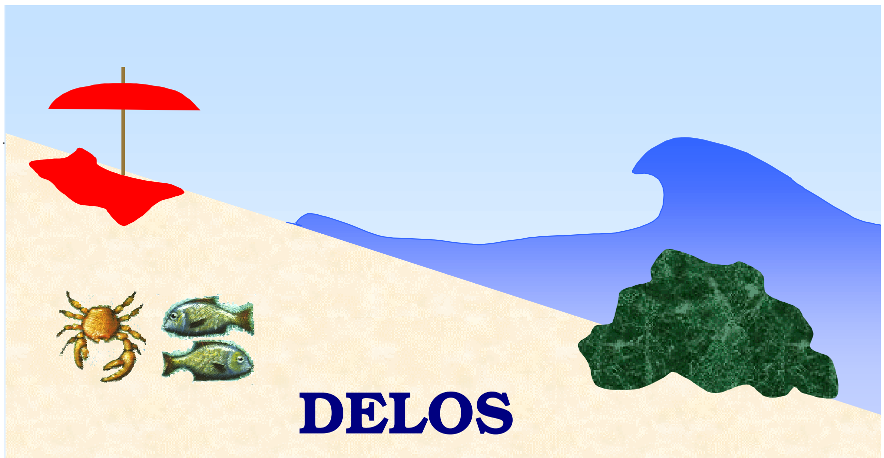
EU Fifth Framework Programme 1998-2002
Energy, Environment and Sustainable Development

Environmental Design of Low Crested Coastal Defence Structures



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Assessment of direct and indirect effects of breakwater design on species assemblages in soft bottom habitats

Contract n°EVK3-CT-2000-00041

DELIVERABLE 33

Assessment of direct and indirect effects of breakwater design on species assemblages in soft bottom habitats

RESULTS

LCS at Cubelles (Catalunya, Spain)

Community descriptors

A total of 2125 individuals of infaunal organisms have been counted, belonging to 88 species grouped into 20 major taxa and yielding a total biomass of 2.454 AFDW mg. The mayor dominant groups in the whole community were amphipod crustaceans and annelid polychaetes for the abundance (55.8% and 36.1%, respectively) and polychaetes, bivalve molluscs, amphipods and gastropod molluscs for the biomass (34.0%, 34.1%, 11.5% and 10.4%, respectively.

Table 1.- Contributions to the abundance and biomass of major taxonomic taxa found at the Cubelles study site. Bold text indicates the dominant groups at each treatment.

	ABUNDANCE		
GROUP	**C**	**S**	**L**
AMPHIPODA	**43.2**	**67.6**	**56.5**
POLYCHAETA	**48.4**	**26.7**	**33.2**
CUMACEA	0.4	2.1	5.0
BIVALVIA	3.5	0.8	1.1
MYSIDACEA	0.2	0.7	1.1
DECAPODA	2.1	0.3	0.8
ECHINOIDEA	0.0	0.0	0.5
ISOPODA	0.7	0.3	0.5
OSTRACODA	0.1	0.5	0.5
ACRANIA	0	0	0.3
OPHIUROIDEA	0.0	0.1	0.3
OPISTOBRANCHIA	0.0	0.0	0.3
ACTINIARIA	0.2	0.1	0.0
CIRRIPEDA	0.0	0.6	0.0
COPEPODA	0.1	0.0	0.0
GASTROPODA	0.1	0.1	0.0
HOLOTHUROIDEA	0.1	0.0	0.0
NEMERTINI	0.6	0.0	0.0
PANTOPODA	0.0	0.0	0.0
SIPUNCULIDA	0.2	0.0	0.0

