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

Environmental Design of Low Crested Coastal Defence Structures

D 34

Identification of the impact time-courses on surrounding assemblages

Contract n°EVK3-CT-2000-00041

DELIBERABLE 34

Area of influence of the LCS on the soft-bottom assemblages at a successive distances from the LCS

One of the main conclusion achieved as a result of the previous experiments carried out within the frame of the WP 3.1, which have been reported in the deliverables D18 (on the effects on the sediments surrounding the LCS) and D33 (on the effects of LCS on the surrounding soft bottom assemblages) has been that the different responses of macrobenthic community to the presence of LCS are driven by the different hydrodynamic and sediment morphodynamic patterns at the different studied sites which, in turn, represent differences in currents and resuspension processes occurring around the different LCS.

The aim of the studies here reported as D34 were to analyse the extension of the area of influence of the LCS on the surrounding soft bottoms and on their infaunal assemblages. For this purpose, a new sampling design allowing to collect samples at a successive distances from the LCS, have been adopted by the different teams, in agreement with the particular characteristics of each study site.

Effects of LCS at successive distances in Altafulla (Spain)

Characteristics of the sampling design

The sampling design carried out in the LCS at Altafulla bas based in the results of the theoretical hydrodynamic model developed by the partner UPC. This model has generated a basic system of currents (Fig. 1) which, in turn, provides an idea of the main forces driving the environmental conditions around the structure. According to this model and to the basic methodology described in D4, a series of sampling stations were collected in June 2002 following the sampling design described in Fig. 2.

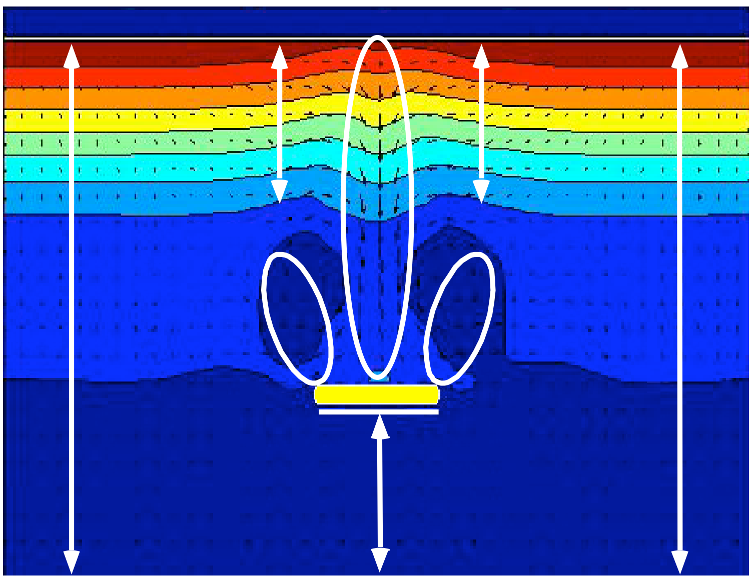


Figure 1.- Scheme of the theoretical model of currents around the Altafulla breakwater. Long arrows indicate the normal situation without LCS. Short arrows and ellipses indicate the main differential areas generated by the presence of the LCS.

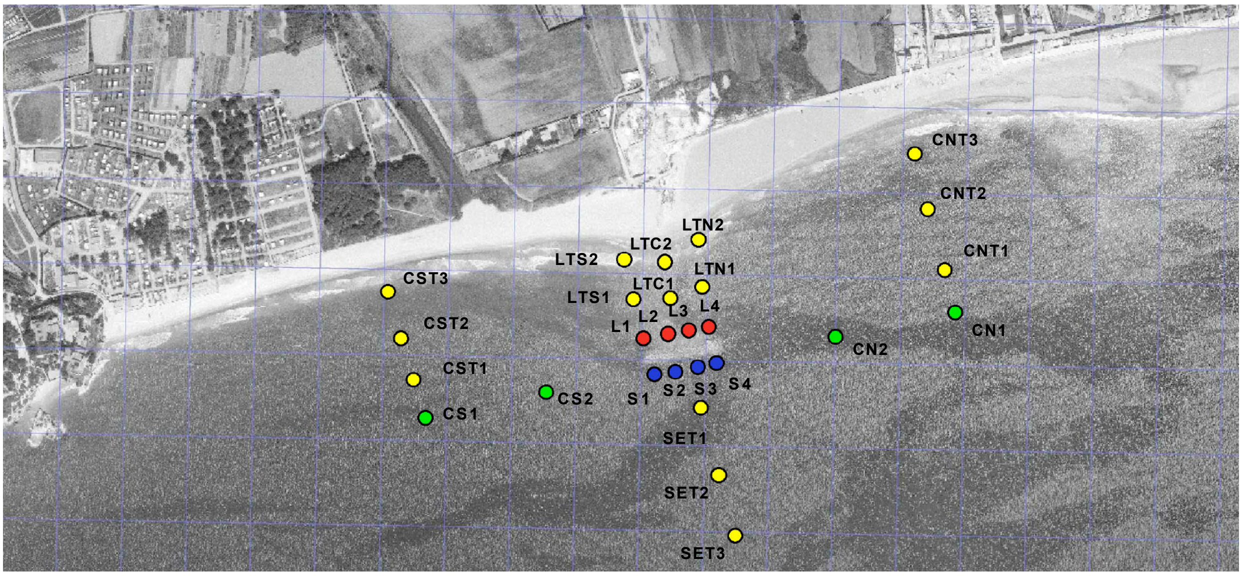


Figure 2.- Scheme of the sampling design based on the theoretical model of currents around the Altafulla breakwater. Green (controls), reed (landward) and blue (seaward) spots indicate the position of the sampling stations based on the initial ANOVA design (see D18 and D34). Yellow spots indicate the position of the stations added in agreement to the new sampling design.

Results

Environmental variables. Depth around the Altafulla LCS averaged 2.6 m, ranging from 0.1 at landward to 8 m deep at seaward. Grain size of the sediment averaged 216μm, and ranged from 403 μm at landward to 150 μm in the deepest station at seaward. Accordingly, the percentage of fine sediments averaged 2.59%, with the lowest values at landward (virtually 0%) and the higher values (4.95%) also in the deepest station at seaward, while the organic matter content averaged 0.744% (ranging from 0.427% at landward and 1.649% at seaward, near the LCS. Finally, the chlorophyll-a contents averaged 2.977, ranging from 0.535 in the shallowest station at the south control transect to 9.356 at the deepest station at seaward (Table 1).

The high variability reported in the previous studies carried out in Cubelles and Altafulla (based in an ANOVA design, see D33) were also clearly shown by the current sampling design. In fact, there were only three significant results derived from the correlation analysis among environmental variables, among which the % of fine sediments and the chlorophyll content increases with increasing depth, and the chlorophyll content decreased with the increasing grain size. The other significant correlation is the obvious negative relationship between the % of fine sediments and grain size (Table 2).

Therefore, it was clear that the main factors controlling the environmental variability around the LCS and at successive distances from the structure were did not show a simply linear behaviour, and this fact can be clearly viewed be mean of the contour maps showing the patterns of the different environmental variables (Fig. 3)

Table 1.- Values of the environmental variables in tur studies stations around the Altafulla LCS.

Sampling Station	Depth (m)	mean grain size (µm)	% of fine sediments	% Organic Matter	Chlorophyll-a contents
CST3	0.8	205	2.73	0.5003	0.5346
CST2	1.2	199.7	3.05	1.2925	1.6038
CST1	2.8	217	2.77	0.6998	2.4057
CS1	2	168.0	3.757	0.7269	2.5839
CS2	2.3	202.1	2.043	1.0206	2.1384
LTS2	0.8	196.3	0	0.7917	5.346
LTS1	2.3	176.9	3.83	0.7917	3.4749
L1	2.9	293.2	0	0.6266	3.3858
L2	3.2	183.6	3.67	0.7535	3.4749
LTC2	0.1	343.4	1.52	0.4529	2.673
LTC1	0.3	192.7	3.41	0.4266	1.6038
L3	3	208.2	3.287	0.8229	1.782
LTN2	0.5	402.8	1.68	0.6462	2.1384
LTN1	2.2	191	3.21	0.8613	3.7422
L4	2.7	196.8	3.313	0.8752	2.673
S1	2.4	233.9	1.87	0.5893	1.3365
S2	2.3	228.4	0	0.7006	2.2275
S3	2.7	205.2	2.937	0.9518	3.7422
S4	4.1	183.2	3.21	1.6492	4.1877
SET1	4.3	181.6	3.32	0.7125	4.2768
SET2	7	158.2	3.76	0.5611	3.7422
SET3	8	150.5	4.95	0.5857	9.3555
CN2	2.5	224.4	0.987	0.7466	2.3166
CNT3	2.1	205	2.73	0.6457	2.1384
CNT2	3	262.6	1.95	0.5207	1.3365
CNT1	2.5	272.5	2.25	0.51	2.1384
CN1	2.7	168.3	3.75	0.6288	4.0095

Table 2.- Results of the Pearson correlation analysis of the soft-bottom sediment variables around the LCS in Altafulla. Coeff. is the Pearson correlation coefficient. P is the significance value. NS means non-significant.

	Depth (m)		Mean grain size		% fines		% organic matter	
	Coeff.	**p**	**Coeff.**	**p**	**Coeff.**	**p**	**Coeff.**	**p**
Mean grain size	-0.30168	NS						
% fines	**0.37475**	**0.05**	**-0.83881**	**0.00001**				
% organic matter	0.11758	NS	-0.24794	NS	0.09809	NS		
Chlorophyll-a	**0.42434**	**0.03**	**-0.57723**	**0.002**	0.35401	NS	0.28119	NS

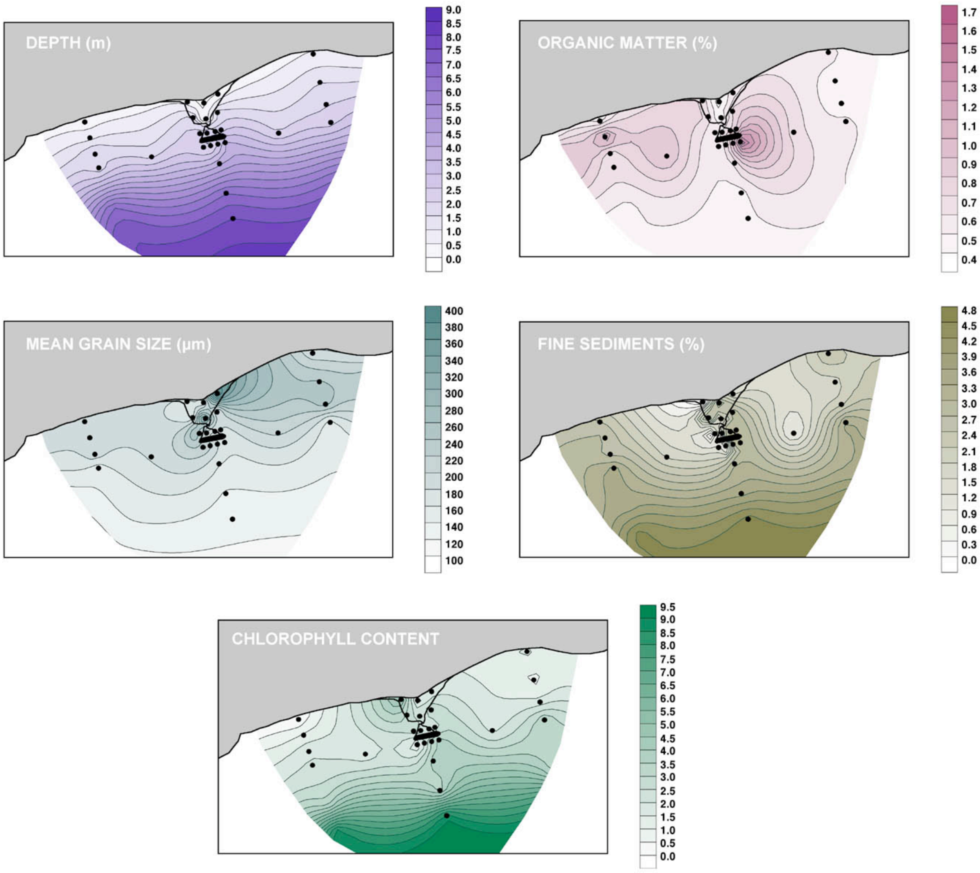


Figure 3.- Contour maps showing the patterns of distribution of the main environmental variables measured around the Altafulla LCS.

