Distribution and dynamics of epibiota on hard structures for coastal protection

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Abstract

Hard structures for protection against erosion of shores are some of the most common human-made constructions in coastal areas. Nevertheless, little is known as to how marine organisms respond to their presence. The composition and distribution of intertidal epibiota at different positions around different types of defence structures (groynes and breakwaters) at three stations along the Emilia Romagna coast (Italy) were analysed. Sampling covered a range of scales: meters (distance among replicate plots), hundreds of meters (distance among replicate areas) and tens of kilometres (distance among stations). The colonisation and dynamics of conspicuous species over 1 year, following maintenance works on two structures, were also quantified. Assemblages on defence structures were characterised by a notably low richness of species, by strong spatial dominance of mussels and green ephemeral algae, and by high rates of colonisation. Abundance of mussels, *Enteromorpha intestinalis* and filamentous algae differed significantly among nearby areas within stations. Mussels were significantly less abundant along the landward side of breakwaters compared with all other positions on both groynes and breakwaters. Overall, however, fewer differences, than expected, were observed in the distribution of species at different positions around groynes and breakwaters, probably as a consequence of the low complexity of the colonising assemblages. Possible factors explaining the patterns of distribution observed are discussed, including the roles of harvesting of mussels and frequent maintenance works on the structures. The implications of the low richness of species observed in terms of management of defence structures and other human-made constructions are discussed.
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1. Introduction

Human-made structures are common in marine coastal habitats all over the world, and their extent is set to increase considerably in the nearby future (Collins, Jensen, Lockwood, & Lockwood, 1994; Glasby & Connell, 1999). They serve a variety of purposes, including maritime and urban activities, coastal defence, oil and gas extraction and mariculture. In recent years, they have been regarded as potentially useful tools to help control fishing activities, enhance the productivity of commercial species and mitigate habitat losses (Bohnsack & Suther-

land, 1985; Pickering, Whitmarsh, & Jensen, 1998). The full impact of the resulting changes on the coastal habitats and assemblages of marine organisms is not well known, but early indications suggest that it may be profound (Chou, 1997; Connell & Glasby, 1999; Davis, Van-Blaricom, & Dayton, 1982; Turner, Ebert, & Given, 1969). Construction of structures often results in the fragmentation and destruction of natural habitats and their replacement with artificial habitats. These are, in turn, colonised by new assemblages of plants and animals, which may have important impacts, perceived as either positive or negative, on coastal areas (Connell, 2000; Glasby, 1999; Page, Dugan, Dugan, Richards, & Hubbard, 1999; Relini, Tixi, Relini, & Torchia, 1998; Wolfson, VanBlaricom, Davis, & Lewbel, 1979).

Hard-substrate defence structures are among the most common human-made constructions in coastal

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areas. The primary purposes of the defence structures are to prevent or reduce erosion and flooding of the coastline, and stabilise and retain beach fill material. The most frequent constructions are longitudinal structures, such as walls, quays and offshore breakwaters, and transversal structures, such as groynes and dikes. In Europe, defence structures of different materials (e.g. wood, concrete, limestone) have been built since the 1960s, and they are now common along sandy shores (see the EU Demonstration Programme 1997–1999 for an updated account of defence structures along the European coasts, Commission européenne, 1999). Despite the proliferation of defence works, and the fact that their construction has often resulted in dramatic changes in the coastal environment (Bacchiocchi, Airoldi, Ceccherelli, Lamberti, & Drei, 1999; Cencini, 1998; Correggiari, Frascari, Miserocchi, & Fontana, 1992; King, Cooper, Morfett, & Pope, 2000), there has been surprisingly limited research as to how the marine organisms respond to these structures. Little is known about the types of assemblages that grow on defence structures (Bulleri, Menconi, Cinelli, & Benedetti-Cecchi, 2000; Collins et al., 1994; Leewis, Waardenburg, & Meijer, 1989; Reish, 1964). Even less is known about the development and distribution of epibiota, or about the responses of colonising organisms to different types of defence structures. This limits the possibility to develop models of predicted impacts, and to identify options for the design and management of defence structures.

The present study is part of a multidisciplinary research project aimed to promote effective and environmentally compatible designs of defence structures along the European coasts. In this context, attention is devoted to identify as to how the defence structures influence the epibiota. Quantitative data concerning the distribution and dynamics of epibiota on different types of defence structures along the Emilia Romagna coast (Italy) are presented. This coast consists of a flat alluvial sandy system with no natural rocky reefs. Severe erosion has occurred since the middle of the 20th century, which has led to proliferation of protection schemes (Cencini, 1998). According to recent censuses (IDROSER, unpublished report; DELOS, unpublished data), over 60% of Emilia Romagna shores are protected by defence structures, but almost no information is available on their ecology.