	BIOMASS		
GROUP	**C**	**S**	**L**
POLYCHAETA	**11.0**	**41.5**	**49.4**
BIVALVIA	**69.7**	3.5	**29.2**
AMPHIPODA	1.4	**18.1**	**11.6**
DECAPODA	**11.3**	0.0	4.8
ISOPODA	0.0	0.1	1.3
CUMACEA	0.0	0.4	1.1
ECHINOIDEA	0.0	0.0	1.0
MYSIDACEA	0.0	0.3	0.8
ACRANIA	0.0	0.0	0.5
OSTRACODA	0.0	0.1	0.2
OPHIUROIDEA	0.0	0.1	0.2
OPISTOBRANCHIA	0.0	0.0	0.0
ACTINIARIA	3.4	0.0	0.0
CIRRIPEDA	0.0	4.2	0.0
COPEPODA	0.0	0.0	0.0
GASTROPODA	2.7	**31.7**	0.0
HOLOTHUROIDEA	0.1	0.0	0.0
NEMERTINI	0.0	0.0	0.0
PANTOPODA	0.0	0.0	0.0
SIPUNCULIDA	0.3	0.0	0.0

The contributions of the major groups to the abundance and biomass at the different treatments have been summarized on Table 1. It should be pointed out that polychaetes and amphipods are the major contributors to the abundance in all treatments (higher percentage for the amphipods around the LCS and for the polychaetes in the control). As for the biomass, the major contributors are the polychaetes, gastropods and amphipods at the seaward site, the polychaetes, bivalves and amphipods at the landward site and the bivalves, decapods and polychaetes in the controls.

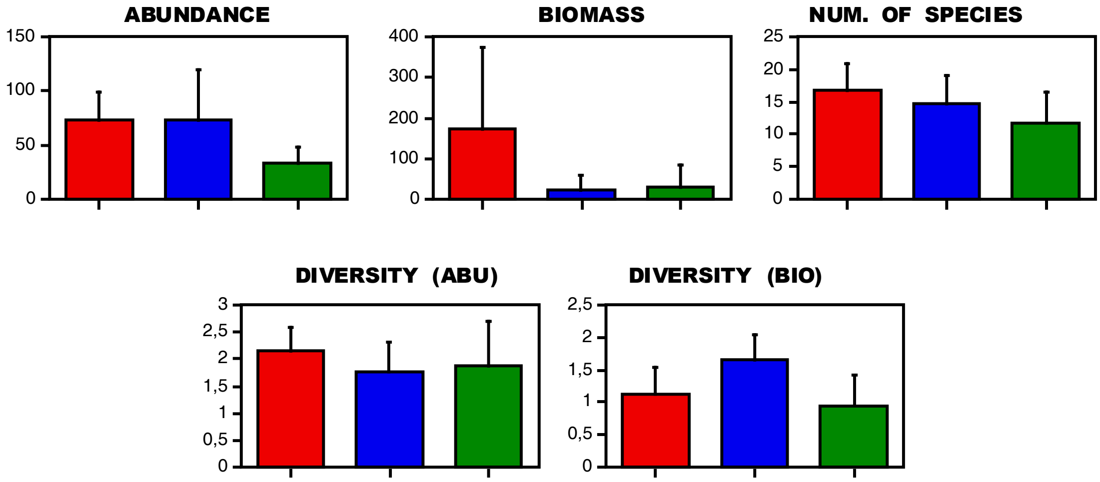


Figure 1.- Variability of the variables describing the benthic communities at the Cubelles study site. RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

A	ABUNDANCE		BIOMASS	
	R	p	R	p
Variability	0.309	0.03	0.246	0.004
Treatment	0.484	0.03	0.560	0.002

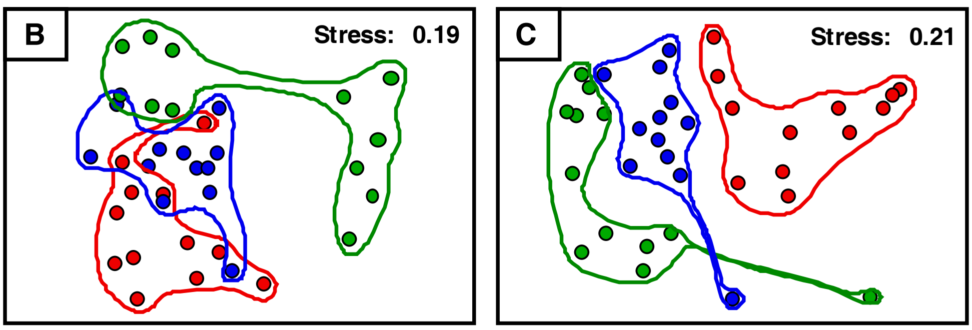


Figure 2.- A.- Results of the ANOSIM based on abundance and biomass data. B.- Results of the MDS based on abundance. B.- Results of the MDS based on biomass. RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