Faunal descriptors. The number of species around the Altafulla LCS is highly variable, averaging 15 species, but ranging from 2 species at landward to 41 species in the deepest station at seaward. Similarly, the density averaged 1473 ind. m^{-2}, ranging from 50 ind. m^{-2} at landward to 5870 ind. m^{-2} in the deepest station at seaward and the biomass averaged 10.7 g m^{-2}, ranging from 0.3 g m^{-2} at the shallowest station of the southern control to 157.7 g m^{-2} at the deepest station at seaward. Species richness, diversity based on abundance and diversity based on biomass averaged 1.99, 1.89 and 1.47, respectively, with the minimum values located at the landward station LTN1 and the maximum values along the seaward transect, for the species richness and the diversity based on abundance, and at landward side closer to the LCS for the diversity based on biomass (Table 3).

The relationships between environmental variables and faunal descriptors were very complex. According to the Pearson correlation analyses (Table 4), three main trends can be pointed out. First, the several positive correlations of the biological descriptors with depth, % of fine sediments and chlorophyll content; second, the negative correlations of all faunal descriptors (except diversity based on abundance) with mean grain size; third, the absence of significant correlation of faunal descriptors with the organic matter content of sediments.

Table 3.- Results of the analysis of the soft-bottom community descriptors in Altafulla

Sampling station	Number of Species	Abundance (Ind. m^{-2})	Biomass (g m^{-2})	Species Richness	Diversity (Abundance)	Diversity (Biomass)
CST3	3	84	381	0.4514	0.9555	0.7391
CST2	16	1001	9886	2.171	2.126	1.373
CST1	20	1052	7333	2.73	2.546	1.778
CS1	30	3614	13625	3.5077	2.218	1.937
CS2	15	1002	3843	1.9767	2.0743	1.511
LTS2	17	2604	3494	2.034	1.128	1.921
LTS1	15	1950	1074	1.848	1.814	2.056
L1	20	1592	5463	2.582	2.1423	1.4011
L2	17	1914	1759	2.1177	2.088	2.178
LTC2	6	218	618	0.9286	1.526	0.5909
LTC1	15	1702	1598	1.882	2.003	1.887
L3	11	496	1066	1.6023	1.8583	1.5677
LTN2	10	417	1363	1.492	2.138	1.047
LTN1	2	50	3110	0.2556	0.641	0.0271
L4	13	835	2048	1.8367	2.017	1.7773
S1	9	307	977	1.41	1.9617	1.3723
S2	6	240	705	0.8953	1.4607	0.9109
S3	13	562	1829	1.8327	2.1627	1.686
S4	11	514	1140	1.61	1.9567	1.5368
SET1	17	1452	1930	2.198	2.045	2.094
SET2	32	3403	30759	3.812	2.713	1.79
SET3	41	5871	152685	4.609	2.389	0.4056
CN2	17	925	2558	2.2867	2.3507	1.6578
CNT3	13	1302	1830	1.673	1.297	1.711
CNT2	9	2718	1451	1.012	0.8693	1.019
CNT1	11	619	1055	1.556	1.994	1.97
CN1	29	3329	34109	3.455	2.6053	1.745

Table 4.- Results of the Pearson correlation analysis of the soft-bottom infaunal descriptors around the LCS in Altafulla. Coeff. is the Pearson correlation coefficient. P is the significance value. NS means non-significant.

	Depth (m)		Mean grain size		% fines		% organic matter		Chlorophyll-a	
	Coeff.	**p**	**Coeff.**	**p**	**Coeff.**	**p**	**Coeff.**	**p**	**Coeff.**	**p**
Number of Species	**0.40316**	**0.03705**	**-0.55318**	**0.00276**	**0.44809**	**0.01908**	0.04367	NS	**0.48395**	**0.01054**
Abundance (Ind. m^{-2})	0.35407	NS	**-0.5764**	**0.00165**	**0.48976**	**0.00951**	-0.12853	NS	0.3615	NS
Species Richness	**0.40728**	**0.03498**	**-0.54679**	**0.00317**	**0.45341**	**0.01754**	0.07236	NS	**0.4573**	**0.01647**
Biomass (g m^{-2})	0.28681	NS	**-0.53091**	**0.00438**	0.36389	NS	0.20943	NS	**0.46006**	**0.01575**
Diversity (Abundance)	**0.38251**	**0.04894**	-0.25889	NS	0.3425	NS	0.02137	NS	0.2914	NS
Diversity (Biomass)	0.18438	NS	**-0.3859**	**0.04681**	**0.39872**	**0.03939**	0.12731	NS	0.25314	NS

As it happens with the environmental factors, the patterns of the faunal descriptors around the LCS and at successive distances from the structure (fig. 4), were not simply linear and the organization of the assemblages was the result of the complex interaction of the normal trends of the environment and the modification induced by the presence of the LCS, with the main focus of disturbance being located at the southern landward side of the structure (Fig. 4).

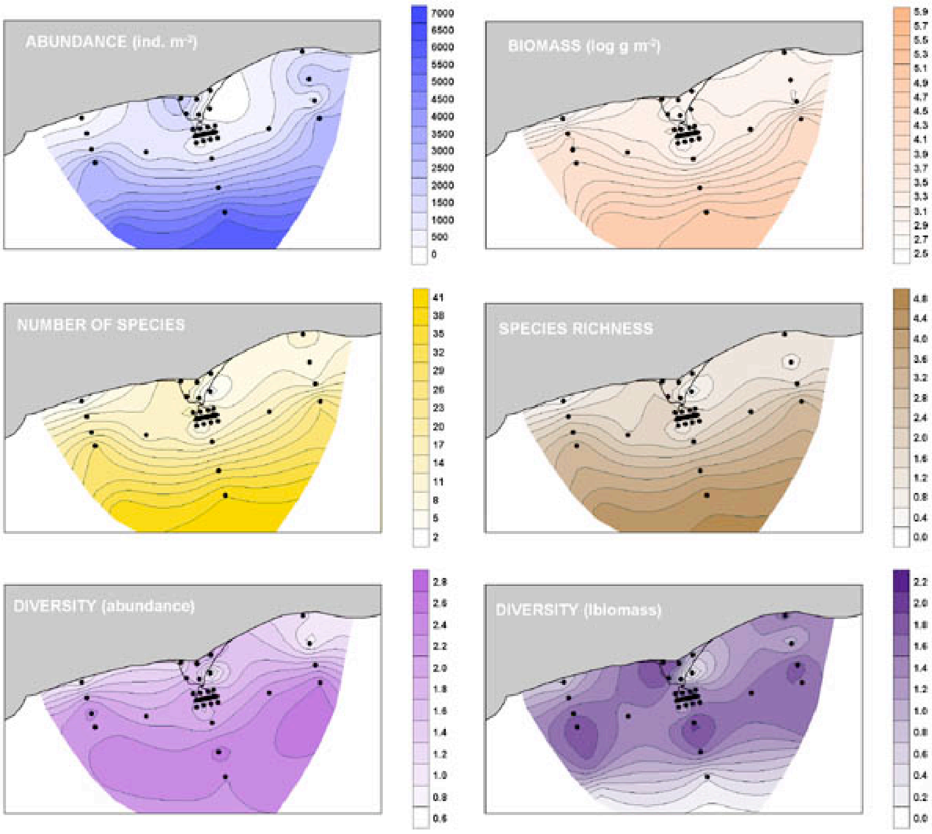


Figure 4.- Contour maps showing the patterns of distribution of the faunal descriptors around the Altafulla LCS.

The influence of the presence of LCS on sediment conditions can be represented by the changes occurring along a transect from the shallowest landward station to the deepest seaward station (fig. 5). The main trends observed can be summarized as follows:

1.- The highest variability occurs, for all environmental variables analyzed, at the landward side of the structure.

2.- The most marked influence of the presence of the LCS on the structural variables of the sediment occurs with respect to the % of fine sediments and grain size.

On the other hand, the influence of the presence of LCS on the infaunal descriptors, as represented the changes occurring along a transect from the shallowest landward station to the deepest seaward station (fig. 5), pointed out two main trends, which can be summarized as follows:

1.- as for the environmental variables, the higher variability for the infaunal descriptors always occurs at landward.

2.- All infaunal descriptors show low values at seaward than at the corresponding stations in the control transects, which are located to equivalent distances from the shoreline.

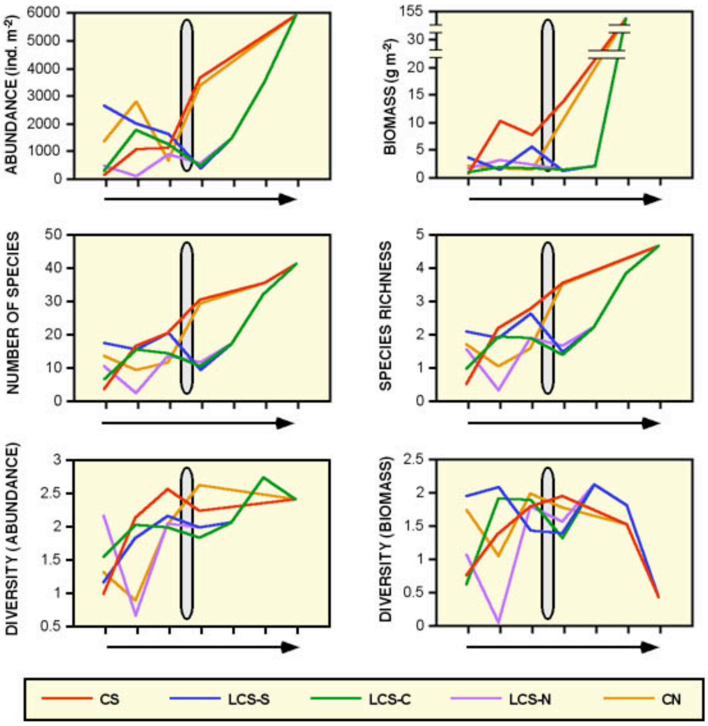


Figure 5.- Main changes in sediment conditions along a transect from the shallowest landward station to the deepest seaward station, due to the presence of the Altafulla LCS.

