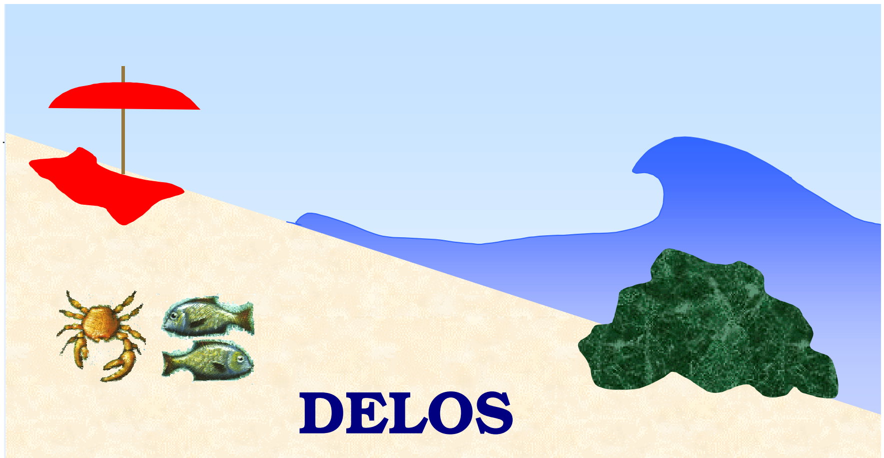
EU Fifth Framework Programme 1998-2002
Energy, Environment and Sustainable Development

Environmental Design of Low Crested Coastal Defence Structures



D 46

Identification of design features to maintain biodiversity of epibiota

Contract n°EVK3-CT-2000-00041

DELIVERABLE 46

Identification of design features to maintain biodiversity of epibiota

Introduction

In the Deliverable 35 the epibiota colonising LCS and other coastal defence structures was for the first time characterised along several European shores, including UK, Italy, Spain and Denmark. The composition and distribution of epibiotic communities on LCS described in relation to the position on the defence structures and other environmental factors such as geographical variation and tidal range. That study contributed to characterise the epibiota on man made structures and to identify which factors outside the control of engineering designers influence these assemblages. In this Deliverable, the effects of breakwater design features on the diversity and abundance of epibiota will be examined. Broad scale surveys and local, more specific comparisons were carried out mainly along the UK and Italian coasts to identify which key features have a major influence on the assemblages. In most studies, multivariate statistical analysis and Multidimensional Scaling plots (MDS plots) were used. A brief description of the principles on which this analysis is based is provided in the appendix at the end of this deliverable.

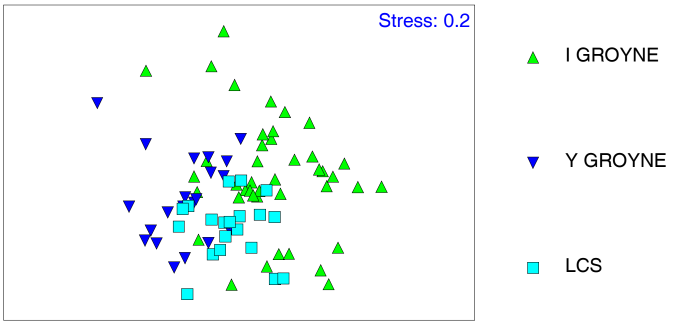
Effects of key features in the design of coastal defences on epibiota along the British shores

Major results from the broad scale survey along the English and Welsh coast

A broad scale survey was carried out in 2001 and 2002 along the south, west and east coast of England and on the north coast of Wales. In total, 82 structures were sampled, of which 20 were LCS. During the survey quantitative data on composition and abundance of epibiota were collected from LCS and other coastal defences. Data were collected at mid tidal level, in order to standardise the sampling across the structures. For the majority of coastal defences, however, species present on the whole structure were also recorded. For each structure, the following parameters were measured or recorded: 1) type of structure; 2) total height of the structure, from the base up to the crest; 3) height from the base to mid tidal level, corresponding to the sampling area; 4) length of the structure; 5) distance of the structure from the shoreline; 6) gap between structures 7) building material; 8) size of the building blocks 9) age of structure. Multivariate analysis was then used to identify which features influenced the assemblages. The analysis was based on mean abundance of species.

1) Type of structure

Three different types of structures were sampled: LCS, groynes and fishtail groynes (Figure 1). The assemblages differed significantly between groynes and fishtail groynes (ANOSIM: $R = 0.28$, $p<0.001$) and between LCS and fish tail groynes (ANOSIM: $R=0.15$, $p<0.001$), although the coefficient of dissimilarity is very low. No significant differences were observed, however, between the epibiota of LCS and normal groynes (ANOSIM $R= 0.077$; $p>0.05$). Simper analysis showed that the major difference between the assemblages of the two types of groynes was the abundance of barnacles and *Fucus spiralis*, these being more abundant on the fishtail groyne. Barnacles on the fishtail groynes were also more abundant than on LCS. When considering species diversity only, differences between the three different types of structures were very small and not significant (Figure 2).



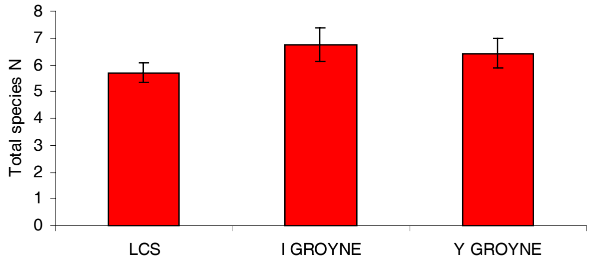
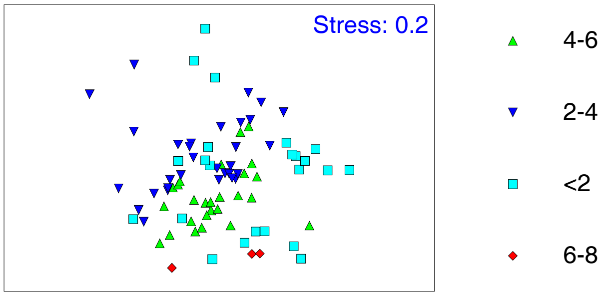


Figure 1 – nMDS plot of assemblages on different types of coastal defences.

Figure 2 – Mean number of species for each type of structure.

2) Total height of structure

The different heights of the structures were grouped under 4 height classes (Figure 3). The assemblages differed significantly among the different height classes (ANOSIM, $p<0.01$), although the coefficient of dissimilarity R was generally quite low, less than 0.2. Structures between 6 and 8 metres high differed markedly from all the other height classes. This difference, however, is likely to be due to the very low number of structures falling in this category. Also, it was shown that total height did not affect diversity, as no significant correlation was found between the two variables (Pearson's $r=0.12$, $p>0.05$; Figure 4). When diversity on the whole structure was considered, however, this was highly correlated with the height of structure (Figure 5). This can be explained by the fact that higher structures are generally built lower on the shore, which is richer in species; thus a higher number of species can colonise the coastal defences.



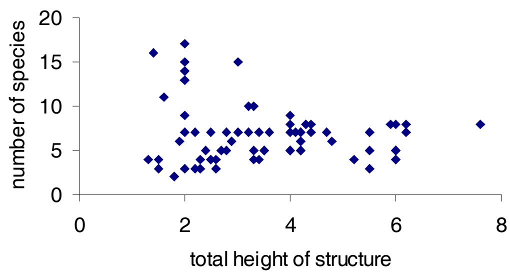


Figure 3 – nMDS plot of assemblages on structures of different height (measured from the base up to the crest).

Figure 4 – Correlation between diversity at mid tidal level (expressed as total number of species) and the total height of the structures (measured from the base up to the crest).

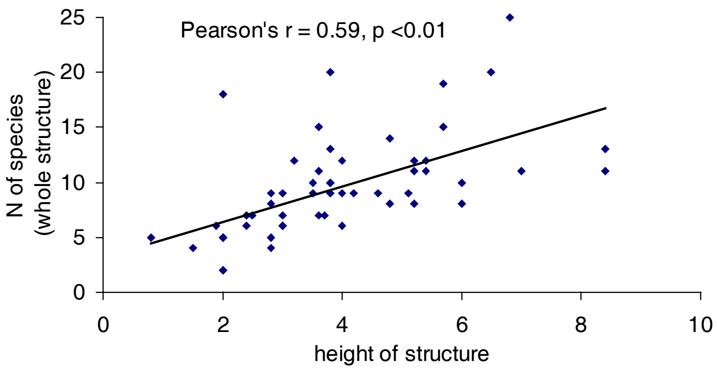


Figure 5 – Correlation between diversity on the whole structure (expressed as total number of species) and the total height of the structures (measured from the base up to the crest).

3) Height of structure to mid tidal level

To confirm the observations previously made, the height from the base of the structure (sediment level) to the mid tidal level (MTL), where sampling was carried out, was measured. This measure provides a more precise indication of the position of the structures on the shore, then the total height. Epibiota was not significantly different between structures having different height to MTL (ANOSIM, p=0.9; Figure 6). A similar, not significant, result was found when this parameter was correlated with diversity at MTL (Figure 7). The total diversity of the structure, however, was positively correlated with the height to mid tidal level. This result suggests therefore that the location of coastal sea defences on the shore is considerably affecting the diversity of species colonising the structures. In the case of LCS structures, height to MTL appeared to affect both the abundance and diversity of epibiotic assemblages, as shown by the multivariate analysis (ANOSIM, R=0.59, p<0.001; Figure 9) and the correlation analysis (Figure 10).

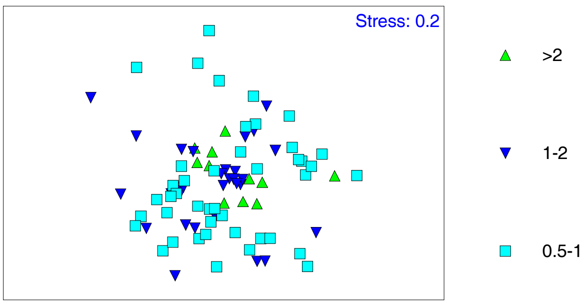


Figure 6 – nMDS plot of assemblages on structures of different height to mid tidal level.

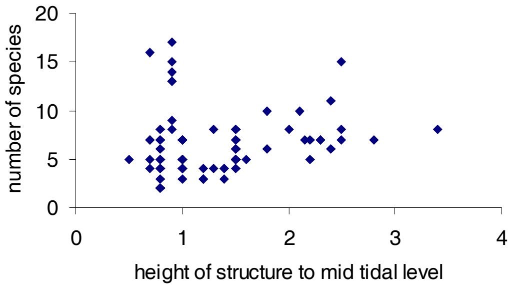


Figure 7 – Correlation between diversity at mid tidal level (expressed as total number of species) and the height of structures to mid tidal level.

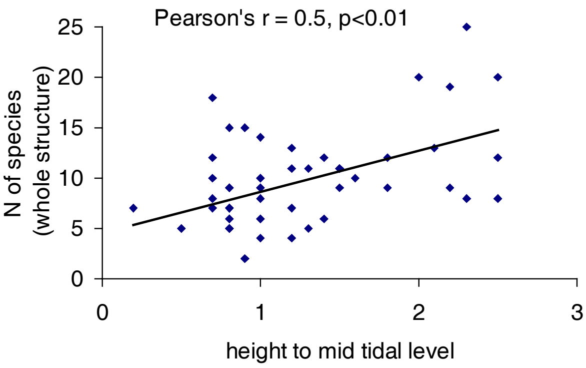


Figure 8 – Correlation between diversity on the whole structure (expressed as total number of species) and the height of the structures to mid tidal level.