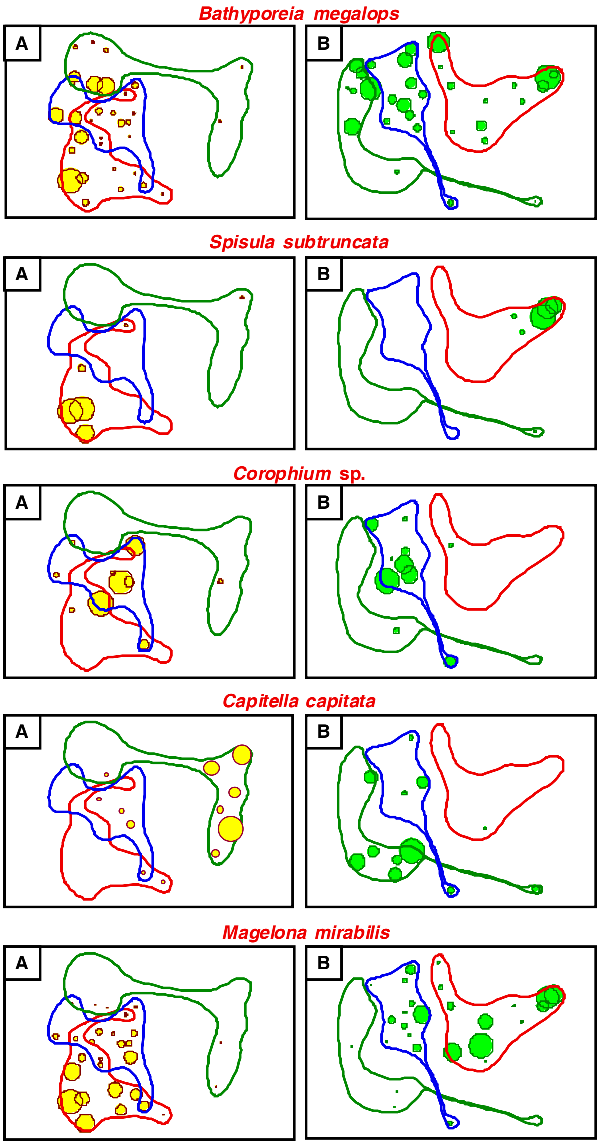


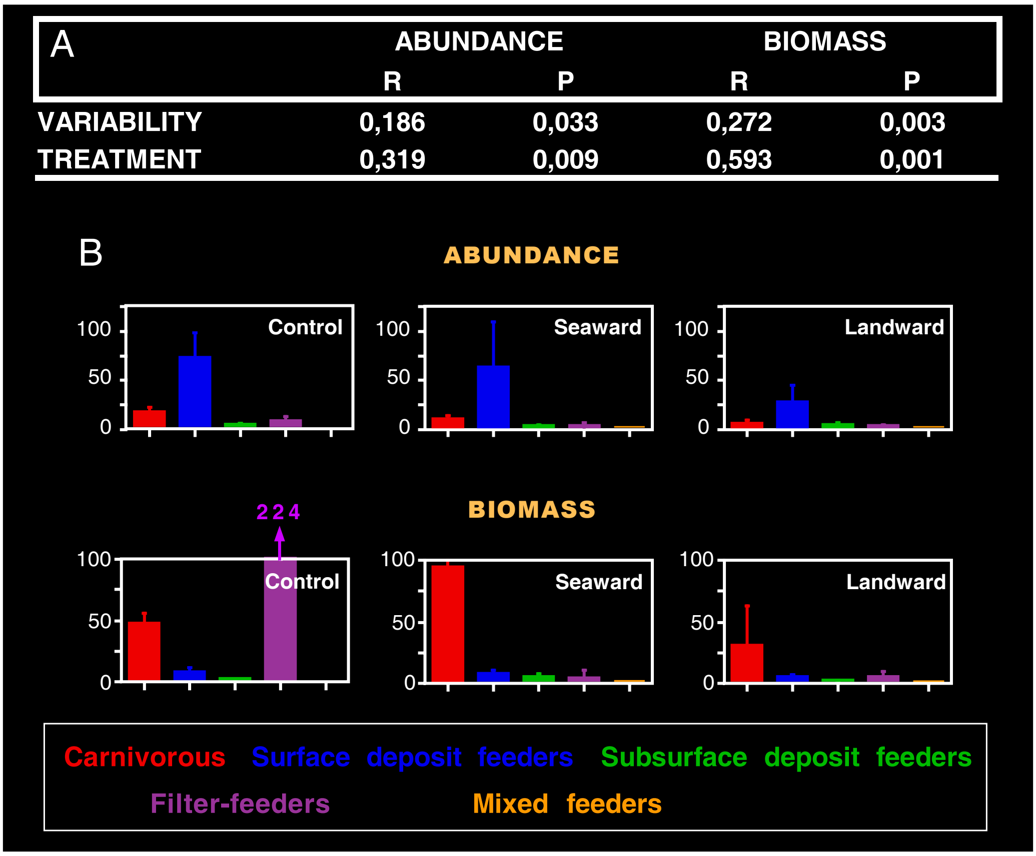
Figure 3.- Patterns of distribution of infaunal species characterizing the treatments as pointed out by the results of the MDS and SIMPER analysis. A: Abundance. B: Biomass. RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

When analysing the biological variables used to describe the benthic communities (Fig. 1), we observed that there were non-significant differences among treatments in the number of species and the Shannon diversity index (based on abundance). Moreover, as expected, the within-treatments variability was only significant for these two variables. Conversely, the abundance, biomass and Shannon diversity index (based on biomass) significantly differed among treatments ($F = 11.231$, $p = 0.0036$; $F = 6.414$, $p = 0.0185$; $F = 5.879$, $p = 0.0233$; respectively). In these cases, however, the origin of the differences found can be attributed to three characteristic patterns: the abundance was significantly lower in the landward side of the LCS than in the control and seaward, the biomass was significantly higher in the control than around the LCS and the diversity based on biomass was higher in the seaward side of the LCS than in the control and landward.

The high within-treatment variability existing among the infaunal communities at the Cubelles study site was also pointed out by the nested ANOSIM both when using abundance and biomass species x sample data matrix (Fig. 2A).

Independently of this characteristic trend, however, there were significant differences between seaward, landward and control treatments for both sets of data. The results of the MDS analysis based on abundance seems to corroborate the differences between treatments (Fig. 2B), but those based on biomass proved to be particularly discriminating, and this was clearly pointed out in the MDS (Fig. 2C).

Some of the infaunal species found at the Cubelles study site, such as the amphipod crustacean *Bathyporeia megalops*, contributed to increase the similarity between treatments by having a more or less homogeneous distributional pattern (Fig. 3). However, some other species showed characteristic patterns of distribution, which allowed to define the differences observed among treatments (Fig. 3). The bivalve *Spisula subtruncata* was only present in the controls (with the exception of a single specimen found at the landward side of the LCS). The amphipod *Corophium* sp. was characteristic of the seaward treatment. The polychaete *Capitella capitata* was mainly present at the landward stations. Finally, but also highly significant, some species allowed to characterize a particular group of stations by their absence. This is the case of the polychaete *Magelona mirabilis*, which was commonly found in the control and seaward treatment and was absent from the landward stations.



