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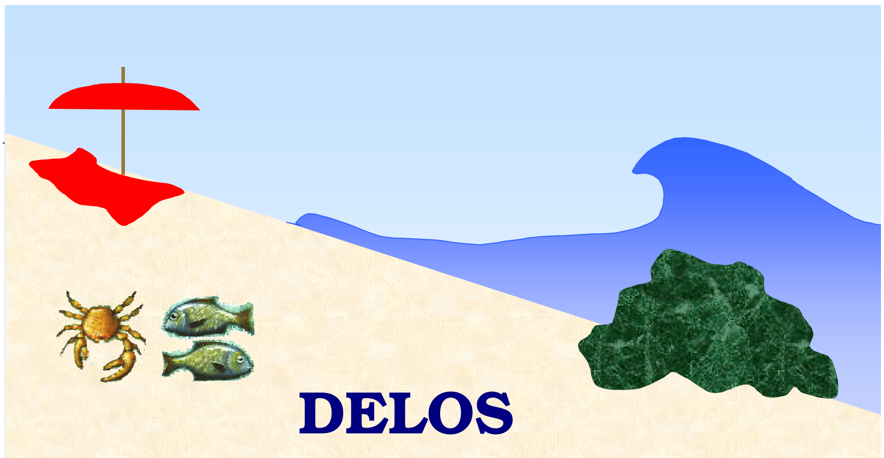
Energy, Environment and Sustainable Development

Environmental Design of Low Crested Coastal Defence Structures



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Assessment of direct and indirect effects of breakwaters on the recruitment, growth and survival of epibiota

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Introduction

Sea level rise due to climate change and increased storminess represents a serious threat to many coastlines which become more vulnerable to erosion and flooding. As a result, an increasing number of permanent, rock defence structures are built along several sandy shores. The construction of coastal structures results in the loss and fragmentation of natural sandy habitats and their replacement with artificial rocky habitats. These are colonised by new assemblages of plant and animals, which did not previously occur in the area. Coastal defence structures might therefore facilitate the expansion of area of distribution for rocky shore species, causing important effects on coastal assemblages (Connell, 2000; Davis et al, 2002). Little research, however, has been carried out on epibiota colonising these artificial structures. The first objective of WP 3.2 aimed therefore at a first characterisation of the composition, abundance and distribution of epibiota on LCS and other periodically overtopped defence structures such as rock groynes, jetties and rock armours. Large scale surveys of several breakwaters were carried out in the UK and Italy and, at a local scale (due to the limited number of defence structures available), in Spain and Denmark. These investigations provided a comprehensive description of the epibiotic assemblages of coastal defences located in very different environments; the Mediterranean coasts, which are characterised by minimal tidal range and the macrotidal Atlantic coasts. The effects of breakwater design features on composition and distribution of epibiota will be described in the Deliverable 46.

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1. Coastal defence structures as new substrata for hard-bottom species

1.1 Species composition of epibiotic assemblages.

1.1.1 Macrotidal English and Welsh coasts (UK)

During Year 1 and 2 the composition of epibiota was assessed on over 80 structures located in the south, west and east English coasts and on Welsh shores. In total, over 50 taxa, of which 43 at species level, were observed on breakwaters (Table 1). Despite the relative high number of species, most of coastal defence structures showed much less diverse assemblages, characterised by very few taxa. These consisted mainly of ephemeral algae such as *Enteromorpha* sp. and *Porphyra* sp., fucoids (mainly *Fucus spiralis*), barnacles (mainly *Semibalanus balanoides* and *Elminius modestus*), the limpet *Patella vulgata* and *P. depressa* and littorinids (*Littorina littorea* and *Littorina saxatilis*). Depending on locations, *Mytilus edulis* was also commonly found on breakwaters. The other species were recorded only on a limited number of structures. The low diversity observed on several breakwaters is likely to be caused by the location of the structures on the shore, as a large number of them are generally built between mid and high tidal levels. This reduces drastically the number of species which can cope with desiccation and thermal stresses occurring at low tide. Breakwaters located lower on the shore and towards the subtidal were colonised by a great number of species of algae and marine invertebrates and the assemblages were very similar to natural rocky shore communities (formal comparisons between defence structure and rockyshores will be examined in Deliverable 46). Diversity on coastal defence structures located on the mid shore was, however, lower than on a natural rocky shore One possible explanation is the lack of topographic complexity on the breakwaters. The building blocks of the breakwaters have generally a relatively smooth and homogenous surface compared to that on a rocky shore, characterised by rock pools, crevices and gullies which provide a variety of habitats for species. For example at Elmer, the presence of rock pools formed at the base of the LCS provides a suitable habitat for lower shore and subtidal species such as sponges, hydroids, bryozoans and picnogonids. Great variation in the composition of epibiota, however, was also observed between structures. This is probably due to the recruitment and area of distribution of species, which vary considerably geographically. Coastal defence structures can also be considered as stepping stones for species extending their area of distribution. In Liverpool, on the north west coast of England, the polychaete *Sabellaria alveolata* was recorded for the first time in that area on two LCS surveyed.

Table 1 – List of taxa identified on LCS and other coastal defence structure in the UK. Names in bold indicate most common species recorded on structures.

***Enteromorpha* spp.**
Ulva lactuca Linnaeus
***Porphyra* spp.**
***Blidingia minima* (Kutzing)**
***Pelvetia canaliculata* (Linnaeus)**
Condrus crispus Stackhouse
Mastocarpus stellatus (Stackhouse)
Cladophora rupestris (Linnaeus) Kutzing
Ectocarpus sp.
Plocamium cartilagineum
Lomentaria articulata (Hudson) Lyngbye
Corallina officinalis Linnaeus
Lithothamnia
Ceramium sp.
***Fucus spiralis* Linnaeus**
Fucus vesiculosus Linnaeus
Fucus serratus Linnaeus
Ascohpyllum nodosum (Linnaeus)
Laminaria digitata (Hudson)
Laminaria saccharina (Linnaeus)
Himantalia elongata (Linnaeus) Gray
Halichondria sp.
Bryozoans
Bugula neritina (Linnaeus)
Hydrozoans
Dynamena pumila (Linnaeus)
Actinia equina (Linnaeus)
Anemonia viridis (Forskal)
Metridium sp.
Sagartia spp.
Sabellaria alveolata (Linnaeus)
***Patella vulgata* Linnaeus**
Patella depressa Pennant
Gibbula umbilicalis (Da Costa)
Gibbula cineraria (Linnaeus)
Osilinus lineatus (Da Costa)
Crepidula fornicata (Linnaeus)
Nucella lapillus (Linnaeus)
Littorina obtusata (Linnaeus)
***Littorina littorea* (Linnaeus)**
***Littorina saxatilis* (Olivi)**
Melaraphe neritoides (Linnaeus)
***Mytilus edulis* Linnaeus**
Ostrea edulis Linnaeus
***Semibalanus balanoides* (Linnaeus)**
***Elminius modestus* Darwin**
Chthamalus spp.
Balanus perforatus Bruguiere
Picnogonids
Carcinus maenas (Linnaeus)
Necora puber (Linnaeus)
Porcellana platycheles (Pennant)
Asterias rubens