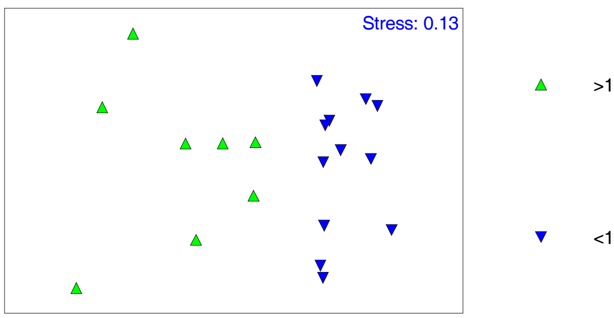


Figure 9 – nMDS plot of assemblages on LCS of different height to mid tidal level. Height to MTL was grouped under two height classes, < 1m and > 1m.

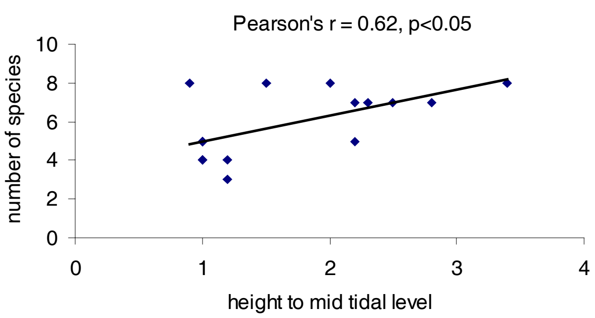
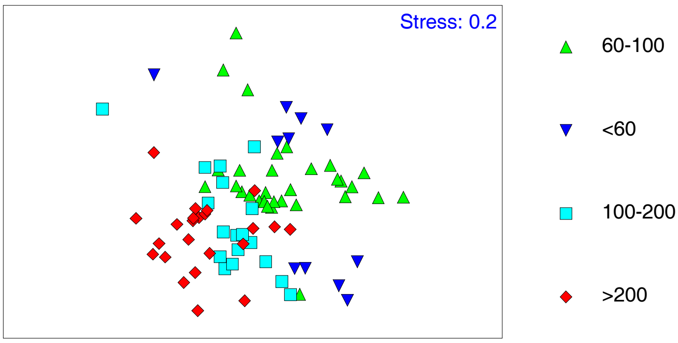


Figure 10 – Correlation between diversity on LCS (expressed as total number of species) and the height of the structures to mid tidal level.

4) Total length of structure

The length of structures also affected the epibiotic assemblages. Multivariate analysis showed significant differences between the groups of structures of different length (Figure 11). Epibiota on structures less than 60m long were highly different from structures longer than 200m (ANOSIM R = 0.73, $p<0.001$), whilst structures loner than 100m resulted very similar (ANOSIM R = 0.09, $p<0.05$). When only the number of species was considered, no significant correlation was found with the length of structures (Pearson's r = -0.12, $p>0.05$; Figure 12). No comparison between LCS could be made due to the limited range of lengths.



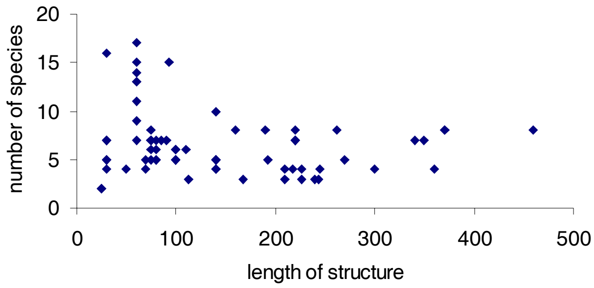


Figure 10 – nMDS plot of assemblages on structures of different length.

Figure 11 – Correlation between diversity (expressed as total number of species) and the length of the structures.

6) Distance of structure from the shoreline

This analysis could be made only for the LCS type of structures, as the groynes are all connected to the shoreline. The low number of LCS available, however, did not allow the statistical comparison between structures at different distances from the shoreline, as most of them were built between 150 and 200m.

7) Building material

No differences were observed in the abundance and composition of epibiota colonising structures of different material (ANOSIM R= -0.14, $p>0.05$; Figure 12). The assemblages on limestone structures appeared to be more variable than on granite, as also shown by the MDS plot, where distances between granite samples are much closer than distance between limestone samples.

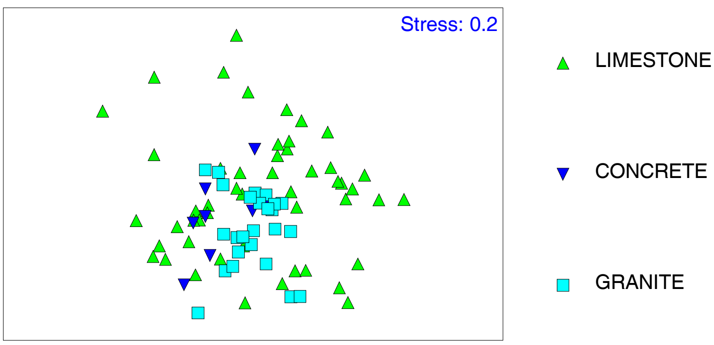


Figure 12 – nMDS plot of assemblages on structures of different building material.

8) Size of building blocks
Most of the structures investigated consisted of building block of similar size, ranging between 1.5 and 2 m mean diameter, whilst very few blocks were greater than 2m in diameter or smaller than a metre. Thus formal statistical analysis could not be carried out, due to the unbalanced number of samples. No marked differences, however, were observed in the epibiota colonising blocks of different sizes.

9) Age of structures
The epibiota colonising structures of different age varied considerably, although no clear patterns could be identified (Figure 13). Structures less than 5 years old differed significantly from structures 5 to 10 years old and more than 20 years old (ANOSIM $R = 0.3$, $p<0.05$). However, they did not differ from structures 10 to 20 years old (ANOSIM $R<0.1$, $p>0.05$). Significant differences were also observed between structures older than 20 years and structure 15 to 20 years old. Epibiota significantly differed on LCS less than 10 years old and older than 10 years old (ANOSIM, $R= 0.38$, $p<0.05$; Figure 14). These apparent contrasting results (younger structures should show a different assemblages form older structures) might be explained by the large variability in the geographical location of the structures. A formal comparison on a subset of structures of different age and located in the same area will be examined in the following paragraph.

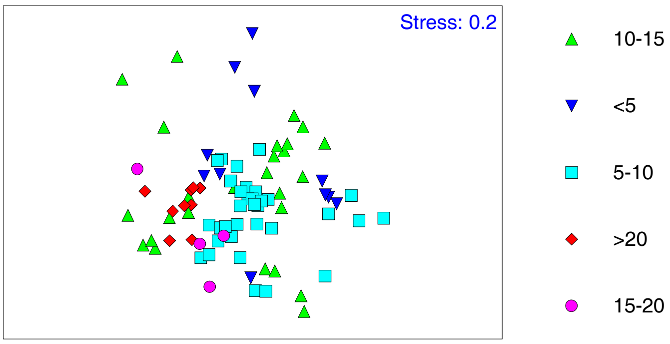


Figure 13 – nMDS plot of assemblages on structures of different age.

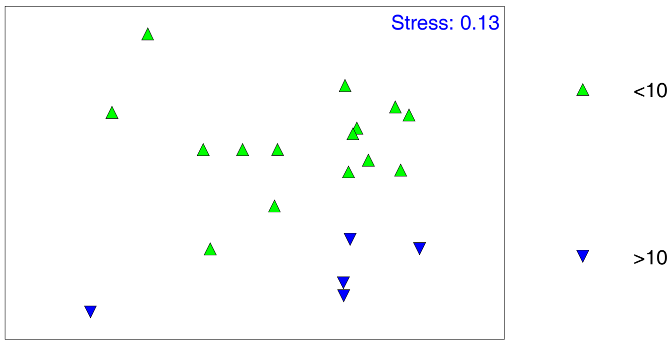


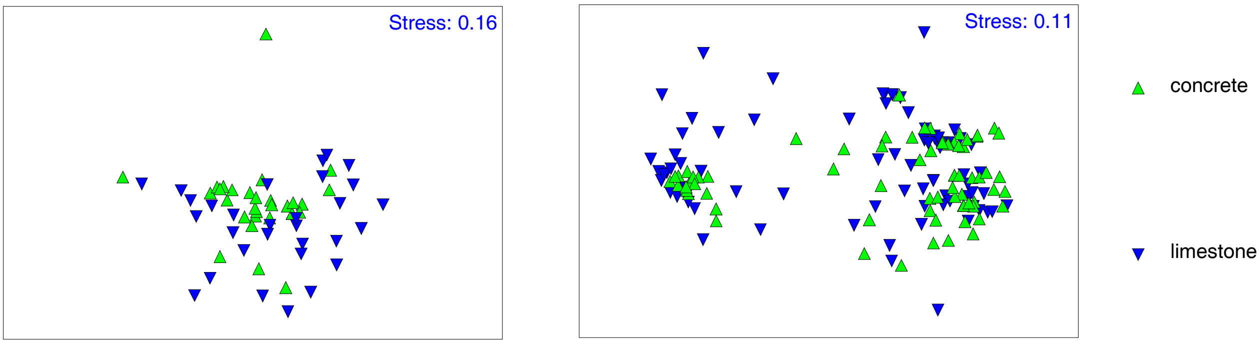
Figure 14 – nMDS plot of assemblages on LCS of different age.

Effects of design features on epibiota: comparisons at local scale

As already discussed in the D35, epibiota is influenced by various environmental factors such as hydrodynamics, tidal range, larval supply etc. These factors can vary greatly between geographical locations. The patterns observed in the previous paragraphs and the potential influence of these two design features on epibiota could be therefore obscured or confounded with the geographical variability of these assemblages. To confirm the patterns previously described, more specific comparisons were made on a subsets of structures located in the same area. At local scale, the influence of following design features on epibiota was also investigated: surface complexity of the blocks, pore size, presence of rock pools at the base of the structures.

Effect of building material
The effect of rock type on the abundance and composition of epibiota was investigated in 2002 on structures which consist of a mixture of limestone and concrete blocks, one fishtail groyne located

in Felixstowe (east of England) and two fishtail groynes located in Liverpool (west of England). In both locations, no significant differences were found between the epibiotic assemblages colonising the concrete and limestone blocks. The epibiota colonising concrete and limestone blocks did not show apparent differences in the composition. Both assemblages mainly consisted of ephemeral algae (*Enteromorpha* sp., *Porphyra* sp.) barnacles (*Semibalanus balanoides*, *Elminius modestus*), fucoids (*Fucus spiralis*, *Fucus vesiculosus*) and littorinids (*Littorina littorea*, *L. saxatilis*). In Felixstowe, the coefficient of dissimilarity R between the two assemblages was very low, 0.07 (Figure 15a). A similar result was obtained in Liverpool, where no differences (ANOSIM R= 0.02) where found between assemblages on the two types of building material (Figure 15b). As it was already noticed from nMDS plot of the whole set of structures sampled, epibiota on limestone rock seems to be much more variable than on concrete; samples from limestone are more spread than samples from concrete in both location (Figure 15a and b).



a b

Figure 15 – nMDS plot of assemblages on concrete and limestone blocks on fishtail groynes located in Felixstowe (a) and Liverpool (b).