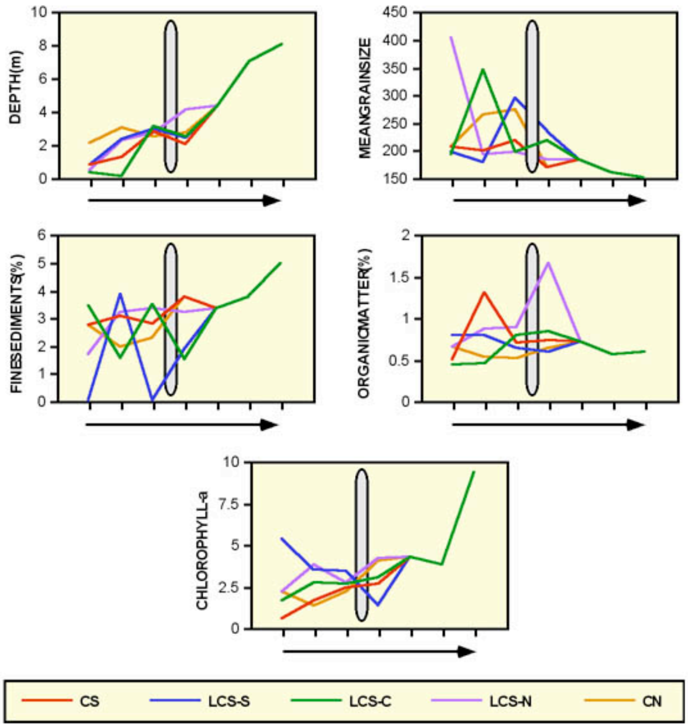


Figure 6.- Main changes in the infaunal descriptors along a transect from the shallowest landward station to the deepest seaward station, due to the presence of the Altafulla LCS.

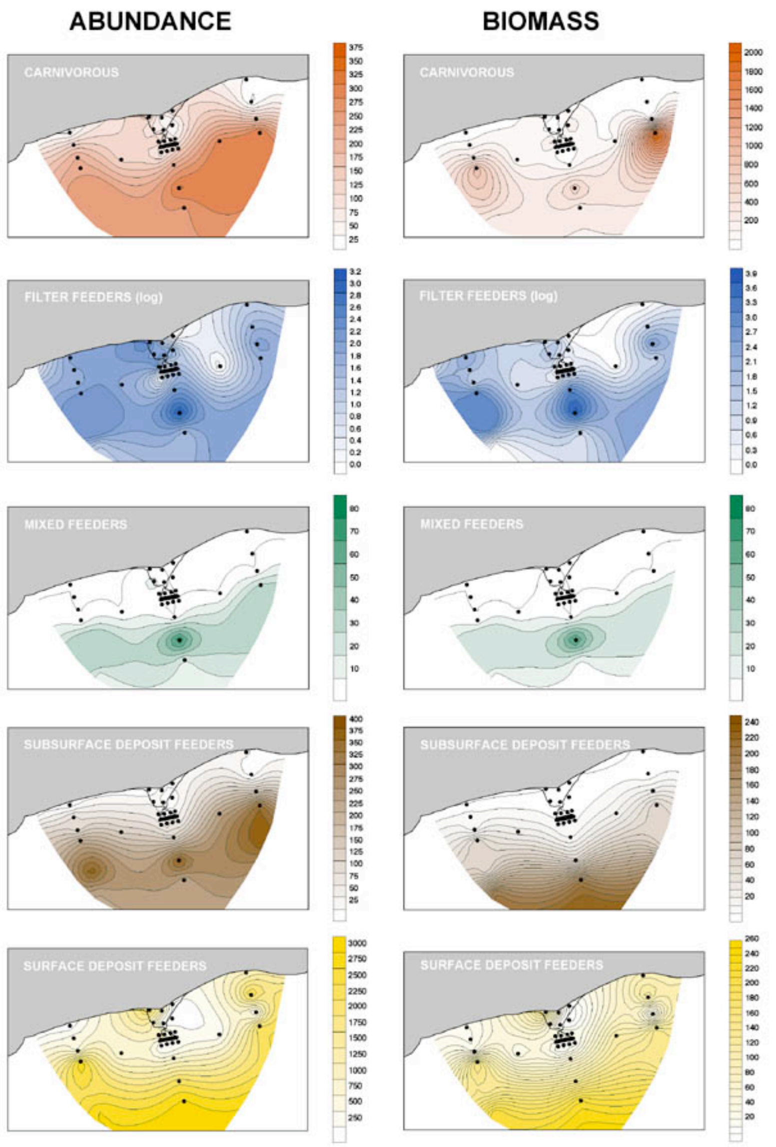


Figure 7.- Contour maps showing the patterns of distribution of the infaunal assemblages (grouped according to the trophic-functional indexes) around the Altafulla LCS.

The infaunal assemblages around the Altafulla LCS are dominated by the same trophic functional groups, both in terms of abundance and biomass. The order of dominance between the, however is inverted when considering abundance with respect to biomass. In the first case, the surface deposit feeders (67%) are clearly the most dominant, followed by the filter feeders (15%) and the carnivorous (9%). In second case, however, there is a clear dominance of filter feeders, which include nearly the 80% of the total biomass, being then followed by the carnivorous (14%) and the surface deposit feeders (4%).

The distribution of infaunal assemblages into trophic-functional groups around the around the Altafulla LCS was very similar when analyzed as abundance or biomass data. The highest values were always located in the deepest stations or in the control sites, and there is a marked variability for all groups around the LCS, with clear differences between southern and northern stations (the former showing highest values that the latter.

Effects of LCS on sediment infauna at increasing distances and tidal levels from the structures in UK

Introduction and aims

Results from the study carried out at Elmer in Year 1 provided evidence for an effect of the LCS on the soft-bottom community sampled around the structures. The aims of the studies carried out in year 2 were the followings: 1) to confirm the pattern observed inYear 1; 2) to investigate the extent of the effects of LCS at increasing distances from the structures. Two locations were selected: Elmer, and Liverpool. The sampling design applied to these locations was slightly different.

At Elmer, the soft-bottom community and the sediment descriptors were sampled on the landward and seaward side of the eight structures and in control areas at increasing distances from the structures along the coast, eastward and westward. At each distance the control areas were chosen at two different tidal levels, corresponding to the landward and seaward side of the structures, to avoid possible confounding of effect of tidal elevation with the effects of LCS (Figure 1). Control areas defined as C1 are the closest to the LCS (approx. 150m); areas defined as C2 are at intermediate distance from the LCS (approx. 500m) and areas defined as C3 were located at approx. 1000m.

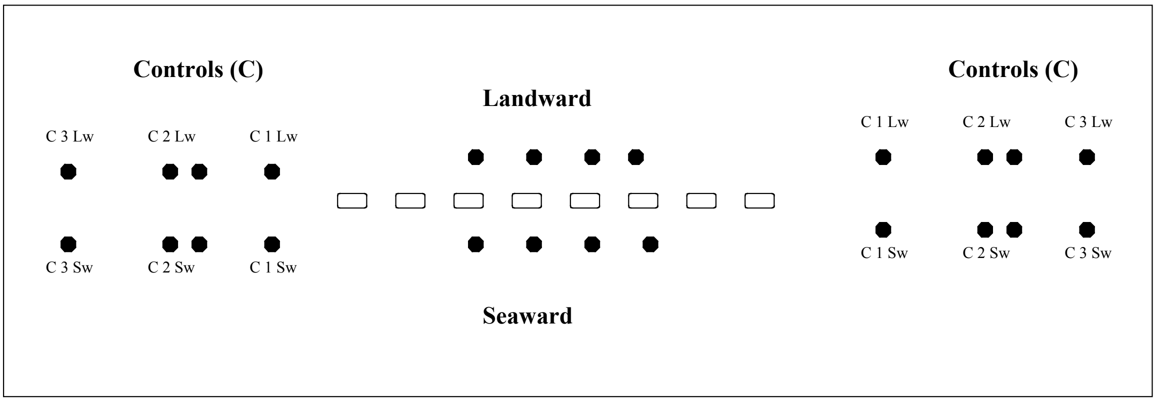


Figure 1 - Sampling design applied to the Elmer sea defence structures. Each black circle indicates a sampling area (six cores / area). Areas and sediment cores were randomly selected within each location (landward, seaward and controls).

The study in Liverpool was carried on two selected LCS structures which were connected to the shores. In Liverpool the tidal range (10 m in spring tides) is considerably larger than that at Elmer (6 m in spring tides), therefore control areas were selected at one tidal level only and at one distance from the structures. Additional sampling was carried out at increasing distances towards inshore and offshore waters (Figure 2). Lw 1 defines an area close to the shoreline, approx. 50 m from the landward side of the LCS; Lw 2 is approx. 20 m from the LCS and Lw 3 is 2-3 m from the LCS. Similarly Sw 4, is 2-3m from the seaward side of the LCS, Sw 5 is 20 m far from the LCS and Sw 6 is approx. 50 m far from the LCS.

Results

Effects of LCS on soft bottom community at Elmer:

At Elmer a total of 35 taxa were identified in the sediment cores collected around the breakwaters and in control areas. The number of taxa on both seaward and landward side of the breakwaters was 17 and 18 respectively, although only 12 species were found on both locations. Most of the species were Polychaetes and Amphipods, while only one species of Bivalves was found. The list of species found is shown in Table 1.

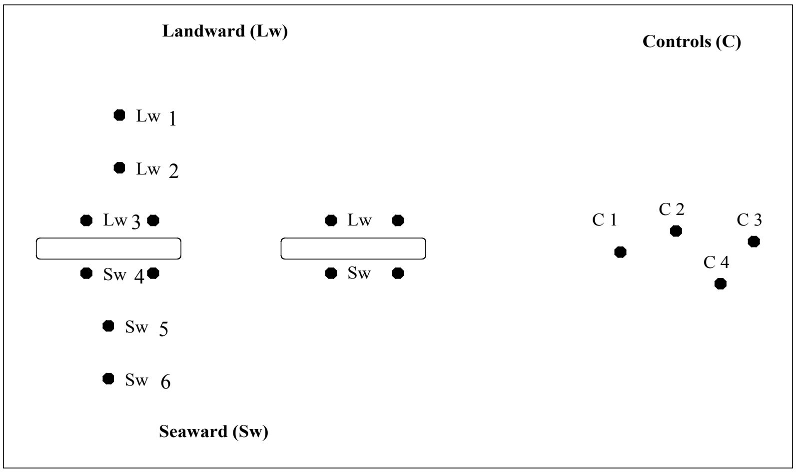


Figure 2 – Sampling design applied to the Liverpool sea defence structures. Each black circle indicates a sampling area (six cores in each area). Areas and sediment cores were randomly selected within each location (landward, seaward and controls).

Table 1 – List of total taxa identified at Elmer LCS.