1.1.2 Microtidal North coast of Denmark

During Year 1 the composition of intertidal epibiota was assessed at 3 localities (14 structures) on the coast of Northern Denmark. During Year 2 the composition of both intertidal and subtidal epibiota were assessed at two of the localities (at 2 larger LCS by 10 transects at depth of 0.0, 0.5, 1.0, 1.5, and 2.0 meters). Algae and invertebrates contributed equally to the biodiversity. In total, over 45 taxa, of which 36 at species level, were observed on the breakwaters. Among these, 33 taxa (23 species) were observed in the intertidal (Table 2). The structures positioned lower on the shore were dominated by the red algae *Mastocarpus stellatus*, *Chondrus crispus*, and *Ceramium rubrum* as well as by the mussel *Mytilus edulis*, particularly of juveniles (SL<2cm), barnacles, and the locally abundant bryozoan, *Electra pilosa*. The distribution of epibiota is significantly related to the vertical position of the structures. Several of the structures were situated higher on the shore, where they were hardly fringed by the sea. These structures were either bare or sparsely colonised by *Enteromorpha* spp. and juvenile *Mytilus edulis*. For practical reasons, these structures have been omitted from the general multivariate analyses. The assessed structures includes both harbour defences and beach defences. The majority of the structures are positioned on sandy shores where rocky substrate is sparse. The presence of partly submerged boulders increases the biodiversity of the epifauna component (including both algae and invertebrates) on the shore. However, the biodiversity increases significantly with increasing depth of the structure.

Table 2 - List of intertidal taxa indentified on LCS in Northern Denmark. Names in bold indicate the most abundant species of algae and invertebrates found in intertidal habitats.

ALGAE	INVERTEBRATES
Enteromorpha spp.	*Dynamena pumila* (Linnaeus)
***Enteromorpha linza* (Linnaeus) J. Agardh**	Gastropods
Ulva lactuca Linnaeus	*Littorina littorea* (Linnaeus)
Cladophora spp.	***Littorina saxatilis* (Olivi)**
Hildenbrandia rubra (Sommerf.) Menegh.	***Littorina neritoides* (linnaeus)**
Porphyra umbilicalis (Linnaeus) C. Agardh	*Nucella lapillus* (Linnaeus)
***Mastocarpus stellatus* (Stackhouse) Guiry**	*Mytilus edulis* (SL>2 cm) Linnaeus
***Chondrus crispus* Stackhouse**	***Mytilus edulis* (SL<2cm) Linnaeus**
***Ceramium rubrum* (Huds.) C. Agardh**	Polychaetes (tubiferous)
Polysiphonia spp.	**Barnacles**
	Semibalanus balanoides (Linnaeus)
Phaeophyta, filamentous.	***Idotea*** spp.
Furcellaria lumbricalis (Huds.) Lamour.	Amphipods
Fucus spiralis Linnaeus	*Carcinus maenas* (Linnaeus)
Fucus vesiculosus Linnaeus	***Electra pilosa* (Linnaeus)**
Fucus serratus Linnaeus	*Asterias rubens* Linnaeus
Ascophyllum nodosum (Linnaeus) Lejol.	
Sargassum muticum (Yendo) Fensholt	
Laminaria spp.	

1.1.3 Microtidal Adriatic coast (Italy)

The presence and abundance of conspicuous species in intertidal habitats on coastal defence structures located on the Adriatic coast (province of Ravenna) were recorded over 2 years. A total of 16 species of algae and 10 species of invertebrates were found (Table 3). Assemblages were dominated by the mussel *Mytilus galloprovincialis*, and by ephemeral algae such as the green alga *Enteromorpha intestinalis.* The most abundant marine invertebrates included oysters (mainly *Ostrea edulis* and *Crassostrea gigas*), *Chthamalus stellatus*, *Balanus perforatus* and the limpet *Patella coerulea*. The gastropods *Melaraphe neritoides* were seen only occasionally during these studies. Conversely, crabs (*Pachygrapsus marmoratus*) were observed frequently, but due to their high mobility they were not quantified. The most abundant algae observed included *Ulva laetevierens*, *Gelidium spinosum, Antithamnion cruciatum* and *Polysifonia breviarticulata.* Other species of algae were less abundant in the assemblages. Encrusting algae were surprisingly rare, and included only *Ralfsia verrucosa.*

Table 3. Most abundant species of algae and invertebrates found in intertidal habitats on coastal structures within the province of Ravenna.

Species
ALGAE
Microfilm (microalgae, spores, germlings)
Antithamnion cruciatum (C.Agardh) Nageli
Bryopsis plumosa (Hudson) C. Agardh
Bryopsis hypnoides Lamouroux
Ceramium diaphanum (Lighfoot) Roth
Cladophora vagabunda (Linnaeus) Hoek
Codium fragile (Suringar) Hariot
Enteromorpha intestinalis (Linnaeus) Nees
Gelidium spinosum S.G. Gmelin
Gracilaria sp.
Porphyra sp.
Polysifonia breviarticulata (C. Agardh) Zanardini
Polysifonia subulata (Ducluzeau) P. & H. Crouan
Ralfsia verrucosa (Areschoug) Areschoug
Scytosiphon lomentaria (Lyngbye) Link
Ulva laetevirens (Areschoug)
INVERTEBRATES
Balanus perforatus Bruguiére, 1798
Chthamalus stellatus (Poli, 1791)
Crassostrea gigas (Thumberg)
Melaraphe neritoides Linnaeus, 1758
Mytilus galloprovincialis Lamark, 1819
Monodonta mutabilis Philippi, 1846
Ostrea edulis Linnaeus, 1758
Patella caerulea Linnaeus, 1758
Pachygrapsus marmoratus (Fabricius, 1787)
Sabellaria alveolata Linnaeus, 1767

1.1.4 Microtidal south coast of Spain

During the first and second year the LCS-systems situated in Cubelles and Altafulla (Spain,NW-Mediterranean) were surveyed. The LCS system at Cubelles is formed by three barriers of 130 m length built up over 10 years ago, Altafulla LCS is a simple system of one barrier with a total length of 116 m built up 12 years ago. The barriers were built up to protect nourished beaches from erosion. The survey aimed at the characterisation of the diversity and abundance of species living on these LCS in the small intertidal zone. A total of 41 algae were identified (some of them to genus level), one species of cyanobacteria, two species of Cnidaria, nine species of Molluscs (Gastropoda, Bivalvia, and Polyplacophora), six different groups of Crustacea, two different groups of Echinodermata (Asteroidea and Echinoidea), one species of Ascidian and one species of Pantopoda; Turbellaria, Bryozoa and Polychaeta were treated as groups and not identified at further taxonomic level (Table 4). Between algae living on coastal defences in Cubelles and Altafulla , *Corallina elongata* and *Gelidium pusillum* were the most abundant , while between invertebrates the bivalve *Mytilus galloprovincialis* was the most abundant.