Effect of age of structure

Two comparative studies at local scale were carried out in Poole and Brighton, both located in the south of England. In Poole, a set of eight limestone groynes was sampled in 2002. Four structures were built in 1995 and four in 2001, but they are all located along the same sandy beach. The second study carried out in Brighton area involved sampling of six granite groynes, three located in Rottingdean, built in the early 1994 and three built in Saltingdean in the mid 1995. These two sites are very close therefore the same environmental conditions apply.

Multivariate analysis abundance and composition of species colonising the rock groynes in Poole showed clear differences between the two different ages (Figure 16). Structures within the same age group showed very similar assemblages, as shown by the two way nested ANOSIM ($R = 0.14$, $p>0.05$). The two age groups differed markedly, instead (ANOSIM, $R = 0.52$, $p<0.05$). Results from SIMPER analysis showed that the species, which mostly contributed to this dissimilarity, were limpets (*Patella vulgata*) and fucoids (*Fucus serratus*), more abundant on the older structures and the ephemeral algae *Enteromorpha* sp., which largely dominated the assemblages on the more recent groynes. This pattern reflects the colonisation and successional processes, which generally occur on a rocky shore. When a new substrate is available, the first pioneer species are ephemeral algae, generally E*nteromorpha* sp. and *Porphyra* sp. These are lately replaced by fucoids, barnacles and limpets. Also, the diversity of species is generally lower on new substrates.

In Brighton the two sets of groynes previously described differ one and half year in age. Three comparisons were made. Early colonisation on groynes one year old (Saltingdean groynes) and two years old (Rottingdean) was compared using data collected in 1996. The groynes were then resampled in 2002, to compare late colonisation. A third comparison between early and late colonisation was made using both sets of data. Results from the first comparison showed then during the first years after construction of the groynes, assemblages highly differed between the structures one year and 2.5 years old (ANOSIM R = 0.94, p<0.001; Figure 17). As already observed for the groynes in Poole, on the more recent groynes ephemeral algae dominated the assemblages whilst the later colonisers fucoids and barnacles were almost absent. These species were very abundant on the 2.5 years old groynes in Rottingdean instead. The assemblages on 1 year old groynes in Saltingdean appeared also more homogenous than on the older structures.

The second comparison was made between epibiota on the same groynes in Saltingdean and Rottingdean, 8 and 9.5 years respectively after construction (in this case, mean value were used). The two assemblages appeared to be much more similar at this stage of colonisation (Figure 18). No significant differences were also detected by the ANOSIM test between the two sets of groynes (R = 0.02, p>0.05), suggesting that in long term colonisation becomes very similar and one and half year difference is negligible.

The third analysis involved the comparison of data from early colonisation (structures 1 and 2.5 years after construction) with data from late colonisation (the same structure 8 and 9.5 years after construction). First the assemblages on the same set of structure were compared (i.e. assemblages on Saltingdean groynes 1 and 8 years of construction). Results from ANOSIM analysis showed that the assemblages on Saltingdean groynes changed considerably with time (ANOSIM R = 0.65, p<0.001; Figure 19). The assemblages after 1 year of colonisation were dominated by ephemeral algae, whilst 7 years later these were dominated by limpets and barnacles.

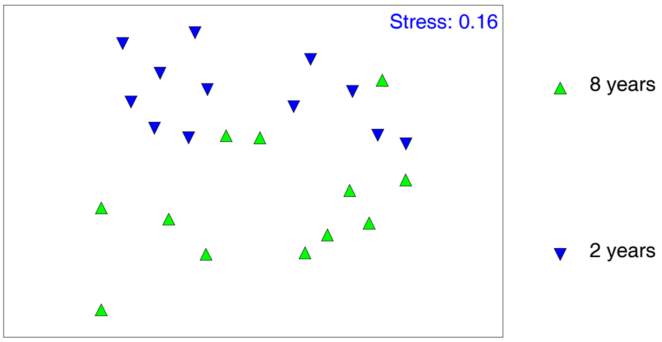


Figure 16 – nMDS plot of assemblages on limestone groynes 8 and 2 years old located in Poole.

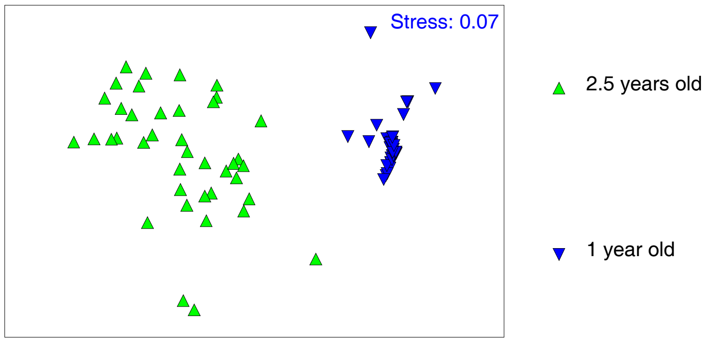


Figure 17 – nMDS plot of assemblages on granite groynes 2.5 and 1 year old located in Brighton.

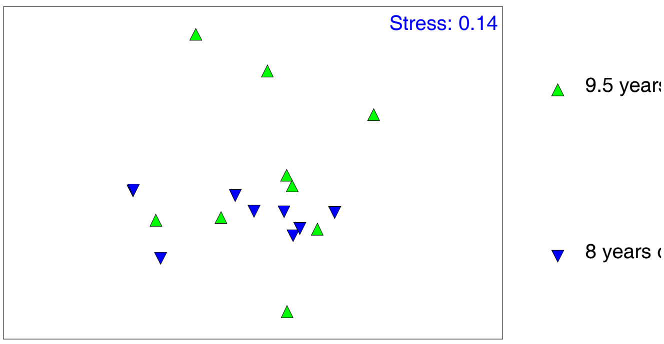


Figure 18 – nMDS plot of assemblages on granite groynes 9.5 and 8 years old located in Brighton.

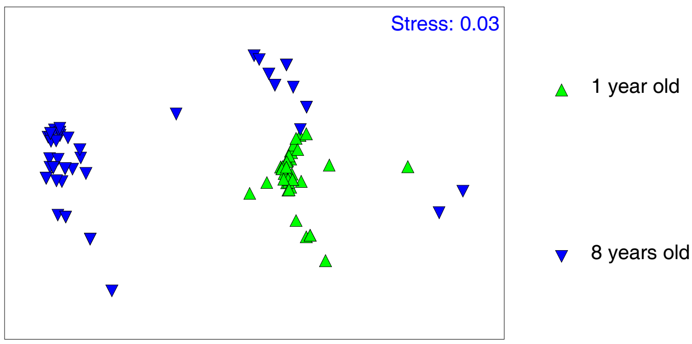


Figure 19 – nMDS plot of assemblages on granite groynes located in Brighton 1 and 8 years after their construction.

The assemblage on the second set of groynes, (Rottingdean groynes 2.5 and 9.5 years after construction) also changed considerably (ANOSIM R = 0.54, p<0.001; Figure 20). However, less clear differences in the composition of the assemblages were shown by SIMPER analysis. Fucoids and ephemeral algae were relatively abundant during both early and late colonisation, although in different proportion.

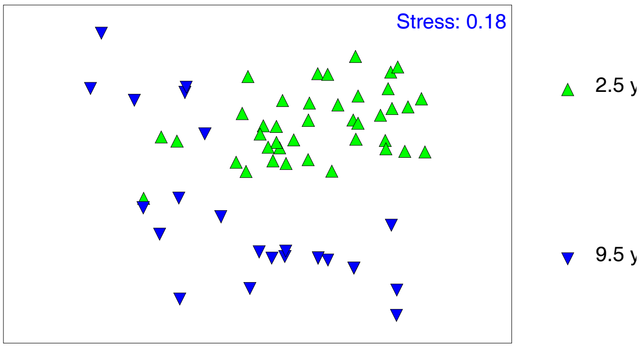


Figure 20 – nMDS plot of assemblages on granite groynes located in Rottingdean 2.5 and 9.5 years after their construction.

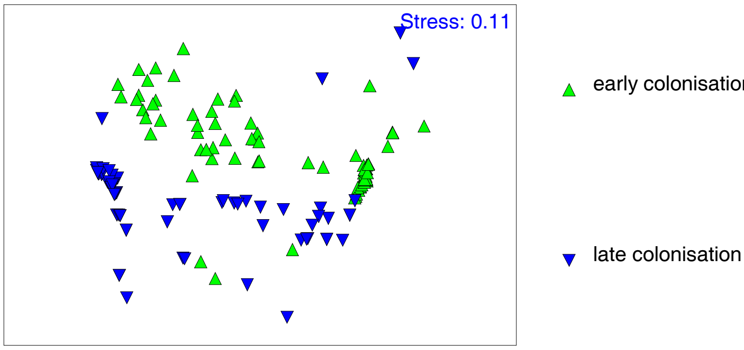


Figure 21 – nMDS plot of assemblages on granite groynes located in Saltingdean and Rottingdean in the early and late stage of colonisation.

Figure 21 summarise the observation previously made. When data from both groynes were analysed together, it was apparent that the differences between assemblages colonising the groynes few years after construction (less than 3 years) significantly changed with time (ANOSIM R = 0.58, p<0.001; Figure 21). Overall *Enteromorpha* sp. and *Porphyra* dominated assemblages during the early stages of colonisation, whilst barnacles, limpets and fucoids colonised the groynes subsequently. Assemblages of new structures are also generally more homogeneous and much less diverse than more mature assemblages.

Effect of surface complexity

The effect of surface complexity of the building blocks on diversity of epibiota was investigated using an experimental approach at Elmer, West Sussex. The experiment was carried out using concrete slabs with smooth surfaces and with blind holes of different sizes attached to the horizontal and vertical surfaces of the building blocks. Four different types of slabs, with increasing surface complexity were considered: no holes, small holes, large holes and mixed holes (small+big). The experiment started in March 2002 and is still in progress. In each occasion composition and abundance of epibiota settling in the panels were recorded. Colonisation of epibiota followed a similar pattern in both structures and on both orientations. However, clear differences in colonisation by epibiota were soon evident on panels of different complexity (Figure 22). Panels with a smooth surface were less colonised by organisms, except for barnacles. Also, a reduced number of species settled on these panels over time. The effect of orientation was less apparent, although a higher taxonomic diversity characterised panels fixed to the horizontal surfaces of the blocks (Figure 23). Horizontal panels function also as nursery site for many intertidal species such as gastropods, bivalves and crabs. This experiment, which is still in progress, suggests that higher habitat complexity can increase biodiversity by providing protection from desiccation, refuges form grazers and predators and habitat diversification.

