EU Fifth Framework Programme 1998-2002
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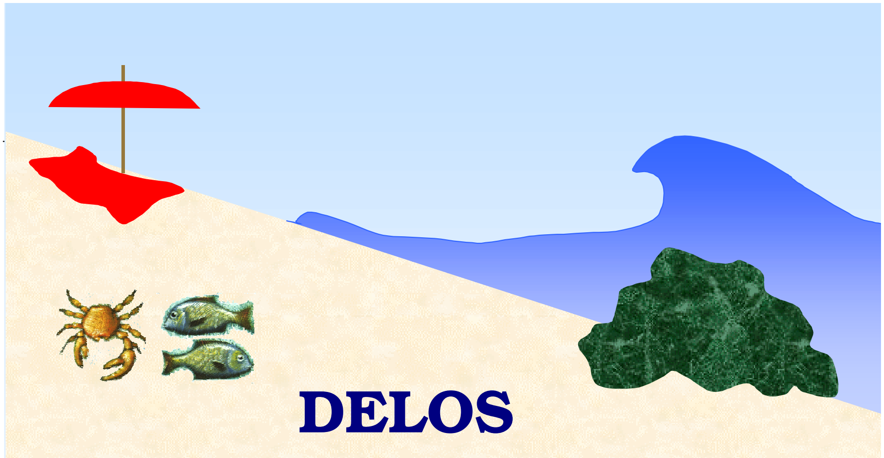
Environmental Design of Low Crested Coastal Defence Structures



Deliverable 47

WP 3.4

Evaluation of the potential of breakwaters as a tool to aid conservation of coastal assemblages

Contract n°EVK3-CT-2000-00041

D.47 EVALUATION OF THE OVERALL POTENTIAL OF BREAKWATERS AS A TOOL TO AID MANAGEMENT OF COASTAL ASSEMBLAGES

Background and aim

The quality, size and spatial arrangement of habitats are major determinants of the diversity and abundance of species present in biological communities (Bell et al. 1991, Hanski and Gilpin 1997, Lenihan 1999). These factors have received wide, although contrasting, attention in the management of terrestrial systems for predicting the consequences of the development of urban structures, the design of nature reserves and restoration plans (Simberloff 1988). In contrast, less attention has been devoted to the quality of habitats in coastal marine areas, especially concerning the deployment of man-made structures such as port installations and structures for coastal protection (Chou 1997, Connell and Glasby 1999).

Man-made structures are common in marine coastal habitat to serve as shoreline support (e.g. Fig. 1). Such "armoring" often involves the placement of hard-bottom substrata in areas previously lacking them. Despite the resulting increase of rocky habitats, which in some areas can affect over half of the natural shoreline, little is known about how marine organisms respond to the addition of artificial structures (Davis et al. 2002, Bacchiocchi & Airoldi 2003). Where no natural hard-substrata exist, man-made structures may act as corridors across naturally isolated rocky reefs, thus promoting the expansion of a number of species. Evaluating the broad scale alterations, perceived as either positive or negative, that can result as a consequence of the proliferation of structures over large stretches of coasts is crucial to assessing the potential of breakwaters as a tool to aid the management of coastal assemblages.

Fig. 1. Coastal defence structures along the Italian coasts of the north Adriatic sea

In the previous deliverables (D.29, D.39 and D.40) the relationships between the location of breakwaters and the abundance of epibiota over large spatial scales, the effects of artificial structures on the regional distribution and diversity of hard bottom assemblages, and corridor effects on species dispersal were identified. In the present deliverable population parameters are estimated to be included in a model to predict large-scale effects of breakwater spatial arrangement (i.e.

location, relative proximity to natural reefs and other artificial structures) on the distribution and population dynamics of species of hard bottom substrata. Further, the possible effects of breakwaters in promoting the expansion of introduced species are analysed. Results are used to draw conclusions on the potential of breakwaters as a tool to aid management of coastal assemblages, finalised to application in the guidelines.

