away from natural rocky areas, but relatively little attention has been given to evaluating their effects on the surrounding benthic ecosystems (Davis *et al.*, 1982; Ambrose and Anderson, 1990; Posey and Ambrose, 1994; Badalamenti and D'Anna, 1997; Bortone *et al.*, 1998).

Artificial substrates may induce physical and/or biological changes on adjacent soft-bottom habitats. For example, they may affect currents and waves, altering the sediment-size distribution and favouring accumulation of organic material (Ambrose and Anderson, 1990). Organic enrichment of sediments may also be caused by the activity of reef-associated organisms. Moreover, predators attracted by greater food availability may induce a decrease in infaunal densities around the reef (Davis *et al.*, 1982).

To increase knowledge in this field, the epifaunal and infaunal organisms around the Senigallia artificial reef (central Adriatic Sea) were investigated with the aim of obtaining a detailed description of the benthic community and of evaluating the influence of the reef on the surrounding seabed.

Materials and methods

The study was carried out at the Senigallia artificial reef and at a control site located at a distance of 2.5 nm (Figure 1). Both sites are situated along the central Adriatic coast, about 1.2 nm offshore, on a sandy-muddy bottom (depth 11 m) and far from natural hard

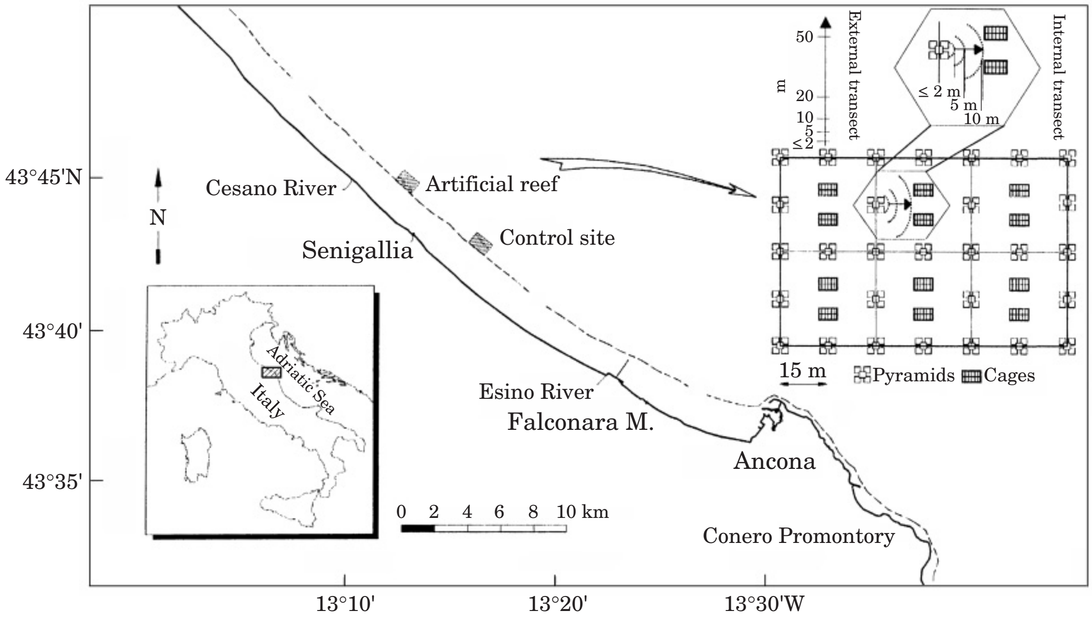

Figure 1. Location of the Senigallia artificial reef and the open-sea control site, with a diagram showing the external and internal transects with the sampling stations.

substrates. The reef was deployed in 1987 and consists of 29 pyramids, each of five $8\ m^3$ WBIC concrete blocks. The pyramids are placed on a stone bed arranged in a rectangle at a distance of about 15 m from each other and interspersed with 12 concrete cages (4 × 5 × 6 m) for shellfish culture.

The area is exposed to winds between the NW and SE and is eutrophic, receiving nutrient-rich fresh water from the Cesano river and, sometimes, from the Po river. The main current runs parallel to the shoreline (from NW to SE) and its average daily intensity often exceeds 25 cm s^{-1}. The annual water temperature range is 7–26°C and the water column is well mixed.