<u>**Elmer**</u>
Nemertea
Polychaeta
Mysta picta
Phyllodoce maculata
Phyllodoce mucosa
Glycera tridactyla
Nephtys sp.
Scoloplos armiger
Malacoceros fuliginosus
Pygospio elegans
Scololepsis squamata
Spio filicornis
Spiophanes bombyx
Magelona mirabilis
Capitellidae
Arenicola marina
Arenicola marina (juv.)
Oligochaeta
Amphipoda
Pontocrates altamarinus
Pontocrates arenarius
Urothoe poseidonis
Calliopidae
Bathyporeia elegans
Bathyporeia guilliamsona
Bathyporeia spp.
Gammarus sp.
Isopoda
Eurydice pulchra
Sphaeroma sp. (juv)
Idotea baltica
Cumacea
Cumopsis goodsiri
Decapoda
Crangon crangon
Brachyura
Carcinus maenus
Bivalvia
Macoma balthica

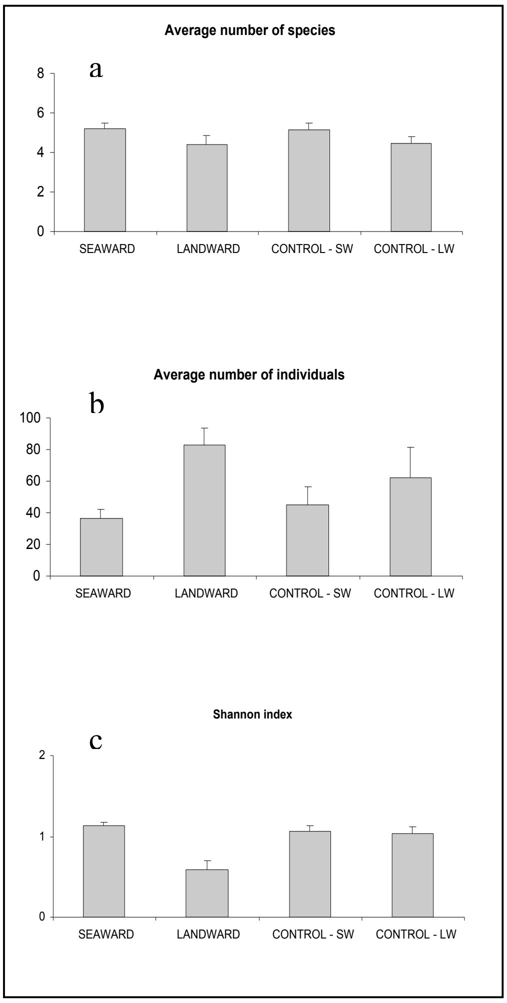


Figure 3 – Comparison of mean number of species (a), total abundance, expressed as number of individuals (b) and diversity, expressed as Shannon index (c) on the seaward, landward and control areas sampled.

Univariate analysis did not show any significant difference (ANOVA, n.s.) in the total number of species, total abundance or diversity between landward, seaward and control areas (Figure 3). However, it appeared that the landward side was characterised by the highest abundance of benthic organism and the lowest diversity. Highly significant variability (ANOVA $p<0.01$) was also observed within each location, but mainly among the areas on the landward side of the LCS. A more clear pattern was observed in the multivariate analysis of the whole soft-bottom community. As shown in the MDS plots and in the ANOSIM tables (Figure 4, Table 2), considerable differences were detected between the communities sampled on the landward and seaward side. The community on the seaward side of the LCS appeared to be more similar to the control areas than the community on the landward side. Small differences were observed between the controls located at the same level of the landward areas and the controls located on the seaward areas, showing that differences due to tidal elevation were considerably smaller than differences observed between landward and seaward side.

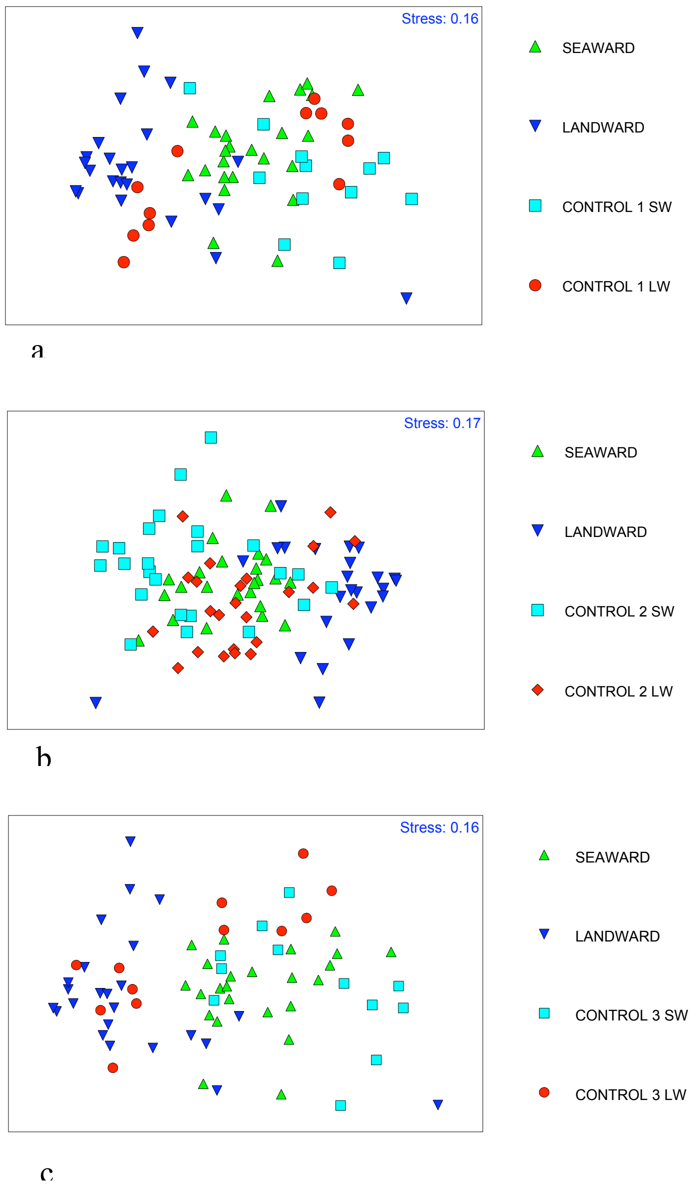


Figure 4 – nMDS plots of infaunal communities at Elmer. C1 areas indicate the closest control locations to the LCS (a), C2 the intermediate distance (b) and C3 the furthest apart (c).

Table 2 – Results from two way nested ANOSIM analysis of infaunal communities around LCS and control areas at Elmer.

Comparison seaward vs landward vs control 1	
Differences between areas within location	**R = 0.48; p<0.01**
Differences between locations	**R = 0.39; p<0.03**
Pairwise tests between locations	**R**
Landward vs Seaward	0.63
Landward vs Control 1 Lw	0.25
Landward vs Control 1 Sw	0.86
Seaward vs Control 1 Sw	0.29
Seaward vs Control 1 Lw	0.22
Control 1 Lw vs Control 1 Sw	-0.25
Comparison seaward vs landward vs control 2	
Differences between areas within location	**R = 0.5; p<0.01**
Differences between locations	**R = 0.29; p<0.02**
Pairwise tests between locations	**R**
Landward vs Seaward	0.63
Landward vs Control 2 Lw	0.49
Landward vs Control 2 Sw	0.63
Seaward vs Control 2 Sw	0.03
Seaward vs Control 2 Lw	-0.01
Control 2 Lw vs Control 2 Sw	0.08
Comparison seaward vs landward vs control 3	
Differences between areas within location	**R = 0.53; p<0.01**
Differences between locations	**R = 0.40; p<0.02**
Pairwise tests between locations	**R**
Landward vs Seaward	0.63
Landward vs Control 3 Lw	0.25
Landward vs Control 3 Sw	0.79
Seaward vs Control 3 Sw	0.32
Seaward vs Control 3 Lw	0.43
Control 3 Lw vs Control 3 Sw	-0.5

Table 3 – Results from SIMPER analysis for species which mostly contributed to the differences between communities around the LCS and in the main control areas at Elmer. Only species contributing to the 60 % of differences are shown.

SIMPER ANALYSIS			
Landward vs Seaward			
Species	**Mean abundance**		**% Contribution**
	Landward	Seaward	
Bathyporeia sarsi	70.63	13.58	63.07
Landward vs Control 2 Lw			
Species	**Mean abundance**		**% Contribution**
	Landward	Control	
Bathyporeia sarsi	70.63	38.17	66.53
Seaward vs Control 2 Sw			
Species	**Mean abundance**		**% Contribution**
	Seaward	Control	
Bathyporeia sarsi	13.58	12.88	35.77
Urothoe poseidonis	10.75	14.25	22.2
Total			57.97

This also confirms that the influence of LCS on the infaunal community is stronger than the effects caused by differences in tidal level. All control areas showed a relatively homogenous community, independently of the relative distance from the breakwaters. This suggests that the LCS had a very localised effect, mainly on the landward side of the structures. High variability was also observed within each location, as shown by the two way nested ANOSIM (Table 2). Results from SIMPER analysis showed that the differences observed in the infaunal communities around the breakwaters were mainly caused by the abundance of the species *Bathyporeia sarsi*, which accounted for 60% of the differences (Table 3). This species was considerably more abundant on the landward than on the seaward side and control areas.

The analysis of trophic structure showed a clear dominance of surface deposit feeders in all the locations investigated (Figure 5). This group consisted mainly of *Bathyporeia* spp., *Spio filicornis* and *Urothoe poseidonis*. No apparent differences were also shown in the mean abundance of the trophic groups in the various locations. Filter feeders were absent.

