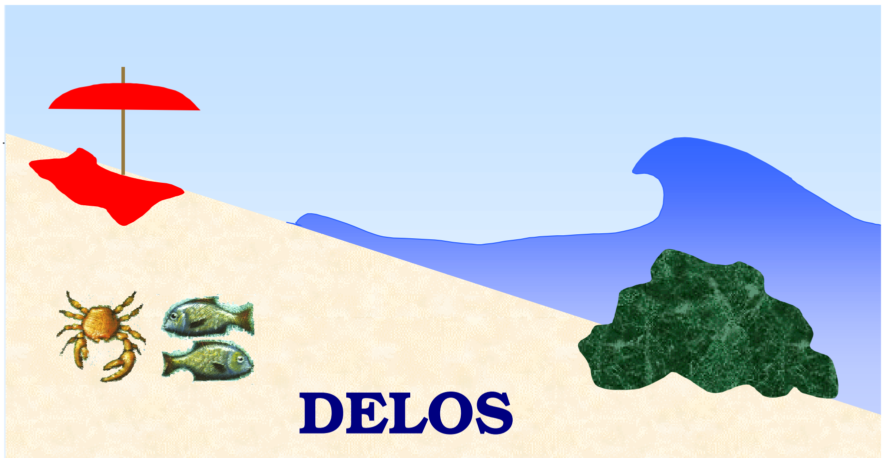
EU Fifth Framework Programme 1998-2002
Energy, Environment and Sustainable Development

Environmental Design of Low Crested Coastal Defence Structures



Deliverable 45

WP 3.1

Identification of design features to maintain biodiversity of soft-bottom assemblages

Contract n°EVK3-CT-2000-00041

DELIVERABLE 45

Identification of design features to maintain biodiversity of soft-bottom assemblages

RESULTS OBTAINED BY THE CSIC (SPAIN)

DESCRIPTION OF THE STUDY SITES

The CSIC team has been focusing their research on soft bottoms in two sites with very different characteristics, from the point of view of the complexity of the system, the Cubelles system and the LCS at Altafulla.

Cubelles

The LCS in Cubelles is a part of a series of structures extending along 3 Km of coast. The longest one placed in between of the series was built to protect the inlet and outlet seawater flows coming from the thermal power station of Cubelles. The others, including the target one, were built to protect beaches and, particularly at the study site, the construction was followed by beach nourishment. The studies LCS (figure 1) is composed of three structures parallel to the coastline and is laterally closed by two groins (the southern one semi-submerged). The main characteristics and measurements of the structure are summarized in Fig. 1).

The characteristics of the soft bottoms and the infaunal community surrounding the Cubelles LCS can be summarized as follows. The only significant environmental difference shown by the analytical design was that depth was consistently lower at the seaward side. The infaunal community around the LCS and in the control were basically the same, with polychaetes and amphipods being the major contributors to the abundance. The origin of the differences found around the LCS can be basically attributed to an infaunal abundance lower in the landward side than in the control and seaward, this resulting in significant differences between seaward, landward and control treatments, independently of the a characteristically high within-treatment variability. In all treatments, however, some species showed characteristic patterns of distribution, which allowed to define the observed differences.

Altafulla

The LCS in Altafulla is a simple, single structure, located in front of a beach, and was built to protect the sand added facing a rocky point, this resulting in a single large beach which joined the two previously separated northern and southern ones. The structure is, thus, smaller and more open than the previously studied one in Cubelles.

The characteristics of the soft bottoms and the infaunal community surrounding the Altafulla LCS can be summarized as follows. In the case of the environmental factors, two main differences among treatments were observed. The sediments were slightly but consistently coarse at seaward and finer at control sites. Like in Cubelles, the infaunal community around the LCS and in the controls were basically the same, with polychaetes and amphipods being the major contributors to the abundance and there was a characteristically high variability within treatments. The infauna, however, showed significant differences in abundance between seaward and landward, while the controls only differed from landward.

In addition to the ANOVA design that will allow the comparisons between Cubelles and Altafulla explained in the next section, a new experiment to assess the area of influence of the LCS on the surrounding soft bottoms (implying the collection of samples along transects at a successive distances from the LCS) was carried out also in Altafulla (based a theoretical morphodynamic model developed by the UPC).

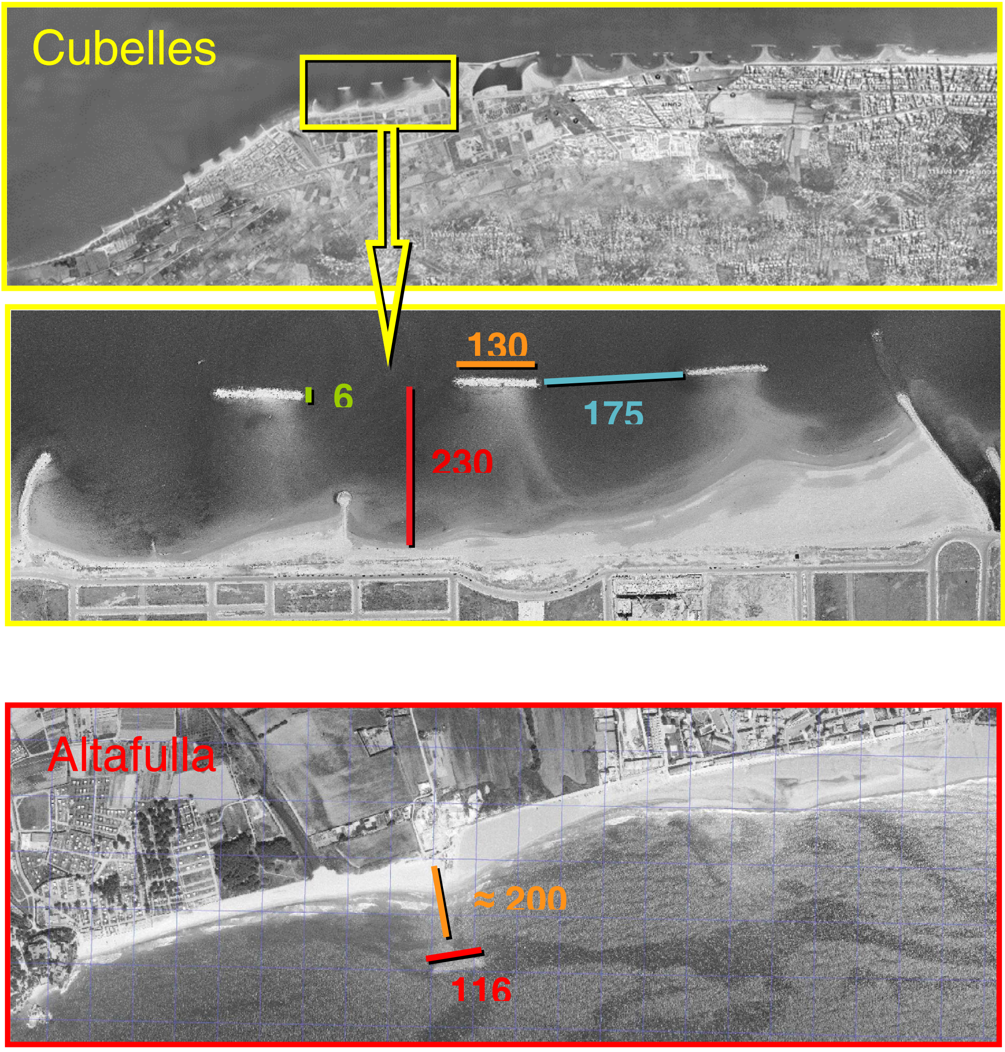


Figure 1.- The two LCS systems studied by the CSIC, Cubelles and Altafulla (NE Mediterranean coasts of the Iberian Peninsula).

The results of this new experimental design pointed out that the sediments were finer when deeper and far from the LCS, while this trend coincide with an increase of the abundance of microphytobenthos. This seems clearly derived from the influence of a generally higher hydrodynamism around the LCS. Accordingly, most infaunal biological descriptors tended to increase their values with depth and tended to decrease with the increasing grain size.

However, around the LCS these relationships were non-linear as the presence of the LCS induces a disruption in the normal progress of all variables from the shoreline to deeper waters. Moreover, the observed tendencies are not strictly perpendicular to the coastline and the southern and northern areas tend to show different trends witch are certainly linked to the hydrodynamics around the LCS.

Two additional characteristics of the soft bottoms and infauna around the Altafulla LCS, pointed out with the help of the new experimental design, is that showed: 1) a higher variability at landward and 2) lower values in sites seaward the LCS than at the corresponding sites along the control transects. Both trend are, thus, caused by the disturbance induced by the presence of the LCS.