From April 1997 to March 1999, infauna samples were collected from $1600\ cm^2$ squares (side 40 cm; depth 20 cm) through a suction sampler. At the reef, sampling sites were chosen along two transects: the internal transects stretched from a central pyramid and consisted of three stations (2, 5, and 10 m); the external ones extended from the edge of the reef into the open sea and included five stations at 2, 5, 10, 20, and 50 m distance from an outer pyramid (Figure 1). During each survey, two internal and two external transects, as well as a sampling station at the control site, were randomly selected and three replicate samples were taken at each location.

Samples were sieved through a 0.5-mm mesh and the contents fixed in 5% formalin. All organisms were sorted, identified to the lowest possible taxon, and counted. Abundance (N=number of individuals m^{-2}), total species richness (S), mean species richness (S_m), and mean Shannon–Wiener diversity index (H′; Pielou, 1974) were computed for the overall period, for each season, and for each sampling site. N, S_m, and H′ were compared among seasons using an unbalanced, fixed affects, one-way analysis of variance (ANOVA; Lindman, 1992). Prior to statistical analysis, normal distribution and equality of variances were evaluated using the Bartlett and Kolmogorov–Smirnov tests, respectively (Lindman, 1992). In the case of density, a logarithmic transformation was required to pass the test. The Tukey HSD test, corrected for unbalanced samples, was used to make comparisons across all pairs of group means when the corresponding ANOVA tests were significant ($p<0.05$). Similarities among the sampling stations in each season were then evaluated by means of hierarchical cluster analysis (Smeath and Sokal, 1973). Starting from the similarity matrix, calculated using the percentage similarity index (Pielou, 1974), clustering was performed with the mean linkage algorithm.

Results

Over the two sampling years, 166 taxa were identified comprising 4 major taxonomic groups: molluscs (65), polychaetes (43), crustaceans (35), and echinoderms (11). The highest S values were observed inside the reef at I5 (109) and I2 (100) away from the structures (Table 1), while S at I10 was lower and similar to the maximum reported along the external transect at E50.

Table 1. Total species richness by sampling station and taxonomic group (C: crustaceans; E: echinoderms; M: molluscs; P: polychaetes; O: others).

	C	E	M	P	O	Total
I10	16	6	40	21	8	91
I5	24	8	40	29	8	109
I2	20	5	43	24	8	100
E2	18	5	40	17	8	88
E5	14	4	37	20	7	82
E10	16	5	31	23	8	83
E20	12	4	39	19	5	79
E50	12	7	46	22	5	92
Control	15	7	46	21	7	96

Still lower values were registered at lesser distances from the reef, with a minimum at E20 (S=79). S at the control site was higher than the values obtained along the external transect, but lower than the maximum values reported inside the reef. Molluscs represented numerically the most important group at all sites (37–50% of the total infauna recorded), followed by polychaetes and/or crustaceans (13–28%).

Mean species richness over the entire period was similar on the internal and external transects up to E20 from the reef (Figure 2a). Higher values were obtained at a distance of 50 m and at the control site. ANOVA showed highly significant differences among seasons ($p<0.001$) with the highest values in spring and summer (Table 2).

Mean densities recorded inside and outside the reef (Figure 2b) ranged between 749 at E5 and 989 ind. m^{-2} at E50. Comparison between internal and external locations situated at the same distances from the pyramids showed higher densities inside the reef mainly caused by a greater abundance of a few cnidarians (not identified Actinaria and *Obelia dichotoma*), amphipods (*Caprella equilibra* and *Corophium acherusicum*), bivalves (*Mytilus galloprovincialis* and *Paphia aurea*), gastropods (*Hyala vitrea* and *Nassarius reticulatus*), and polychaetes (*Capitella capitata*, *Glycera unicornis*, and *Prionospio cirrifera*). The density obtained at the control site was much higher (2062 ind. m^{-2}) than those reported along the transects, mainly owing to the high abundance of *C. equilibra* and *N. reticulatus* in spring, *P. cirrifera* in winter, and *Chamelea gallina*, *Corbula gibba*, and *Owenia fusiformis* during the whole year. Highly significant differences ($p<0.001$) were observed between seasons, with the lowest density values recorded in winter (Table 2).