A	ABUNDANCE		BIOMASS	
	R	P	R	P
VARIABILITY	0,186	0,033	0,272	0,003
TREATMENT	0,319	0,009	0,593	0,001

Figure 4.- A.- Results based on trophic-functional strategies of the soft-bottom macroinfauna at the Cubelles study site. A.- ANOSIM. B.- Variability of abundance an biomass data.

The trophic functional strategies of soft bottom macroinfaunal organisms around the LCS, showed different strategies according to the parameter selected to analyze the data set. The ANOSIM point out a significant difference among treatments, although the variability within them was also significantly different (Fig. 4A). According to abundance data, surface deposit feeders clearly dominate in all treatments, followed by the carnivorous organisms (Fig. 4B). A clear trend towards the decrease of the abundances from control sites to the landward, with intermediate values at seaward, can be observed, although the pairwise test shoved that the only significant differences occurred between landward and control and seaward treatments (Table 1).

The trophic functional data based on biomass showed a different pattern from those based on abundances. Although the ANOSIM point out a significant difference among treatments, as well as a significantly different variability within them (Fig. 4A), the biomass data proved again to discriminate more precisely among treatments (Fig. 4B). Control sites were dominated by filter feeders (mainly bivalves), followed (with much lower biomasses) by the carnivorous. Conversely, this last group was the more dominant at seaward and landward sites, although this dominance was more marked at the former than at the later. The relevance of this pattern was pointed out by the significance of the differences among all treatments in the pairwise tests (Table 1).

Table 1.- Results of the Pairwise test based on trophic-functional groups.

		abundance		biomass	
TREATMENTS		**R**	**P**	**R**	**P**
CONTROL,	SEAWARD	-0,083	NS	0,688	< 0.03
CONTROL,	LANDWARD	0,542	< 0.03	0,839	< 0.03
SEAWARD,	LANDWARD	0,448	< 0.03	0,427	< 0.03

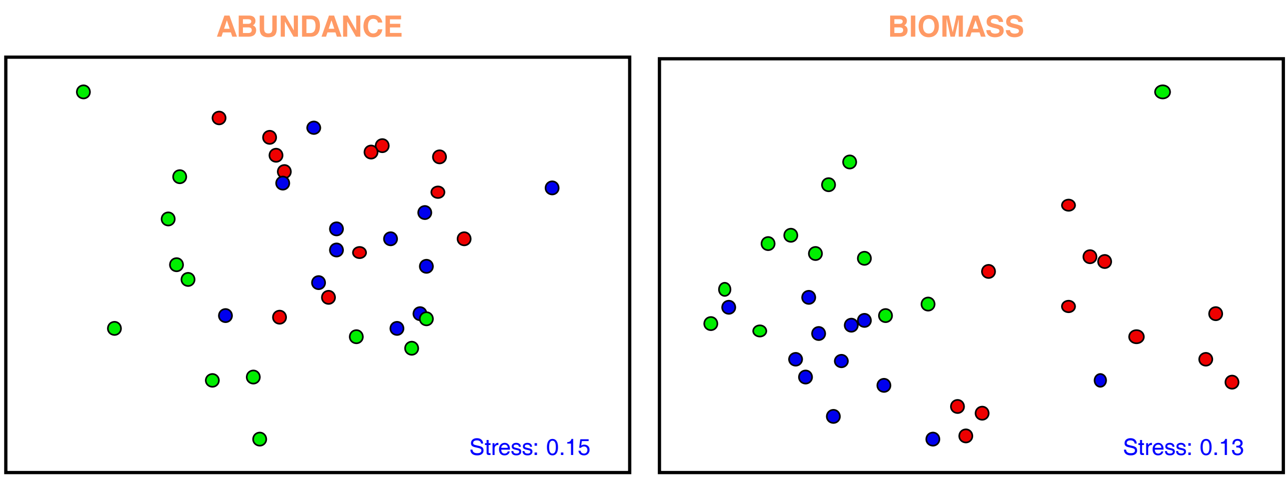


Figure 5.- Results of the MDS based on abundance and biomass of trophic-functional groups.
RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

The results of the MDS based on trophic-functional groups showed less clear trends than those based on a species per sample matrix, particularly those based on abundance (Fig. 5), where the position of control and seaward sites where non-distinguishable (in agreement with the ANOSIM results). The trend showed by the MDS based on biomass were clearer, with the controls well-isolated from the seaward and landward sites, which were themselves located in different positions in the analysis (Fig. 5).