CUBELLES VERSUS ALTAFULLA

The comparative analysis of the infaunal assemblages surrounding the Cubelles and Altafulla LCS pointed out the the overall species composition in the two study sites was very similar, this corresponding in all cases to more or less modified facies of the fine sand community of *Spisula subtruncata* (with the exception of some of the shallowest stations, which were facies of the beach surf community)

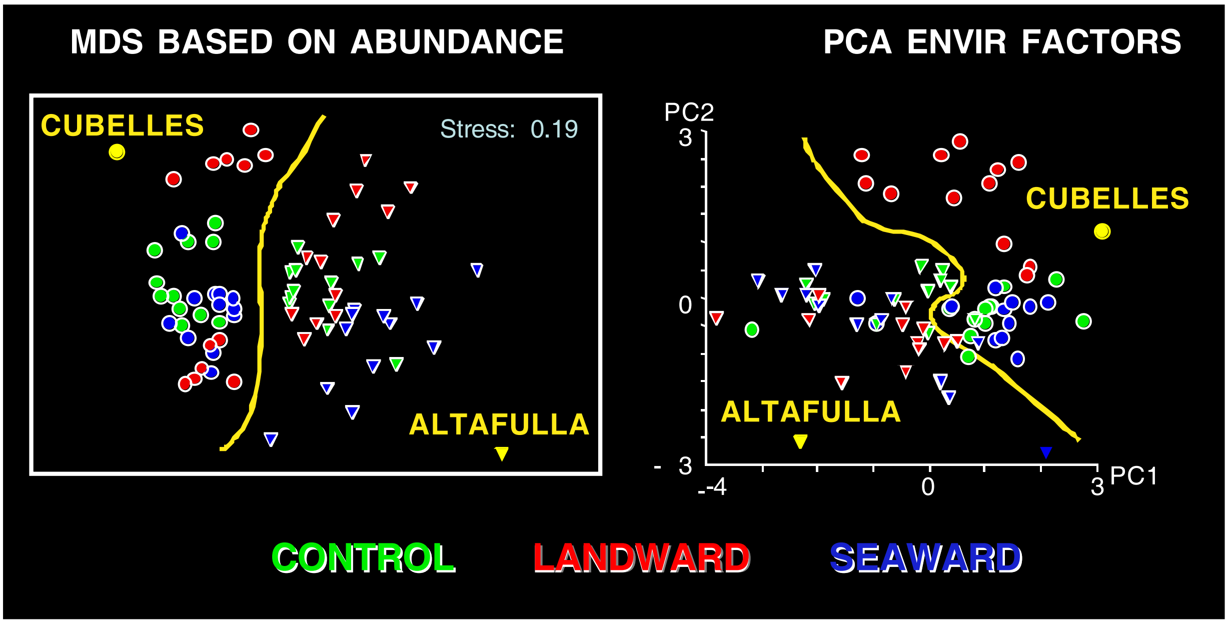


Figure 2.- Multivariate analysis allowing to compare the different treatments and samples stations in Cubelles and Altafulla on the basis of infaunal abundances (MDS) and environmental descriptors (PCA).

Besides the fact that both localities harbour similar species, the respective assemblages clearly differ in their structure, as reflected by the position of the different stations in the MDS based on abundances (Fig. 2). In fact, all the sampling stations corresponding to Cubelles were completely isolated from those of Altafulla. In both sites, however, the three treatments (seaward, landward and controls) did not follow similar internal patterns of distribution (Fig. 2), this suggesting that the processes that may be involved in the organisation of the soft bottom fauna could play slightly different around the two LCS systems. The infaunal assemblages in Altafulla were richer that those in Cubelles, and the abundance and diversity also tended to be higher; conversely, the biomass tended to be lower in Altafulla (Fig. 3). However, this trend is valid for the control and landward treatments while all biological descriptors showed lower values in Altafulla than in Cubelles at seaward (Fig. 3).

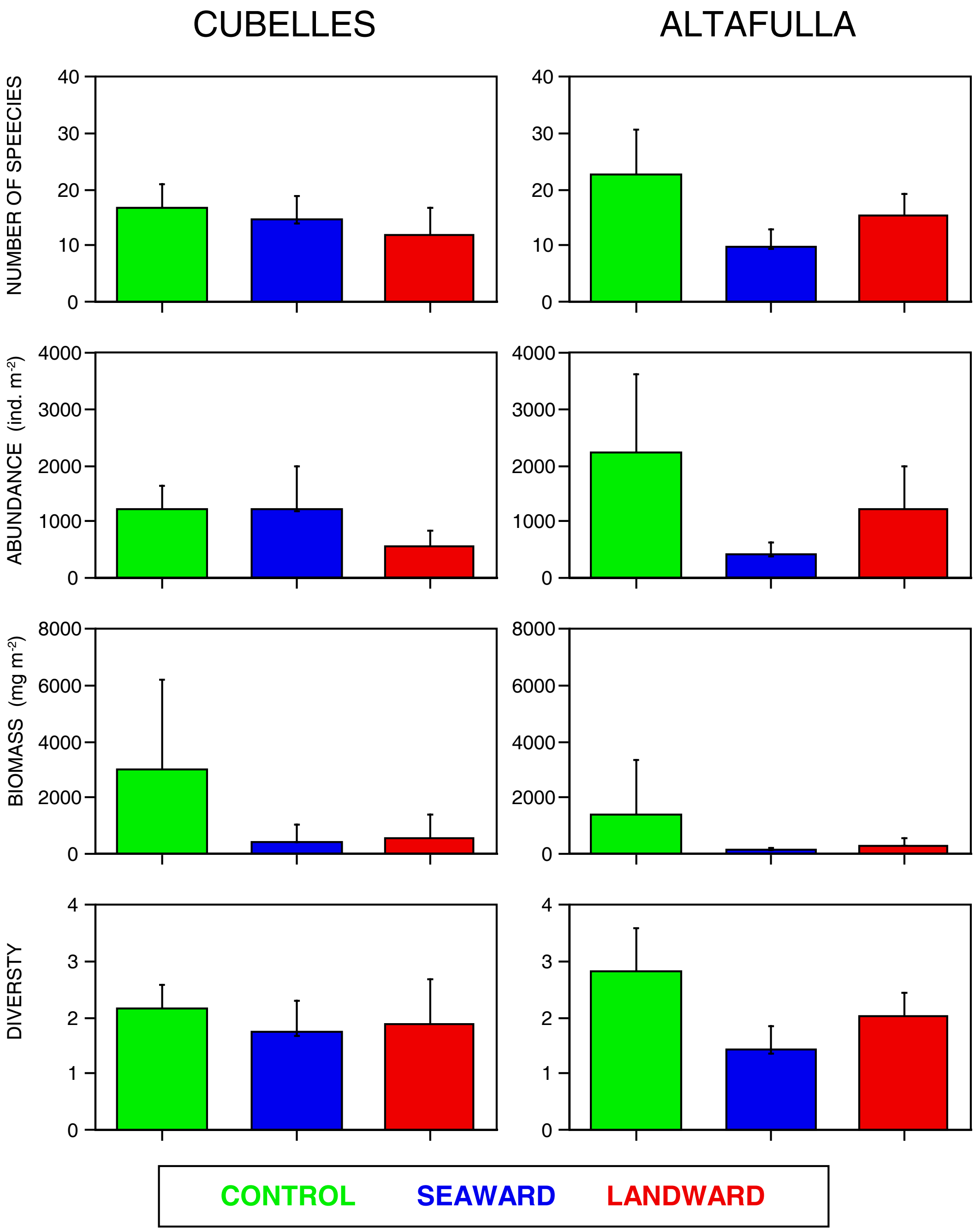


Figure 3.- Summary of the main faunal descriptors at the two studied LCS systems.