Population dynamic of the limpet *Patella caerulea* Linnaeus on breakwaters in the north Adriatic Sea

Aims

The specific aims of the present studies were:

1) to collect a number of population parameters (size distribution, density, sex ratio, recruitment, growth rate, mortality) for a model species (*Patella caerulea)* to be included in the metapopulation model that will be developed to predict the effects of number, size and intervening distances between defence structures on the dispersal of hard bottom species;
2) to identify the spatial scales at which estimates of population parameters vary;
3) to test whether population parameters vary depending on flow regime (exposed *vs* sheltered sides of breakwaters);
4) to test whether population parameters vary depending on the size of defence structures;

The studies were carried out along the Italian shores of the North Adriatic Sea. In this area natural rocky reefs are rare, and over 60 % of the coastline is characterized by the presence of hard structures for defence and stabilization of shores (Fig. 1). The limpet *P. caerulea* (Fig. 2) was chosen as a model species for the following reasons (see Deliverable D3-Identification of model species for WP3.4): 1) it has a limited dispersal, 2) it has an uneven distribution across structures, and 3) it likely plays an important ecological role in influencing the distribution of species that are a nuisance to beach tourism, such as ephemeral green algae.

Methods

Experiment 1:

?? 2 stations (Lido Adriano and Cesenatico)

?? landward *vs* seaward side

?? 3 random breakwaters for each combination of station and side

?? 2-3 boulders for each breakwater at Cesenatico with a total of 114-158 limpets, and 13-27 boulders for each breakwater at Lido Adriano with a total of 52-114 limpets (boulders were selected among those colonised by *P. caerulea*)

Boulders were marked permanently in

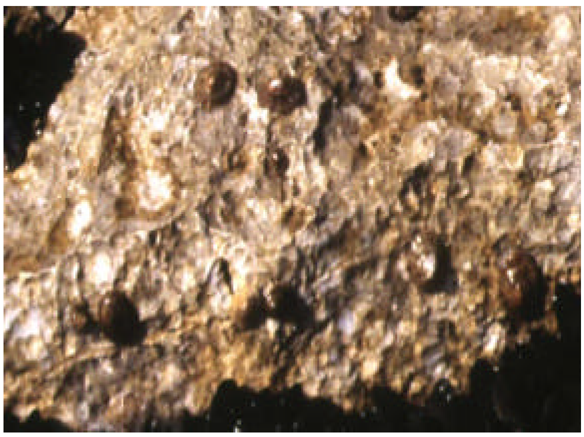


Fig 2 – Individuals of *Patella cerulea* on low crested breakwaters at Cesenatico

August 2001, and all limpets were counted and measured on each boulder. Sampling was carried out approximately every 6 months, for a total duration of 2 years. Estimates were obtained of the size of boulders as well as the abundance of mussels, *Enteromorpha intestinalis* and bare rock.

Experiment 2 (only landward sides at Cesenatico):
?? small *vs* large breakwaters
?? 3 breakwaters (maximum 600 m apart)
?? 2-3 boulders for each breakwater with a total of 127-211 limpets
Methods were the same as in Experiment 1

Control experiment 3 (at Cesenatico on the landward sides of 2 large breakwaters and 1 small breakwater among those included in the 1st experiment):
?? 2 breakwaters (1 boulder per breakwater)
?? about 60 limpets per boulder
All limpets were marked permanently, by gluing tags to their shells, and measured. Sampling of marked limpets and new recruits was recorded about every 2 months. Sampling is currently being repeated, with a projected sampling period of December 2003.

Experiment 4 (at Cesenatico)
About 700 individuals of *Patella caerulea* belonging to 9 different size classes were collected at Cesenatico during November 2001-March 2002 and analysed in the laboratory, in order to quantify the sex-ratio for this species. No specimens were collected at Lido Adriano due to the low abundance of limpets at this site.

Results

During the first sampling period, the relationships between shell length and width and between shell length and biomass of *P. caerulea* were quantified (Fig. 3). These relationships were used to optimise fieldwork, as only shell length was measured during subsequent samplings.