Defence structures along Emilia Romagna are mainly groynes and offshore breakwaters. Groynes are set perpendicular to the shore in order to retain or arrest the long-shore movement of sediment, while breakwaters are set parallel to the shore to reduce wave effects. Different design criteria result in different hydrodynamic and physical conditions around the structures (Burcharth, 1993), with possible important effects on the distribution of epibiota (Glasby, 2000; Glasby & Connell, 2001). In this study, the composition and abundance

of intertidal epibiota on groynes and breakwaters in the province of Ravenna were analysed. Specifically, whether the distribution of epibiota differed among positions around groynes and breakwaters, and whether patterns were consistent at different spatial scales, ranging from meters to tens of kilometres, were investigated. The dynamics of epibiota following maintenance works at some defence structures were also analysed.

2. Methods

2.1. Study area

Studies were done on defence structures on three shores within the province of Ravenna (Italy) in the North Adriatic Sea (Fig. 1A). The shores comprise a sandy flat coastal system longer than 300 km and almost uninterrupted except for the mouths of rivers, channels and lagoon systems and for human-made structures. The area is subject to moderate wave conditions and to a relatively large tidal range (over 80 cm) compared with the rest of the Mediterranean Sea. Information on the geomorphology, hydrology and environmental characteristics of the region can be found in Bondesan, Calderoni & Dal Cin, (1978), Correggiari et al. (1992), Zavatarelli, Raicich, Bregant, and Russo (1998) and Poulain (2001).

Study shores (hereafter called stations) were located at Casal Borsetti, Lido Adriano and Lido di Dante (Fig. 1B). Stations were characterised by the presence of schemes of groynes and offshore detached breakwaters, which were constructed as protection measure against erosion (Fig. 1C). All the defence structures were built with large blocks of limestone, about 0.5–2 m in diameter (Fig. 1D). Groynes had a similar shape and age at all the stations; they consisted of about 70-m-long structures, perpendicular to the shore that were built in the early 1980s. Breakwaters were more heterogeneous in shape and age. At Lido di Dante, they consisted of two low-crested structures (i.e. crest emerging at low tides) parallel to the shore, about 350 m long and about 150 m from the shoreline, that were built in 1995–1996. At Casal Borsetti and Lido Adriano, breakwaters consisted of several high-crested structures (i.e. crest always emerging) parallel to the shore, about 80 m long and about 30–150 m from the shoreline, that were built in the 1970s.

2.2. Structure and distribution of epibiota

The distribution of intertidal epibiota on defence structures was investigated during August and September 1999. Sampling was done in low-shore habitats (0–30 cm above mean-low-water). Abundance of
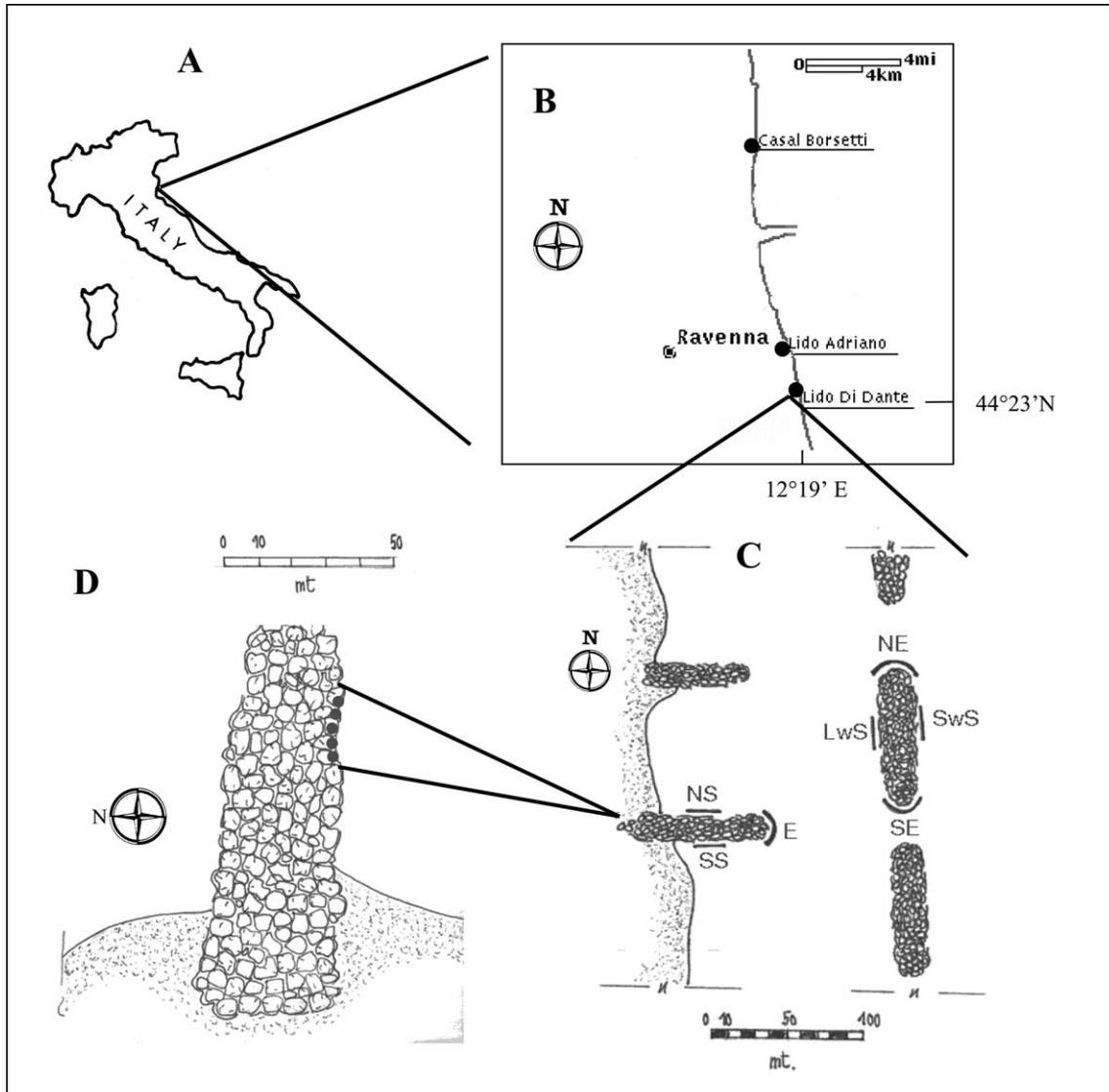
Fig. 1. (A) Location of the study area, (B) location of the three study stations (Casal Borsetti, Lido Adriano and Lido di Dante), (C) location of areas at different positions around groynes (NS, north side; E, end; SS, south side) and breakwaters (NE, north end; SE, south end; SwS, seaward side; LwS, landward side) and (D) example of location of replicate plots in one area (10 m long transect). In (C) and (D), symbols for areas and plots are not to scale.