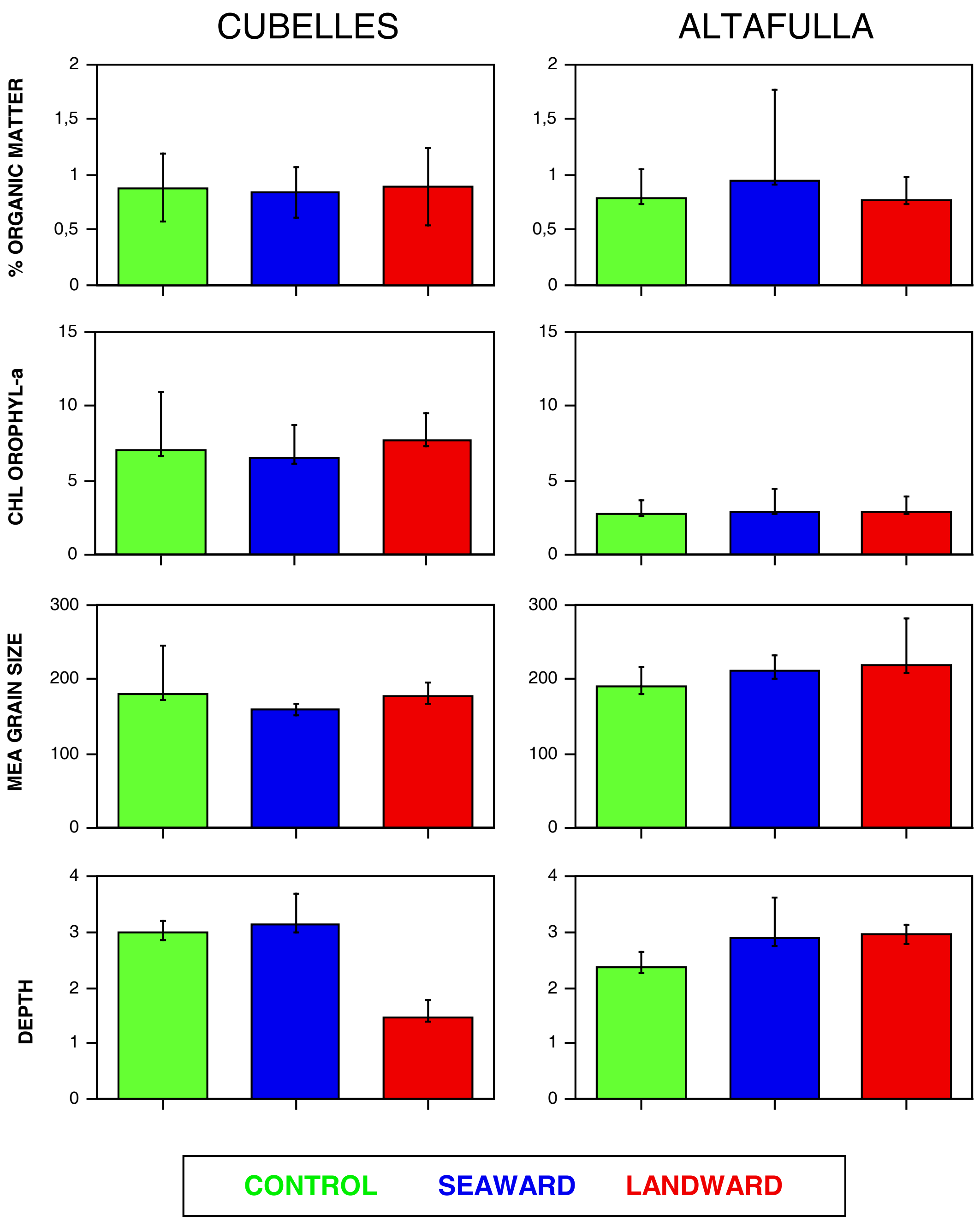


Figure 4.- Summary of the values of he environmental descriptors measured in Cubelles and Altafulla.

When looking for the possible explanations of the above trends, the attention should be addressed to the environmental descriptors. The multivariate analysis based on these descriptors also pointed out a clear difference between Cubelles and Altafulla (Fig. 2). In that case, the distribution of the respective sampling stations seems to be driven by the opposite trends shown by depth, chlorophyll content and mean grain size in the PCA (Fig. 5). This can be also observed when comparing the averages for all environmental descriptors in both localities (Fig. 4). Cubelles has, in average, higher chlorophyll content and slightly finer sediments, while the most relevant difference regarding depth concerned the landward stations, which seems to be particularly shallower in Cubelles.

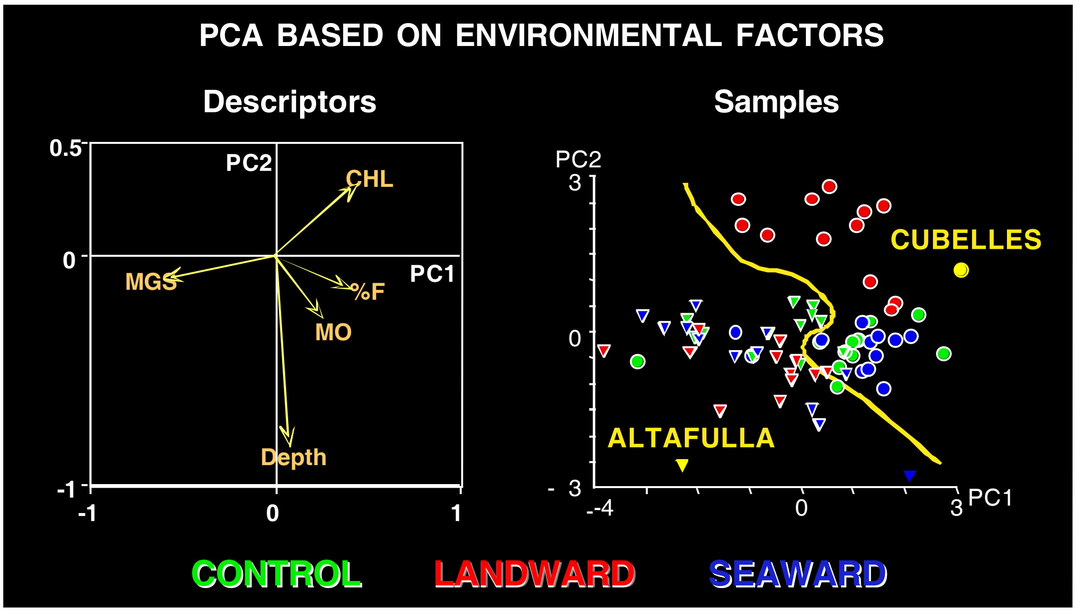


Figure 4.- Multivariate analysis based on environmental descriptors (PCA), position of sampling station (sameas Fig. 2 on the right) and relative weight of each environmental descriptor.

RESULTS OBTAINED BY THE MBA (UK)

The influence of LCS on sediment characteristics and soft-bottoms assemblages was investigated by the MBA at Elmer (West Sussex) and North Wirral (Liverpool), located in the south and west English coast respectively.

LIVERPOOL STUDY SITE– King's parade breakwaters

Location

The study focussed on two breakwaters (King's Parade) which are located in the North Wirral coastline. This coastline is characterised by a macrotidal regime, with 10m maximum tidal range. In general the shore consists of fine sand flats, forming dunes and gullies. Littoral drift is predominatly in the North East direction. The North Wirral coast is subject to erosion caused by a combination of high spring tides and exposure to large waves under stormy conditions. Also, beach erosion is increased by the apparent lack of sediment supply from the North Wales coast.

Structure design

King's parade breakwaters are part of a wider coastal defence scheme that protects the north Wirral coastline in proximity of Liverpool. These breakwaters were built between 1984 and 1985 to reduce beach erosion, thus encouraging deposition of beach material and increasing the amenity value of the beach. Both breakwaters consist of pre-cast concrete T units (diodes) and armourstone blocks and are shore-connected (Figure 1a-c). The type of mixed structure in concrete and armourstone is overall more porous than that built with natural stone. This allows the construction of a lower crest level, in consequence of a reduced overtopping effect.. The two breakwaters have a slightly different design, although they are both connected to the shore. One breakwater (Figure 1a) has a Y shape, whilst the other has a T shape (Figure 1b). Their crest level is 4 m and the offshore segment of the Y and T shaped breakwaters is 240m and 260m long respectively. The distance of the offshore segments from the shoreline is approximately 200m. Due to the extensive tidal range and minimal beach slope, there are no differences in the tidal level, between the landward and seaward side of the breakwaters.

Figure 1 – King-s parade breakwaters in the North Wirral coast (Liverpool): a) Y shaped LCS; b) T shaped LCS; c) close-up of the LCS showing the mixed structure in concrete and limestone blocks.

Summary of biotic and biotic characteristics of sediments around Liverpool LCS

The presence of a shore-connected link on the landward side of the two structures did not appear to affect the assemblages, as no significant differences were found between the communities and sediment descriptors either sides of the link.

The LCS modified considerably the characteristics of the soft-bottoms surrounding the breakwaters. Chlorophyll *a* content on the landward side was on average almost the double than on the seaward side of the structures. However, in control areas and at increasing offshore and inshore distances from the structures chlorophyll *a* was much reduced, showing increasing eutrophic conditions in proximity of the structures. Surprisingly, organic matter was very low near the structures, whilst increased higher on shore. In control areas and further offshore from the structures organic matter had intermediate values. A clear gradient was also observed in the granulometry measured around the breakwaters, control areas and at increasing inshore and offshore distances from the structures. The sediment in the study area investigated was mainly sand. However, on the landward side of the structures the sediment was finer, consisting also of silt/clay. This component was present also at the inshore distances from the structures, but decreasing towards the shoreline. The seaward sediment apparently was not affected by the structures, consisting of sand as in the control areas. A summary of the main gradients of sediment descriptors around the breakwaters is depicted in Figure 2.

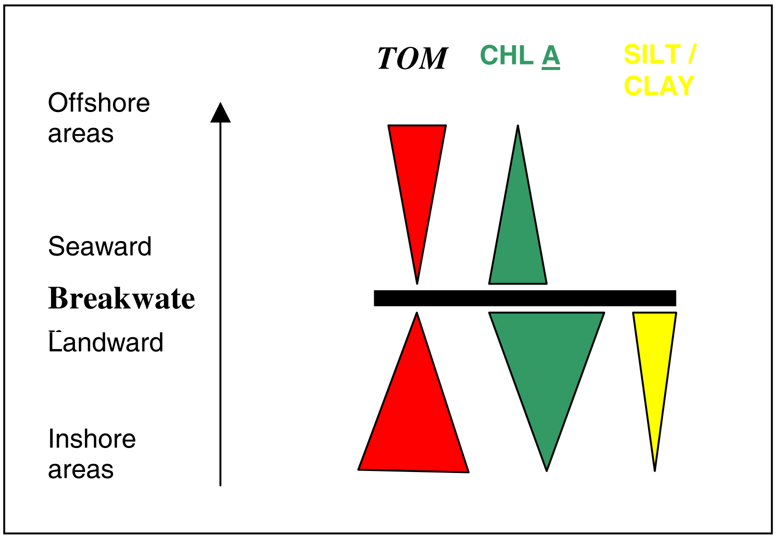


Figure 2 – A summary diagram of gradients in observed sediment features observed at either side of the breakwaters. The width of the triangle indicates the gradient of the different parameters around the breakwaters. the Inshore areas are located higher on the shore whilst off-shore areas are located lower on the shore in respect of the breakwater. The sediment component of silt/clay was not present on all areas located on the landward side of the structure.