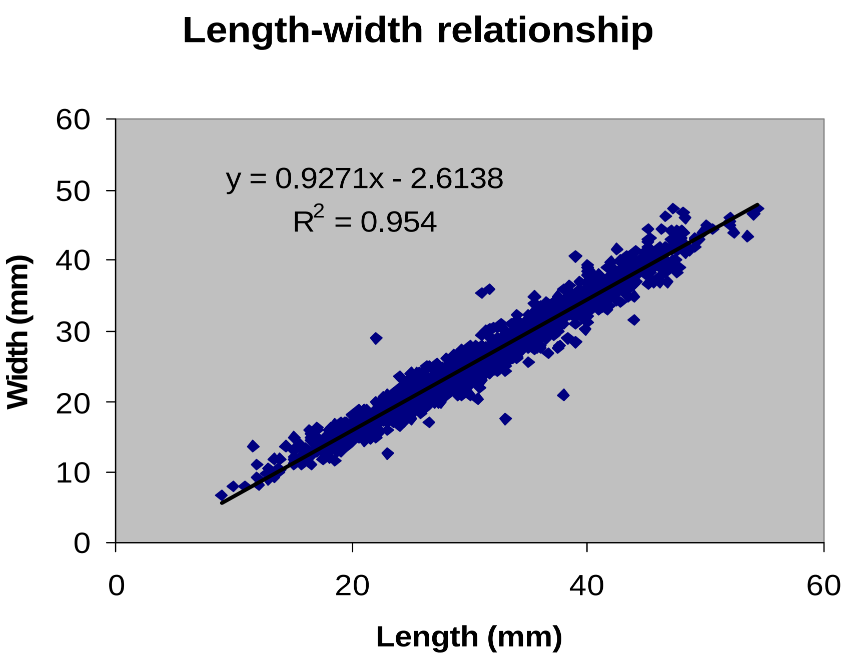


Fig. 3 – Relationship between shell length and width in *Patella caerulea*

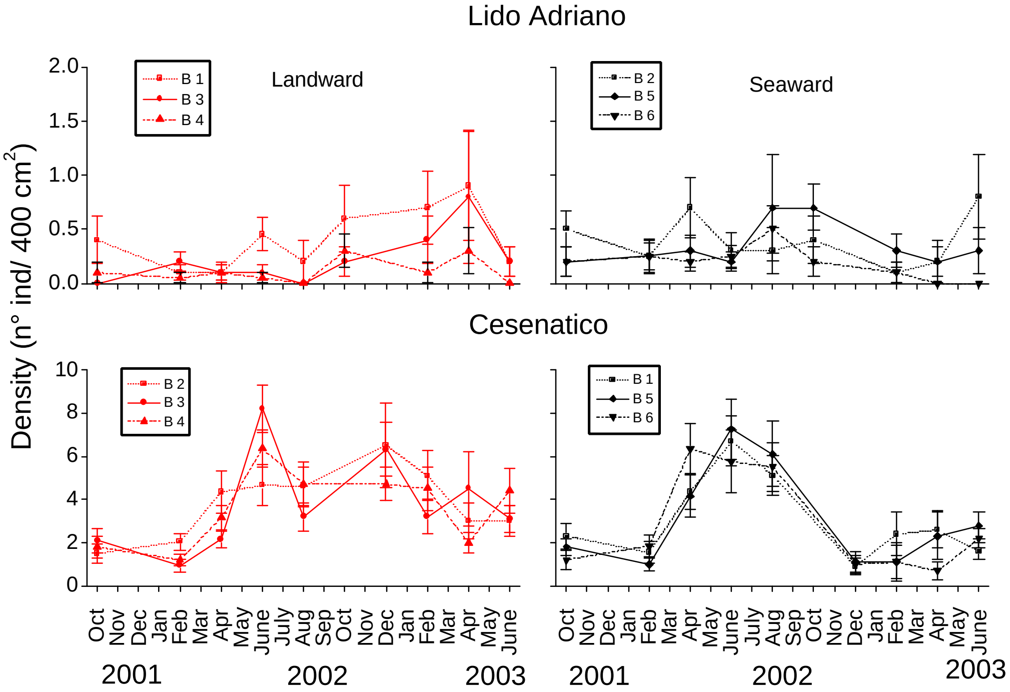


Fig. 4 – Density (±1 SE) of *Patella caerulea* on the landward and seaward sides of breakwaters at Lido Adriano and Cesenatico

Density of limpets varied as a function of location of breakwaters. Limpets were significantly more abundant at Cesenatico than at Lido Adriano (Fig. 4). At Lido Adriano, average density of limpets was greater on the seaward sides of breakwaters than on the landward sides, while an opposite trend was observed at Cesenatico. Density of limpets also varied as a function of size of breakwaters. In particular, from June to December 2002 limpets were 3 times more abundant on small than on large breakwaters, and a similar trend seems to be occurring also in the summer 2003 (Fig. 5).