Table 4 - Species of algae (first two columns) and invertebrates (third column) found on coastal defence structures at Cubelle and Altafulla during studies in 2001 and 2002.

ALGAE		**INVERTEBRATES**
Lyngbya confervoides	*Dasya spp rigidula*	*Aglaophenia kirchenpaueri*
Bryopsis cf duplex	*Gastroclonium clavatum*	Cnidaria unidentified
Bryopsis plumosa	*Gelidium pusillum*	*Acanthochitona communis*
Chaetomorpha sp.	*Gelidium pusillum (spatulatum)*	*cf. Ocinebrina edwardsi*
Chaetomorpha capillaris-crispus	*Gigartina acicularis*	*Thais haemostoma*
Cladophora sp.	*Grateloupia filicina*	*Fissurella sp.*
Cladophora cf. coelothrix	*Herposiphonia tenella*	*Patella sp.*
Cladophora rupestris cf.	*Hypnea musciformis*	*Striarca lactea*
Ulva sp.	*Jania sp.*	*Ostrea sp.*
Acinetospora vidovichii	*Jania corniculata*	*Mytilus galloprovincialis*
Callithamnion corymbosum	*Jania rubens*	*Mytilaster minimus*
Centroceras clavulatum	*Lithophyllum incrustans*	POLYCHAETA
Ceramium sp.	*Lithophyllum lichenoides*	CRUSTACEA unidentified
Ceramium ciliatum	*Lomentaria clavellosa*	*Balanus sp*
Ceramium diaphanum	*Polysiphonia spp.*	Decapoda
C. gracillimum v. byssoideum	*Polysiphonia furcellata*	*Acanthonyx lunulatus*
Ceramium rubrum	*Pterocladia cappilacea*	Amphipoda
Ceramium tenerrimum	*Pterosiphonia pennata*	Caprellidae
Corallina elongata	*Rhodophyllis divaricata*	Isopoda
Corallina granifera	*Sphacelaria sp.*	BRYOZOA
Cruoriops cruciata		*Paracentrotus lividus*
		Coscinasterias tenuispina
		Microcosmus sp.
		Turbellaria
		Pycnogonum pusillum

2. Factors affecting the distribution, abundance and dynamics of epibiota on coastal defence structures

A series of studies were carried out at several localities along the coasts in UK, Denmark, Italy and Spain in order to identify the main effects of breakwaters on the abundance, distribution and dynamics of epibiota. Results indicated that the distribution and composition of epibiotic assemblages on defence structures are not homogeneous, but are influenced by various factors, including wave exposure (e.g. landward vs. seaward), geographical location of the structures (Bacchiocchi & Airoldi, 2003) and tidal range (UK only). In Italy, high rates of disturbance and colonisation also affected the dynamics of assemblages (Bacchiocchi & Airoldi, 2003).

2.1 Effect of wave exposure of defence structures on epibiota

2.1.1 Macrotidal English and Welsh coasts (UK)

The study assessed the abundance and diversity of epibiota colonising the landward, seaward and the round heads of the LCS. For this purpose, only LCS parallel to the shore were taken in consideration and quantitative data were collected at mid tidal level. The diversity and abundance of epibiotic assemblages differed significantly between the exposure sides of LCS. This was evident using both multivariate (Figure 1; Table 5) and univariate analysis (Figure 2, Table 6). The major difference was observed in the assemblages between the sheltered landward side and the exposed seaward side and round heads. On the landward side of the structures fucoids (*Fucus* spiralis, *F. vesiculosus*) and *Enteromorpha* sp. were relatively abundant, whils limpets (*Patella vulgata*) and *Littorina littorea* were less frequent. On the seaward and end sides, the epibiota was dominated by barnacles, limpets and littorinids. Mussels (*Mytilus edulis*), when present, were also generally found only around the ends and on the seaward side. Barnacles, however, were generally common also on the sheltered sides of the breakwaters. Interestingly, there were differences also in the distribution of barnacle species. *Semibalanus balanoides* was more abundant on the seaward sides whilst *Elminius modestus* dominated the landward sides of the LCS. The composition and distribution of epibiota on defence structures appeared to be significantly affected by the wave exposure as it occurs on a natural rocky shore (Raffaelli and Hawkins, 1996). For example, algae generally cannot resist the abrasion and dislodgement forces which characterise exposed sites, whilst limpets tend to avoid sheltered areas. Diversity, based on Shannon's index, did not vary considerably between the different exposure sides. However, the epibiota colonising the round heads appeared to be slightly less diverse than the landward side.

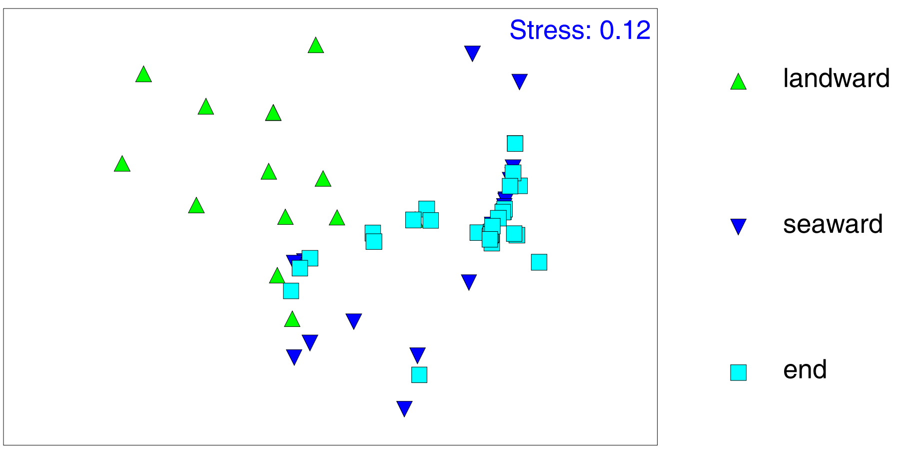

Figure 1 – nMDS plot of epibiotic assemblages colonising the different exposure sides of LCS.

Table 5 – ANOSIM results for differences in epibiotic assemblages between exposure sides of LCS.