The LCS had also an effect on the infaunal communities, although this was localised mainly on the landward side. The community on the landward side was significantly different in composition and abundance from the seaward side and control areas (Figure 3). The main difference can be attributed to the almost exclusive presence on the landward side of the species *Corophium arenarium* that burrow in fine sediments. The community of the landward side was also characterised by lower diversity (indicated by Shannon's Index and total number of species) but relatively high abundance of individuals. The infaunal community on the seaward side was relatively similar in species and abundance to the control areas, but differentiated considerably from the more offshore areas. However, not statistical differences could be detected when these parameters were formally compared.

The infaunal community was dominated mainly by polychaetes and crustacean amphipods. The relative proportion of these two groups is similar in all the areas investigated except for both landward and seaward sides, where there the abundance of amphipods is approximately the double than that of polychaetes. The dominance of amphipods over polychaetes is mainly caused by the extreme abundance of two species only, C*orophium* on the landward side and *Bathyporeia sarsi* on the seaward side.

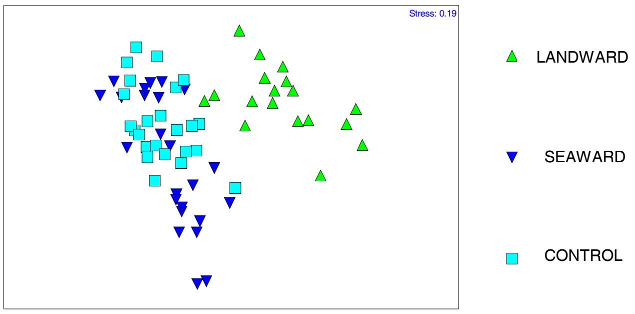


Figure 3 – MDS plot of abundance and composition of the infaunal community around the breakwaters in Liverpool.

ELMER STUDY SITE

Location

Elmer defence scheme is located in West Sussex coastline, in the south of England. The mean tidal range is 6.3m. The beach consists of shingles high on the shore and medium to fine sand lower on the shore. The beach is predominantly exposed to south-westerly winds and the sediment drift is from west to east. The coastline prior the construction of the defence scheme was subject to rapid erosion and the residential low lying area behind the shore was often flooded due to storms or extreme spring tides.

Structure design

The Elmer defence scheme was built between 1991 and 1993 and consists of 8 shore-parallel breakwaters (Figure 4a). These structures were designed to reduce the near shore wave energy and retain the shingle nourishment material on the top of the shore. As a consequence, the protection of residential houses from flooding also increased. The rock islands are made of Norwegian granite and do not have a core, thus overtopping is relatively reduced (Figure 4b). Their crest level is approximately 6m and their width is 4m. They are located 130m from the shoreline, although this distance varies slightly between structures. Most of the structures show the formation of a tombolo on the landward side, thus on this side the tidal level is slightly higher than on the seaward side.

Figure 4 – Elmer defence scheme. a) aerial view, showing tombolo formation on the landward side; b) close up on one structure.

Summary of biotic and biotic characteristics of sediments around Elmer LCS

At Elmer, the MBA carried out two studies, in 2001 and 2002. The first study was limited on the effects of LCS on the infaunal community and sediment descriptors, whilst the second investigated the extent to which these effects were evident along the shore and the effect of tidal level. Here a summary of results from both studies will be outlined. The small difference in tidal level between landward and seaward caused by the tombolo formation appeared not to be important, thus the results obtained were not affected.

Results from the two studies were consistent. The sediment characteristics showed only slight differences between the different locations, particularly between the landward and seaward sides of the structures (Figure 5). Chlorophyll *a* was generally lower on the landward side than on the seaward side, this being similar the control areas located at increasing distances from the structures. Organic matter was evenly distributed in the locations investigated, except for the landward where a slightly higher value was recorded. On this side of the structures sediment was also finer, showing a small percentage of silt/clay. All the sediment descriptors, however, did not show statistically significant difference, also due to the high within location variability. In conclusion, no clear pattern could be observed in the sediments surrounding the breakwaters, these being very similar to control areas along the coastline.

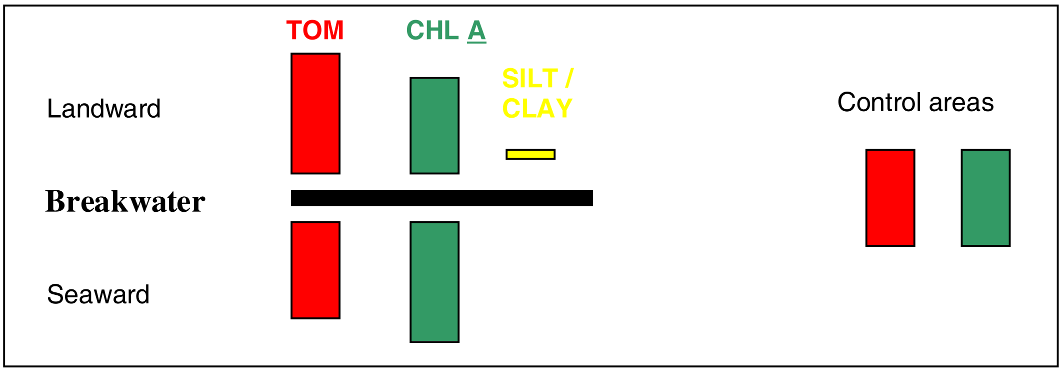


Figure 5 – A summary diagram of the relative proportion of TOM, Chl *a* and silt/clay sediment around the LCS and in control areas. Silt/clay was present in minimal quantity on the landward side of the structures only.

Similarly to the Liverpool study, the LCS modified the infaunal community on the landward side of the structures. Significant differences between the landward and the seaward side were clearly shown by the multivariate analysis (Figure 6). In contrast with the results obtained from the Liverpool study, the dissimilarity between landward and seaward at Elmer structures was attributed to the species *Bathyporeia sarsi*, which was 5 times abundant on the landward side. On the landward side diversity was lower (indicated by Shannon's index and total number of species) but abundance was higher than in other locations. The seaward side and the other control areas along the coast were very similar in diversity and abundance of organisms. As for the Liverpool study, the univariate analysis of these parameters did not show, however significant differences between treatments, probably due to the high variability which characterised all the areas investigated.

Crustaceans dominated the infaunal communities in all the locations considered. On the landward side, however, the disproportion between polychaetes and crustaceans, was particularly high. On this side of the structure, the average abundance of amphipods was approximately ten times higher than that of polychaetes. Once again, the extreme abundance of *Bathyporeia* species was the main cause for the difference observed.

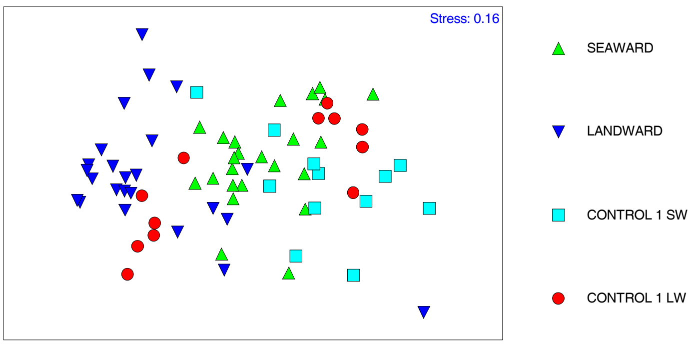


Figure 6 – MDS plot of abundance and composition of the infaunal community around the LCS at Elmer.

SOME CONSIDERATIONS ON THE INFLUENCE OF LCS DESIGN FEATURES AND ENVIRONMENTAL FACTORS ON SOFT-BOTTOMS IN UK

The two study sites in Liverpool and Elmer are located in very different regions of England, in the west and the south English coast respectively. In particular, the study site in Liverpool is located at the mouth of a large estuary and the beach consists of sand flats, whilst Elmer defence scheme is located in a more exposed beach on the open coast. The two locations also differ in tidal range (10m *versus* 6m), species recruitment (very high in Liverpool and low at Elmer), nutrients and local hydrodynamics. These factors have an important effect on sediment characteristics and infaunal communities. Here the effects of LCS on soft-bottoms will be considered in relation of the environmental setting, highlighting similarities and differences between the two study sites.

All the biotic and abiotic variables investigated showed a high degree of spatial variability in both study sites. The high level of variation within location was generally higher than between locations, thus univariate analysis often failed to detect significant differences between treatments. Despite this variation, however, it was possible to identify some common patterns, often validated by multivariate analysis. There was a clear effect of LCS on soft-bottoms, but on the landward side only. This effect was localised in a few square meters around the breakwaters. The effect of LCS on the landward side included changes in the sediment characteristics and the infaunal community.

The first effect observed was the modification of the sediment grain size, which shifts from sand to silt/clay. This finer sediment was virtually absent in all the other areas investigated. The silt / clay component accumulated in Liverpool was however greater than at Elmer, corresponding to 10% of the total sediment. The reduced accumulation of fine sediment at Elmer (1% of the total sediment) can be attributed to the higher hydrodynamics in respect of Liverpool, where most of the wave energy is probably dissipated offshore. Furthermore, the type of structure might influence the composition of sediment on the lee of LCS. In Liverpool, the lower part of the structures, from the base to 3 m height, consist of limestone blocks of various sizes. The porosity, in this part is very low and most of the cavities between the blocks are filled with sediment and mussels which help sediment trapping. This might considerably reduce the water flow through the pores, creating relatively still water condition behind the breakwaters.