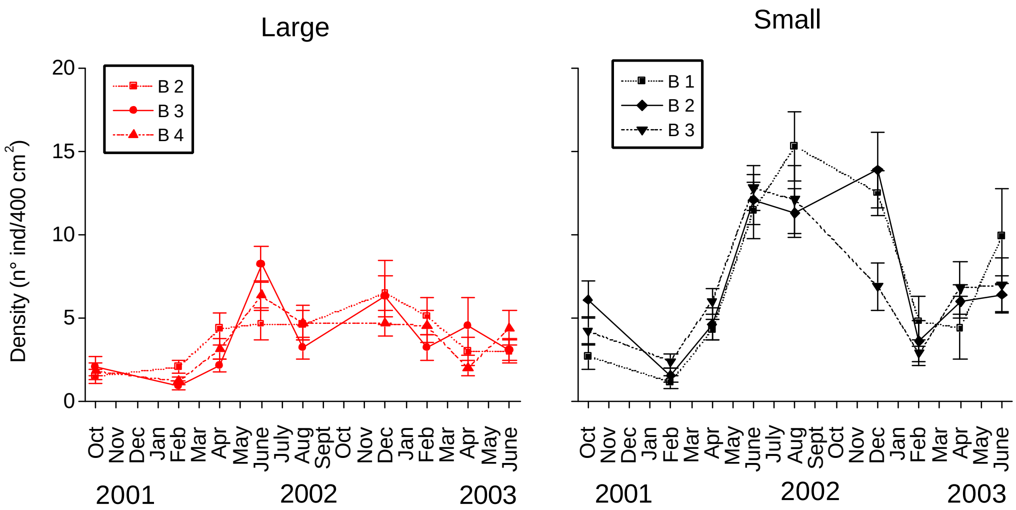


Fig. 5– Density (±1 SE) of *Patella caerulea* on the small and large breakwaters at Lido Adriano and Cesenatico

The length frequency distribution of individuals of *Patella caerulea* from each boulder was plotted for each sampling period. From this distribution, a distinct size class of new recruits, which had settled in winter 2002, could be recognized in February of 2002 at both stations of Lido Adriano and Cesenatico (Fig. 6). Conversely, no peak in recruitment was observed in February 2003, suggesting that recruitment of *P. cerulea* is highly variable among years.

Several population parameters (average density, proportion of new recruits, proportion of adult individuals surviving per boulder, and change in the overall size of population over one year) were estimated for each individual boulder using all limpets on the boulder. Interestingly, density of limpets, proportions of new recruits and proportion of adult individuals surviving were both greater on small than large breakwaters (Table 1), again suggesting that the size of breakwaters affects the population structure of limpets. In turn, density of limpets seems to affect the abundance