The mean Shannon–Wiener diversity index hardly varied along the internal and external transects, except for a high value at E50 (1.08; Figure 2c). H′ was lowest at the control site (0.82) mainly because of the seasonally varying dominant species listed above. No statistical differences among seasons were obtained for this index (Table 2).

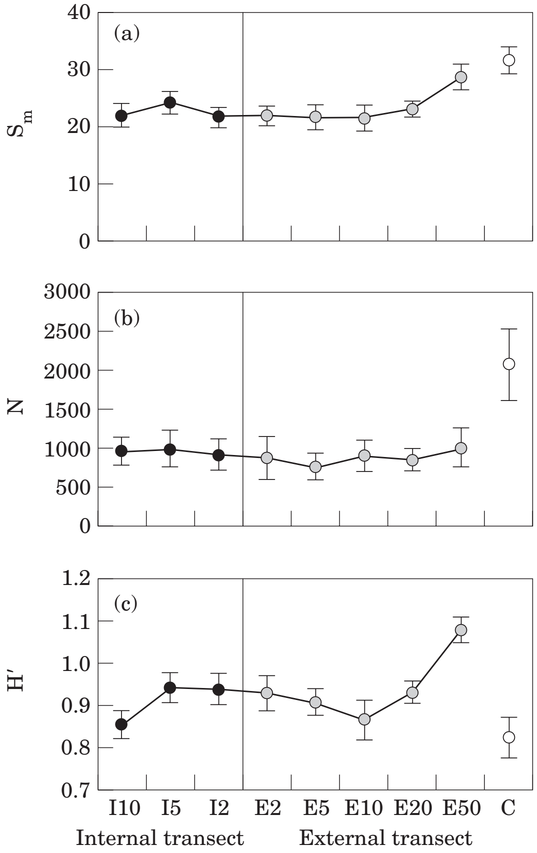

Figure 2. Mean species richness (a), abundance (b), and H′ (c), with their respective standard errors, for the internal and external transects (see Figure 1) and for the control site (C).

From the cluster analysis based on the percentage similarity index among density values, four main groups could be distinguished in all seasons (Figure 3), which reflected their distance from the structures and/or their position inside or outside the reef. The control site was always isolated because of its high total densities (group D; Table 3).

Distance from the structures seemed to be the main group feature in winter and summer. In winter, the stations included in group A showed similar densities of gastropods and/or amphipods, while those in group B were characterized by a high abundance of polychaetes, especially *C. capitata*. Group C contained only one station (E50) that differed from the others because of its low density (Table 3).

In summer, similarity among stations was determined by mollusc abundance. Sites in group A showed low densities of bivalves and gastropods, while high bivalve densities distinguished group B. Similar densities of

Table 2. One-way ANOVA for the factor season (S_m: mean species richness; ln N: log density; H′: Shannon–Wiener diversity index).

	d.f.			
	Between	Within	p	Tukey test
S_m	3	148	<0.0001**	Summer, Spring $\gg$ Autumn, Winter
ln N	3	148	0.0004**	Winter $<$ Autumn; Winter $\ll$ Spring, Summer
H′	3	148	0.16	—