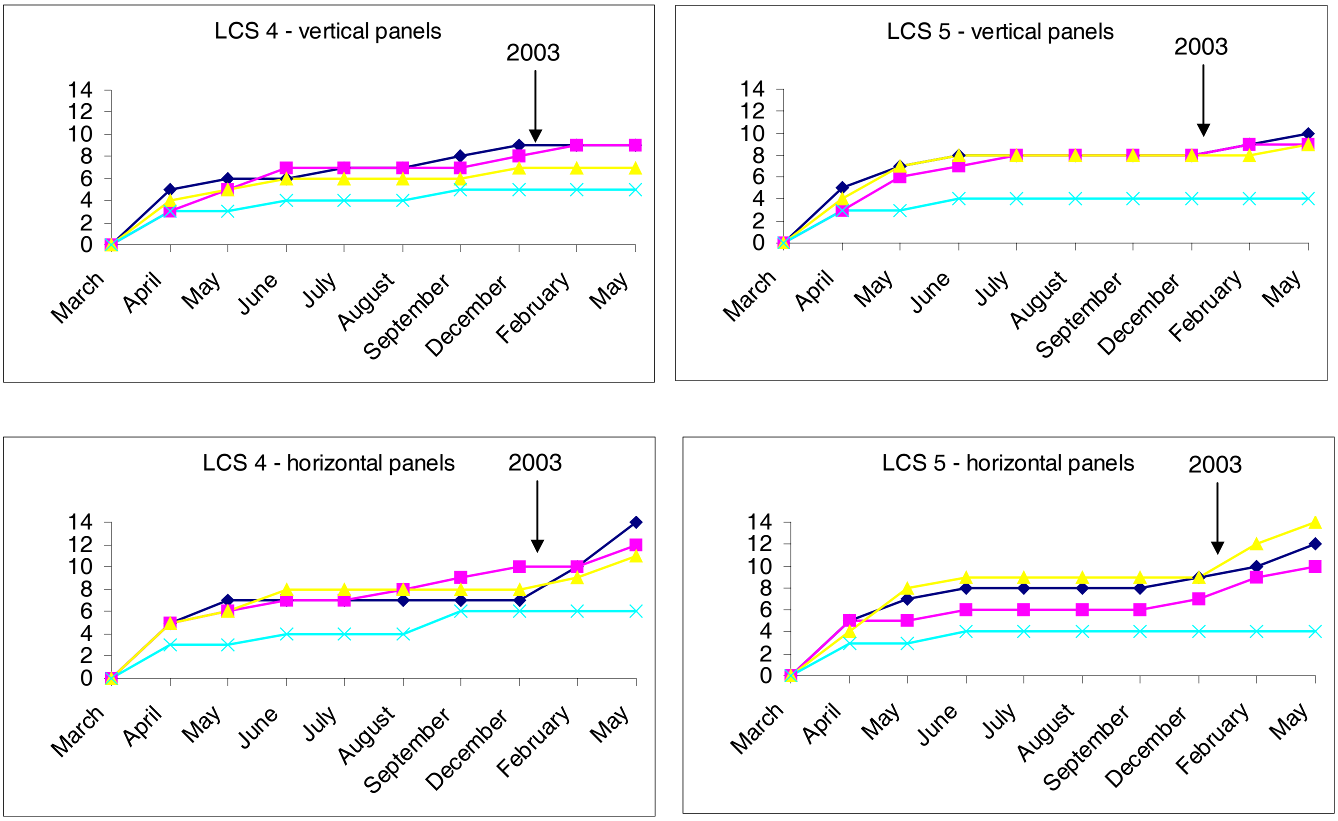


Figure 22 - Colonisation trajectories on concrete panels with different level of surface complexity attached to horizontal and vertical surfaces of LCS 4 and 5 blocks at Elmer.

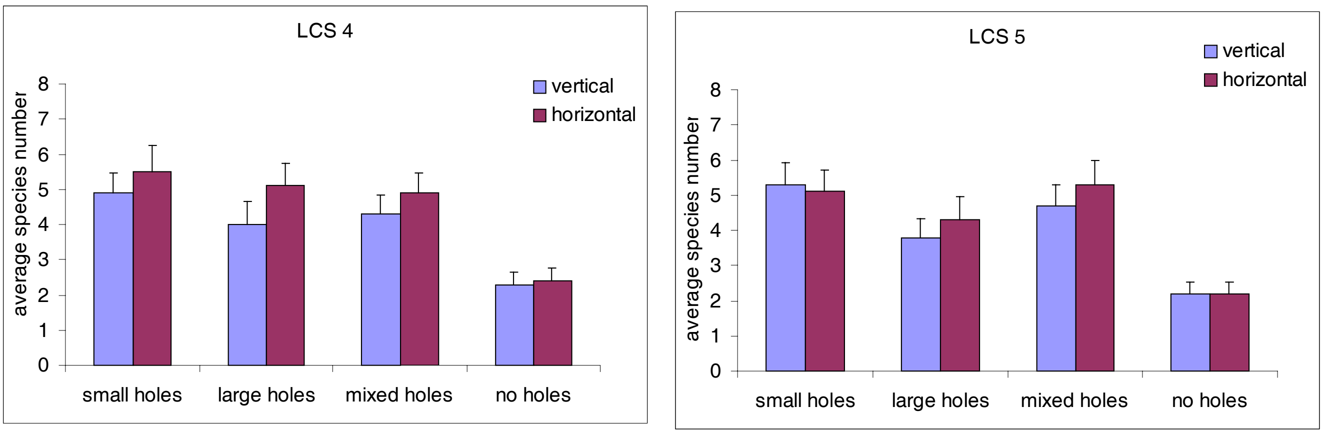


Figure 23 - Number of species (averaged over time), which settled on concrete panels with different level of surface complexity, attached to horizontal and vertical surfaces of blocks of LCS N. 4 and 5 at Elmer.

Effect of pore size on marine growth

This study aimed at providing information on the effect of pore size within a structure on marine growth. Composition, abundance and thickness of epibiota around the pores and their dimensions (approximate diameter, depth) were recorded on four LCS in Liverpool in 2002. In total 60 pores of different size were sampled. Thickness of fouling around the growth was often over 10 cm (Table 1). Mussels were the organisms causing the thickest cover around the pores. Thickness was up to 16cm and some of the pores were completely filled up with several strata of mussels and the pore size was reduced more then 70%. Fucoid algae and barnacles appeared not to have such effect, as thickness usually was not greater than 4 cm.

Table 1 – Pore size (given as approximate pore diameter), maximum and mean values of thickness of algae and marine invertebrates around the pores and percentage of reduction of the pore size due to the presence of marine growth. Results are given for selected pores where fucoids, mussels or barnacles were dominant (>60% cover). Values in brackets refer to standard error.

	Pore diameter (cm)	**Thickness of marine growth (cm)**		**Reduction in pore size (%)**	
	Mean value	Mean value	Max. value	Mean value	Max. value
Fucoids	65.4 (4.26)	2.1 (0.29)	3.8	6.6 (0.91)	12.6
Mussels	44.4 (2.32)	6.7 (0.91)	15.8	31.1 (4.41)	78.8
Barnacles	57.1 (4.94)	0.7 (0.06)	1	2.6 (0.35)	6.7

The effect of marine growth was more evident on smaller pores, which resulted in a considerable reduction of the pore size. The reduction in pore diameter due to the presence of attached organisms appeared less evident in bigger pores (>60 cm diameter), as shown in Figure 23. This is probably due to different hydrodynamics and probability of dislodgement from the substratum.

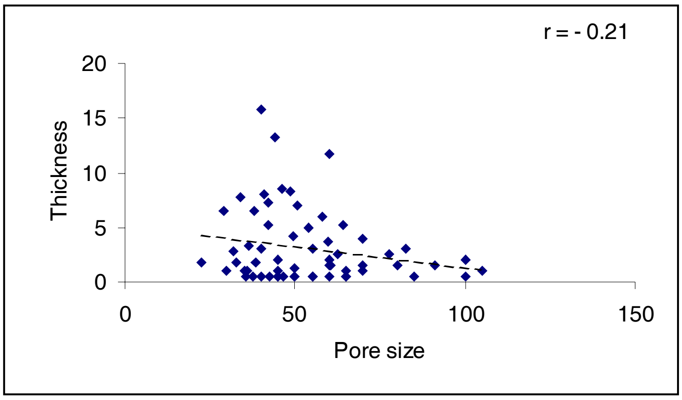


Figure 23 – Relationship between the pore diameter and thickness of marine growth.

Effect of presence of rock pools on diversity of structures

This study aimed at quantifying the effect of rock pools forming at the base of structures on diversity of epibiota and evaluating the benefits of including these rock pools in the design of LCS. Species colonising rock pools located at the base of eight LCS at Elmer and on the surrounding building blocks were recorded in 2002 and 2003. On two LCS, for each pools width, length and depth were also recorded. In total, 72 species were identified in the rock pools *versus* 21 on blocks (Table 2). The number of species recorded in the pools was significantly higher than on the blocks (t test, $p<0.05$; Figure 24). The higher number of species found on the building blocks on LCS 7 and LCS 8 can be explained by the fact that only few, shallow pools were found on these structures. Many species (belonging to Hydroids, Ascidians, Sponges) found in the pools are very sensitive to desiccation therefore could not survive on blocks during low tide. Water stands in rock pools even after low tide, creating suitable conditions for a wider number of species. Diversity in rock pools, however, appeared to depend on their depth and volume, but not their size, expressed as area (Figure 25a, b, c). This study highly suggests that species diversity on LCS can significantly increase in presence of rock pools, thus improving the ecological values of coastal defences. Rock pools could be therefore included as part of the design of defence structures.

Table 2 – List of species observed in rock pools located at the base of LCS and on the surrounding blocks at Elmer.

Rock pools	**Building blocks**
Algae	Algae
Gracilaria verrucosa	*Chondrus crispus*
Lithothamnia	*Mastocarpus stellatus*
Corallina officinalis	*Ceramium rubrum*
Chondrus crispus	*Enteromorpha* sp.
Mastocarpus stellatus	*Ulva lactuca*
Ceramium rubrum	*Fucus spiralis*
Dilsea carnosa	Hydroids
Lomentaria articulata	Sea anemones
Nemalion sp.	*Actinia equina*
Halurus flosculosus	*Anemonia viridis*
Polysiphonia fucoides	Polychaetes
Sargassum muticum	*Platynereis dumerilii*
Enteromorpha sp.	Crustaceans
Ulva lactuca	*Elminius modestus*
Laminaria saccharina	*Semibalanus balanoides*
Fucus serratus	*Carcinus maenas*
Fucus spiralis	Molluscs
Griffithsia flosculosa	*Gibbula cineraria*
Chondra dasyphyla	*Patella vulgata*
Polysiphonia macrocarpa	*Littorina neglecta*
Polysiphonia nigrescens	*Littorina littorea*
Helminthocladia calvadosii	*Littorina saxatilis*
Chylocladia verticillata	*Crepidula fornicata*
Cladophora rupestris	*Nucella lapillus*
Furcellaria lumbricalis	*Mytilus edulis*
Dictyota dichotoma	
Heterosiphonia plumosa	
Sponges	
Sycon ciliatum	
Suberites sp.	
Halichondria panicea	
Hydroids	
Dynamena pumila	
Tridentata distans	
Kirchenpaueria pinnata	
Cereus pedunculatus	
Sea anemones	
Actinia equina	
Anemonia viridis	
Polychaetes	
Hesionidae	
Platynereis dumerilii	
Polydora ciliata	
Syllidae	
Lanice conchilega	
Sabellidae	
Spirorbidae	
Sea spiders	
Nymphon brevirostre	
Achelia echinata	
Achelia longipes	
Anoplodactylus angulatus	
Crustaceans	
Elminius modestus	
Semibalanus balanoides	
Ampithoe rubricata	
Corophium bonnellii	
Idotea granulosa	
Palaemonidae	
Caprella acanthifera	
Carcinus maenas	
Halacaridae	
Gastropods	
Gibbula cineraria	
Gibbula umbilicalis	
Patella vulgata	
Littorina littorea	
Littorina saxatilis	
Crepidula fornicata	
Ocenebra erinacea	
Nucella lapillus	

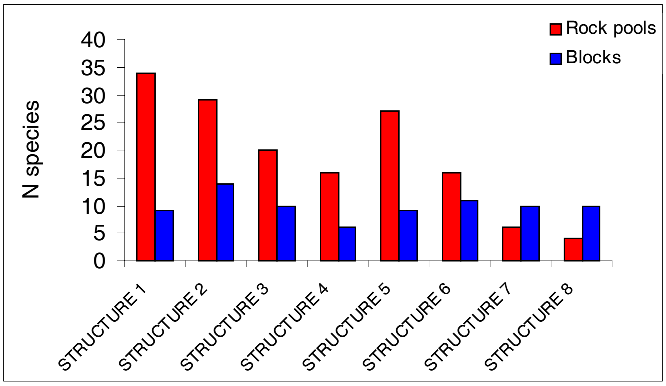


Table 2 – List of species observed in rock pools located at the base of LCS and on the surrounding blocks at Elmer.