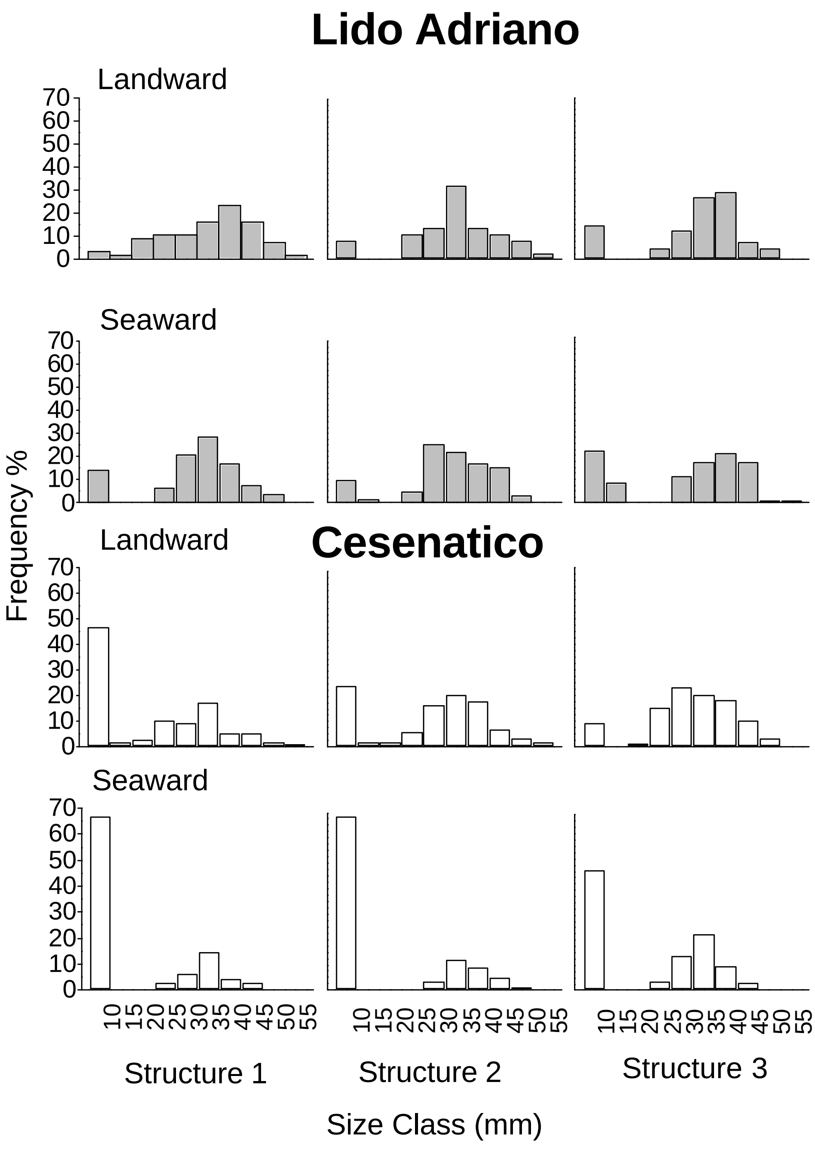


Fig. 6. Length frequency distribution of *Patella caerulea* on the landward and seaward sides of breakwaters at Lido Adriano and Cesenatico in February 2002

Table 1. Results of ANOVA made to compare average density of limpets, proportion of new recruits, proportion of adult individuals surviving per block, and change in the overall size of population over one year between large and small breakwaters in Cesenatico. a = $p<0.05$, ns = non significant

	Large breakwaters	Small breakwaters	Significant differences
Density (ind/400 cm^2)	3.25	7.07	a
Average size (T_1) (mm)	30.86	29.73	ns
Average size (T_2) (mm)	25.40	20.47	ns
Average size (T_3) (mm)	22.55	19.96	ns
Recruits/Adults (T_2)	0.38	0.56	ns
Adult survival (T_2/T_1)	0.64	0.72	ns
Change in population size (T_3/T_1)	2.43	2.68	ns

of green ephemeral algae, as suggested by the significant negative correlation between density of limpets and cover of green algae observed on small and large breakwaters at Cesenatico in May 2003 (Fig. 7).

Limpets were found to be fertile from about November to May. A ratio between sexes of about 1:1, independent of limpet size was found. This result is not consistent with previous observations from populations of *P. caerulea* from the Tyrrhenian sea (Bacci 1975). Additional studies are in progress to test whether the sex ratio of 1:1 is consistent over years and in relation to different characteristics of the habitat.

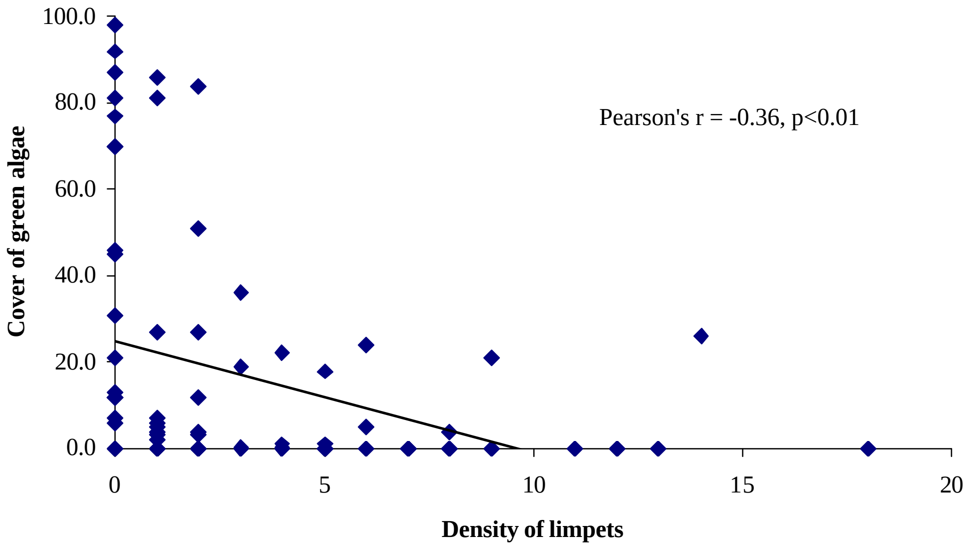


Fig. 7. Correlation between percentage cover of green ephemeral algae and density (n° individuals over 400 cm^2) of the limpet *Patella caerulea* on small and large breakwaters at Cesenatico

Colonisation of breakwaters by the invasive alga *Codium fragile* ssp. *tomentosoides*