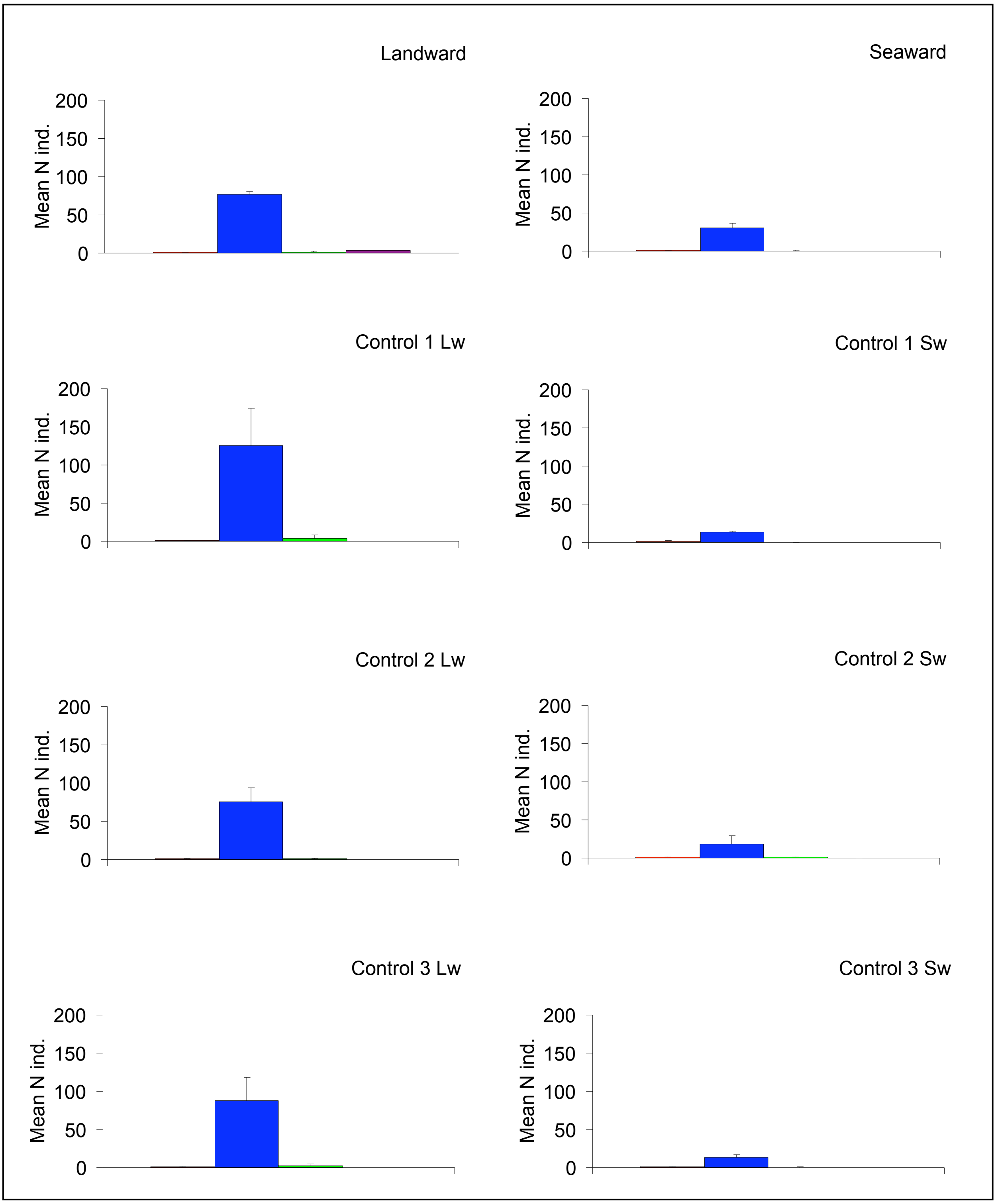


Figure 5 – Mean abundance of trophic groups in the locations at Elmer. Carnivorous; Surface deposit feeders; Sub-surface deposit feeders; Mixed feeders.

Surface deposit feeders appeared also to be more abundant on the landward side of the structures than on the seaward side, this pattern being consistent also in the control areas. Multivariate analysis of the abundance and distribution of all the trophic groups around the LCS and at increasing distances from the structures (Figure 6) showed differences between landward, seaward and the control areas (ANOSIM $p<0.001$). However these differences disappeared between landward, seaward sides and the controls areas located at the furthest distance from the structures (ANOSIM $p=0.08$). As for the abundance of infaunal species, high variability within treatment characterised all the locations investigated (ANOSIM, $p<0.001$).

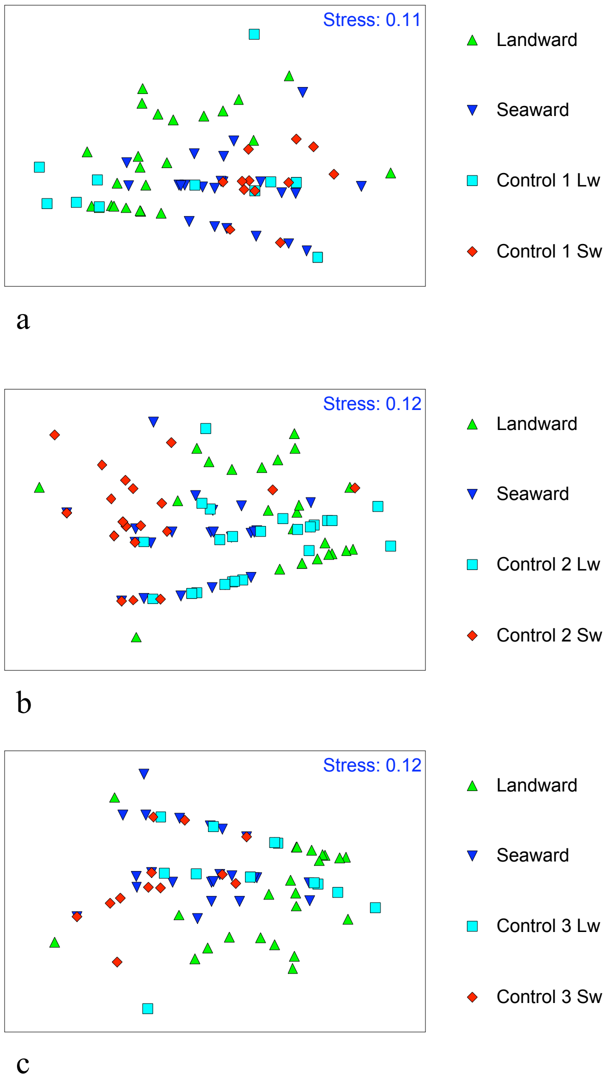


Figure 6 – nMDS plots of infaunal communities at Elmer based on trophic groups. C1 areas indicate the closest control locations to the LCS (a), C2 the intermediate distance (b) and C3 the furthest apart (c).

Effects of LCS on soft bottom community at Liverpool:

In Liverpool a total of 44 taxa were identified in the sediment cores collected around the breakwaters and in the control areas (Table 4). The number of taxa identified on the seaward (Sw 4) and landward (Lw 3) side of the breakwater was 23 and 21 respectively, of which 13 species were in common. A similar number of species was also observed in the control areas, whilst the inshore (Lw 1, 2) and offshore (Sw5, 6) locations showed considerably lower numbers of species. Most of the species were Polychaetes and Amphipods, but a few species of Bivalves were also found. These species were present in all locations except for the offshore seaward locations.

Table 4 – List of total taxa identified in Liverpool LCS.

Liverpool
Nemertea
Polychaeta
Harmothoe lunulata
Mysta picta
Anaitides (Phyllodoce) mucosa
Glycera lapidum
Syllidae
Nereis diversicolor
Nephtys sp.
Scoloplos armiger
Paraonis fulgens
Microspio mecznikowianus?
Polydora ciliata
Pygospio elegans
Scololepsis squamata
Spio filicornis
Spiophanes bombyx
Streblospio websteri
Magelona mirabilis
Capitellidae
Ophelia rathkei
Owenia fusiformis
Lanice conchilega
Oligochaeta
Amphipoda
Gastrosaccus spinifer
Bathyporeia sp.
Bathyporeia elegans
Bathyporeia pelagica
Bathyporeia pilosa
Bathyporeia nana
Bathyporeia sarsi
Corophium arenarium
Isopoda
Eurydice pulchra
Cumacea
Cumopsis goodsiri
Pseudocuma longicornis
Decapoda
Crangon crangon
Brachyura juv.
Portunidae
Collembola
Anurida maritima
Bivalvia
Cardiidae
Parvicardium ovale
Cerastoderma edule
Angulus tenuis
Fabulina fabula
Macoma balthica

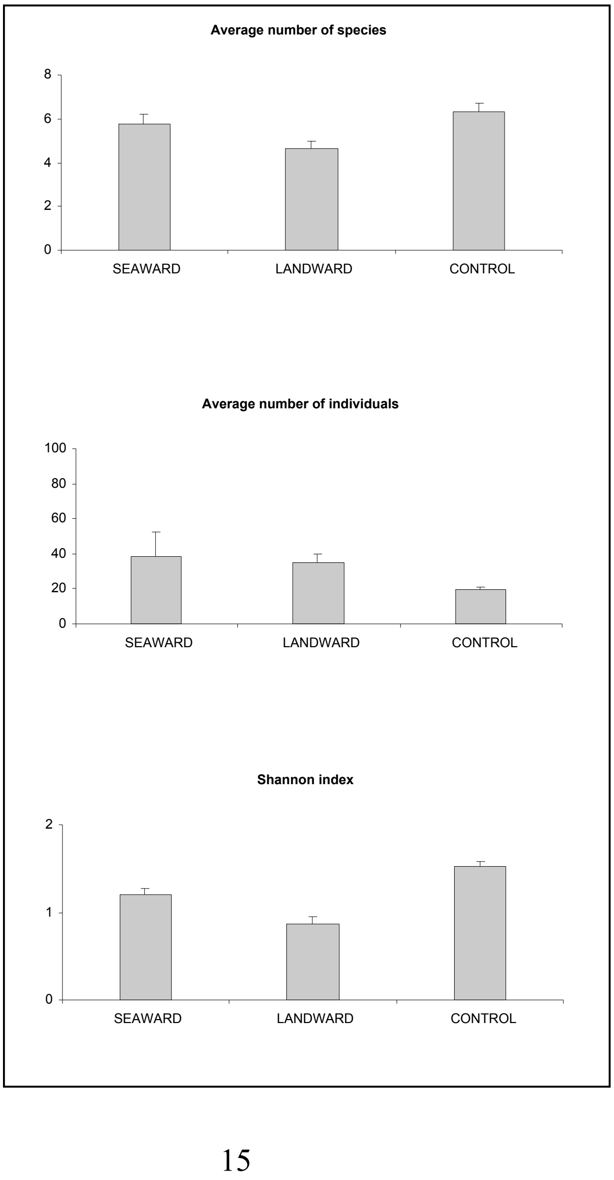


Figure 7 – Comparison of the mean number of species (a), total abundance, expressed as number of individuals (b) and diversity, expressed as Shannon index (c) on the seaward (Sw 4), landward (Lw 3) and control (C) areas sampled.

There were no significant differences (ANOVA, n.s.) in the total number of species and total abundance between landward, seaward and control areas (Figure 7). Diversity differed significantly (ANOVA, p<0.001). A more diverse community characterised the control and seaward areas, whilst a lower index was observed on the landward location. As for the Elmer study, highly significant variability (ANOVA p<0.01) was observed within each location, particularly on the landward side of the LCS.

The multivariate analysis of communities around the LCS and in control areas showed a similar pattern observed at Elmer. The community on the landward side was very well separated from the community of the seaward side and controls. By contrast, little differences were detected between seaward and control areas (Figure 8, Table 5). Furthermore, areas close to the structures (landward 3 and seaward 4) differed significantly from areas located more inshore or offshore (Figure 8b, c). In particular, the community from the offshore areas (seaward 5 and 6) differed strongly from all the others areas.