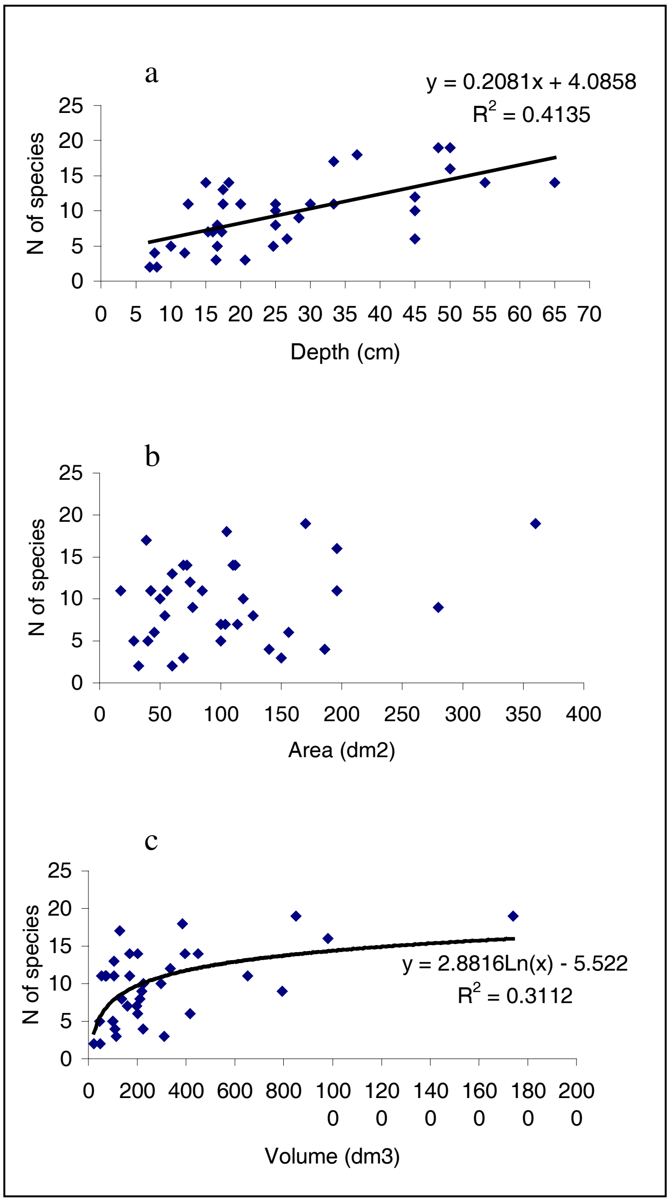


Figure 25 – Number of species observed in rock pools in relation to depth (a), volume (b) and area (c).

Conclusions

Results from the broad scale survey and local scale investigations allowed the identification of design features, which mostly influence the abundance, and diversity of epibiota in the UK. The results provide therefore useful information to be considered in the design guidelines for a more environmentally sensitive design of coastal defences. In the following table (Table 3) the effects of various breakwaters design parameters on epibiota are summarised.

Table 3 – Summary table of effects of design features on abundance and diversity of epibiota and possible implications for the design of LCS.

DESIGN FEATURES	EFFECTS ON EPIBIOTA	NOTES	CONSIDERATIONS
Type	*	LCS did not differ from groynes	Groynes can be used as model for LCS.
Total height	**	Higher structures increase the whole diversity.	Building LCS lower on the shore would increase diversity, as a higher number of species can colonise the structures below MTL.
Height of structure to mid tidal level (MTL)	***	As above	
Distance from the shoreline	(***)	Low number of LCS structures did not allow formal comparison.	Although not formally tested, it is likely that LCS built further offshore will have a higher diversity.
Building material	None	Epibiota was more variable on limestone than on concrete.	The choice of material is not essential for the colonisation of epibiota; however assemblages on smooth concrete tend to be less diverse.
Size of building blocks	Not formally tested	Limited range of block sizes.	--
Age	***	Recent structures (< 3 ys old) highly differed from older structures (> 8 ys old).	Colonisation of LCS takes at least 5 ys before a mature, more diverse assemblage can develop. For this reason, maintenance work on LCS should be limited to the minimum.
Surface complexity of building blocks	***	More complex surfaces increase number of species colonising LCS. The effect is more marked on horizontal surfaces.	Small crevices, pits and holes should be incorporated, whenever possible, in the horizontal surfaces of building blocks to increase habitat and species diversity.
Pore size	**	Marine growth is thicker in small pores, particularly when colonised by mussels.	A pore size larger than 50 cm diameter is suggested to keep pores free of excessive marine growth and original flow conditions through the LCS.
Rock pools	***	The presence of deep rock pools significantly increases diversity of species on LCS	Diversity can be increased also by incorporating artificial rock pools in the design of LCS.

Key features in the design of man-made structures which influence colonisation by epibiota along the Italian shores

1. Results of a broad scale survey

A broad scale survey of man-made structures was carried out in May 2001 along the Emilia-Romagna (Italy) shore. The aims of this study were to map all the coastal structures along 40 km of coast and to identify a relation between colonising epibiota and features of structures. For each structure, several parameters were recorded, including: location, type of structure, age, material and abundance of conspicuous species of intertidal epibiota (using a semi-quantitative visual method). For breakwaters and groins, abundance of species was quantified in relation to position on the structures (landward and seaward sides for breakwaters, and northern and southern sides for groynes). A multivariate approach (MDS, Primer; Clarke, 1993) was adopted to establish which parameters were most related to the distribution of intertidal assemblages.

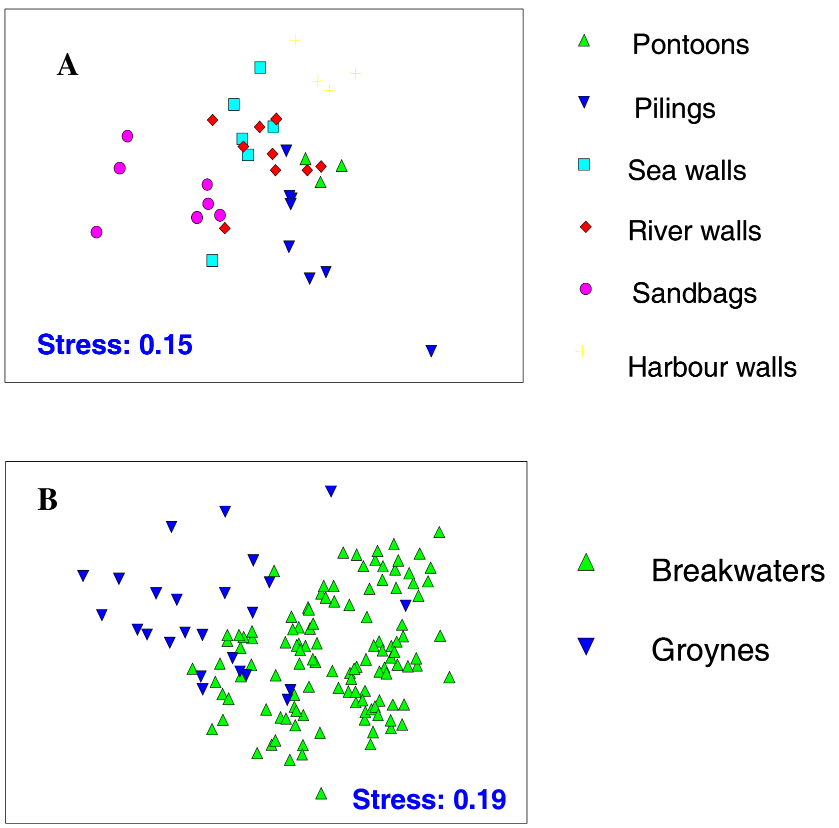


Figure 1 nMDS plots of the assemblages associated with different typologies of structures

In total, 133 structures were mapped. These included 79 breakwaters (emerged and semi submerged), 13 groynes, 7 seawalls, 10 structures built with sandbags, 3 pontoons, 4 harbour walls, 8 pilings and 9 river walls. Multivariate analyses revealed differences in the composition of epibiota in relation to the typology of structures. The MDS plot showed that assemblages on the harbour walls, structures made with sandbags and pilings were distinctly grouped, while assemblages on river walls, pontoons and sea walls were overlapped (Figure 1, A). Distribution of epibiota differed also between breakwaters and groins (Figure 1, B). The principal species responsible for these differences were the limpet *Patella cearulea*, the green alga *Enteromorpha intestinalis and* the red alga *Antithamnion cruciatum*. On average, limpets and *A. cruciatum* were more conspicuous on breakwaters, while *E. intestinalis* was more abundant on groins.

Most of the structures were built with blocks of natural calcareous rock, while other types of materials were less common. In particular, blocks of concrete were used for the building of harbour structures, while sandbags were used to build short groynes perpendicular to the beach. Metal (i.e. iron) was used for the building of pontoons and pier pilings. The MDS plot showed that assemblages on structures of different materials were separated. Assemblages on sandbags differed from assemblages on all other materials. Assemblages on concrete and metal were rather similar to each other but separated from those on natural calcareous rocks (Figure 2).

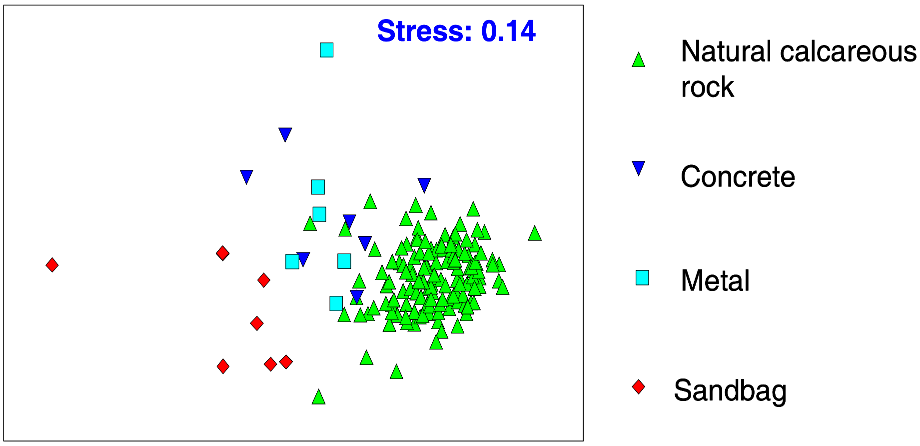


Figure 2 nMDS plot of the assemblages associated with structures of different materials

Limpets and barnacles were absent or nearly absent on structures of metal, sandbags and concrete, while they were abundant on natural calcareous rock structures. Conversely, *Enteromorpha intestinalis* and *Ulva laetevirens* were more common on structures of metal, sandbags and concrete than on natural calcareous rock.

The ages of the structures were variable. The oldest were more than 30 years old, the youngest less than 10 years old. Despite the fact that the variability in the age of structures was high, assemblages associated to coastal defence did not seem to be affected by age. The MDS plot showed little differences among assemblages on structures of different ages (Figure 3). This result may be explained by the frequent maintenance works to the structures (i.e. addition of new blocks during repair of the structures) that could negatively affect the diversity of epibiota and mask the effect of age.