Global R= 0.44; p<0.001		
Pair-wise tests	Dissimilarity coeff.	Probability
Landward - Seaward	0.47	0.001
Landward – Ends	0.73	0.001
Seaward - Ends	0.21	0.009

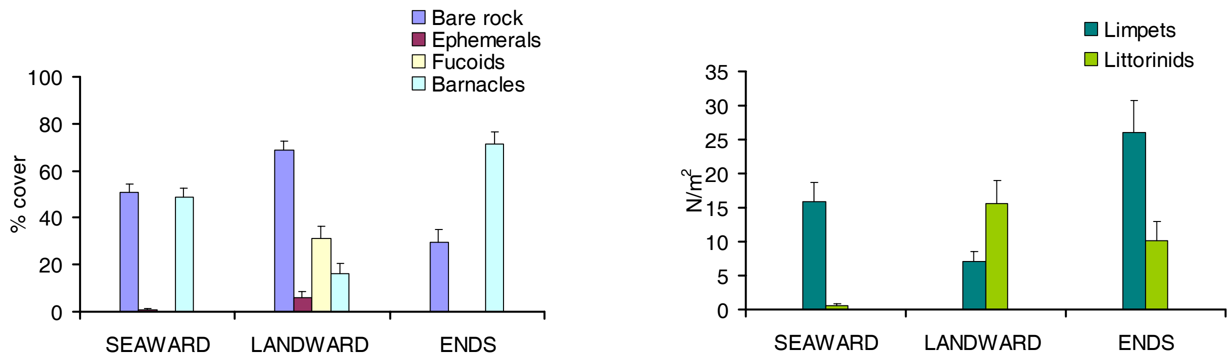

Figure 2 - Total abundance of most important taxa recorded on the LCS system at Elmer (West Sussex), South coast of England. (n=5, +SE).

Table 6 – ANOVA significant results for differences in abundance of main taxa between exposure sides of LCS at Elmer.

Species	**ANOVA**	**SNK test**
Barnacles	p<0.01	Seaward, Ends > Landward
Fucoids	p<0.01	Landward> Seaward, Ends
Limpets	p<0.05	Seaward, Ends > Landward
Littorinids	P<0.05	Landward, Ends > Seaward

2.1.2 Microtidal North coast of Denmark

The structures were either build as extensions of the existing shore line and positioned high on the beach. Hence all structures were exposed to water on the seaward side only. However, wave exposure appeared to have significant effect on the local distribution of epifauna. In the intertidal, several species were found mainly or exclusively on the backward faces of the seaward rocks, e.g. *Fucus spiralis*, *Laminaria digitata*, *Nucella lapillus*, and *Electra pilosa*), whereas particular juvenile *Mytilus edulis* appeared more abundant on the frontal faces (i.e. facing the sea) of the seaward boulders. Similar patterns were also recognised in the subtidal, were several invertebrates appeared mainly or exclusively on the frontal faces, e.g. several algae species, or on the faces of backward cave-like crevices behind the seaward boulders (e.g. *Halichondria panicea*, *Metridium senile*, *Tectura testudinalis*, and *Cancer pagurus*). In the intertidal, wave exposure probably explains why some are lacking on the frontal faces of the boulders. In the subtidal, multivariate analyses failed to detect any overall pattern of differences between frontal and backward faces of seaward boulders. Nevertheless, local differences may probably exist. Light intensity and competition for space probably explain part of the subtidal differences in distribution of algae and sessile invertebrates. However, the distribution of some of the mobile invertebrates (e.g. *Tectura testudinalis* and *Cancer pagurus*) may probably be related to degree of wave exposure and ability to attach firmly to the substrate. The distribution of such species may probably benefit from shelters in space filled structures.

2.1.3 Microtidal Adriatic coast (Italy)

Multivariate and univariate analyses revealed differences in the composition of epibiota between the landward and seaward sides of breakwaters in all the localities investigated (Figure 3). The principal species responsible for these differences were oysters, *Mytilus galloprovincialis,* the green alga *Enteromorpha intestinalis* and microfilm (which consist of a mixture of spores, juvenile, unidentifiable macroalgae and sediment). On average, oysters and microfilm were more abundant on the landward side of breakwaters, while *M. galloprovincialis* and *E. intestinalis* were more conspicuous on the seaward sides of breakwaters. These different patterns of distribution may be probably related to a lower regime of water flow on the landward side of breakwaters with respect to the seaward side. A greater biomass of filter-feeders has been frequently recorded at exposed with respect to sheltered natural rocky reefs, due to a higher water turnover and consequent increase in the supply of food. (Bustamante & Branch, 1996). Studies are in progress to evaluate if other factors (e.g. recreational harvesting of mussels and other organisms) are related to the differential distribution between landward and seaward sides of the structures.

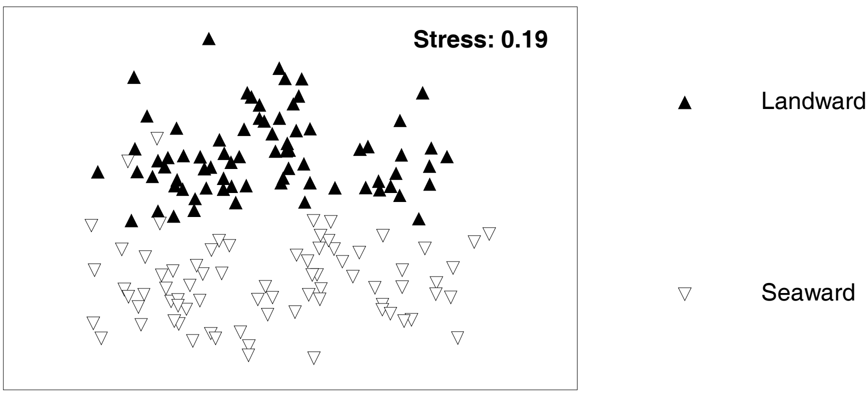

Fig. 3 - nMDS plot of assemblages colonising the landward and the seaward sides of breakwaters.

2.1.4 Microtidal south coast of Spain

To assess the effects of breakwaters on epibiota assemblages, randomly distributed sampling points were chosen within the structure on the seaward side, landward side and between blocks and on natural rocky shore near the structures, as reference sites. At Cubelles no significant differences in number of species and abundance of epibiota assemblages were found between landward and seaward side, while epibiota assemblages living on breakwater, were significantly different from reference sites ones (Figure 4) The reference sites were characterized by the abundance of *Corallina elongata* and *Mytilus galloprovincialis,* and presence of *Ulva* sp., all three species characteristic of Mediterranean supralitoral communities with moderate levels of eutrofication. By contrary, LCS was characterized by the presence of the mobile compressed invertebrate *Patella* sp. The red algae *Herposiphonia tenella* was only present in the landward side of the structures.