conspicuous species was quantified as a function of type of structure (groyne and breakwater) and position around the structures. Three positions were identified around groynes (north side, end and south side), and four positions were identified around breakwaters (north end, seaward side, south end and landward side) (Fig. 1C). At each station (Casal Borsetti, Lido Adriano and Lido di Dante), sampling was done at all positions around two groynes and two breakwaters selected at random. In each position, sampling was done along 10 m long central transects, hereafter referred to as 'areas' (Fig. 1C). In each area, abundance of conspicuous species of algae and animals, and of bare rock (i.e. rock not covered by any macroscopic visible species) was estimated in five replicate plots (Fig. 1D). The

study, thus, covered a range of spatial scales: meters (distance among replicate plots), hundreds of meters (distance among replicate areas) and tens of kilometres (distance among stations).

Plots were surfaces of 20 cm × 25 cm: this size was chosen based on the results of cost–benefit analyses done during previous pilot studies (Airoldi, Camorani, Bacchiocchi, & Ceccherelli, 2000). Abundance of vagile organisms in each plot was quantified as number of individuals per unit area. Abundance of sessile species (on both primary and secondary substrata) and of bare rock was quantified as percent cover by using the visual method (Benedetti-Cecchi, Airoldi, Abbiati, & Cinelli, 1996). A frame divided into a grid of 25 small squares was used, and a score from 0 to 4% was given to each

species in each square. Species present with covers below 1% were given an arbitrary value of 0.5%. Algae and animals that could not be identified to species or genus in the field, or that could be confused with other species, were grouped into larger taxonomic complexes or into morphologic groups (see Section 3). Voucher specimens were collected for later identification and are housed at the Laboratory of Experimental Ecology in Ravenna (University of Bologna).

Data were analysed using three-way, mixed-model ANOVAs, with station (three levels: Lido di Dante, Lido Adriano and Casal Borsetti) as random factor, position around groynes and breakwaters (seven levels: north side, end and south side along groynes and north end, seaward side, south end and landward side along breakwaters) as fixed factor orthogonal to station and area (two areas) as random factor nested in the interaction between station and position. Cochran's *C*-test was used to check for homogeneity of variances. When necessary, data were transformed to stabilise variances. When position was found to have a significant effect on the distribution of species, Student–Newman–Keuls (SNK) tests were used for a posteriori multiple comparisons of means in order to identify possible differences among plots sampled at different positions around groynes and breakwaters.

2.3. Colonisation and dynamics

Maintenance works were undertaken in May 1999, to increase the stability of the low-crested breakwaters at Lido di Dante, by addition of new limestone blocks never before exposed to seawater. Recruitment of algae and sessile invertebrates on these new blocks was investigated from early July 1999 to August 2000. Sampling was carried out at low-shore levels, and was repeated at monthly intervals during spring and summer, while only one sampling was done during the autumn and winter in December 1999. The dynamics of established assemblages on surrounding old blocks was also quantified at the same time, in order to identify the time necessary for new assemblages to become established. Six old and six new blocks were selected at random along a 50-m-long transect on each of the two breakwaters at Lido di Dante. The blocks selected for the study were generally located along the crests of the breakwaters, where most of the new blocks had been added. For each block, a 20 cm × 25 cm plot was identified on the sheltered side of the block. Plots were marked permanently with epoxy putty (Subcoat S., Veneziani), in order to allow relocation over time. Some blocks, however, sank or were overturned during storms, thus the number of plots that could be relocated decreased over time (see Section 3). Abundance of dominant species in plots on both new and old blocks was estimated as previously described. Due to loss of replicates, data were not analysed

statistically, and the temporal trends were interpreted from graphs.