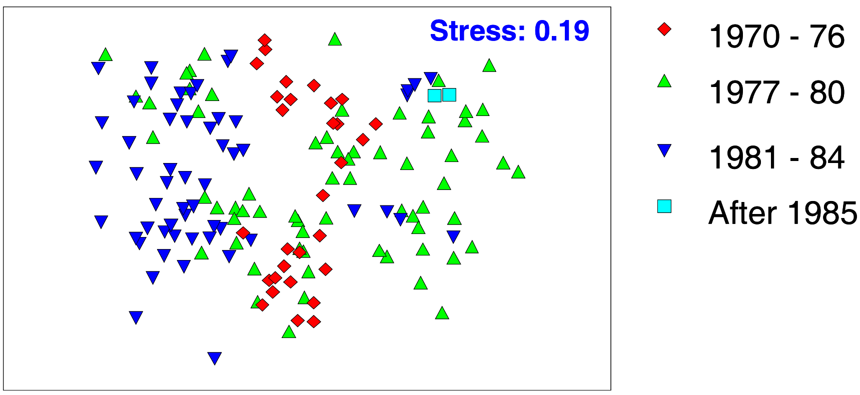


Figure 3 nMDS plot of the assemblages associated with structures of different ages

2. Results of quantitative studies

The broad scale survey showed that the abundance of conspicuous species seemed to be related to the typology and substratum composition of structures. Age of the structures did not seem to be related to the abundance and the compositions of conspicuous species on coastal defence structures. Predictions derived from broad scale survey were tested during quantitative studies carried out at several localities along the shore of the province of Ravenna.

2.1 Analysis of the distribution of epibiota around different types of structures

Aims of the study

The aims of the present study were: (1) to investigate whether the distribution of epibiota differed among positions around groynes and breakwaters and (2) to test whether patterns were consistent at different spatial scales, ranging from meters to 10s of kilometres.

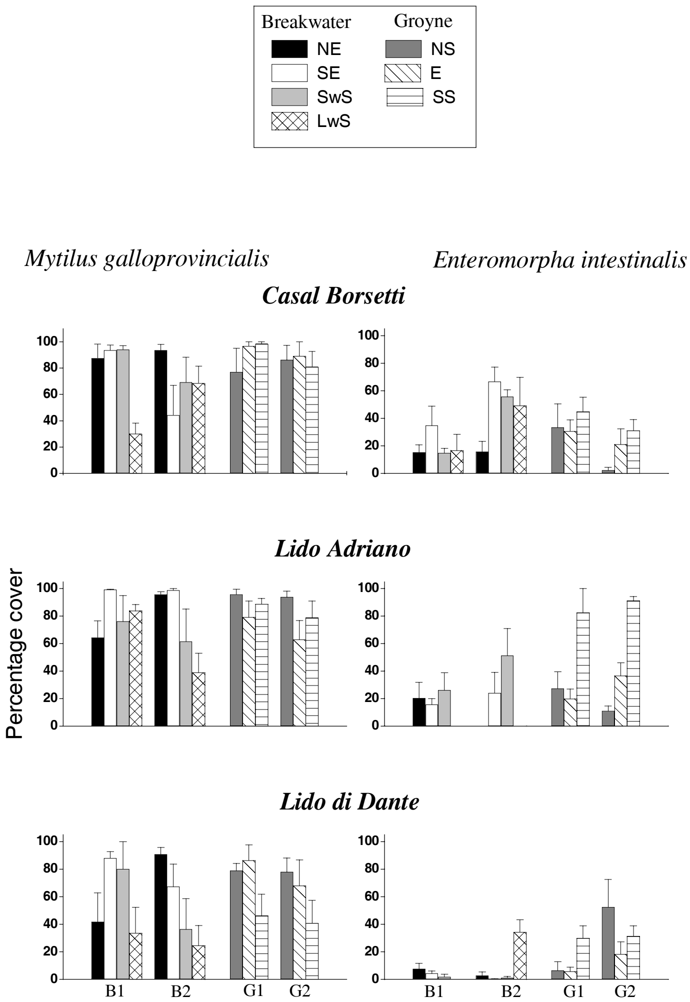


Figure 4. Percentage cover (+ SE, n = 5) of *Mytilus galloprovincialis* and *Enteromorpha intestinalis* at three stations and at different positions around groynes and breakwaters. At each station sampling was done at all positions around two breakwaters (B1, B2) and two groynes (G1, G2). Positions around groynes are: (NS = North Side, E = End and SS = South Side) position around breakwaters is: (NE =North End, SE = South End, SwS = Seaward Side and LwS = Landward Side).

Methods

The composition and distribution of intertidal epibiota were analysed at different positions around two groynes and two breakwaters selected at random at each of three stations along the Emilia Romagna coast (Italy). 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). Five replicate plots of 20 x 25 cm were sampled at each position using a visual method (Benedetti-Cecchi et al., 1996). Further details can be found in Bacchiocchi & Airoldi (2003).

Results

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. Mussels were significantly less abundant along the landward side of breakwaters compared to all other positions around both groynes and breakwaters (Figure 4). Overall, however, fewer differences were observed than expected in the distribution of species at different positions around groynes and breakwaters, probably as a consequence of the notably low complexity of these assemblages at the time when the study was done.

2.2 Effects of substratum composition

Aims of the study

The aim of this study was to test the hypothesis that the composition and the abundance of epibiota changes in relation to the type of material used to construct artificial structures.

Methods

The hypothesis was tested by quantitative sampling and a manipulative experiment. Sampling was done in October 2001 at low-shore habitats along the jetties of Ravenna Harbour, where concrete tetrapods and natural calcareous blocks alternate. At each jetty, sampling was done along 40 m long transects located approximately at the interface between tetrapods and blocks of natural calcareous rock. Twelve replicate plots were sampled on each different type of material in each of two areas, using a visual method.

The experiment was done by using artificial panels (17 x 17 cm) of different materials. Four types of substratum were compared: limestone, granite, marble and PVC (the latter to test whether this type of material could be useful to build panels to use in other experiments). Twelve replicates panels for each substratum type were deployed on the seaward side of the low crested breakwater at Lido di Dante. Epibiota colonising these panels was recorded by photographic sampling.

Results

Very few species were present on both concrete tetrapods and natural calcareous rocks. These included the mussel *Mytilus galloprovincialis Ostrea* spp., *Balanus* spp., *Chthamalus* spp., *Serpulidae* spp., *Enteromorpha intestinalis, Ralfsia verrucosa* and a mixture of juvenile unidentifiable macroalgae that we grouped under the category "microfilm". Patches of byssal thread and bare substratum were also largely present on the blocks.

Significant differences were found in the distribution of some species between concrete and natural calcareous rocks (Table 1). In some cases, patterns were consistent across the two areas. For example the microfilm was consistently more abundant on natural calcareous rocks than on concrete (Figure 5). Conversely, species, such as mussels, showed inconsistent trends in the two areas, being more abundant on concrete than on natural calcareous in one area, and more abundant on natural calcareous rocks than on concrete in the other (Figure 5).

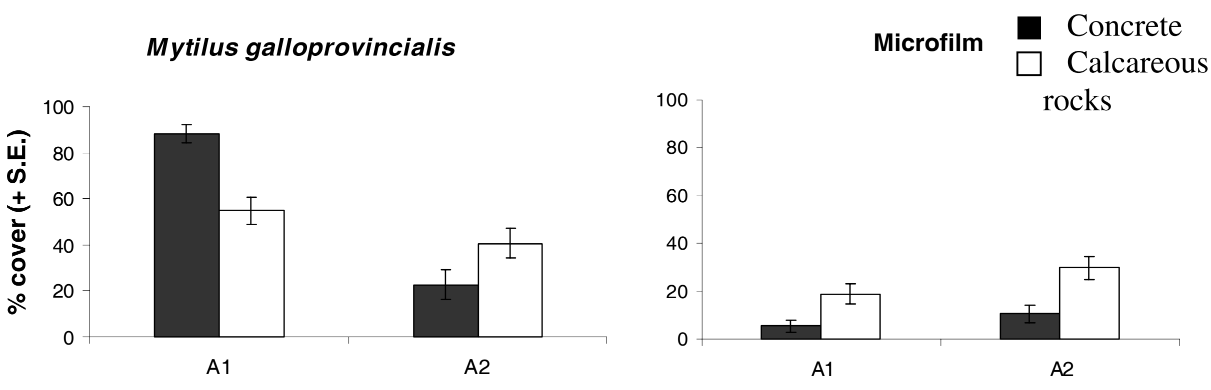


Figure 5. Percentage cover of mussels (*Mytilus galloprovincialis*) and microfilm on concrete and natural calcareous rocks at two areas along the jetties of Ravenna harbour

The abundance of bare substratum and byssal thread suggests that assemblages on jetties were influenced by recent harvesting of mussels for commercial purposes, which may have confounded effects due to substratum type.

Table 1 Results of ANOVA on percentage cover of dominant species in two areas and on different materials. Factors: area (2 areas; A1= south jetty, A2= north jetty; fixed); material (L= limestone block; C=concrete block). *p<0,05; **p<0.001; ns= no significant

Source of variation		df	MS	F		Cochran's C-test	SNK test
M. galloprovincialis							
Area	=A	1	19120,1	47,55	**	C = 0,311 ns	A2<A1
Material	=M	1	705,3	1,75	ns	none	
ArxMa		1	7854,1	19,53	**		**A1**: L<C; **A2**: C<L
RES		44	402,1				
Microfilm							
Area	=A	1	768,0	4,16	*	C = 0,396 ns	A1<A2
Material	=M	1	3136,3	16,98	**	none	C<L
ArxMa		1	102,1	0,55	ns		
RES		44	184,7				

Early colonisation on panels at different materials confirmed the hypothesis that abundance of some species on coastal defence structures is influenced by the type of substratum, although effects may vary over time. Microfilm was the first taxonomic group to colonise panels. After 4 weeks percentage cover of microfilm on marble and PVC was significantly greater than on concrete and granite (Figure 6, Table 2). After 6 weeks however, differences did not persist and microfilm covered on average 99% of panels of each substratum, while its cover in natural assemblages was only 50%. Microfilm quickly declined, reaching a percentage cover less than 1%, on panels and in natural assemblages at the end of the experiment.

Table 2 Result of ANOVA on percentage cover of dominant species and bare rock on panels of different material, after 4 and 14 weeks. *p<0.05; **p<0.01; n.s.=no significant

Source of variation	gl	MS	*F*		Cochran's *C*-test	SNK test
Microfilm 4 weeks						
Substratum	3	8995	14.8	**	C=0.504 ns	PVC = Marble > Granite > Concrete
Residual	28	608			(none)	

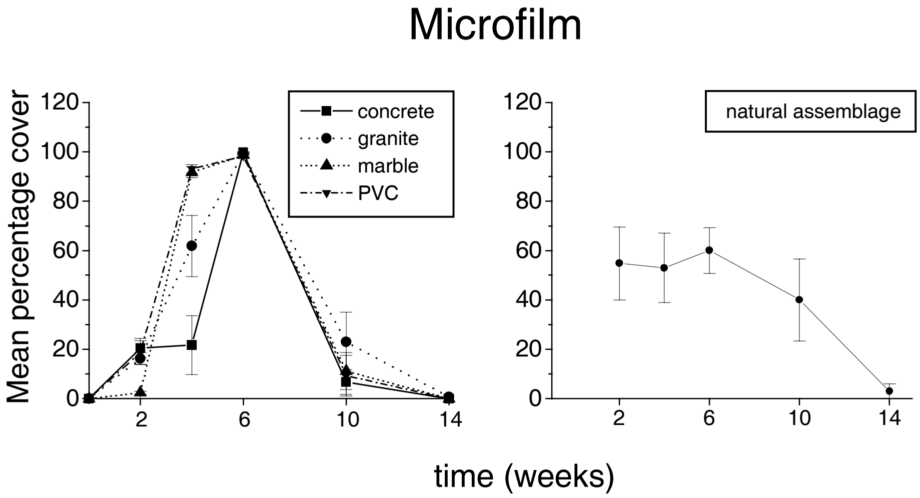


Figure 6. Percentage cover (+SE=8) of Microfilm on four different panels (concrete, granite, marble, PVC) and on natural assemblages.