The amount of total organic matter (TOM) measured in the sediments in Liverpool was on average three times higher than that at Elmer. This was expected, as organic matter is found on average in higher concentration in estuaries than the open coast. The distribution pattern of the organic matter around the breakwaters and control areas was however very different in the two study sites. In Liverpool organic matter in proximity of the breakwater was on average, half the amount measured in the control areas and the highest values were recorded high on the shore, in correspondence of the breakwater. The low values recorded in proximity of the breakwater could be due to consumption by bacterial mats and deposit feeders, such as *Corophium arenarium.* At Elmer, TOM was slightly higher on the landward side than on the seaward side and control areas, but this difference was minimal. Low organic matter is generally typical of more exposed beaches. The two sites differed also in the type of sediment surrounding the breakwater. In Liverpool, only sediments around the breakwater were highly anoxic, whilst at Elmer the anoxic layer was small and did not differ between locations.

Similarly to organic matter, chlorophyll *a* concentration was greater in Liverpool than Elmer. The higher concentration of chlorophyll *a* in the Liverpool study site indicates the presence of a certain level of eutrophication. The landward side of the structures and, to a minor extent, the areas located high on the shore, showed particularly high levels of chlorophyll. The pigment was three times higher on the landward than on seaward side of the breakwaters. Chlorophyll *a* in Liverpool was, on average, higher nearby the structures than in control areas. Very similar values were observed in the various locations at Elmer, suggesting no effect of the LCS on this parameter. The reduced level of chlorophyll *a* at Elmer indicates a less eutrophic state of waters and sediments but also a higher hydrodynamics.

The effects of LCS on the infaunal communities were similar in pattern, but differed in terms of magnitude. In both study sites, the sediment infauna on the landward side differed significantly from the seaward side and control areas. Differences in abundance and composition of infaunal assemblages between landward and seaward were much greater in Liverpool than at Elmer. This sharper gradient in the infaunal community is likely to be caused by stronger difference in hyrodynamics and consequently in sediment granulometry. This provides more diversification in the habitats that might lead to an increase in species diversity. In Liverpool a considerable number of species were exclusive of one location. The landward and seaward areas had in common 13 of the species identified, whilst the other 7 and 10 species were exclusive of the two locations respectively. Another 6 species were observed only in the control location. This suggests that despite the total number of species did not vary significantly, there was a considerable increase in the total species diversity. The presence of LCS appears therefore to increase diversity, as 7 of the species found in proximity of the breakwaters were not present in all the sampling areas sampled, including the control location and the increasing offshore and inshore distances. The LCS seems to affect also the abundance of infaunal assemblages, as the total number of individuals in proximity of the LCS was almost the double of that observed in control areas. This large difference, however, does not reflect an increase in the abundance of all species, but it is mainly caused by the presence of very large numbers of the amphipod *Corophium* on the landward side and *Bathyporeia* on the seaward side. The dominance of these two taxa could lead to the total exclusion of more rare species and consequently reduce the overall diversity.

At Elmer, difference in the infaunal communities between the landward side of LCS and the control areas were less evident. Infaunal communities also differed significantly between the landward and the seaward side, particularly in terms of species composition. In total, 11 taxa were present on both sides, whilst 6 and 5 species were exclusive of the landward and seaward respectively. Similarly to Liverpool, seven species were observed only in proximity of the LCS, but the species composition varied considerably also in the control areas. The variability that characterised all the areas investigated might be explained by the more exposed and dynamic conditions of the beach at Elmer. Sediment conditions and consequently infaunal communities can change considerably from one place to another. This high variability characterised also the abundance of infaunal communities, as the number of individuals for each species varied greatly between locations. The total abundance on the landward side was considerably higher than that on the seaward side, but such difference was also observed between control areas at increasing distances from the structures.

RESULTS OBTAINED BY THE FF (ITALY)

The FF team has been focusing its research on soft bottom in two subsequent years at Lido di Dante, stressing out the spatial effect of the LCS presence.

DESCRIPTION OF THE STUDY SITES

Lido di Dante is a seaside resort located on the Emilia-Romagna coast 7 km far from the city of Ravenna, Italy. Lido di Dante area is located between Fiumi Uniti river mouth and Bevano river mouth. The coastline in front of Lido di Dante is characterised by a flat dissipative sandy beach, with a wide surf zone, exposed to wind and wave action mainly from the southeast during the summer, and from northeast during the winter. The beach sediments are composed of fine to medium sands. The seabed has a quite gentle slope, of about 6m/Km. Tides in the area have a maximum range of 0.90 m.

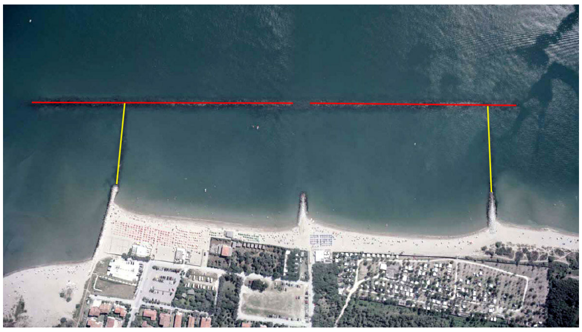


Fig. 1 – An aerial picture of Lido di Dante. The breakwater (red lines) and the submerged traits of the groins (yellow lines) are highlighted.

A semi-submerged breakwater of 770 m long protects the beach (Fig. 1). The breakwater is almost parallel to the coastline and placed at 180 m from there, at 3.5 m depth. In addition, three rocky groins are 300 m apart. The breakwater presents a gap in its centre, about 30 m wide. Both the northern and the southern groins have submerged traits that connect the groin heads to the barrier. Such complex of different structures creates an area almost completely confined from the surrounding seabed.

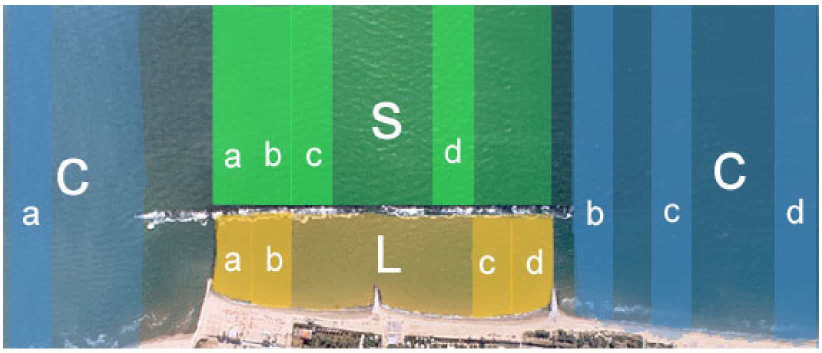


Fig. 2 – Layout of the experimental design of the first year study (2001). C = control site; L = landward site; S = seaward site. a, b, c, d = sampling areas.

LCS EFFECT ON THE SURROUNDING SOFT-BOTTOM (FIRST YEAR STUDY, 2001)

The aim of the study, carried out in Lido di Dante in July 2001 (First Year Study, Deliverables 18, 33), was to assess the response of the benthic communities inhabiting the sediments surrounding the low crested structures (Fig. 2).

The analyses on the benthic fauna were coupled with measurements of some of the main sedimentary descriptors: silt/clay fraction, Total Organic Matter (TOM) content, Chl *a* concentration and shell debris amount.

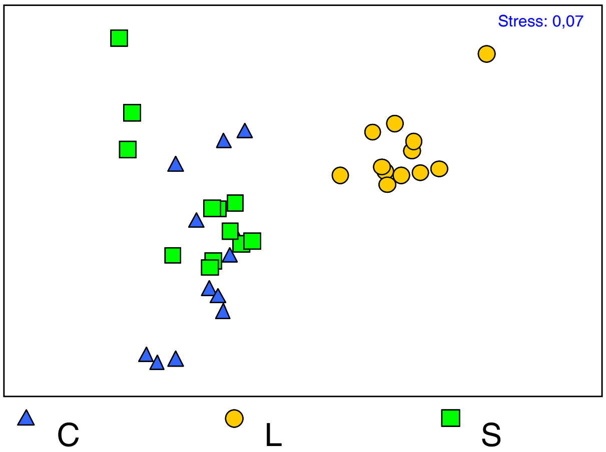


Fig. 3 – nMDS plot of macrobenthic communities based on fourth-root transformed species abundance data of the First Year Study. C = control site; L = landward site; S = seaward site.

The characteristics of soft bottoms and of infaunal community surrounding the Lido di Dante LCS can be summarized as follows. As for sediment descriptors, the only statistically significant difference revealed by the analyses concerns the amount of shell debris, which was consistently higher at the landward (L) site than in the other ones. Total abundance and biomass of infaunal organisms did not differed among sites. This was due to the high within-treatment variability, especially in the control site (C). However, the infaunal community of the landward site resulted significantly different from those of the other two sites, whereas no differences occurred between community structure in the control (C) and seaward (S) sites (Fig. 3). Polychaetes were the taxon which mainly contributed to the abundance values in the L site. Otherwise, bivalves were very abundant in the C and S sites, mainly because of the dominance of *Lentidium mediterraneum*, a typical species of the Adriatic Coast biocoenosis.