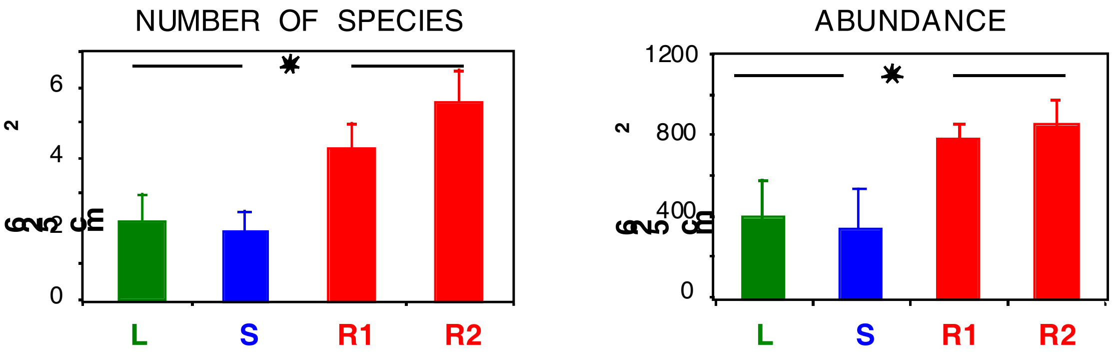

Figure 4 - Number of species and abundance of the epibenthic communities sampled in Cubelles LCS (L= landward side, S= seaward side, R1= reference 1 and R2= reference 2). The asterisk indicate significant differences at $p < 0.05$).

In Altafulla the epibenthic communities on the structure had significantly different characteristics than communities from natural environments. Species abundance and diversity, is higher in the reference sites than on the structure (Figure 5). Within the structure significant differences were found between the community facing seaward, landward side and between blocks. Filter feeders (*Mytilus* and *Balanus*) are abundant in the exposed site and between blocks, probably due to high water exchange and low sedimentation/scour. In contrast, the landward side is rich in opportunistic small algae (i.e. finely branched and epiphytes) typical of more confined environments.

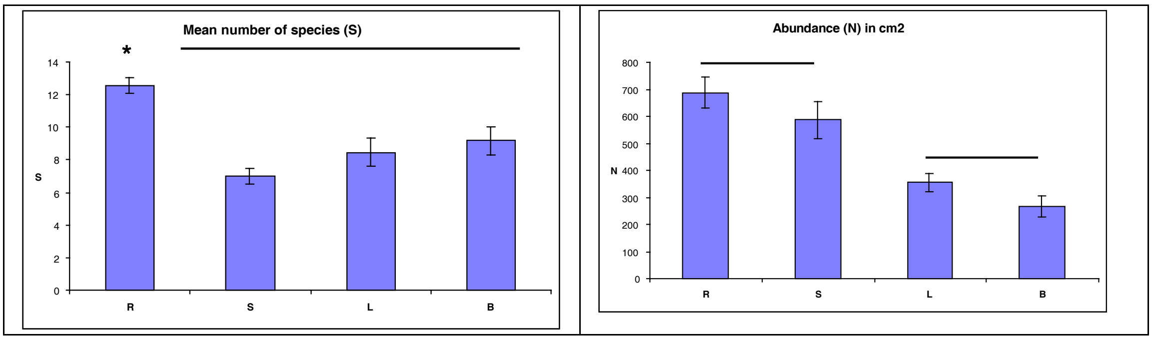

Figure 5 - Number of species and abundance of the epibiotic communities sampled in Altafulla LCS (L= landward side, S= seaward side, R= reference and B= between blocks). The asterisk indicates significant differences at $p < 0.05$).

In Cubelles , the multivariate analysis of the data allowed distinguishing three different groups (Fig. 6), which corresponded to the reference site communities, the land ward side of the structure and the seaward side of the structures.

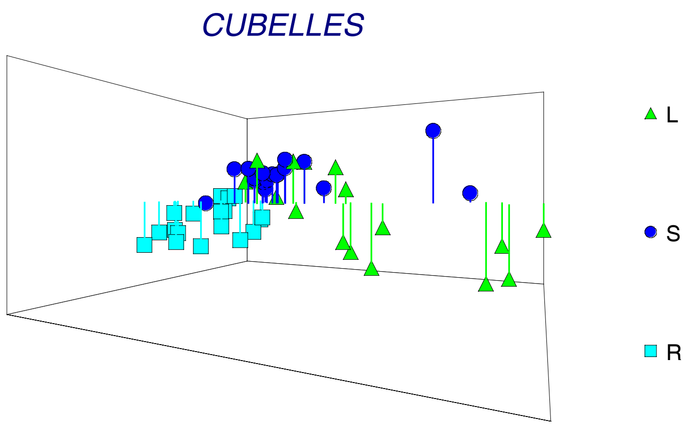

Figure 6 - L=landward side, S=seaward side and R= reference site

The MDS for Altafulla (figure 7) shows a clear separation of the landward samples from all the other samples. There is a gradient from landward to seaward to reference site. The samples from in between the blocks cannot be clearly separated from the seaward samples and from those of the reference site.

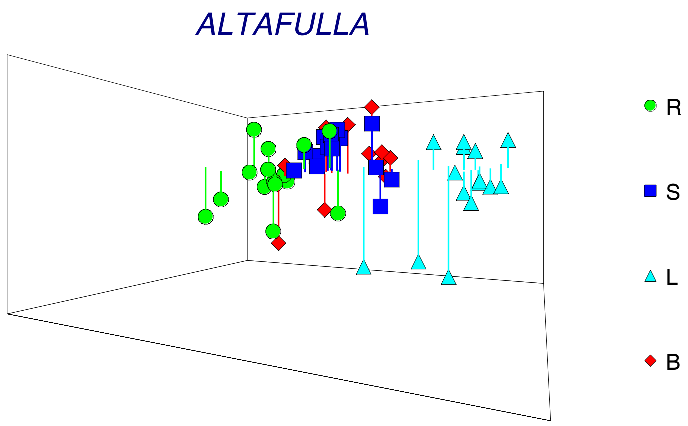

Figure 7 - L=landward side, S=seaward side , R= reference site and B= between blocks

2.2 Effects of location of coastal defence structures on epibiota

2.2.1 Macrotidal English and Welsh coasts (UK)

Geographical locations affected the abundance and composition of epibiota on coastal defence structures (Figure 8). The abundance and composition of assemblages on structures located in the south coast of England were significantly different from those on structures located in the west English coast (ANOSIM, $p<0.002$). No differences, however, were observed when only the presence/absence of species were considered, suggesting that geographical variation affects also the abundance (Figure 9). Geographical variation depends on various factors, including larval supply, currents, wave regime and tidal range. For example, in Liverpool mussels are super-abundant on LCS because recruitment is particularly high in that area. Oysters were found abundant on the east coast of England but they were rarely found on structures located along the English west coast.