3. Results

3.1. Structure and distribution of epibiota

Few taxa were found in intertidal assemblages associated with breakwaters and groynes. Animals included *Mytilus galloprovincialis* Lamarck, oysters (these were *Ostrea edulis* Linnaeus and *Crassostrea gigas* (Thunberg), but, as a consistent species distinction in all plots was difficult, they were grouped as 'oysters'), Serpulidae indet., *Chthamalus stellatus* (Poli), Balanidae indet., Ascidiiae indet. and Actinidae indet. Specimens of *Patella caerulea* Linnaeus were sometimes observed, but they were very rare and never occurred in the sampled plots. No snails were seen either during this study, or during the subsequent work. Conversely, crabs were observed frequently, but due to their high mobility, they were not quantified in the present study. Algae included *Enteromorpha intestinalis* (Linnaeus) Nees, *Ulva laetevierens* (Areschoug) and filamentous species. Filamentous algae were difficult to recognise in the field except for *Cladophora vagabunda* (Linnaeus) Hoek and *Polysiphonia breviarticulata* (C. Agardh) Zanardini. Further, they generally occurred as a mixture of species, thus they were grouped as 'filamentous'. Later examination of voucher specimens showed that filamentous algae also included *Polysiphonia subulata* (Ducluzeau) P. & H. Crouan, *Ceramium diaphanum* (Lighfoot) Roth, *Cladophora* spp. and germlings of *E. intestinalis* and *U. laetevirens*. Encrusting algae were surprisingly very rare and included only *Ralfsia verrucosa* (Areschoug) Areschoug.

Assemblages were dominated by the mussel *Mytilus galloprovincialis*, with an average cover of 74%, and by the green alga *Enteromorpha intestinalis* that grew on both rock and mussels with an average cover of 29% (Fig. 2). The distribution of *M. galloprovincialis* was heterogeneous, varying among nearby areas and among stations (Table 1); overall, mussels were less abundant at Lido di Dante than at Casal Borsetti and Lido Adriano (Fig. 2). Further, there was a consistent trend of lower abundance of *M. galloprovincialis* on the landward sides of breakwaters with respect to all other positions around both breakwaters and groynes (Table 1, SNK test). Cover of *E. intestinalis* differed among areas (Table 1), while no significant variations were observed between stations or between positions around different types of defence structures.

Filamentous algae were the only other abundant taxon on breakwaters and groynes, while other species were too rare for meaningful analyses. Filamentous algae colonised both rock and mussels, and their cover
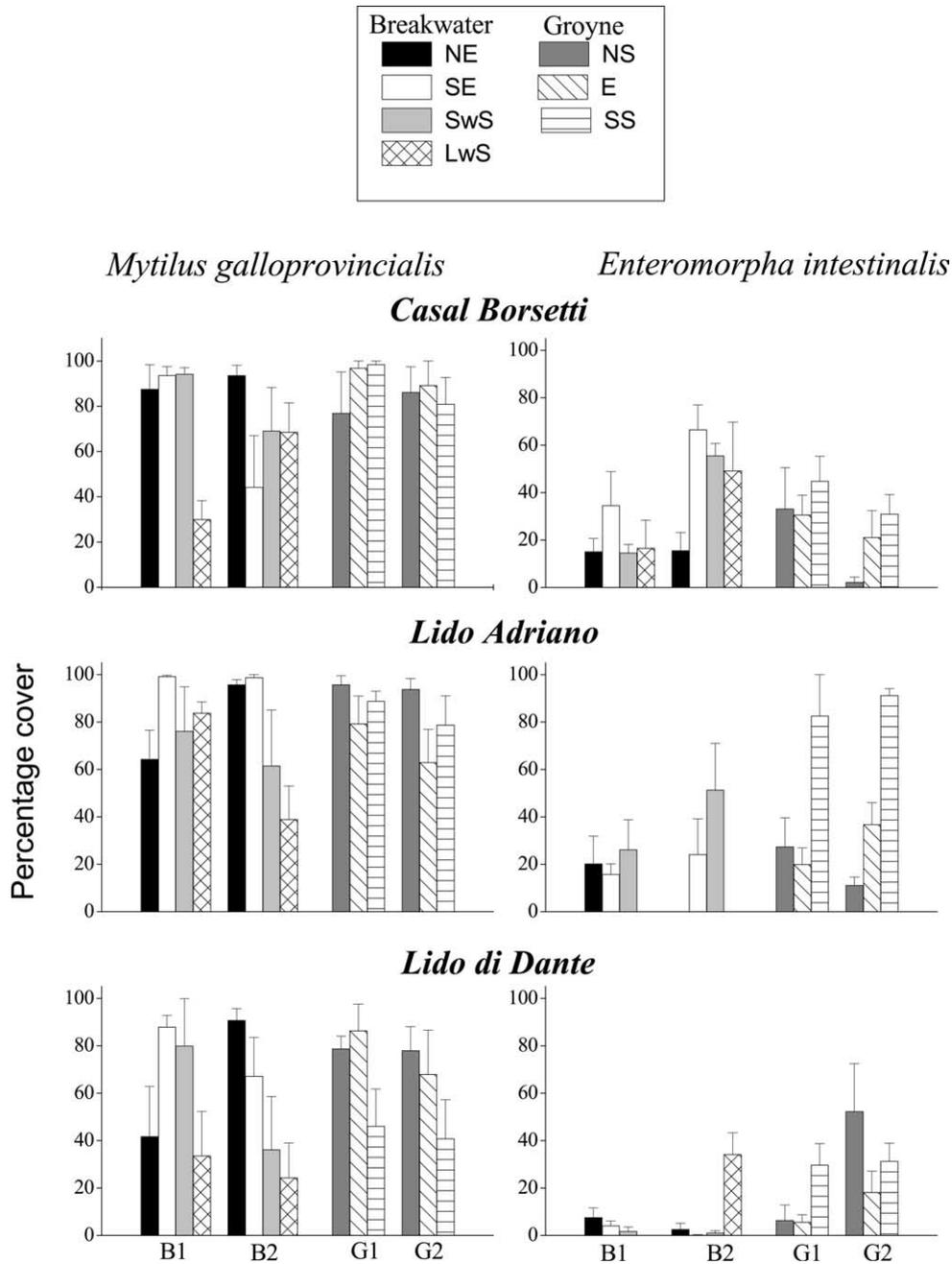
Fig. 2. Percentage cover (+SE, $n = 5$) of *Mytilus galloprovincialis* and *Enteromorpha intestinalis* at three stations and at different positions around groynes and breakwaters. At each station, sampling was done at all positions around two breakwaters (B1, B2) and two groynes (G1, G2). Symbols for positions are coded as in Fig. 1C.