LCS EFFECT AT DISTANCE FROM STRUCTURES (SECOND YEAR STUDY, 2002)

The study carried out in Lido di Dante in July 2002 (Second Year Study, Deliverable 34) was undertaken to identify and quantify the response of the benthic communities at different depths on the internal side of the LCS (Fig. 4): i.e., respectively, at 1.0 m (L1) and 2.5 m (L2.5) depth at the Landward site and, similarly, at 1.0 m (C1) and 2.5 m (C2.5) depth at the Control site. The analytical procedures for the benthic fauna and for the sedimentary descriptors were the same of the previous study, with the exception of the grain size analysis.

Fig. 4 – Layout of the experimental design of the second year study (2002). Sampled isobaths are evidenced in the picture. C = control site; L = landward site. a, b, c, d, e = sampling areas.

As for environmental factors, at 1.0 m depth in the landward site (L1), the sediment was mainly represented by fine sand, whereas it consisted of medium sand in the control site at the same depth (C1). An higher content of TOM was measured in the landward site than in the control site, at both the considered depths.

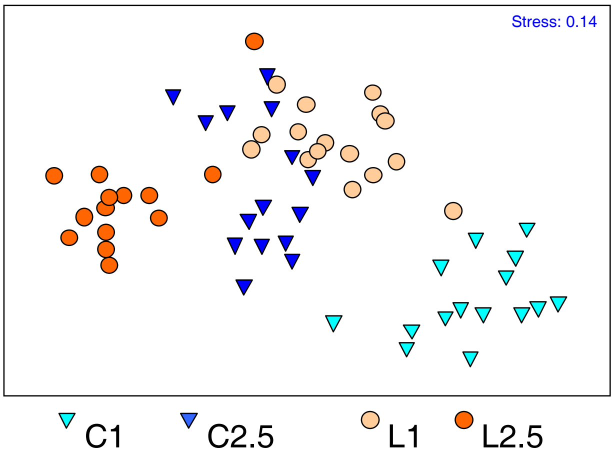


Fig. 5 – nMDS plot of macrobenthic communities based on fourth-root transformed species abundance data of the Second Year Study. C = control site; L = landward site; 1 = 1.0 m depth; 2.5 = 2.5 m depth.

Macrofaunal assemblages were influenced by the presence of the breakwaters even in the areas closer to the shoreline (L1). Multivariate analysis revealed a marked effect of LCS on the composition and structure of macrobenthic communities at both depths. In fact, sample-points grouped close together according to each treatment combination (Fig. 5). Furthermore, it is possible to identify a gradual change of the community structure shifting from the most wave exposed areas at 1.0 m depth in the control site (C1) toward the ones characterized by a progressive decrease of the hydrodynamic stress on the sediments (L1 > C2.5 > L2.5).

LCS OVERALL EFFECTS ON SOFT-BOTTOM

Considering that the water depth at the sampling points in both Landward (L) site and Control (C) site during the first year study (2001) was similar to that of the sampling points located on the 2.5 m isobath during the second year study (2002), it is possible to make a comparison among data gathered from the above isobath in the two years.

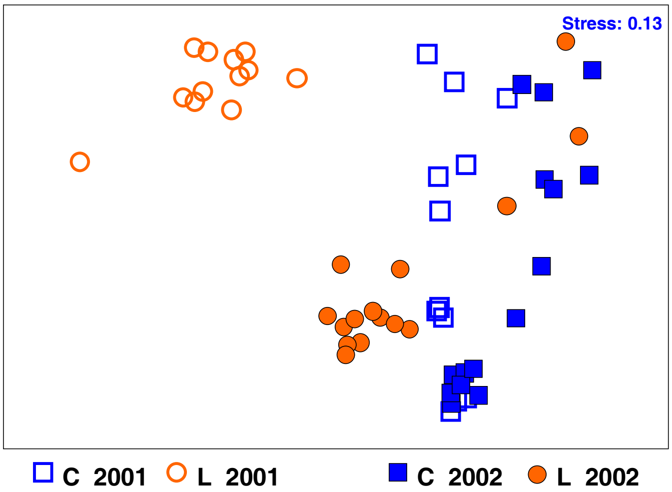


Fig. 6 – nMDS plot of macrobenthic communities based on fourth-root transformed species abundance data of the two years of study. C = control site; L = landward site.

Significant differences in abundance and composition of macrofaunal communities of the landward site with respect to those of the control site were observed during both studies, even if some structural differences in species composition occurred also between the two different years, particularly in the landward site (Fig. 6).

In both years, abundance and biomass of the control site (C) community (but also of the seaward site in the first year) were strongly dominated by the bivalve *Lentidium mediterraneum*, a species known to be well adapted to energetically dynamic habitats. The occurrence of this species and the composition of macrobenthic assemblages inhabiting the control site suggests that this community was mainly structured by the strength of physical factors. Conversely, a more structured community seemed to be settled at the landward site (L), characterised by an higher number of species and an higher diversity (Fig. 7). This general pattern was confirmed also by the results of the second year study, when an higher average number of species was recorded in the landward site, depths being equal (Fig. 7).

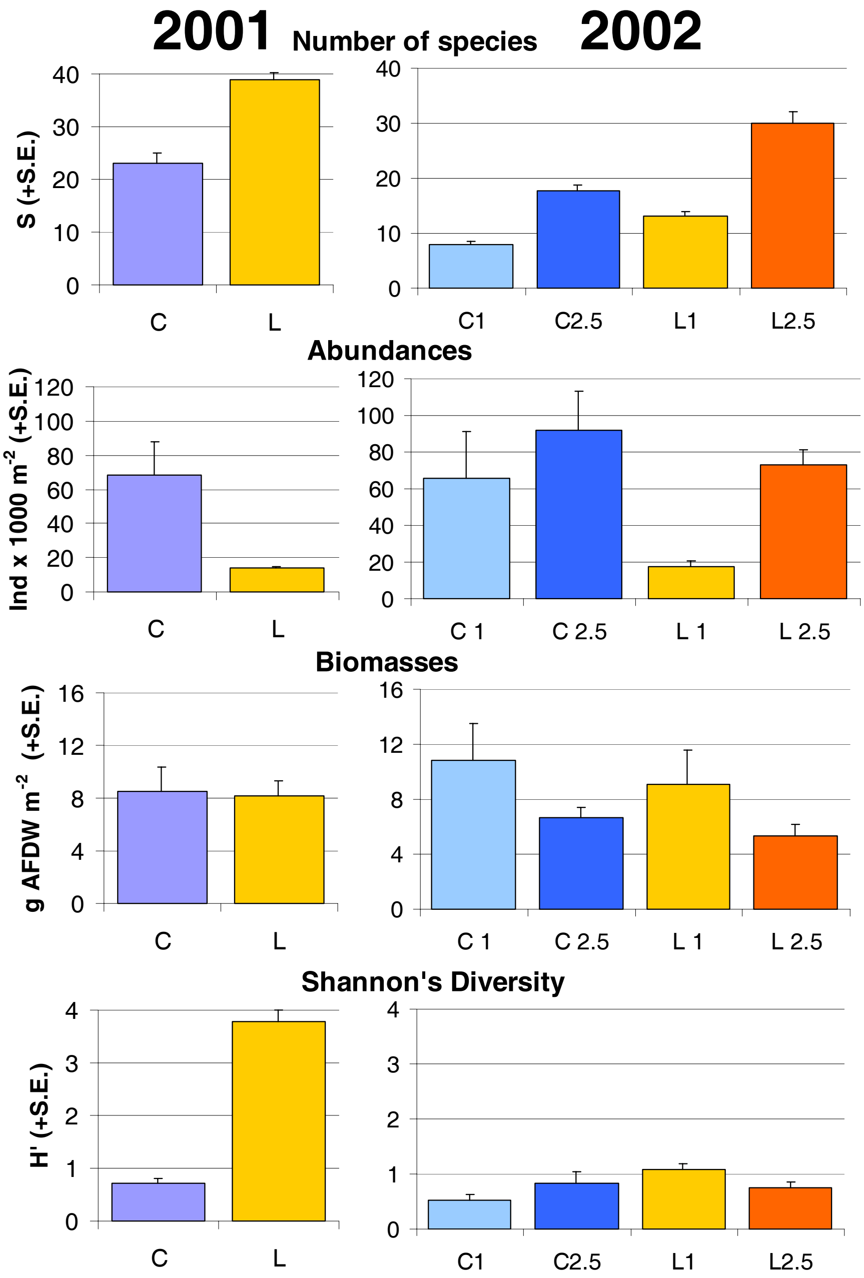


Fig. 7. - Summary of the main faunal descriptors in the two years of study at Lido di Dante. AFDW = Ash Free Dry Weight; for labels see Fig. 4

Whereas macrobenthic community showed a clear response to the presence of LCS, sedimentary descriptors seemed to be less effective in revealing differences. This was mainly due to the marked variability of their values both in space and years, as shown by the PCA ordination (Fig. 8). The first PC axis (45.6% of the total variance) is that of increasing (from left to right) values of shell debris, even if also the other variables play some role in the same direction. The second PC axis (32.6% of the total variance) is that of increasing (from bottom to top) values of TOM.