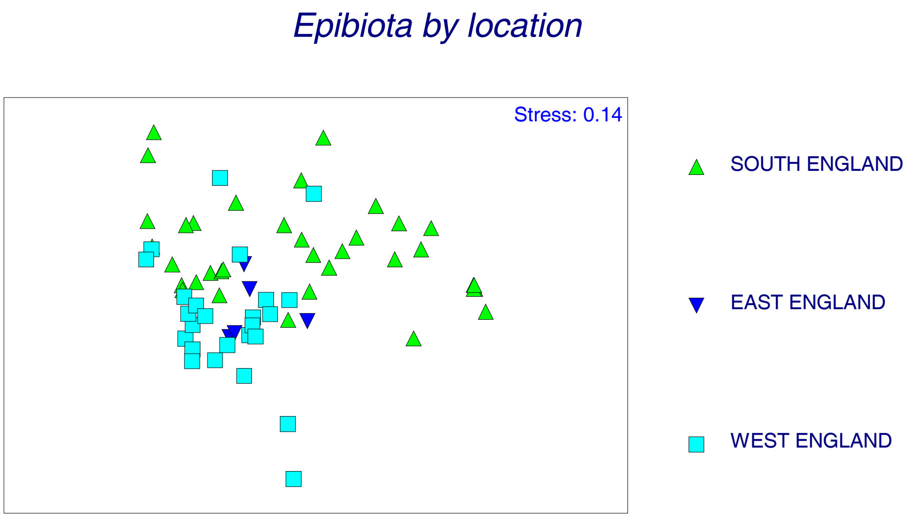

Figure 8 – nMDS plot of epibiotic assemblages on structures located along the south, west and east cost of England.

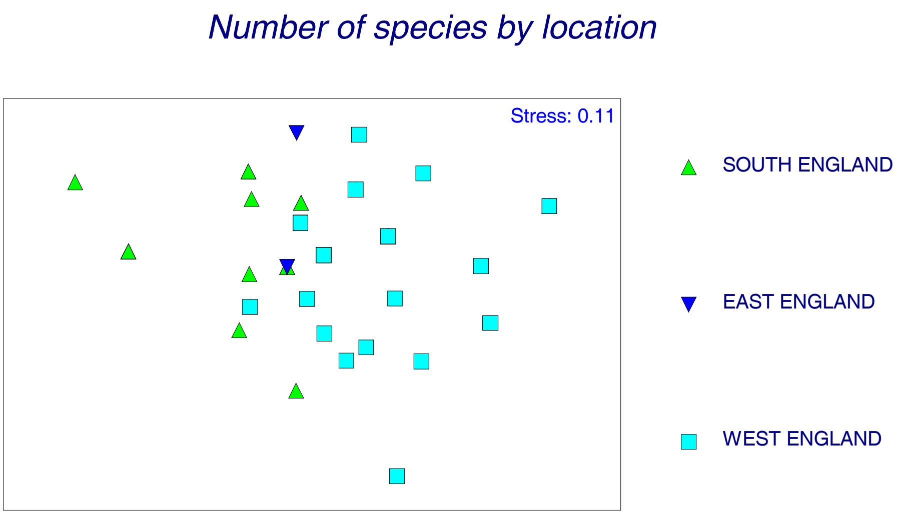

Figure 9 – nMDS plot of epibiotic assemblages on structures located along the south, west and east cost of England. In this analysis only the number of species were considered.

2.2.2 Microtidal North coast of Denmark

The abundance and composition of epibiota was to some extent affected by geographical location. Multivariate analyses showed that the intertidal assemblages (Figure 10, ANOSIM 1-way, global R:>0.5; p<0.001) associated with coastal structures differed between Northern (at Hirtshals, towards the North Sea-Skagerak) and Eastern (at Skagen East, towards Skagerak-Kattegat) structures (ANOSIM 1-way, R: 0.7). The epibiota of both the Northern and Eastearn structures showed only some separation from the Western structures (at Loenstrup, towards the North Sea) (ANOSIM 1-way, R:>0.45). Multivariate analyses of the combined intertidal and subtidal assemblages (Figure 11) showed similar results of difference between the North (Hirsthals) and the East (Skagen)(ANOSIM 2-way crossed, differences between locality across all depth, global R: 0.57, p<0.001). The differences could be explained by e.g. geographical gradients of salinity or species dispersal patterns, as well as wave exposure. The abundance and composition of epibiota was affected also by the vertical location. Interestingly, multivariate analyses (Figure 12, ANOSIM 2-way crossed, differences between depth across all localities (i.e. transects), global R: 0.53, p<0.001) showed that the assemblages differ significantly between the intertidal (0.0m), the shallow subtidal (0.5m) and the subtidal (1.0, 1.5, and 2.0m). The intertidal differed significantly from the remaining depths (ANOSIM pairwise test, R: 0.88-0.99, p<0.001). The shallow subtidal differed only in part from the subtidal (ANOSIM pairwise test, R:<0.46), whereas no difference was detectable between the subtidal depths (ANOSIM pairwise test, R: 0.31 to -0.025). Studies are in progress to evaluate whether degree of wave exposure is related to the overall distribution.

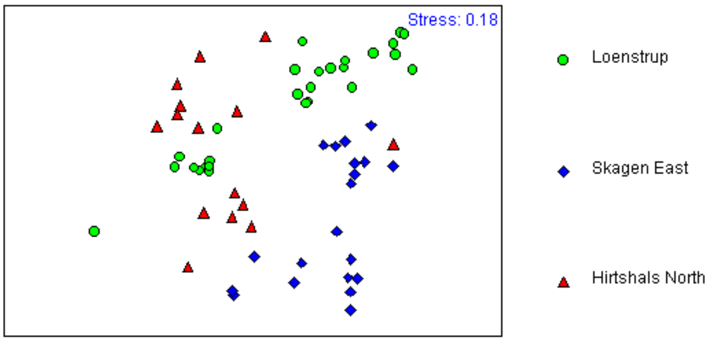

Figure 10 - nMDS plot of intertidal assemblages associated with breakwaters at the 3 locations along the shore in Northern Denmark.