was on average 11%, with peaks of abundance above 40% at some areas in Lido di Dante (Fig. 3). Abundance of filamentous algae varied significantly among nearby areas (Table 1), while no consistent differences were observed as a function of position or station. Patches of bare rock were frequent in the assemblage. Mean percentage cover of bare rock was 4%, with peaks of abundance up to 35% (Fig. 3). On average, bare rock was significantly less abundant at Lido Adriano (Fig. 3,

Table 1), while no differences were observed among areas or positions.

3.2. Colonisation and dynamics

After the addition of new blocks, defence structures at Lido di Dante were unstable for a few months. Some blocks, both new and old, sank or were overturned during storms. The number of marked plots that could

Table 1
Results of ANOVAs and SNK tests on percentage covers of dominant species at different stations and at different positions around groynes and breakwaters. Factors are: station (CB, Casal Borsetti; LA, Lido Adriano; LD, Lido di Dante), position (NS, north side; E, end; SS, south side around groynes; NE, north end; SE, south end; SwS, seaward side; LwS, landward side around breakwaters) and area (two areas). Data of filamentous algae and bare rock were transformed to $\sqrt{(x+1)}$ and $\ln(x+1)$, respectively. Significant P values ($P < 0.05$) are shown in bold type

Source of variation	df	MS	F	P	SNK test
Mytilus galloprovincialis					
Station (St)	2	7453.03	4.51	**0.0235**	
Position (Ps)	6	5091.90	3.67	**0.0263**	Ps: LwS < SwS = SS =
StxPs	12	1387.10	0.84	0.6131	NE = E = SE = NE
Area (StxPs)	21	1652.93	1.95	**0.0110**	
Residual	168	849.72			
Enteromorpha intestinalis					
Station (St)	2	2552.71	1.20	0.3202	
Position (Ps)	6	4632.65	1.47	0.2669	
StxPs	12	3143.77	1.48	0.2079	
Area (StxPs)	21	2122.49	3.55	**0.0000**	
Residual	168	597.58			
Filamentous algae					
Station (St)	2	12.41	0.86	0.4392	
Position (Ps)	6	10.84	2.10	0.1289	
StxPs	12	5.16	0.36	0.9656	
Area (StxPs)	21	14.50	3.46	**0.0000**	
Residual	168	4.18			
Bare rock					
Station (St)	2	6.65	4.62	**0.0218**	
Position (Ps)	6	2.83	1.07	0.4304	
StxPs	12	2.64	1.84	0.1069	
Area (StxPs)	21	1.44	1.33	0.1625	
Residual	168	1.08			

be relocated, thus decreased over time (Fig. 4), and, at the end of the study, only 14 blocks (four new and 10 old) remained of the original 24 among the two breakwaters.