2.3 Effects of age of coastal defence structures

Aim of the study

The aim of this study was to test the hypothesis that the composition and abundance of dominant species on coastal structures along the North Adriatic coast differ between structures of different ages time since each structures was built.

Methods

For each of the 3 age classes ("new" = less than seven years, "medium" = from ten to twenty years and "old" = more than twenty-five years) considered in the study, sampling was done at 3 stations (selected at random among those potentially available) that were characterised by the presence of schemes of coastal structures of corresponding ages. For some age classes, it was difficult to find schemes of structures of adequate age. In their absence, similar types of artificial structures, such as schemes of groynes or sea walls, were sampled. For each age class and station, sampling was done at 3 different areas, selected at random. For each area, 8 replicate plots of 20 x 20 cm were sampled in July 2001, at low intertidal levels. Sampling was done along the seaward site of LCSs and coastal walls, or along the tip of groynes, in order to sample assemblages exposed to comparable hydrodynamic conditions. Percent cover values of sessile species and bare substratum was quantified by visual methods.

Results

Assemblages were quantitatively dominated by mussels, oysters, limpets, barnacles and several species of algae, among which the most abundant were ephemeral green algae. The nMDS ordination showed some differences among assemblages on structures of different ages (Figure 7). In particular, assemblages on old and medium structures were recognisably grouped, while assemblages on new structures were more heterogeneous. Differences, however, were not statistically significant, due to the large variability among stations and areas.

Similar results were obtained from the analyses of patterns of abundance of dominant individual species. On average, *Mytilus galloprovincialis* was most abundant on old structures, while green ephemeral algae were most abundant on new structures (Figure 8). Differences, however, were not statistically significant, due to the large spatial variability among stations and areas (Table 3).

Observations suggest that possible reasons for the unexpected little differences observed among assemblages on structures of different ages include the very high levels of disturbance from maintenance works to which the structures are periodically subjected. This disturbance prevents the development of mature assemblages, and maintains the assemblages in a continuous stage of "early" settlement, that tends to be dominated by ephemeral green algae.

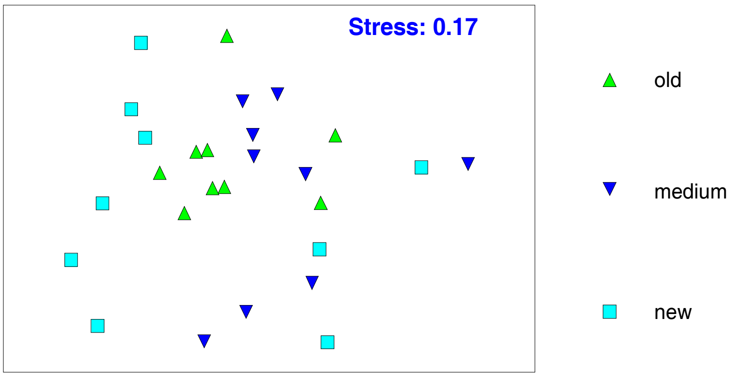


Figure 7. nMDS plot showing ordination of assemblages as function of ages of the structures

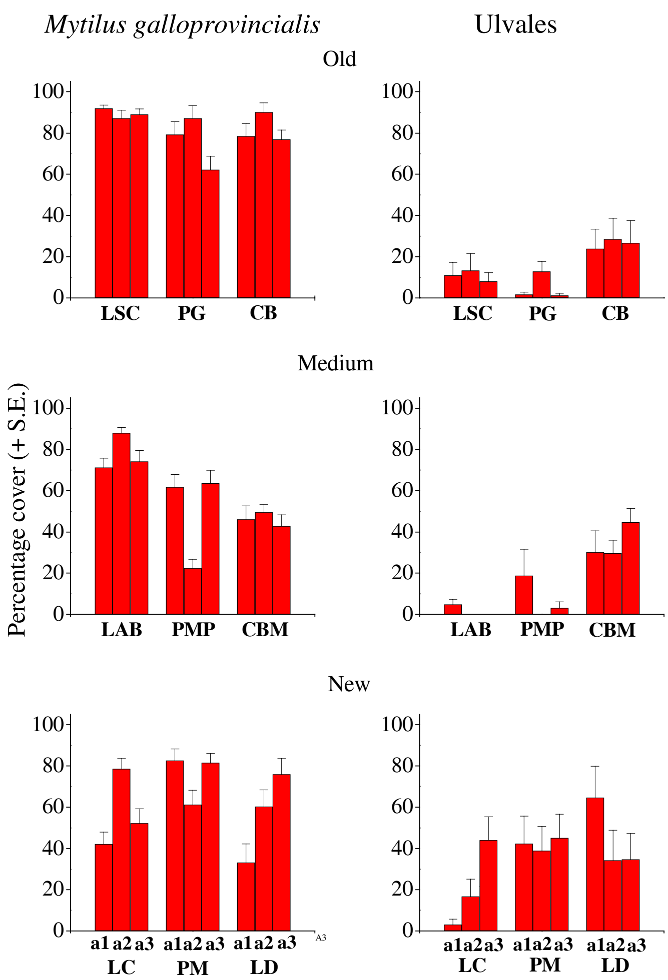


Figure 8. Percentage cover of *Mytilus galloprovincialis* and Ulvales on structures of different ages. Stations are: LSC, PG, CB, LAB, PMP, CBM, LC, PM, LD. The 3 areas are indicated as: a1, a2, a3

Table 3. Results of ANOVA on percentage cover of dominant specie for different classes. Factors: ages (3 levels); station (9 levels, nested in ages); areas (3 levels, nested in stations). *p<0,05; **p<0.001; ns= no significant

Mytilus galloprovincialis					
Source of variation		g.l.	MQ	F	P
Age	=A	2	9915	2.41	ns
Stations (A)	=St(A)	6	4122	2.67	*
Area (St(A))		18	1544	1.94	*
RES		189	795		
Total		215			
Ulvales					
Age	=A	2	11173	2.34	ns
Stations (A)	=St(A)	6	4784	5.45	**
Area (St(A))		18	877	1.40	ns
RES		189	626		
Total		215			

2.4 Effects of maintenance works on epibiota

Aim

Observations of assemblages on coastal structures suggested that frequent disturbance from maintenance works could negatively affect the diversity of epibiota. The aim of this experiment was to test whether the composition and abundance of dominant epibiota differs between structures that underwent maintenance works during the last year and those that did not for at least 3 years.

Method

The experiment was carried out at Cesenatico where maintenance works were done art same of the breakwaters in February 2002. Four breakwaters were randomly selected among those that had undergone maintenance work. Four additional breakwaters that had not undergone maintenance were chosen at random as control areas. Eight replicate quadrats of 20 x 20 cm were sampled on the landward and seaward sides of each breakwater by using the visual estimation method.

Result

Results showed that there were significant differences between assemblages on control and maintained breakwaters at Cesenatico. The principal species responsible for these differences were *Mytilus galloprovincialis* and microfilm (Figure 9). Mussels were more abundant on control than on maintained breakwaters. This difference appeared more substantial on the landward sides of LCSs. Microfilm was more abundant on maintained than control breakwaters on both sides of the structures. One year after maintenance works (January 2003) differences were still observable on landward sides of the breakwaters both for mussels and microfilm. On the seaward sides of the breakwaters percentage cover of mussels and microfilm on maintained breakwaters were the same as on control breakwaters.

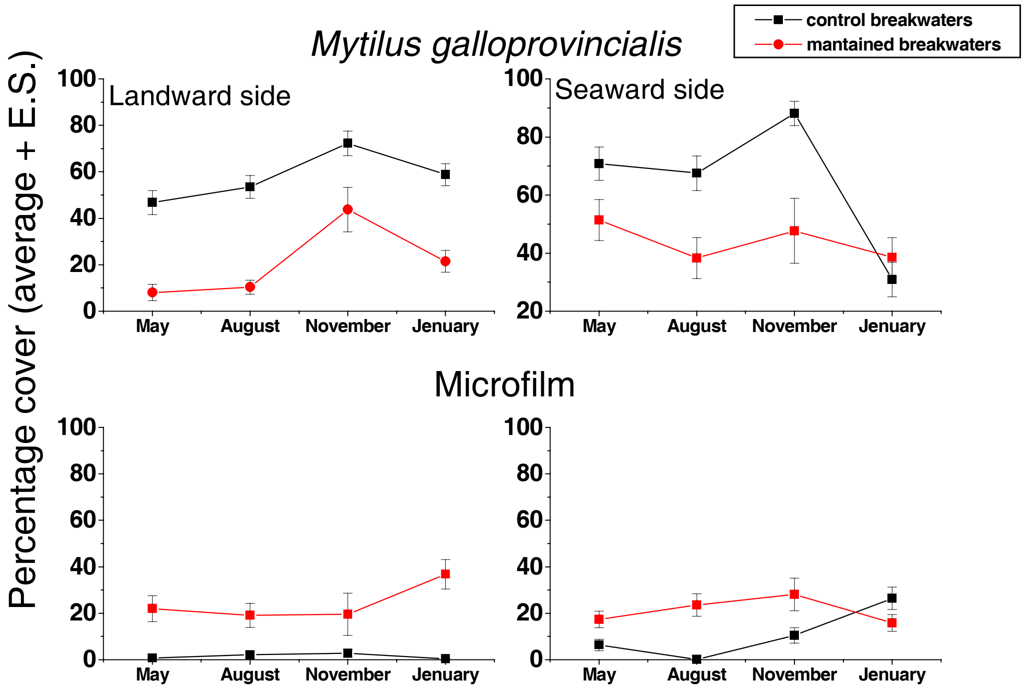


Figure 9. Percentage cover of mussels (*Mytilus galloprovincialis*) and microfilm on maintained and control breakwaters from May 2002 to January 2003. Data are mean values pooled across four breakwaters (n=32).

Conclusion

1) The quantitative study found little differences in the distribution of species at different positions around groynes and breakwaters. The low complexity of the assemblages at the time when the study was done probably explains this unexpected result. Intertidal assemblages on defence structures in the study area were in fact dominated by few species, including the mussel *Mytilus galloprovincialis*, the green algae *Enteromorpha intestinalis* and microfilm. The broad-scale survey showed that abundance of species on human –made structures was related to the typology of the structure. Specifically for coastal defence structures, the abundance of conspicuous species differed between breakwaters and groynes. The broad scale survey covered a larger and more southward area than the quantitative study, so a possible explanation of these contrasting results could be that differences among assemblages on different types of structures emerged more clearly at southern locations where the complexity of assemblages was higher.