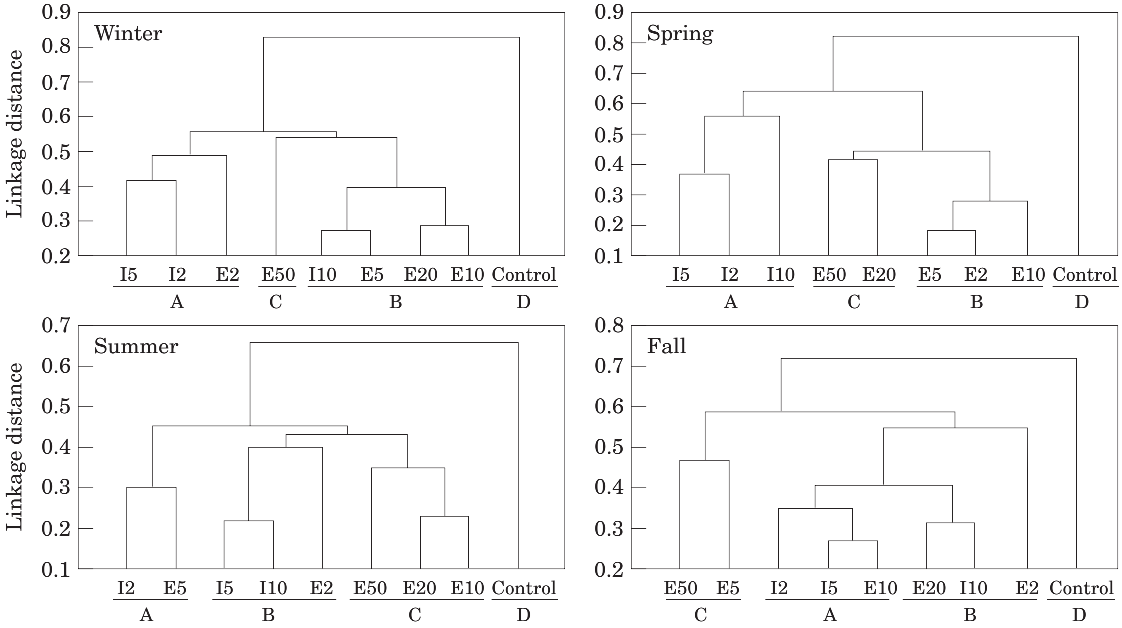

Figure 3. Dendrograms based on percentage similarity indices derived from cluster analysis of density values seasonally recorded along the internal and external transects and at the control site.

gastropods characterized external stations E10–E50 (group C), which also showed higher bivalve densities relative to group A but lower relative to group B (Table 3).

In spring and fall, the distribution of polychaetes and molluscs clearly separated the sites inside from those outside the reef. In spring, all inner stations (group A) shared high abundance of polychaetes, whereas stations outside the reef were characterized by high densities of molluscs, especially bivalves. The separation into two groups (B and C) was due to a higher abundance of amphipods in the former (Table 3).

In autumn, the sites inside the reef (group A) also shared high densities of polychaetes, while the external stations were divided into two groups on the basis of gastropods that were more abundant in group C. The greater similarity between stations of group B and those of group A was caused by their similar total densities (Table 3).

Discussion

The benthic community living in the soft seabed surrounding the Senigallia artificial reef was mainly composed of molluscs and polychaetes typical of the coastal area of the central Adriatic Sea. Although there were seasonal fluctuations, mean species richness and densities computed over the entire sampling period were similar inside and outside the reef, while higher values were recorded at the open-sea control site.

As reported by Ambrose and Anderson (1990), working on the Pendleton Artificial Reef in Southern California, the soft-bottom benthic community around the reef appears to be affected more by physical factors than by predation. No noteworthy density reductions were observed from spring to fall, the period of maximum abundance of fish in the area (Fabi and Fiorentini, 1994; Bombace *et al.*, 1997). Moreover, the highest infaunal densities recorded at the control site involved

Table 3. Density (N ind. m^{-2}) recorded by main group and station along the internal (I) and external (E) transects and at the control site (C) by season (stations indicated by their distance from the structures: 2, 5, 10, 20, and 50 m).