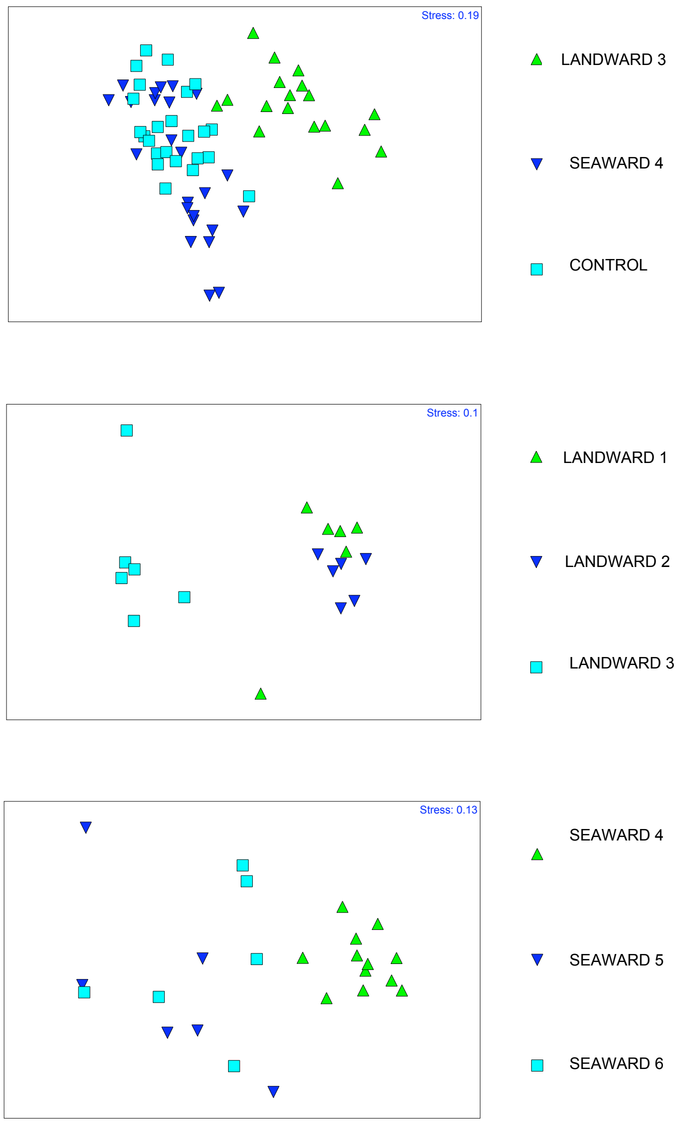


Figure 8 – nMDS plots of infaunal communties sampled on the seaward, landward and control areas (a), at different inshore (b) and offshore distances form the LCS (c) in Liverpool.

SIMPER analysis showed that differences between landward and seaward locations were mainly due to the greater abundance, on the seaward side, of the species *Bathyporeia sarsi* and of the presence of *Corophium arenarium* on the landward side (Table 6). This species also differentiated the communities between landward and control locations. As for the Elmer study great variability was observed between areas within each locations (Table 5).

Table 5 – Results from two way nested ANOSIM analysis of infaunal communites around LCS and control areas in Liverpool. One way analysis was applied to landward (inshore) and seaward

Comparison seaward vs landward vs controls (two way ANOSIM)	
Differences between areas within location	**R = 0.58; p<0.001**
Differences between locations	**R = 0.48; p<0.01**
Pairwise tests between locations	**R**
Landward 3 vs Seaward 4	0.61
Landward 3 vs Control	0.87
Seaward 4 vs Control	0.15
Comparison between landward locations (one way ANOSIM)	
Differences between locations	**R = 0.61; p<0.001**
Pairwise tests between locations	**R**
Landward 3 vs Landward 2	0.82
Landward 3 vs Landward 1	0.76
Landward 1 vs Landward 2	0.20
Comparison between seaward locations (one way ANOSIM)	
Differences between locations	**R = 0.69; p<0.001**
Pairwise tests between locations	**R**
Seaward 4 vs Seaward 5	0.88
Seaward 4 vs Seaward 6	0.83
Seaward 5 vs Seaward 6	-0.03

Table 6 – Results from SIMPER analysis for species which mostly contributed to the differences between communities around the LCS and in the main control areas in Liverpool. Only species contributing up to 60 % of differences are shown.

SIMPER ANALYSIS			
Landward vs Seaward			
Species	**Mean abundance**		**% Contribution**
	Landward	Seaward	
Bathyporeia sarsi	0.17	22.21	31.06
Corophium arenarium	32.17	0.08	25.16
Total			56.23
Landward vs Control			
Species	**Mean abundance**		**% Contribution**
	Landward	Control	
Corophium arenarium	32.17	0	31.24
Spio filicornis	0.89	4.96	12.38
Nephtys sp.	4.39	4.71	8.73
Bathyporeia sarsi	0.17	3.25	8.55
Total			60.89
Seaward vs Control			
Species	**Mean abundance**		**% Contribution**
	Seaward	Control	
Bathyporeia sarsi	22.21	3.25	45.70
Spio filicornis	6.50	4.96	19.39
Total			65.09

In Liverpool, the trophic structure of infaunal communities was more diverse than at Elmer. All the trophic groups were represented in the locations investigated (Figure 9). However, the relative abundance of each trophic group varied considerably among locations. A clear difference was shown between the landward and seaward side of the LCS, the latter being dominated by surface and subsurface deposit feeders. Similar patterns in the relative abundance of the trophic groups were observed for the inshore distances and offshore distances. Both inshore locations showed a dominance of carnivorous, surface and sub-surface deposit feeders, no apparent difference was observed in the offshore locations, probably due to scarce abundance of infaunal organisms. Filter feeders, mainly bivalves, were only present in the more inshore locations, whilst mixed feeders were very scarce in all the seaward locations. Control also appeared to differ from the seaward and landward locations.

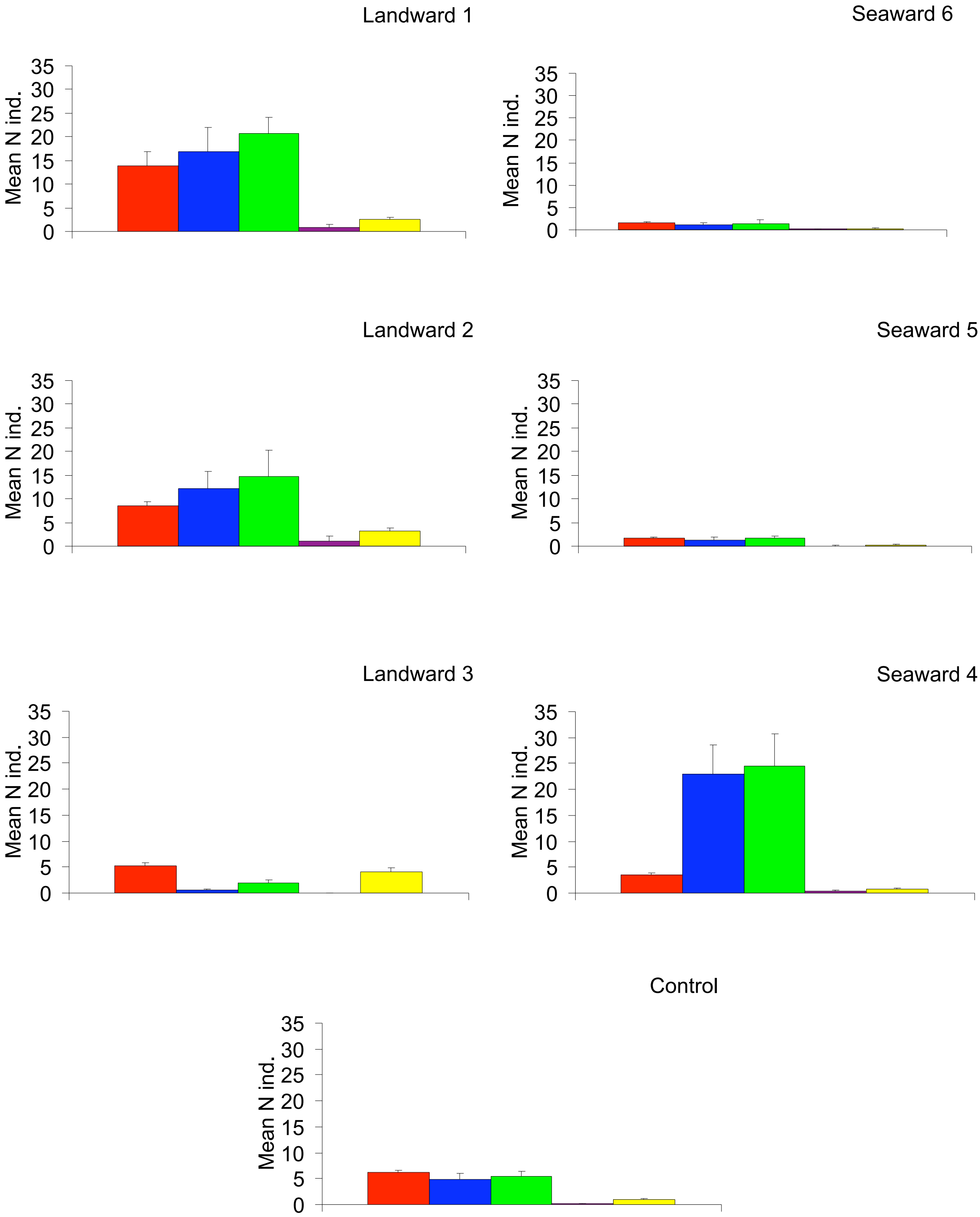


Figure 9 – Mean abundance of trophic groups in the locations at Elmer. Carnivorous; Surface deposit feeders; Sub-surface deposit feeders; Filter feeders; Mixed feeders. Plots in the first column are ordered from most inshore location (landward 1) to the landward side of the LCS (landward 3). Plots in the second column are ordered from the most offshore location (seaward 6) to the seaward side of the LCS (seaward 4).

Multivariate analysis of infaunal communities based on their trophic structure mirrored the results based on abundance of infaunal species (Fgure 10). Marked differences were shown between the landward and seaward side of the LCS (ANOSIM $p<0.05$). Control areas differed significantly from the landward side (ANOSIM $p<0.05$), whilst showed high similarity with the seaward side (ANOSIM $p=0.25$). The landward side differed form both inshore distances (ANOSIM $p<0.001$), these being very similar instead (ANOSIM $p=0.31$). The same pattern was observed for the seaward side and the more offshore distances. The seaward side differed significantly from the two offshore locations (ANOSIM $p<0.05$), which were highly similar (ANOSIM $p=0.87$).

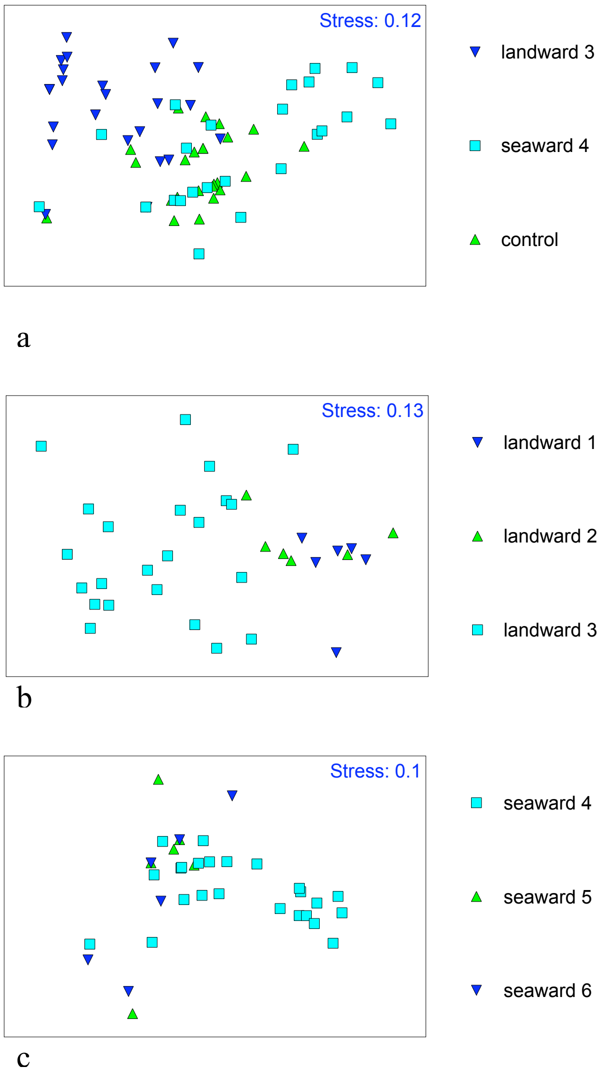


Figure 10 – nMDS plots of infaunal communties in Liverpool, sampled on the landward (Landward 3), seaward (Seaward 4) sides of the structures, control areas and increasing inshore (Landward 1 and 2) and offshore (Seaward 5 and 6) locations. (a), comparison between landward, seaward and control; (b), comparison between landward and increasing inshore distances; (c) comparison between seaward and increasing offshore distances.