The green alga *Enteromorpha intestinalis* was the earliest macroscopic organism to settle on new blocks, showing luxuriant growth within the first month after the blocks were added to the structures (Fig. 4). As a consequence, in July 1999, *E. intestinalis* occupied almost 100% of the available space on new blocks, compared with only 20% observed on old blocks. Abundance of green algae on new blocks declined from July through December 1999, reaching cover values comparable with those observed on old blocks. After that period, the dynamics of *E. intestinalis* on new blocks paralleled that on old blocks. Some differences were still evident in May 2000, when *E. intestinalis* showed values of cover of 100% on new blocks compared with average values of 60% on old blocks. Afterwards, *E. intestinalis* progressively declined to disappearance through August 2000 in both new and old blocks.

Recruitment of *Mytilus galloprovincialis* on the new blocks was not as rapid as recruitment of *Enteromorpha intestinalis* (Fig. 4). Mussels, which were the dominant species on old blocks, were almost absent from new blocks laid in May 1999 until May 2000. After that period, a peak in recruitment was observed, and within 3 months, mussels reached the covers above 70%, to be comparable with those observed on old blocks. The dynamics of *M. galloprovincialis* on old blocks showed an apparent seasonal trend: mussels occupied above 80% of primary space during summer months, while their average cover declined to 45% in December through May.

Filamentous algae were not very dense, their cover being generally less than 10% (Fig. 4). Abundance of filamentous algae on new blocks was similar to that measured on old blocks during the entire period of study. Overall, filamentous algae were present from August to December 1999, while their cover was less than 1% from June to August 2000.

Owing to the very high recruitment of *Enteromorpha intestinalis*, the amount of bare rock on new blocks was very low from the very beginning of colonisation in July 1999 (Fig. 4), with values close to 0%. Overall, the amount of bare rock ranged from 0 to 18%, showing similar average values on new and old blocks. A greater variability was observed among new blocks during summer 2000.

4. Discussion

Intertidal assemblages on defence structures in the study area were composed of few species. At all the stations, much of the space on groynes and breakwaters was occupied by beds of *Mytilus galloprovincialis*. This species is also abundant in the coastal lagoons of the region as well as on other types of artificial coastal structures (Bombace, Castriota, & Spagnolo, 1995; Ceccherelli & Rossi, 1984; Relini et al., 1998), and represents a commercially profitable resource. The green alga *Enteromorpha intestinalis*, which is also common in coastal lagoons, and filamentous algae were the only other abundant species, their distribution probably being influenced by the scarcity of limpets (Lotze, Worm, & Sommer, 2000).

The remarkably low diversity of intertidal assemblages on defence structures in the study area was confirmed as a consistent pattern by subsequent studies carried out at larger spatial and temporal scales (Airoldi et al., unpublished data). This is relevant to the management of these structures. Human-made structures are, in fact, considered a benefit to coastal sandy areas of the Adriatic Sea for their potential to increase local species diversity by allowing the settlement of new species that usually live on rocky reefs (Bombace et al., 1995). Present results, however, suggest that artificial structures may act by changing the patterns of distribution of
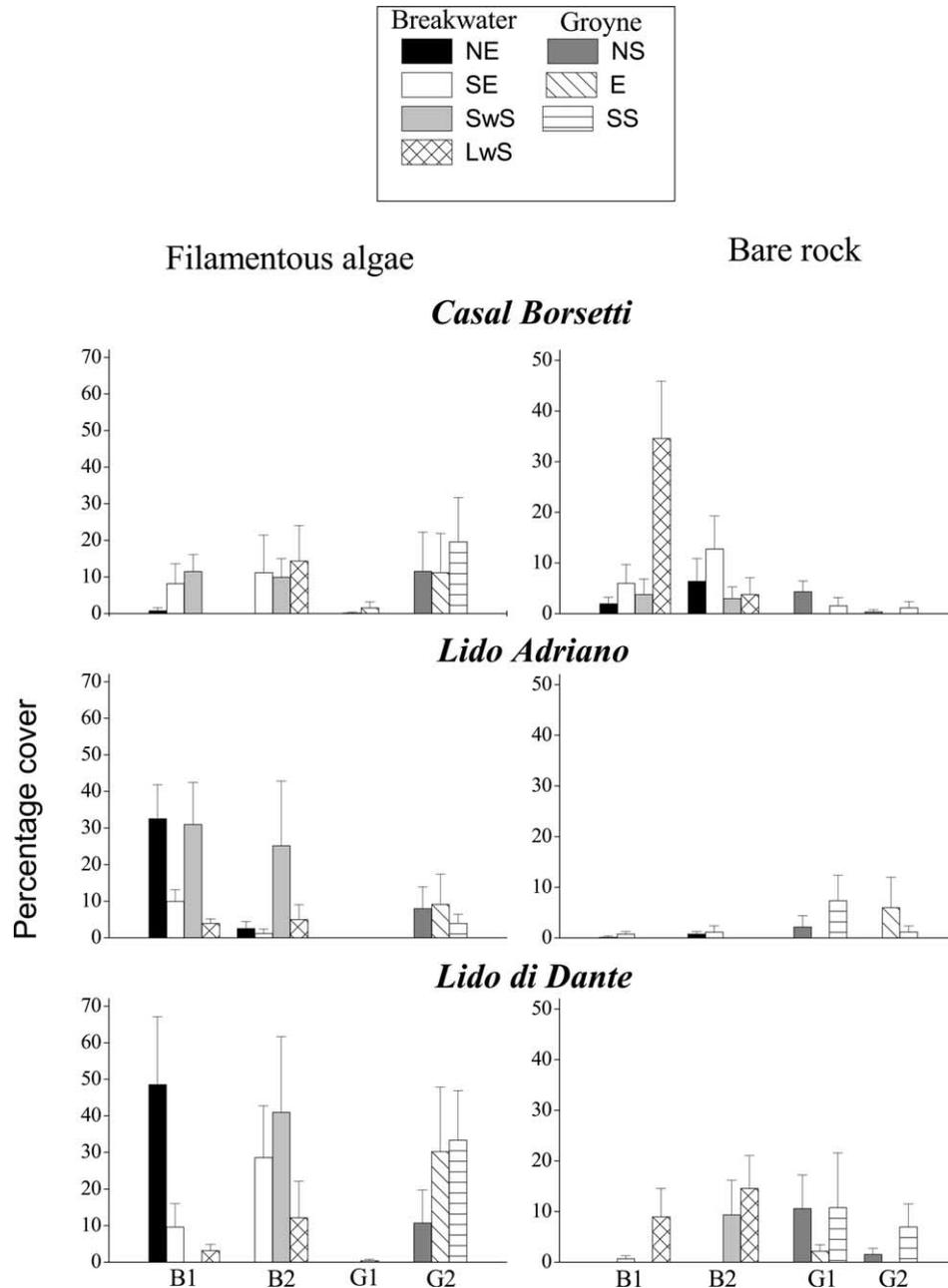
Fig. 3. Percentage cover ($+$ SE, $n = 5$) of filamentous algae and bare rock at three stations sites and at different positions around groynes and breakwaters. At each station, sampling was done at all positions around two breakwaters (B1, B2) and two groynes (G1, G2). Symbols for positions are coded as in Fig. 1C.