Aims

Coastal defence structures along the north-east coast of Italy provide suitable substrata for colonization of the invasive species, *Codium fragile* ssp. *tomentosoides* (Fig. 8). This species, which has become a locally important component of rocky shores throughout the world (Trowbridge 1998), was firstly sighted in the Mediterranean in 1950 (Boudoresque1994). Observations done within WPs 1.2 and 3.2. showed that this species has massively colonised coastal defence structures in the province of Ravenna, thus expanding its distribution well far from natural rocky coasts occurring about 100 km south. We investigated patterns of distribution and abundance of *Codium* on coastal defence structures and attempted to identify the relevant ecological processes operating to produce these patterns. Specifically, the aims of the present studies were: 1) to quantify spatial and temporal patterns of abundance of *Codium* at exposed and sheltered habitats and 2) to analyse whether disturbances, either natural or human, (i.e. from maintenance works or harvesting) that affect the abundance of the mussel *Mytilus galloprovincialis*, which is the main space-holder at low-intertidal levels (Bacchiocchi and Airoldi 2003), may influence the recruitment of *Codium*.

Methods

Sampling was done at Cesenatico, either on the seaward or the landward sides of each of three breakwaters. On each breakwater, the abundance of *Codium* was quantified in five randomly allocated 20 x 20 cm plots on each of three boulders. Abundance was quantified as percentage cover, by using the visual method (Benedetti-Cecchi et al. 1996). Sampling was repeated monthly, from May to October.

The effects of disturbances on recruitment of *Codium* were investigated by removing mussels from some boulders, thus simulating the effects of natural and human disturbances on beds of mussels (see results of Deliverables D.16 and D.46, see also Bacchiocchi and Airoldi 2003). This experiment was repeated in spring and summer to test for the importance of the timing of disturbance. Further, to evaluate whether the effects of mussels on *Codium* varied according to wave-exposure, removals were done either on the landward or the seaward side of the reefs.

Fig 8 – *Codium fragile* ssp. *tomentosoides* on low crested breakwaters at Cesenatico

Results

At the study sites, annual thalli

of *Codium* start developing in early spring, reach the maximum development during the summer and generally disappear in the fall. In June, the number of thalli did not differ between the landward and seaward sides of the breakwaters, but the percentage cover and biomass (wet weight) of *Codium* were larger on the landward side (Fig. 9).