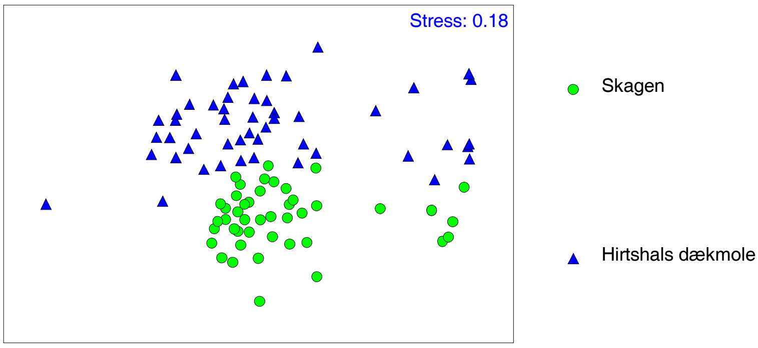

Figure 11 - nMDS plot of combined intertidal and subtidal assemblages associated with breakwaters at 2 locations along the shore in Northern Denmark.

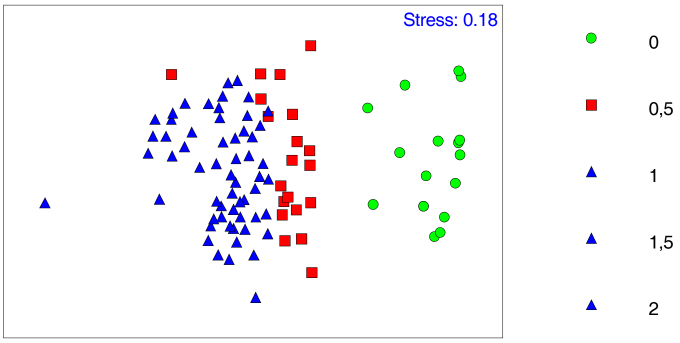

Figure 12 - nMDS plot of combined intertidal and subtidal assemblages associated with breakwaters at 2 locations along the shore in Northern Denmark, at 0.0, 0.5, 1.0, 1.5, and 2.0m).

2.2.3 Microtidal Adriatic coast (Italy)

The species composition of assemblages associated with coastal defence structures within each locality was relatively homogenous. Conversely, differences in the distribution of species were found among different localities along the coast of Emilia Romagna. Multivariate analysis (Figure 13) showed that the assemblages associated with coastal structures differed from North (Lido

Adriano) to South (Cesenatico). Some species, such as the alga *Enteromorpha intestinalis*, became less abundant from Northern to Southern locations while others such as limpet *Patella caerulea* increased their abundance from North to South. A general pattern of increasing species richness from North to South was observed. Thirteen species were found at Lido Adriano and 20 species were found at Cesenatico. Species that were only found at southern localities included the invertebrate *Monodonta mutabilis* and the algae *Gelidium spinosum, Codium fragile* and *Bryopsis hypnoides*. These results are consistent with observation of the distribution of specie over large spatial scale reported in Deliverable 29, which showed increasing species richness from Trieste south to Ancona. At present, little is known about the physical and biological factors underlying differences among localities. These could possibly be influenced either by geographical gradients of salinity and other physical/chemical characteristics of the water or by patterns of species dispersal from natural rocky reefs to artificial structures.

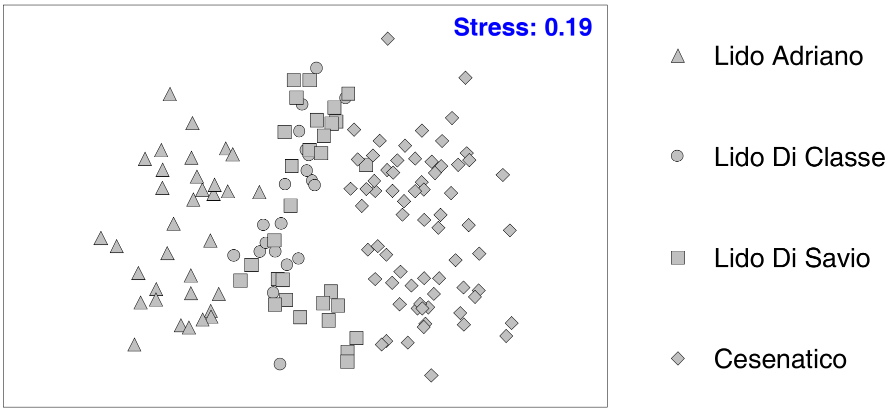

Figure 13 - nMDS plot of assemblages associated with breakwaters at 4 locations along the shores of the province of Ravenna.

2.3 Effects of tidal range on epibiota in the UK

In the UK the tidal range varies considerably along the coastlines, between approximately 2 m in the south coast to 10 m in the west coast of England. Multivariate analysis of the assemblages showed significant differences between the epibiota colonising structures located on shores with different tidal range, less than 6m and more than 6 m (Figure 14). As for the factor location, tidal range appeared to mainly affect the abundance of species rather than the species composition only.
In fact, most of the breakwaters located at similar tidal level investigated where characterised by similar species, although the relative abundance differed considerably.

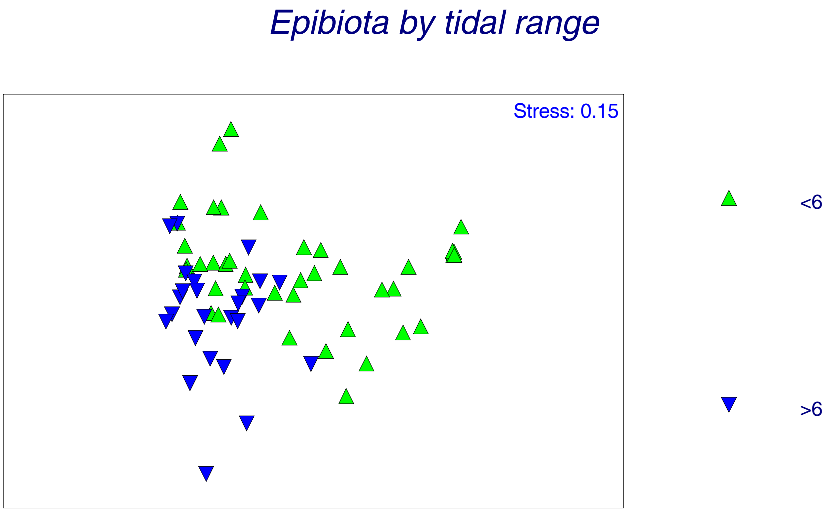

Figure 14 – nMDS plot showing differences in the epibiotic assemblages of structures located on shores with different tidal range.