2) The quantitative analysis of the relationships between the substratum composition of coastal defence structures and the abundance of epibiota suggested little effects of type of material. Differences in abundance between concrete and natural calcareous rock on jetties in the Ravenna harbour were observed only for microfilm, with a higher percentage cover on natural calcareous rock than on concrete. This result contrasts with the evidence that substratum type is an important factor affecting the rocky coasts organisms (Anderson & Underwood, 1994; Glasby, 2000, Glasby & Connell, 2001). Further observations from the broad scale survey and the experiment with panels revealed differences in the structures of assemblages in relation to substratum type. The patchy distribution of *Mytilus galloprovincialis* and the high percentage cover of microfilm suggest that along the jetties mussel harvesting was intense. The effects of substratum composition could have

been masked by the effects of frequent mussel harvesting. An additional study is in progress to test the effects of substratum type on epibenthic assemblages in other localities where harvesting of mussels is less common.

3) Age of the structures did not seem to influence the assemblages on coastal defence in any of the present studies. This result is probably related to the very frequent disturbance from maintenance works, which prevent the development of mature assemblages. Mussels were the species most negatively affected by maintenance especially on the landward side of the structures. After the addition of new blocks, defence structures were unstable for a few months. Some blocks, especially on the landward side, sank or were overturned during storms. This prevented the settlement of mussels for up to one year from when maintenance work was done.

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Study of two LCS systems in the Catalan coast of the NW-Mediterranean

We provide qualitative information on the effect of designing features on epibiota based on the inference from two study sites, Cubelles and Altafulla. The structure systems are situated parallel to shore at a distance ranging from 180 to 230 m. In Cubelles we have a system formed by three barriers of 130 m each. In Altafulla there is a single barrier 116 m of length. In both systems, the water depth in the seaward side is from 2 to 4 m and the boulders are limestone with some units of concrete. The structures are more than 10 years old.

The study of the structures indicate that boulder size of 1 to 2 m^3 with pore sizes of about 0.5 m^3, allow the development of epibiota on both sides of the LCS and even between the blocks. It is important to recall that there is a continuous water exchange between the seaward and the landward sides in both areas. However, differences in the diversity and structure of the communities have been found between seaward, landward and between blocks. In general the landward side is poorly colonised, particularly in filter feeders (i.e. *Mytilus galloprovincialis*) but also in slow growing high structured algae such as *Corallina elongata*, and is rich in fast growing fleshy algae (Table 1) compared to the seaward sides and between blocks. This latest (only studied in Altafulla) is particularly rich in *Balanus* and species supporting strong hydrodynamics. The landward side of the structures is affected by extremely high sedimentation during storm events (see October data in Fig.1) due to the shallow depths. This sedimentation may collapse filter feeders and also have a negative abrasion effect to the community favouring the growth of opportunistic fast growing species.

The communities of the LCS differ significantly from the ones in reference sides (Table 1), particularly in Cubelles were a thermal power plant slightly affects the water temperature around the structures.

Conclusions

The LCS studied seem quite good for the development of the epibionts except that they can be improved by adding more relief to the boulders (i.e. changing the flat surfaces for structures with holes and tunnels more similar to natural rocks). We attribute the main disturbance to the communities to be the abrasion result of the low water depth in the landward side. This effect however should be difficult to overcome because both structures were designed to protect nourished beaches from erosion. In the seaward side the presence of flat surfaces may be a problem for the community to support the strong energy of the waves during storms. Finally, the material of construction, limestone, seams correct because it is the main rock in the shores nearby.

Table 1a. Average composition of the epibiont communities in Cubelles LCS and reference sites in October of 2001. Values are in cm^2 from a sample size of 625 cm^2.

SPECIES	reference	seaward	landward
Corallina elongata	493	347	116
Mytilus galloprovincialis	205	125	-
Ulva sp.	67	-	-
Hypnea musciformis	60	-	-
Gelidium pusillum	35	-	-
Lithophyllum incrustans	31	9	63
Ceramium tenerrimum	7	-	-
Patella sp.	6	7	13
Herposyphonia tenella	-	-	330
Thais haemostoma	-	13	-
Cladophora sp.	13	-	-
Dictyota dichotoma	19	-	-

Table 1b. Average composition of the epibiont communities in Altafulla LCS (seaward side, landward side and between blocks) and reference sites in July 2002. Values are in cm^2 from a sample size of 400 cm^2.

species	reference	seaward	between	landward
Mytilus galloprovincialis	250	30	20	0
Gigartina acicularis	177	30	25	0
Corallina elongata	125	250	360.	73
Ceramium sp.	30	0	8	0
Ceramium rubrum	0	0	10	0
grass*	0	0	0	400
Bryopsis sp.	0	42	4	0
Lithophyllum incrustans	0	10	9	0
Balanus	0	0	96	0

*grass refers to a mixture of *Gelidium pusilum*, *Ceramium sp2* and *Chaetomorpha sp*

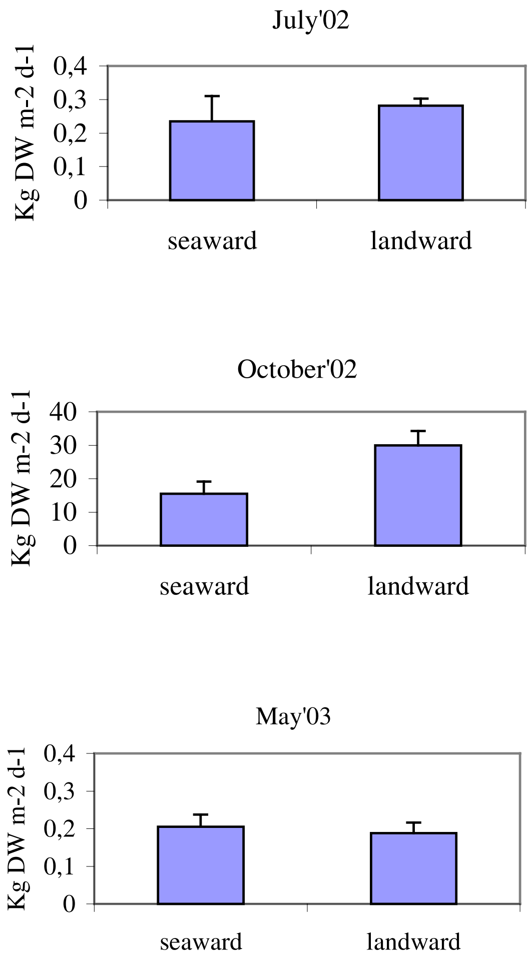


Fig. 1. Average total sediment deposition measured in Altafulla LCS facing the seaward and the landward sides. Traps were deployed over the bottom at 1 m from the structure. Values are the average of three sampling points.

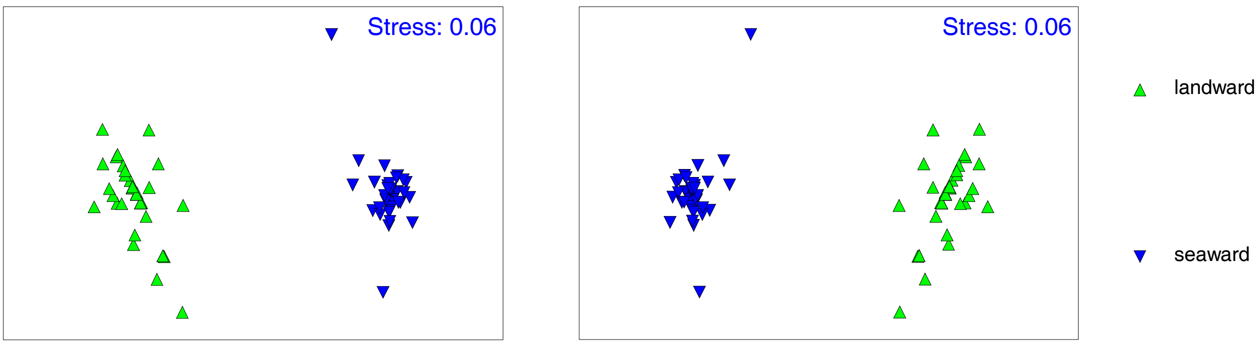
Summary

In UK, Italy and, to a more limited extent, in Spain and Denmark, several studies were carried out in parallel to identify LCS design features affecting the epibiota. These allowed a comprehensive investigation of the ecological effects of LCS and other coastal defences on epibiota in very different environmental conditions (micro- *versus* macrotidal systems, Mediterranean *versus* Atlantic Seas). In all studies there was evidence of selected design features having an important effect on colonisation, distribution and diversity of epibiota. Also, results showed that the importance of some design features in affecting the epibiota could vary considerably, depending on the system where the LCS is built. For example, in UK, where LCS are generally built in the intertidal, the location of the structure on the shore can seriously affect the type of epibiotic assemblages colonising the structure, whilst in a microtidal system such as on the Adriatic coast this parameter does not appear to be very important. The information provided in this deliverable will be integrated in the design guidelines (D59) to promote an effective but environmentally sensitive design of coastal defence structures.

Notes on Multivariate analysis and interpretation of MDS plots

(From Clarke and Warwick, *Change in marine communities: An approach to Statistical analysis and interpretation,* Natural Environment Research Council, UK, 144pp. 1994)

Multivariate analysis bases the comparison of two or more samples on the extent to which these samples share particular species, at comparable levels of abundance. The parameter used is the coefficient of similarity R, calculated between every pair of samples and ranging from 0, equivalent to complete dissimilarities between samples and 1, equivalent to perfect similarity. These coefficients are then ranked and used to create an ordination plot (MDS plot), in which the samples are "mapped" (in two or three dimensions) in such a way that the distances between pairs of samples reflect their relative dissimilarity of species composition. The purpose of MDS plots is to construct a sample map whose inter-point distances have the same rank order as the corresponding dissimilarities between samples. However, there might be some distortion between similarity ranking and the corresponding distance rankings in the ordination plot. This distortion is expressed by the *stress* value always indicated in the top left corner of an MDS plot. Stress values less than 0.15 indicate that the 2-D still represents sufficiently the actual similarity/ dissimilarity of the sample. Figure 1 provides an example of the MDS plot. Each triangle represents a sample, which in this case is the abundance and composition of species recorded in a quadrat 25x25cm on the building blocks of an LCS in Liverpool. The relative distance between triangles represents the similarity between the samples. Samples very similar will be located also very close each other also in the plot. In this example, most samples collected from the landward side are very similar, as well as sample belonging to the seaward side. However a greater distance separates samples from landward and seaward, suggesting that the abundance and composition of species colonising the two sides of the LCS is very different. What is important is the relative distance between samples, which does not change by inverting or rotating the plot (Figure 1). In this plot the stress value equals 0.06, which indicates very low distortion in the representation, thus the relative distances between "triangles" well represent the relative similarities/ dissimilarities between samples.



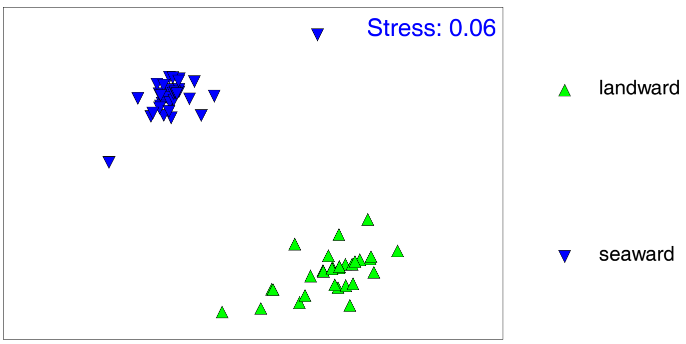


Figure 1 – Example of MDS plot. Each triangle represents a sample, in this case belonging to the landward (green triangles) and seaward (blue triangles) side of an LCS. The three plots represent the same set of samples, but inverted and rotated.