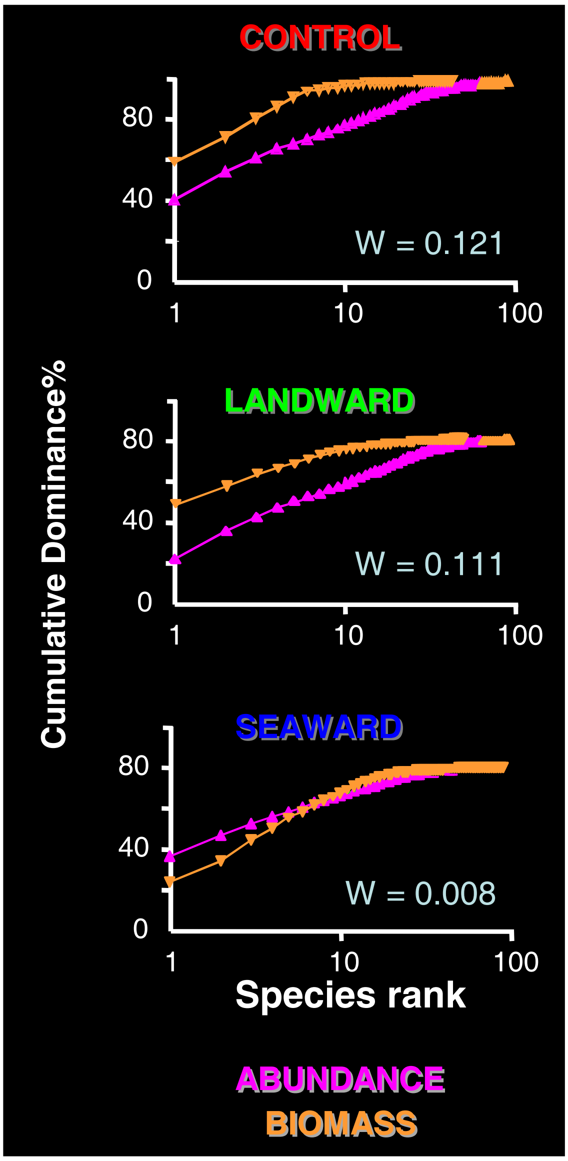


Figure 6.- Results of the Abundance-Biomass Comparison (ABC) curves for the soft-bottom assemblages at Cubelles.

The results of the analysis based on the Abundance-Biomass Comparison (ABC) curves allowed us to measure the degree of disturbance of the infaunal assemblages surrounding the LCS (Fig. 6). According to the W value, all treatments harboured infaunal assemblages that may be considered as non-disturbed, because the values of this index were always upper zero. Curiously enough, the only exception was the seaward site, where the W vas very closer to 0 so that a certain degree of disturbance can be attributed to their populations, this being probably related with a higher hydrodynamics due to the waves breaking on the LCS.