2.4 Dynamics of assemblages on coastal defence structures

Abundance of conspicuous species on coastal defence structures at five stations along the Emila Romagna coast largely fluctuated between June 2001 and October 2002 (Figure 15). Average percentage cover of the mussel *M. galloprovincialis,* for example, ranged from 20 to 80%: temporal patterns of mussel abundance differed among structures located at different station and also among nearby structures within each location, and no clear courses were recognizable. There were large temporal fluctuations also in the abundance of Ulvales (mainly *E. intestinalis*). Temporal patterns differed among stations on the seaward sides of the structures, while on the landward sides the trend was rather homogenous between stations through time. A peak in abundance was observed in February at all the stations, except at Punta Marina, on the landward side, with an average percentage cover of 45%. Differences in percentage cover values ranged from about 0 to 51% on the landward and from 0 to 64% on the seaward sides of the structures. Oysters showed a regular trend in species dynamics through time. On the landward side of the structures, where oysters were generally more abundant, a decrease in their abundance was observed between the years 2001 and 2002 at the station Lido di Savio. At the other stations, the abundance of this species ranged from a minimum of 0, which was found at Punta Marina (for all the dates investigated), to a maximum of 22% at Casal Borsetti in October 2001. On the seaward side of the structures oysters varied from a maximum of 6% in October 2001 at Lido di Savio to 0% at Punta Marina. Observations suggest that temporal variability was likely related to both natural seasonal fluctuations in the abundance of species and the frequent disturbances from natural (e.g. wave action, grazing and predation) and anthropogenic (e.g. collection of a range of organisms for food or bait, and addition of new blocks for maintenance works) factors. Such severe disturbances create patches of space that are generally rapidly colonized by opportunistic species with large dispersal capabilities, thus keeping assemblages at a permanent pioneer stage.

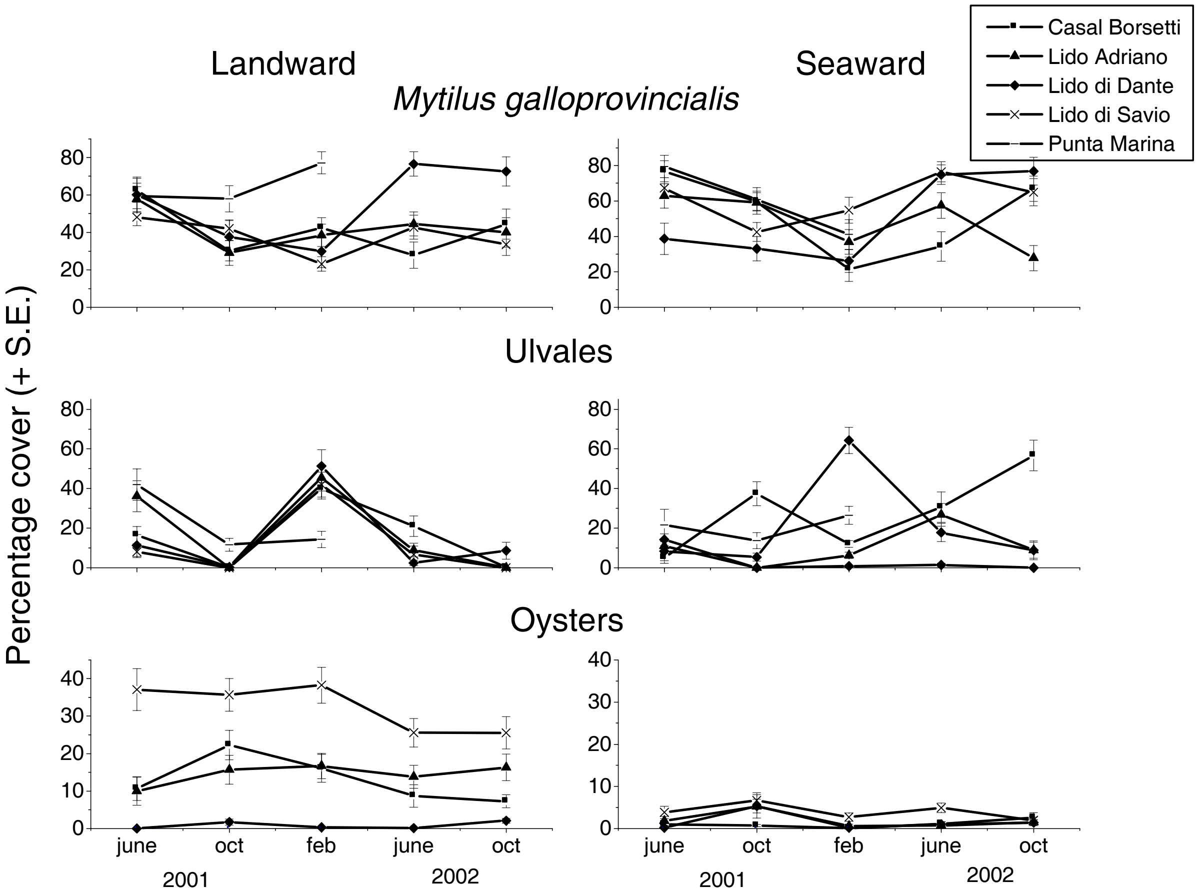

Figure 15 - Temporal variation of the most abundant intertidal specie on the landward and on the seaward sides of coastal structures at five different stations. Data are mean percentage covers (± S.E.; n=24) from June 2001 to October 2002.

Conclusions

These surveys provided the first quantitative data on the composition, distribution and dynamics of intertidal epibiota on coastal defence structures in Europe. Extremely similar patterns were observed in the different European coast despite the large difference in tidal range and latitude. They show that these structures are extensively and rapidly colonised by epibenthic assemblages. The diversity of species is, however, lower than on natural rocky shore, and epibiota are generally dominated by species with a large dispersal range. Diversity, however seems to increase with increasing depth of the structure (Denmark, UK). Environmental factors such as location, wave exposure and tidal range considerably affected, the distribution of epibiota.

In Italy, 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.

The structure of assemblages associated with coastal defence structures seems to be strongly influenced by their location. In Italy, breakwaters in the North part of the province of Ravenna have less species than southern breakwaters. This result probably reflects the presence of a geographical gradient from North to South. This trend may be explained by the close proximity of the Po river plume that may negatively affect the distribution of some species or by the effects related to the large distance of these structures from natural rocky reefs. In the UK the geographical variation observed in the abundance of epibiotic assemblages is mainly caused by larval supply, wave regime and secondarily tidal range. In Denmark, differences observed between locations are probably affected by geographical gradients of salinity or species dispersal patterns.

In all the countries, assemblages on coastal structures seem to be influenced also by their own position on the structure. Differences between the landward and seaward sides of breakwaters were observed in all the locations investigated. In general, suspension feeders (mussels, barnacles) dominated the exposed seaward side, whilst algae were more abundant on the more sheltered landward side. This pattern may be related to differences in the flow regime between sheltered and exposed positions.

In Italy, the high temporal heterogeneity observed on assemblages associated with coastal structures, may be related to disturbance by frequent maintenance work done to the structures. Experiments are in progress to investigate the important role of this factor.

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