locally abundant species rather than by increasing species diversity. Similar hypotheses have been suggested by Glasby (1999) and Glasby and Connell (1999), who raised concern that human-made structures may cause considerable change in the identity and/or abundance of epibiotic species within an area, but in most cases, the possible consequences of these changes on coastal assemblages are not taken into account. In areas where no natural hard substrata occur, such as the coasts of Emilia Romagna, effects due to the extensive presence of artificial structures can be particularly relevant. For

example, while growth of mussels on artificial structures is perceived as a benefit (Relini et al., 1998), the flowering of ephemeral green algae that are torn off the structures and washed up the shore is a major problem for beach tourism.

At the moment, little is known about the physical and/or biological processes underlying the low diversity of species observed on defence structures in this area. Because of the absence of rocky reefs in the area, it is not possible to assess whether assemblages that grow on these structures are representative of natural
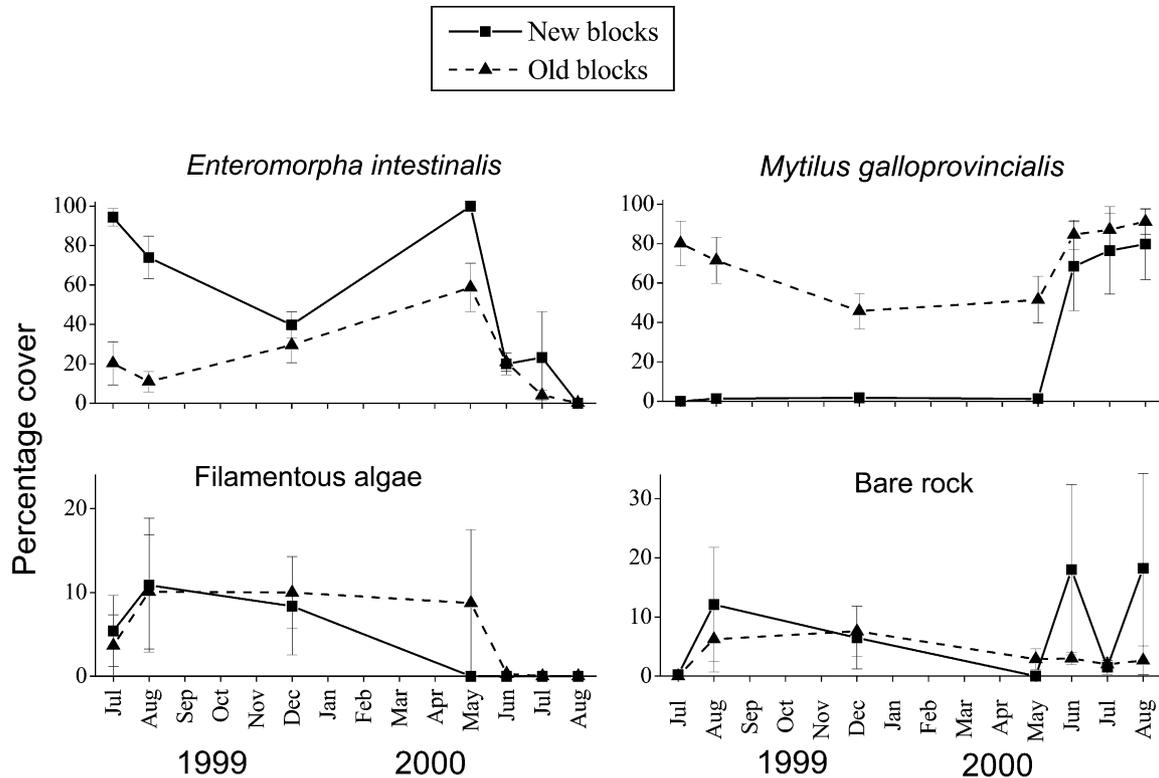
Fig. 4. Percentage cover of most abundant taxa and bare rock on new and old blocks at Lido di Dante, from July 1999 to August 2000. Data are mean cover values ±1 SE, averaged across two areas. Number of replicates decreased over time due to sinking and overturning of blocks. In June 1999, $n = 12$ for old and new blocks; in August 1999, $n = 12$ and $n = 9$ for old and new blocks, respectively; in December 1999, $n = 10$ and $n = 8$ for old and new blocks, respectively; from May to August 2000, $n = 10$ and $n = 4$ for old and new blocks, respectively.