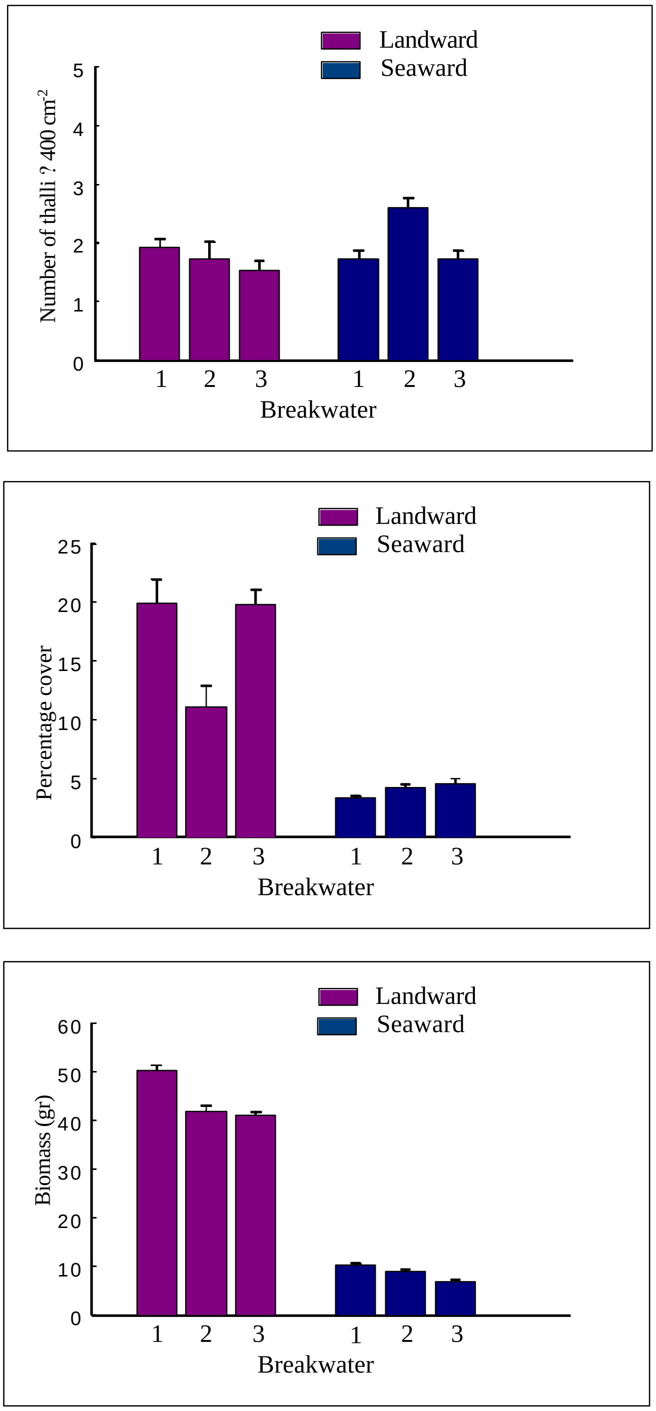


Fig. 9. Number of thalli (A), percentage cover (B) and weight (C) of *Codium* on the landward an seaward sides of reefs in June 2003. Data were averaged across boulders (n = 30)

The removal of mussels in April 2003 led to a significant increase of the percentage cover of *C. fragile* on the landward side, but not on the seaward side ($MS_{Exposure\ x\ Mytilus}$ = 1333.52; $F_{1,4}$ = 39; $P < 0.01$; Fig. 10), in June 2003. Since *Codium* was not fertile at the time at which mussels were removed, it could be hypothesized that holdfasts and/or propagules trapped under the thick three-dimensional matrix of mussels may have generated new thalli, when physical conditions improved. Single layer mussels beds on the seaward side of reefs, which were made by smaller individuals, did not have any effect on the percentage cover of *Codium*.