Effects of LCS at different isobaths in Lido di Dante (Italy)

Since previous investigations showed that almost no differences between control and seaward macrobenthic communities occurred, the present study has been carried out only at Landward (L) and Control (C) sites. At each site two isobaths were chosen, located at 2.5 and 1.0 m depth respectively. Five sampling Areas (a, b, c, d, e), nested in site-isobath (C1, L1, C2.5 and L2.5) interaction, were randomly selected. In each area, three replicates were gathered for both sediment and macrobenthos analyses (Fig 1).

Fig 1 – Experimental sampling design.

Results

Grain size analysis, performed by dry sieving method, showed a marked influence of the presence of LCS, mainly at 1.0 m depth (Fig.2a, c). Treatment C1 was characterized by well-sorted medium sands, as evidenced by median diameter (Md*f*= 1.64 ± 0.06) and quartile deviation (QD*f* = 0.47 ± 0.02), whereas L1 resulted in a moderately well-sorted medium sands (Md*f*= 2.55 ± 0.07; QD*f* = 0.53 ± 0.02). No differences were detected between C and L sites at 2.5 m depth (Fig. 2b, d). Herein both sediments were characterized by moderately well-sorted fine sands.

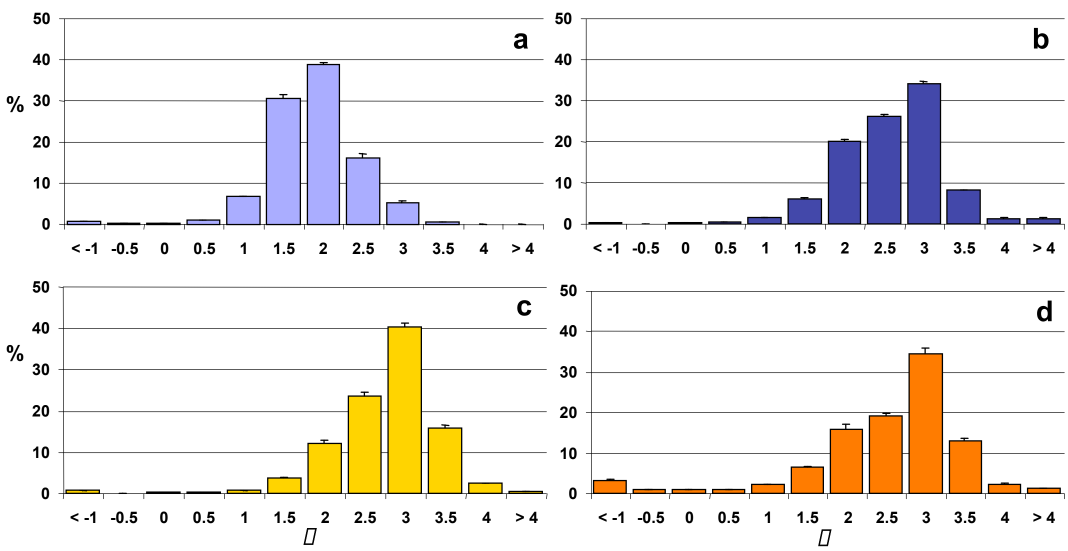


Fig. 2 – Percentage of the sediment weight measured in each grain size fraction (*f*) + S.E. at each treatment (a = C1; b = C2.5; c = L1; d = L2.5).

Analysis of total organic matter (TOM) showed a significant effect of both site (F = 17.12; p < 0.001) and isobath factors (F = 11.07; p < 0.001), with higher average values at L site and at 2.5m depth respectively (Fig. 3).

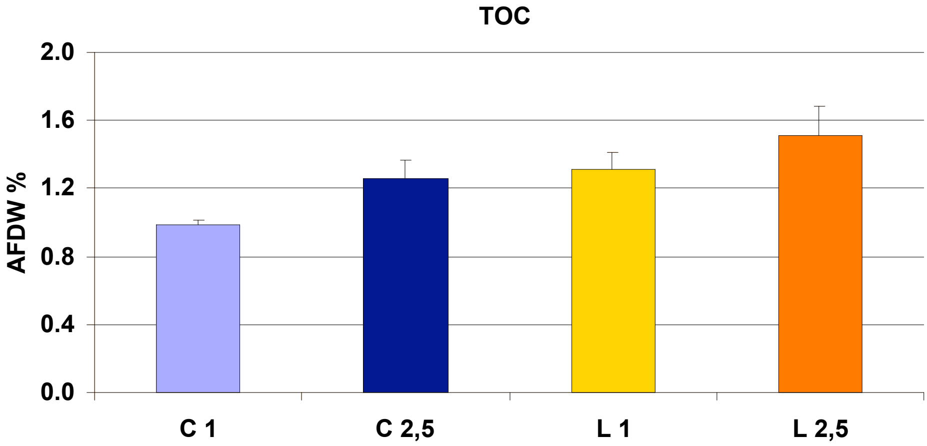


Fig. 3 - Mean AFDW percentages of the TOM + S.E. at each treatment.

As for *Chl a*, only depth factor showed a significant effect (F = 11.28; p < 0.01), with a higher average content at 2.5 m isobath (Fig. 4).

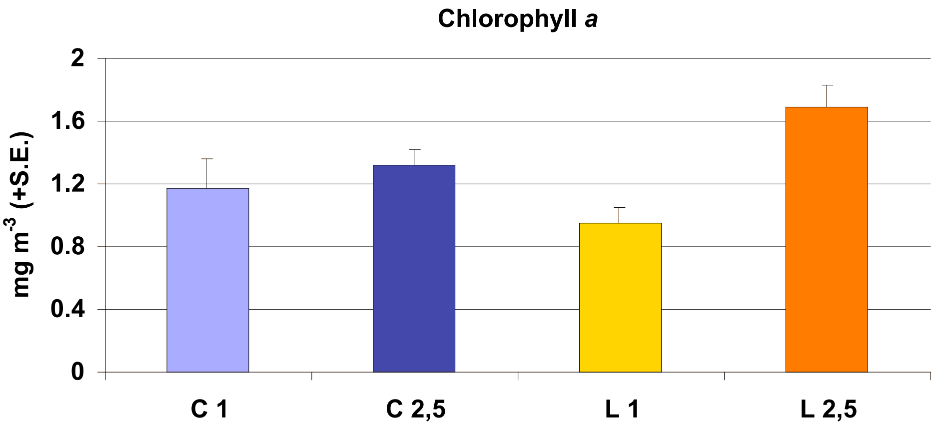


Fig. 4 - Mean concentrations of the Chlorophyll *a* at each treatment.

A total of 218000 individuals of macrobenthic organisms were counted for a total biomass of 605443 mg AFDW. On the whole, 88 species were identified. Average values of both total abundance (Fig. 5a) and biomass (Fig. 5b) showed no significant differences among treatments but a significant within-area variability (F=7.27, p<0.0001). Even if not significant, seemingly higher average density was recorded in the C sites than L ones and in the deeper than in the shallower isobaths. Conversely, average biomass values tended to be higher in the areas closer to the shoreline.

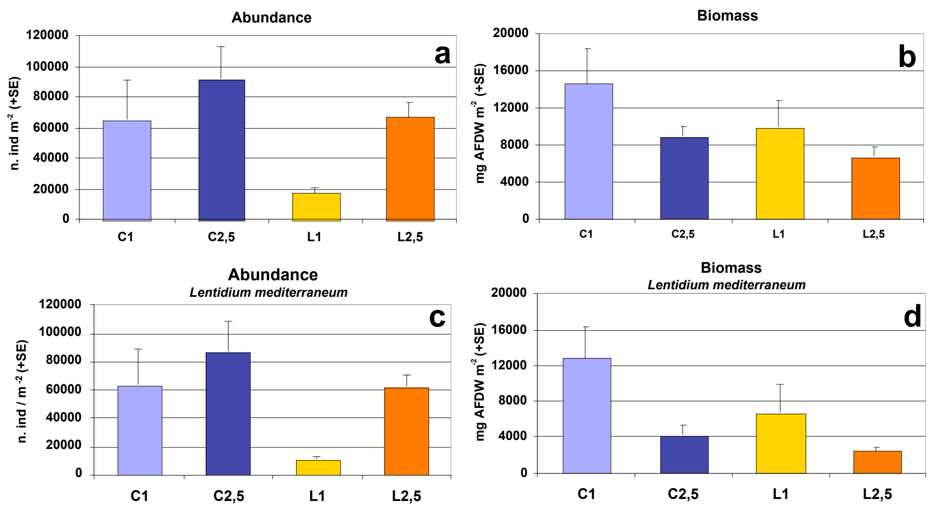


Fig. 5 - Mean values (calculated on areas) of (a) total abundance, (b) total biomass, (c) abundance of *Lentidium mediterraenum*, (d) biomass of *L. mediterraenum*, at each treatment.

These results were mainly due to the huge dominance of *Lentidium mediterraneum* in all treatments. The lowest abundance of that bivalve was recorded at 1 m isobath in the Landward site (Fig. 5 c), but in the same site biomass was relatively high because of the prevalence of large sized individuals (Fig. 5 d).

A significantly higher number of species was recorded in the L site than in the C site, at both depths (Fig. 6 a). The Shannon Index calculated on abundance data (Fig. 6 b) pointed out an increased level of diversity between C1 and L1 treatments, but comparable values between C2.5 and L2.5. Conversely, the same index calculated from biomass data (Fig. 6 c) seemed to follow a pattern similar to that already described for the number of species.