hard-substrate assemblages. The relatively large amount of bare rock, and patterns of colonisation on new blocks suggest that low diversity of species was not related to competitive exclusion from mussels. Possible alternative hypotheses include the influence of physical/chemical characteristics of the water masses from the close Po river plume (Kourafalou, 1999) that may negatively affect the distribution of some species, or the effects related to the great distance from natural rocky reefs (more than 100 km). Many marine species have propagules or larvae that disperse over short distances (Jackson, 1986; Reed, Raimondi, Carr, & Goldwasser, 2000; Santelices, 1990). Thus, colonisation of human-made structures for most species probably proceeds through stepping-stones, and takes long times. Not surprisingly, *Mytilus galloprovincialis* and *Enteromorpha intestinalis*, which are the dominant species on these structures, are both characterised by larvae and propagules that disperse over long distances (Ceccherelli & Rossi, 1984; Lotze et al., 2000).

The low complexity of the assemblages probably explains the unexpected little differences observed in the distribution of species at different positions around groynes and breakwaters. Only mussels were significantly less abundant at the landward side of breakwaters than at all other positions. This pattern may be related to a lower regime of water flow at this sheltered position

compared with other positions (Burcharth, 1993). Greater biomass of filter-feeders is frequently recorded at exposed, compared with sheltered, natural rocky reefs, due to higher water turnovers and consequent increase in the supply of food (Bustamante & Branch, 1996).

In addition to water flow, other factors probably influence the distribution of *Mytilus galloprovincialis* in the study area. Large patches of bare rock were common within the mussel beds. Our observations suggest that these patches may be produced by recreational harvesting of mussels that, although illegal, is intense, particularly during the summer. Harvesting seemed more intense at Lido di Dante than at Casal Borsetti and Lido Adriano, which could possibly explain some of the differences among stations. Further, harvesting seemed to be greater on the landward side of breakwaters, which could contribute to the differences observed among positions. Studies are in progress to evaluate the impact of recreational activities on these assemblages. Harvesting of animals and plants is known to affect the distribution of intertidal assemblages on natural rocky shores (Durán & Castilla, 1989; Dye, 1992; Moreno, 2001), but no work has been done to evaluate the impact of this activity on assemblages on human-made structures.

Abundance of mussels, *Enteromorpha intestinalis* and filamentous algae differed significantly among

apparently homogeneous, nearby areas within stations. Some of these differences may possibly be explained by the temporal heterogeneity of the development of these structures, as suggested by Connell (2001) for other human-made constructions. Maintenance works at defence structures are frequent in the study area, and present results suggest that they affect the dynamics of epibiota. Further, new defence structures are added through time, resulting in potentially important differences in age among the structures. So far, the potential role of this temporal heterogeneity has received little attention.

Analysing patterns of distribution of species is an essential basis for understanding the ecological processes that shape the assemblages, and for identifying appropriate strategies for environmental management (Underwood, Chapman, & Connell, 2000). The results of this study provide the first quantitative data on the composition, distribution and dynamics of intertidal epibiota on coastal defence structures along the North Adriatic shores. They show that these structures are extensively and rapidly colonised by epibenthic assemblages. The diversity of species is, however, low, and epibiota is dominated by species with a large dispersal range and that occur naturally in the area limited to coastal lagoons. The massive introduction of defence structures during the last 30 years along the Emilia Romagna shores may thus have considerably changed the abundance and distribution of some species within this region. Further work is necessary to understand the possible consequences of these changes on the structure and functioning of coastal assemblages in this region.

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