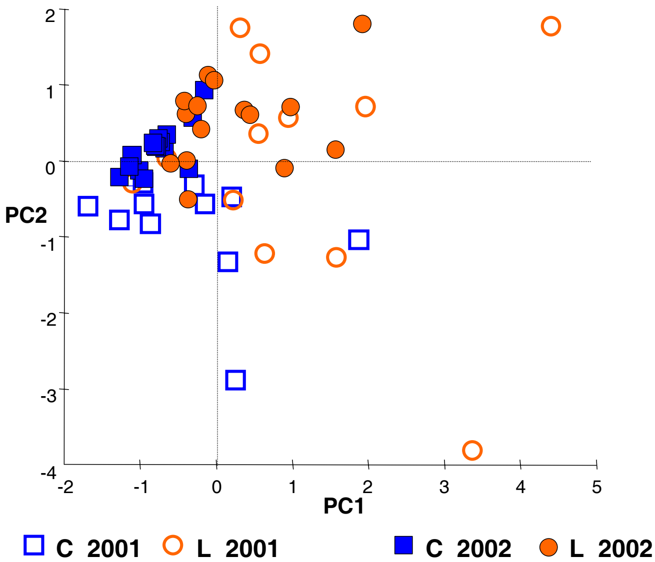


Fig. 8 – PCA plot of sediment variables based on normalized data of the two years of study. C = control site; L = landward site.

In particular, shell debris was constantly higher in the landward site at 2.5 m during the two years (Fig. 9). This result suggests that the LCS acts as a trap for the coarsest material transported by events (such as storms) which let that heavier material to step over the LCS and to accumulate close to the structure. Furthermore, we may hypothesize that the complete enclosure of the protected site do not permits the redistribution of the dead shells along the shoreline.

Living organisms can rapidly respond to those alterations of the benthic habitat in the areas closer to the LCS. In fact, it is interesting to note that the landward site (especially at 2.5 m depth) was colonized by species such as *Musculista senhousia*, *Neanthes succinea*, *Capitomastus minimus,* typical of lagoon and saltmarsh habitats. Conversely, most of the species recorded in the control site, even though typical of the biocoenosis of the Northern Adriatic coast, resulted absent from the landward site.

The significant increase of the TOM in the landward site (Fig. 9) changed the overall trophic conditions. In turn, a significant increase of the abundance of subsurface deposit feeders, which feed on the bulk of the detritus accumulated in the sediment, occurred. Most of the recorded deposit feeders are also tube builders and are able to rearrange the sediments increasing its structural complexity and the amount of organic matter available for bacterial decomposition.

As for the 1.0 m isobath explored during the second year study, it is plain that the reduction in the wave stress allowed the deposition of significantly finer sand behind the LCS (L1) (Fig. 9). This decrease of hydrodynamic stress is mirrored by the distribution pattern of some species. In particular, the isopod *Eurydice sp.* was exclusively found at C1 and the polichaete *Spio decoratus* only at L1. Indeed *Eurydice* is reported as a genus well adapted to shoreline waters stressed by waves, whereas *S. decoratus* is an opportunistic surface deposit feeder inhabiting more sheltered bottoms.

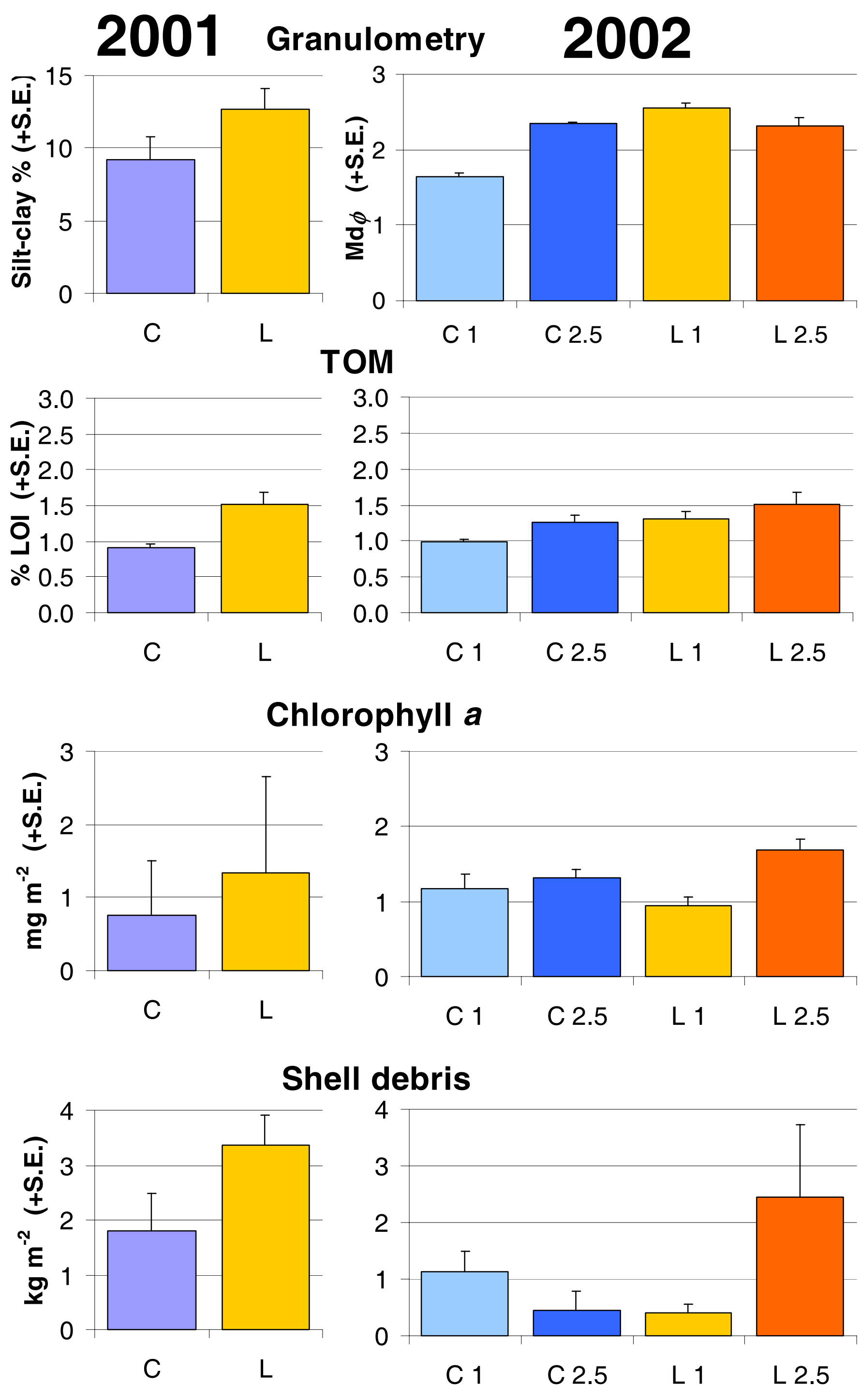


Fig. 9. - Summary of the main sediment descriptors in the two years of study at Lido di Dante. LOI = Loss Of Ignition; for labels see Fig. 4.

DISCUSSION

LCS IN SPAIN

The results obtained by the CSIC in Cubelles and Altafulla allow to define some key features of the LCS that seems for influence the surrounding soft bottoms and infaunal assemblages. The structure of the Cubelles system, with the two lateral groins protecting the landward area, clearly increases the sand retention besides the LCS. This is reflected by the shallow depth at landward (which gives rise to wider hemitombolos reaching the landward side of the structures) as well as by the small grain size of the landward sediments. A certain degree of eutrophia can also be assumed in this locality, as the benthic chlorophyll content are high in all treatments. In Altafulla, the landward stations are deeper, the sediments are slightly coarser and the chlorophyll content is lower, this apparently indicating a higher hydrodynamism around the LCS, which seems a logical consequence of the fact that the structure is not closed laterally. At this locality, the hemitombolo is narrow near the LCS, this giving rise to a sharp decrease in depth from the center towards the laterals of the LCS.

The most evident consequence of the presence of the LCS on the infaunal assemblages is the marked relative decrease of all biological descriptors with respect to the controls (Table 1). This is particularly in terms of biomass (more than 80% in all treatments at the two localities), which is more specifically due to the virtual absence of bivalves around the LCS. At landward, the relative changes are similar at both study sites, with the exception of the diversity (with a more marked decrease in Altafulla). Conversely, the relative changes at seaward in Altafulla were specially drastic, will all descriptors decreasing to less than half of the respective values at the control sites. A possible explanation would be that the original assemblages were richer and closer to a biologically controlled community (i.e less disturbed) in Altafulla so that the disruption induced by the presence of the LCS had stronger consequences. In fact, the original assemblage in Altafulla belonged to the community of Fine Sand with *Spisula subtruncata*, which is not adopted to support high hydrodynamic levels and the communities present in the controls and around the LCS are more or less modified facies of this assemblage. Also the morphology and the arrangement of the LCS is different and this may affect the hydrodynamics around them in a different way, which, in turn, may contribute to explain the different responses of the surrounding infauna. It must be pointed out that the differences in seaward abundance between the two localities are particularly relevant (with that in Cubelles being virtually identical to the controls and that in Altafulla being more than 80% lower).

Table 1.- Percentages of changes of the population of the organic enrichment indicator species *Capitella capitata* and the biological descriptors around the structure with respect to the control assemblages.