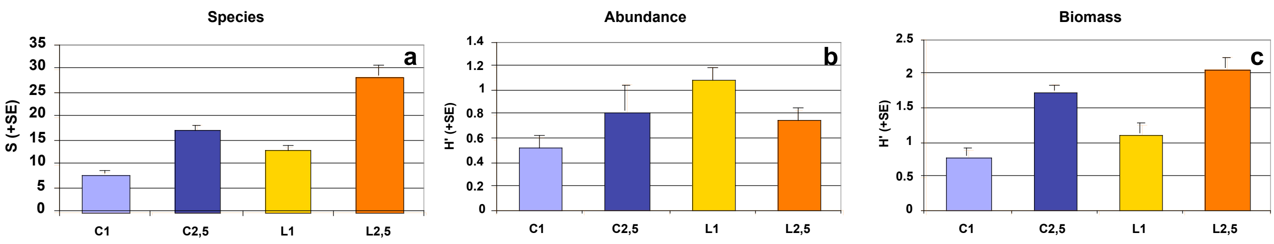
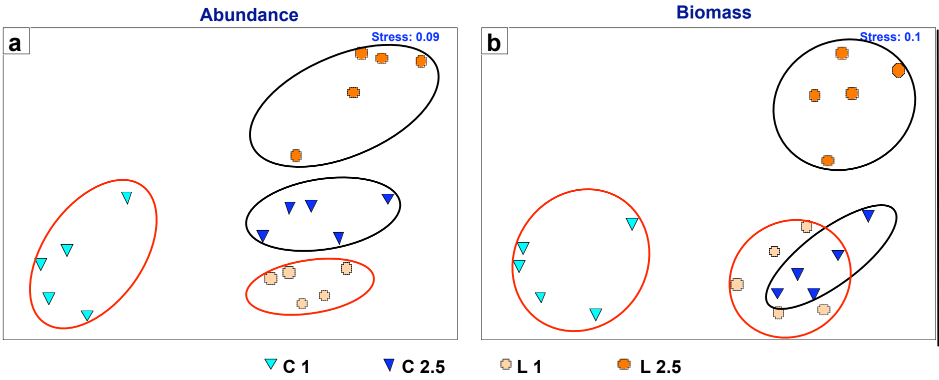


Fig. 6 - Mean values (calculated on areas) of (a) number of species, (b) Diversity on abundance data, (c) Diversity on biomass data, at each treatment.

MDS plot based on abundance (Fig. 7a) revealed a marked effect of LCS on the composition and structure of macrobenthic communities, both for sites and for depth factor (Tab. 1). In fact, sample-points grouped close together according to each treatment combination. As for biomass, whereas the C1 and L2.5 sample points were well spaced (Fig. 7 b), the L1 and C2.5 sample points tended to cluster together. This was probably due to the fact that in the C2.5 treatment most of species were represented by small sized individuals with high densities while in the L1 the same species were represented by larger sized specimens with lower densities (e.g. *L. mediterraneum* and *Cyclope neritea*). ANOSIM results showed that the above observed pattern were statistically significant (Tab. 1).

Fig. 7 - nMDS plot of macrobenthic communities based on (a) Abundance data and (b) Biomass data. Red



and black circle outline treatments at 1.0 m and 2.5 m depth respectively.

Table 1 - Results of Two-way Crossed ANOSIM based on abundance and biomass data.

	Abundance		Biomass	
	R	p	R	p
Sites	0.904	<0.001	0.936	<0.001
Depth	0.948	<0.001	0.948	<0.001

Moreover, other single species gave different contributions either to the abundance or to the biomass of the different treatments. For instance, the isopod *Eurydice sp.* was exclusively present in the C1 whereas the polychaete *Spio decoratus* in the L1 treatment.

The MDS plot based on trophic indexes calculated on abundance data (Fig. 8 a) showed also an effect of LCS on the functional structure of macrofaunal communities. Sample-points formed nearly distinct groups according to all considered factors, although C2.5 sample points appeared much more interspersed with all those of the 1m isobath. The same results were obtained on biomass data, but sample points appeared to be more scattered (Fig. 8 b). Anyway, ANOSIM showed the above differences to be statistically significant (Tab. 2).

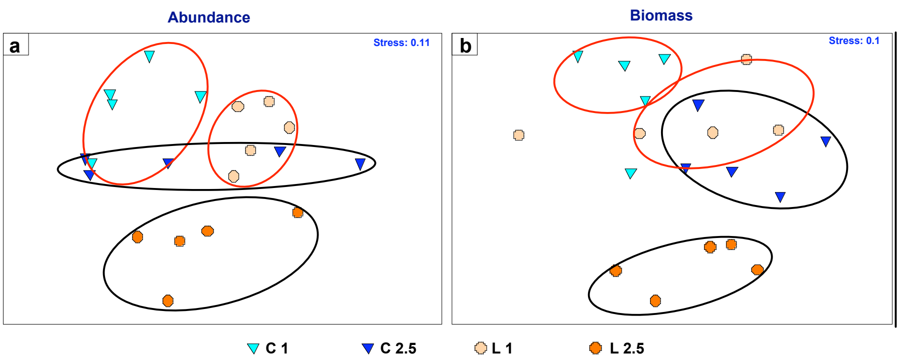


Fig. 8 - nMDS plot of macrobenthic communities based on (a) Trophic group Abundance data and (b) Trophic group Biomass data. Red and black circle outline treatments at 1.0 m and 2.5 m depth respectively.

Table 2 - Results of Two-way Crossed ANOSIM based on abundance and biomass data of trophic groups.

	Abundance		**Biomass**	
	R	**p**	**R**	**p**
Sites	0.558	<0.01	0.420	<0.01
Depth	0.478	<0.01	0.594	<0.01

Summary

Spanish LCS

The LCS system in Altafulla is structurally simpler than that in Cubelles (see D33). Accordingly, the infaunal assemblages were different in both localities, but that in Altafulla resulted to be much rich and diverse than that in Cubelles.

Like in Cubelles, the original ANOVA design (see D33) was able to demonstrate the existence of an influence of the Altafulla LCS on the environmental factors (mainly on the % of fine sediments and mean grain size) and faunal descriptors (only in the abundance), but it was not possible to identify the causes.

The new sampling design based on samples collected at successive distances from LCS allowed to define the relationships between sediment variables and faunal descriptors. The most relevant result, however, was that these relationships were not linear, with the presence of the LCS inducing a disruption in the normal progress of the assemblages from the shoreline to deep waters. In summary, all physical and biological descriptors tended to show low values at sites seaward the LCS than at the corresponding stations in control transects.

Contrary to the results that could be expected from the theoretical model of hydrodynamics around the LCS, the observed changes (both for environmental factors and infaunal descriptors) are not perpendicular to the coastline, with the stations located at the south of the LCS showing different trends than those in the northern area. This trend was particularly relevant at the landward side of the structure, where both the environmental variables and the infaunal assemblages showed a higher variability. The most characteristic pattern concerning the environmental variables is shown by the distribution of fine sediments, which tends to be low around the area of influence of the LCS, then progressively increases with depth, while a similar increase occurs closer to the shoreline along the control transects.

United Kingdom LCS

The study at increasing distances along the coast near the Elmer defence scheme and at increasing inshore and offshore distances in Liverpool showed an overall pattern: the LCS seeem to cause a sharp gradient between seaward and landward, which is stronger than the effect of the tidal level. This was shown by the fact that the communities in the control areas located at different tidal level were relatively similar.

In both Elmer and Liverpool, the LCS appeared to strongly modify the infaunal community on the landward side, this being very different from the seaward side and control areas. Diversity appeared also to be lower on the landward than on the seaward and control areas.

The effects of LCS was mainly localised around the structure, as no effects were observed at increasing distances along the shore (Elmer) or at increasing tidal levels inshore and offshore from the LCS (Liverpool).
However, at Elmer, LCS did not significantly influence the type of sediment around the LCS and did not justify the differences in the infaunal communities. In Liverpool, the

LCS modified markedly the sediment on the landward side, which was much finer and anoxic than on the seaward side and control areas. In this case, LCS increased habitat heterogeneity, facilitating colonisation by species which were not present in any of the other locations, such as *Corophium arenarium.*

Italian LCS

At Lido di Dante, the presence of LCS appeared to affect differently the soft sediment benthic assemblages at 1.0 and 2.5 m depth respectively. Marked differences in abundance, species composition and functional structure have been observed between communities of the Landward and Control areas at comparable depths.

As previously outlined in the past investigation (D 33), *Lentidium mediterraneum* dominates the community in both sites (Control and Landward). But individuals resulted markedly larger at 1.0 m depth than at the deeper 2.5 m isobath. This finding is in agreement with the well known tendency of *L. mediterraneum* to be passively transported by wave motion during its growth, so that larger and heavier specimens tend to accumulate together with coarser sand and viceversa. The different proportions of abundance and biomass of *L. mediterraneum* founded among treatments, reflect the changes of hydrodynamic patterns and sediment transport induced by LCS at Lido di Dante.

The influence of LCS on benthic species assemblages is also evidenced by the particular distribution of some species such as *Eurydice sp.* and *Spio decoratus*, which were exclusively found at C1 and at L1, respectively. That distribution is probably due to different tolerance of the two species to the wave induced stress. The Isopod *Eurydice* is reported as a genus well adapted to shoreline waters stressed by waves, whereas *S. decoratus* is an opportunistic surface deposit feeder inhabiting less stressed bottoms.

On the whole, almost all parameters taken into account showed a gradual change from C1 (the site hydrodynamically more exposed) to L1, C2.5 and L2.5 according to a progressive decrease of hydrodynamic stress. Moreover, the more marked differences for either abiotic or biotic descriptors which have been found between L and C site at 1.0 m isobath seem to suggest that the hydrodynamic influence of LCS is well extended over the shoreline of the protected site.

Eventually the marked differences in terms of either species number or composition revealed how infaunal soft bottom communities react effectively to environmental changes induced by LCS presence. They, therefore, represent a good tool to record the impact and a better alternative to classical soft bottom physico-chemical descriptors such as granulometry or carbon content, which show a very high variability on small-medium scale.

Conclusion

The three teams involved in the WP3.1 have been working in parallel on three LCS with different systems of structures and different environmental circumstances (Fig. 1). This approach allowed to solve the main problem reported from the previous studies (reported as D18 and D33), where it was clearly pointed out that it was always difficult to link physical factors to faunal descriptors in order to identify the causes of the observed trends on the basis of a strict ANOVA design, besides that there are always significant differences between the seaward and the landwards sides of the structures, because of the high within treatment variability.

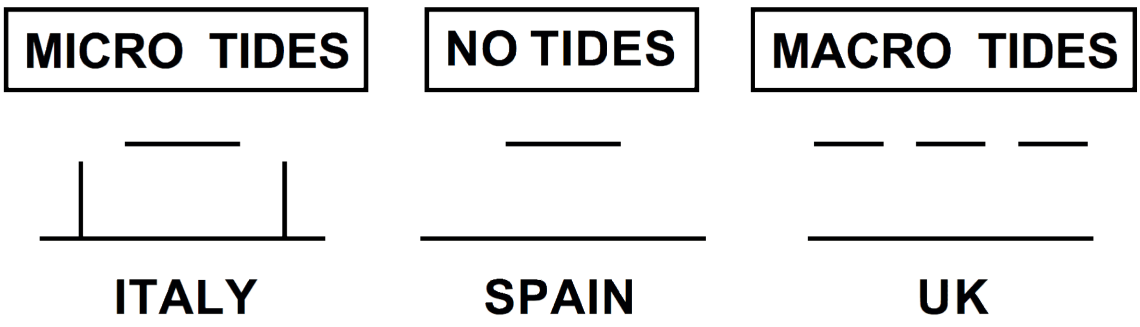


Figure 1.- Scheme of the three study sites.

One of the main conclusion that can be inferred, is that the new sampling design carried out at the three sites (designed according to the particular characteristics of each site) produces an integrated picture of the system, that could be linked (easily) to a dynamic model in order to assess the influence of hydro- and sediment dynamics. This will certainly be a key approach to contribute to the next deliverable in which the WP 3.1 partners are involved (D45), which will provide the key data on breakwater design features for the maintenance and enhancement of biodiversity and functional organisation of soft-bottom assemblages around the LCS.