	Winter									Spring								
		External					Internal				External					Internal		
	C	E50	E20	E10	E5	E2	I2	I5	I10	C	E50	E20	E10	E5	E2	I2	I5	I10
Bryozoa						1	1	1								19		
Cnidaria																		
Anthozoa	6		2	2	2	9	1	3	2	5	1	1	4	1	1		7	1
Hydrozoa				2	4	3		26	1	10					29	79	2	20
Crustacea																		
Amphipoda	27	24	143	101	43	38	35	32	46	1899	231	195	727	472	461	197	226	202
Cirripeda														1			2	1
Cumacea	39	6	30	6	4	3	1	1		31	4	1		1	2		1	
Decapoda	5	2	2	4	6	15	7	5	5	5	7	8	6	4	14	2	2	3
Isopoda				1					1									
Ostracoda					1	1				2	1		5	3	1	42	38	16
Echinodermata																		
Asteroidea	1																	
Echinoidea	4									1								
Ophiuroidea	1	1				1		2	1	4	2		1			2		
Holothuroidea	1		1	1	1	2		1		4	4	16	3	45	18	10	6	
Mollusca																		
Bivalvia	250	46	57	66	56	38	48	70	48	1034	374	219	334	279	254	210	215	146
Gastropoda	136	45	111	169	72	76	241	243	110	504	228	89	105	87	97	303	76	121
Scaphopoda	2	6	4	4		9	1	5	4	27	42	4	3	1	6	5	1	3
Nemertini	4		4	2	1	1			1	14	1	1		6	1	25	40	
Platelminta				1						1	1		1					
Polychaeta	1070	53	217	151	155	67	38	45	159	680	100	40	109	129	69	260	201	151
Sipuncula	3	3		1	2	1	2		1	1		6	2	3	2	15	2	2
Total	1546	185	570	510	345	263	373	432	376	4221	994	578	1298	1030	953	1168	819	664
Total species richness	53	41	45	48	51	43	55	45	80	67	47	49	54	56	66	59	53	

Table 3. *Continued*

	Summer									Fall								
		External					Internal				External					Internal		
	C	E50	E20	E10	E5	E2	I2	I5	I10	C	E50	E20	E10	E5	E2	I2	I5	I10
Bryozoa							1	1				2	2	2			1	2
Cnidaria																		
Anthozoa	1								1	55	2	2	2		2	7	5	1
Hydrozoa	1				6	20	9	11	9			2	2		8	6	1	1
Crustacea																		
Amphipoda	2	2	4	5	6	9	44	98	82	7		17	36	6	17	27	39	36
Cirripeda							1	1								1		3
Cumacea							1											
Decapoda	1			1	1	10	2	5	3	9	2	3			2	2	41	3
Isopoda	1									5						1	1	1
Ostracoda							2	2					5			1	3	1
Echinodermata																		
Asteroidea		1										2						
Echinoidea		1		2				1	1	2	3							
Ophiuroidea	10		1	1	1			1	1	1							1	
Holothuroidea	15	9	37	21	44	18	11	43	36			3	6	2	3	4	4	10
Mollusca																		
Bivalvia	825	550	789	694	449	1304	530	1101	930	411	455	714	452	304	206	457	310	432
Gastropoda	61	234	215	204	147	373	112	426	280	85	1131	195	114	409	61	197	217	380
Scaphopoda	2	29	11	7	3	4	2	7	2	5	123	58	3	8		8	8	15
Nemertini	2	1			3	4	5	2	2	1			2	2		2	1	1
Platelminta					1				1									
Polychaeta	426	99	46	39	140	84	108	139	220	555	123	141	177	88	98	224	216	259
Sipuncula	1	7	1		1	1	1	2	3		3			2				2
Total	1347	933	1104	973	801	1826	828	1838	1571	1135	1843	1138	798	821	397	938	848	1148
Total species richness	47	57	43	42	44	57	57	64	63	50	48	44	43	32	53	64	56	

largely organisms that do not belong to the preferred preys of the most common fish associated with the reef (Fabi *et al.*, 1998).

The artificial structures may alter the surrounding seabed, favouring siltation and accumulation of organic matter inside the reef area. This effect appeared more pronounced in spring and fall, when the cluster analysis indicated a clear difference between the communities inside and outside the reef. The inner area was characterized by deposit and suspension feeders, especially polychaetes associated with very fine sediment. Outside the reef, the community was dominated by molluscs. Among these, sandy-bottom species became more important with increasing distances from the reef structures, including the – even sandier – control site. In summer and winter, the separation between internal and external stations was less marked and the distance from individual structures was more important, indicating that the influence of the reef on the soft-bottom community was reduced to those stations physically closest to the pyramids.

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