CUBELLES					
	Capitella	**sp**	**abu**	**bio**	**div**
LANDWARD	2200	-30.33	-53.50	-82.83	-13.02
SEAWARD	400	-12.96	0.00	-85.99	-18.60
ALTAFULLA					
LANDWARD	6800	-32.97	-45.51	-80.91	-27.76
SEAWARD	0	-57.14	-81.75	-91.41	-48.75

Taking into account the whole studied regions, however, the presence of the LCS induced an increase of biodiversity both in Cubelles and in Altafulla, which could be attributed to the presence of species around the LCS that were not present in the original assemblages. The percentage of increase is different in both localities, 14.3% and 3.4%, respectively, and this is also an expression of the different response to the disturbance caused by the LCS on the respective assemblages. In Cubelles, the number of species absent in the control and present at seaward and landward is, respectively, 20 and 19. At seaward, most species are originally hard-bottom ones, which are collected in the sediment either because the higher hydrodynamism caused them to fall dawn (*Mytilus*, *Paranemonia*, *Balanus, Microcosmus*) of because they are able to abandon the rocky substrates temporally (*Portunus*). At landward, some of the newly appeared species can be associated to calm waters (*Peresiella*, *Cirratulus*), while a few specimens of *Microcosmus* and *Portunus* also occurred. In Altafulla, the number of species absent in the control and present at seaward and landward is, respectively, 7 and 21. At seaward, the newly appeared species are very few and with low numbers and may be considered as accidental. At landward, they are indicators of calm waters, with special mention of *Spisula subtruncata*, a species considered to be characteristic of the sediments of Cubelles in relatively depth, calm bottoms.

Finally, the response of some species can be considered as characteristic, and a good example may be the presence of the indicator species *Capitella capitata* (typically associated to organically enriched environments). The most relevant populations of this polychaete occur at the two study sites mainly at landward (with an enormous proportional increase with respect to the control sites, see Table 1). This can be considered a symptom than the landward conditions are delicate and may easily derive to perturbed ones if water circulation is not enough. Moreover, with respect to the arrangement of the two LCS, *C. capitata* can be found at the deepest stations that are protected form water movements both by the structure itself and the hemitombolo. The more protected they are, the more fragile is the equilibrium. Although the whole characteristics of the area surrounding the Altafulla LCS seems to indicate that the influence of the hydrodynamism is higher there than in Cubelles, the population of *C. capitata* are much developed in Altafulla (about 200 worms per m^2), and specially at landward (where the area harbouring this worm is much deeper) than at the shallowest bottoms in Cubelles (less than 80 worms per m^2). As a consequence, these areas are the most critical and, thus, specific design criteria should be addressed to try to avoid their presence.

LCS IN UK

The studies carried out by the MBA in Elmer and Liverpool showed that the construction of LCS always causes some modifications in the sediment characteristics and the associated infaunal communities. The magnitude of these changes on the soft-bottoms can however vary considerably depending on the environmental setting where the breakwaters are built.

It appears that dissipative beaches like the sandflats in Liverpool tend to be strongly affected by the construction of LCS in the intertidal zone. The sediment surrounding the landward side of the structures becomes much finer and muddier because of the reduced hydrodynamics and as a consequence the habitat becomes highly modified. This leads to reduction or disappearance of species normally present but at the same time creates a new conditions for species more suitable to the new type of habitat.

In the case of a more reflective and exposed beach such as Elmer, LCS seem to have a minor impact on sediment community. This type of beach is characterized by intermediate wave exposure and wave energy and shows a higher variability in terms of sediment and infaunal communities. Changes in sediment characteristics and in the infaunal community still occur but are less evident and often obscured by the natural variation.

The extent of the impacts on soft-bottoms appears to be also influenced by the type of structure. In Liverpool, the two LCS are shore connected and the base of the structure consists of small rocks, with diameter generally under 2.5m. Despite the concrete T units have a large porosity, water flow through the base of the structure is minimal. Water movement on the landward side is therefore much reduced, creating local sheltered conditions. At Elmer, the rock islands do not have a core and the pores of the structures are relatively large, allowing greater water flow from the seaward to the landward side of the structures. The presence of a series of structures also contributes to create zones of turbulence and local currents on the landward side (see D30 for more details). As a result, sediment characteristics on the landward and on the seaward side are relatively similar providing therefore very similar habitats.

Design features of a breakwater can however have a different effect depending on the location where they are built. In areas with high organic load, high recruitment of organisms, particularly mussels and the polychaete *Sabellaria alveolata*, porosity of structures is highly reduced and can lead to a further reduction in the hydrodynamics on the landward side. In this situation, the impact of LCS could be reduced by increasing the water flow through the structures.

LCS IN ITALY

At Lido di Dante benthic communities underwent substantial modifications in presence of the LCS. Those modifications seem to be due, on one hand, to the peculiarity of the infaunal biocoenosis of the North Adriatic Sea and, on the other hand, to the particular design of the breakwater of the Lido di Dante.

Natural communities inhabiting the surf zone of the Adriatic coast are relatively poor in species. Only few of them dominate and characterise the spatial and seasonal evolution of the whole assemblage. This is a typical situation often found in the physically controlled environments, where community structure (i.e. species composition and their relative abundance) is modulated by hydrodynamic factors.

The almost complete connection of the breakwater with the lateral groins encloses the protected area and causes a reduction of wind induced currents. This allows the settlement of species better adapted to stiller water. Therefore, we can hypothesize that reduction of the natural wave stress regime improved the settlement rate of many larval stages which normally would be eroded from sediments. As consequence, in the sheltered site behind LCS, biotic interactions rather than hydrodynamic forces seem to prevail in structuring the benthic community. This allows an overall increase of biodiversity of the species assemblages, which extend as far as the proximity of the shoreline.

A classic ecological paradigm predicts a general reduction of biodiversity when environmental changes induced by anthropogenic impact occur. Instead, at Lido di Dante, the present investigations have shown an increase of biodiversity of benthic communities just in the area impacted by the beach management (LCS). Anyway, these findings cannot be considered simplistically as an improvement of the benthic environment, but rather as a substantial modification of the natural characteristics of the biotope. The co-occurrence of typical lagoon species (e.g. *Musculista senhousia*, *Hediste diversicolor*), of large numbers of opportunistic worms (e.g. *Capitella capitata*, *Spio decoratus)* and of organisms generally found in deeper water (e.g. *Corbula gibba*, *Owenia fusiformis*) indicates a substantial transformation of the benthic community in the protected site. Most of these species are known to be typical of habitats characterized by reduced shear currents and finer sediment, where they can find the optimal conditions to maintain their populations.

The increase in biodiversity could be considered, from a naturalistic point of view, as a positive consequence of the LCS presence, but one should be aware that the environmental modification occurring behind a structure as enclosed as that built up in Lido di Dante has to be regarded as a progressive transformation of the shore habitat in a lagoon-like environment. Therefore we may expect a deterioration toward more insalubrious conditions in the protected area, such as loss in water quality, formation of mucous aggregates, bad smells and so on.

CONCLUSIONS

Changes in sediment characteristics and infaunal communities seem to be an inevitable consequence of the construction of LCS. Independently of the arrangement of the LCS, their presence tends to induce negative changes in the surrounding soft bottom communities in relation to the degree of hydrodynamism. At seaward, they are usually due to its increase while, at landward they are mainly due to its reduction. In this last case, the effects are particularly strong if the construction of the LCS is associated to the presence of additional structures (such as parallel groins) or beach nourishment.

Some of these consequences, however, are not necessarily negative and this is usually an consequence of the response of the peculiar assemblages inhabiting a given soft-bottom area (for instance, this is particularly evident in the case of Lido di Dante and the response of the bivalve *Lentidium*). Moreover, all studies described above showed that, despite the differences observed between landward, seaward and control areas, the overall habitat diversity of the stretch of coast where the LCS are built and as consequence, the species diversity tends to increase. This increase in biodiversity could be regarded, from a naturalistic point of view, as a positive consequence of the LCS presence. However, in connection with this, two questions needs to be asked.

1) Are these changes desirable, even if they are considered “positive”? The answer from the ecological viewpoint is probably no, as the principle is to maintain and the ecosystems in its most natural conditions, and protect them from any human intervention. The effects of LCS on soft-bottoms should be therefore minimized, independently if they cause an increase in diversity or not

2) Which species are responsible for this overall increase in biodiversity? Whether this increase is caused by the presence of accidental species coming from the newly added hard bottoms or from species more or less associated to increasing disturbances (e.g., organic enrichment, increasing presence of brackish waters), it seems evident that the of the increase in soft-bottom infaunal biodiversity is virtually non-relevant from an ecological point of view, and may even be considered as a negative transformation of the environment. Certainly, the presence of these species must be evaluated according to previously existing local knowledge on the communities that will be affected. As a consequence, prior research in that sense must always be done before the construction of the LCS

Finally, it seems feasible to introduce design criteria tending to facilitate a positive evolution of the assemblages once the changes due to the presence of the LCS are completed and the new situation tends to become more stable. In general, these criteria must be addressed to try to avoid as much as possible the development of insalubrious areas in the protected zone (such as the excessively deep areas with low water renewal due to the development of the hemitombolo found at landward in the Spanish LCS or the progressive transformation of the shore habitat in a lagoon-like environment in Italy). Possible solutions may include a reduction of the impact of the LCS by increasing the water flow through the structures as proposed by the MBA.