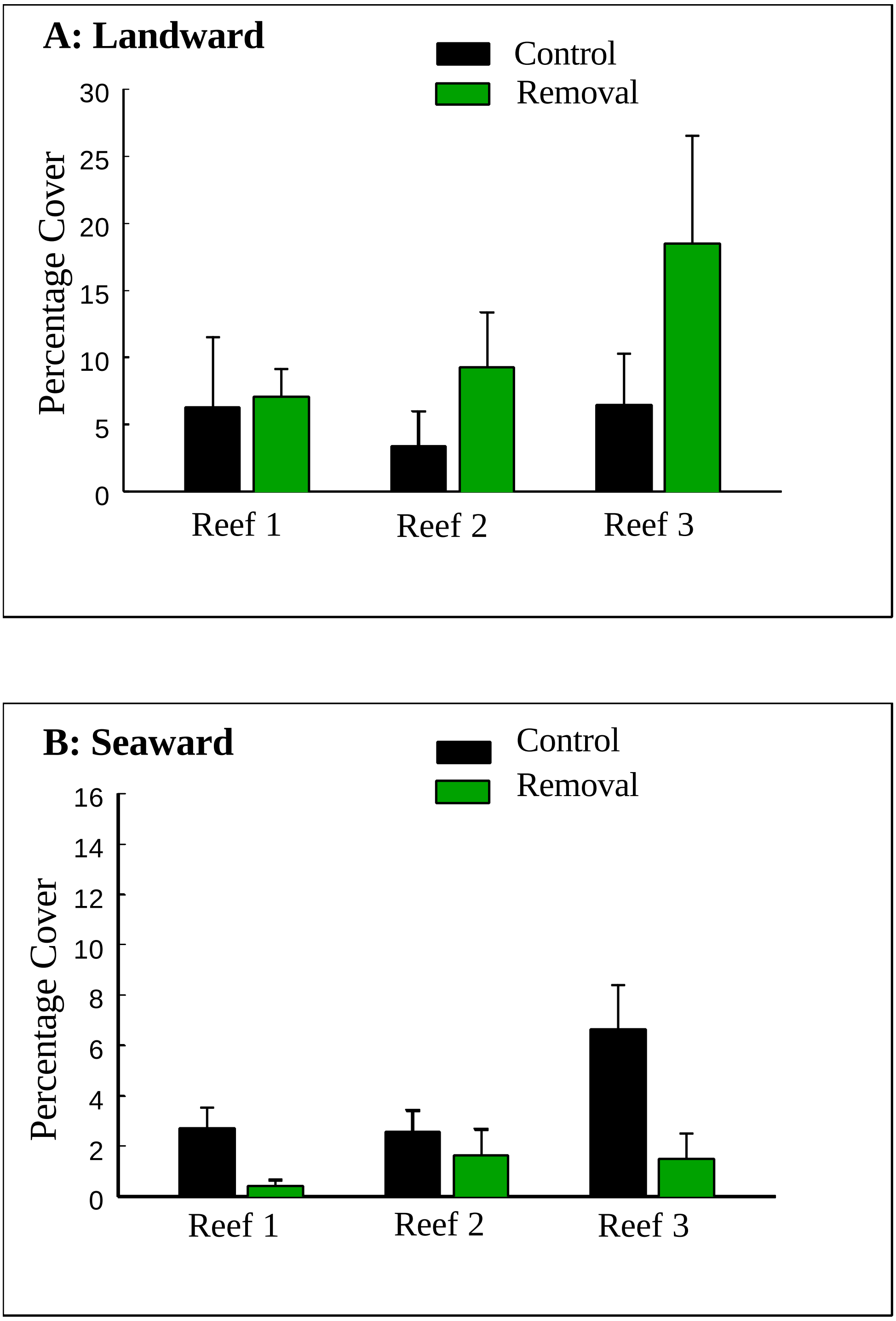


Fig. 10. Percentage cover of *Codium* (+ SE) on mussel removal boulders and on control boulders, after two months from the start of the experiment (June 2003), separately for the landward and seaward sides of reefs.

Conclusions:
large-scale effects of coastal defence structures and implications for the management of coastal assemblages

Results of present and previous deliverables of WP.3.4. may be used to draw conclusions about the potential effects of coastal defence structures over large spatial scales. This information may facilitate informed decisions about the construction of coastal defence structures and the management of coastal areas. Conclusions are presented in a form that may be used as input to the design guidelines.

1) Environmental processes in the coastal zone operate on various spatial scales. Most LCS schemes are implemented at the local scale and have localised impacts, that have been identified in the deliverables of WPs 3.1 and 3.2. However, in some areas, such as the Italian coasts of the North Adriatic sea, structures have proliferated along whole coastlines. When this happens, broad scale alteration of the whole coastline can result. Thus local environmental impacts can scale up in a non-linear manner. Both local and broad scales need to be considered in the design process.

2) Major alterations resulting from the introduction of coastal defence structures over large stretches of coast include the increased availability of hard-bottom and sheltered habitats in areas where they do not occur naturally. Indeed, artificial structures, by providing suitable habitats islands for colonisation of species, function as stepping stones, allowing the dispersal of hard bottom species beyond the limits set by the availability of suitable natural habitats. The increased number of hard bottoms may act as refuges for rare or endangered species, or enhance species that are relevant to commercial or recreational purposes. There is also a risk, however, that the artificial structures may promote the expansion of introduced species, or of species that are a nuisance to beach tourism. For example, along the coasts of Emilia Romagna, the introduced species *Codium* has taken advantage of the availability of hard substrata along an exposed sandy coast, and in particular of sheltered habitats that seem to provide better conditions for its growth.

3) Results show that the spatial arrangement (i.e. location, relative proximity to natural reefs and other artificial structures) of coastal defence structures is of great importance in influencing the type of hard-bottom species that will colonise any novel structure. In particular, the persistence of populations in a network of habitat islands, as those created by schemes of numerous defence structures, is dependent on the habitat area and quality, on the spatial distribution of habitats, and on the dispersal characteristics of the organisms of interest.

4) Human-made structures are considered a benefit to coastal sandy areas (e.g. 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 (e.g. Bombace *et al*., 1995). Results of WP.3.4, however, suggest that, although defence structures become colonised by rocky-bottom species, their assemblages seem to differ from those occurring on nearby natural reefs. Further, artificial structures seem to act by changing the patterns of

distribution of locally abundant species rather than by increasing species diversity. Similar hypotheses have been suggested by Glasby (1999), Connell and Glasby (1999) and Glasby & Connell (1999), who raised concern that human-made structures may cause considerable change to the identity and/or abundance of epibiotic species within an area, but that in most cases the possible consequences of these changes to 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, and should be taken into account when establishing coastal zone management plans covering large stretches of coastlines. For example, while growth of mussels on artificial structures may be 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 may be a major problem for beach tourism.

5) Although assemblages on artificial reefs cannot be referred to as "natural", a comprehensive understanding of the biotic interactions between "native" and exotic species is necessary for their management and should be included as background information necessary to the design procedure. This knowledge could improve our ability to limit the successful dispersal (colonisation and persistence) of marine pests across regional and geographic scales.

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