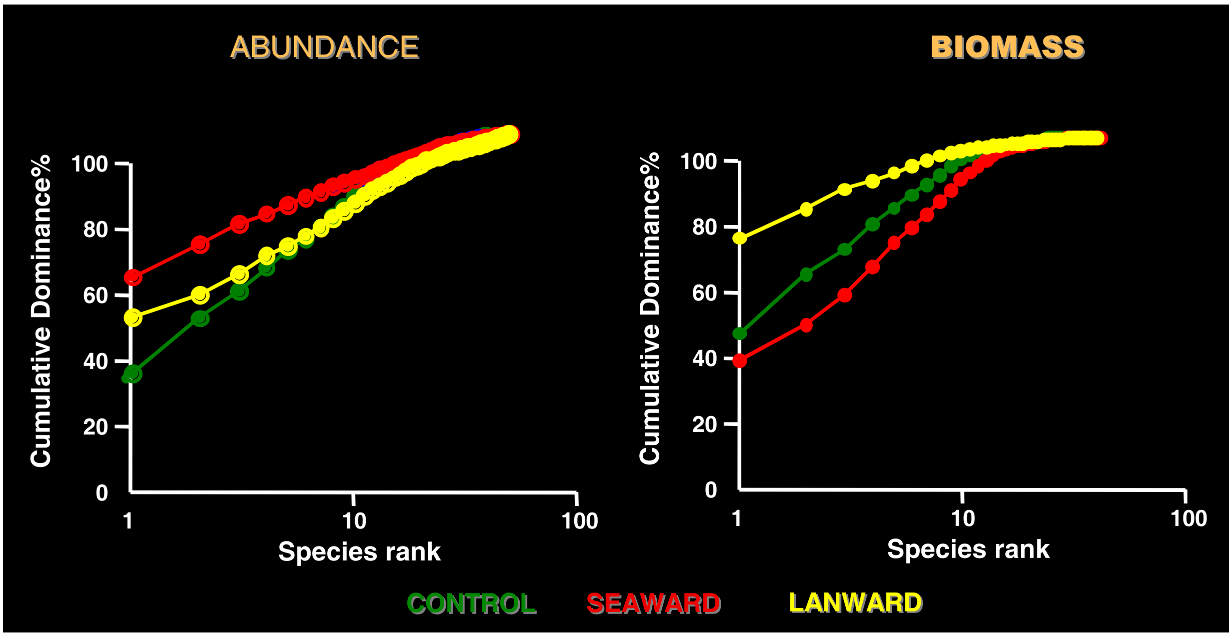


Figure 7.- Results of the K-dominance curves based on abundance and biomass data for the infaunal assemblages at Cubelles.

The results of the K-dominance curves were different when analyzed on the basis of abundance or biomass (Fig. 7). Abundance curves pointed out a similar pattern for seaward and landward sites, with the highly dominant species concentrating about 60% of the individuals present in the assemblages, while this percentage was clearly lower at the control sites (less than 40%). Concerning the abundance, thus, the control sites were more diverse that the remaining treatments. The biomass data indicated that control and seaward sites have a similar pattern, with the most dominant species concentrating about 40% of the biomass. The most marked difference concerns the landward site, where the dominant species included about double percentage of biomass than in the two other treatments, so that the landward assemblage was clearly less diverse than the other two in terms of biomass.

LCS at Elmer (West Sussex, UK)

Community descriptors

A total of 25 taxa (17 at species level) were identified (Table 3). The total number of individuals counted was 2318 yielding a total biomass of 90 mg AFDW. The major dominant groups were Polychaetes (11 species) and Amphipods (5 species). *Spio filicornis* and *Pygospio elegans* were the most abundant species in the Polychaete group, with a total of 422 and 332 individuals respectively. In the Amphipod group, the most common species were *Bathyporeia pilosa* (759 Ind.) and *Urothoe poseidonis* (205 Ind.). Most of the taxa were present in almost all the three sites, although in different proportions. On the landward side, *P. elegans* and *B. pilosa* were the most abundant species (30% and 44% respectively). On the seaward side *S. filicornis* and *U. poseidonis* dominated the assemblage (39% and 18% respectively). In control areas, *S. filicornis* and *B. pilosa* mostly contributed to the total abundance (23% and 36% respectively). However, other taxa contributed significantly to the biomass. For example Nemertea had the highest biomass on the landward side, whilst on the seaward side and control areas *Arenicola marina* mostly contributed to the total biomass. Only few species were exclusive of a site. *Phyllodoce mucosa*, *Crangon crangon* and *Carcinus maenas* were found only on the seaward side of LCS and in the control areas, whilst *Scololepsis squamata* and *Malacoceros fuliginosus* were present only on the landward side. The number of species was slightly higher on the seaward than landward sites. Control sites had, on average, the lowest number of species. However, these differences were not significant (Figure 4).

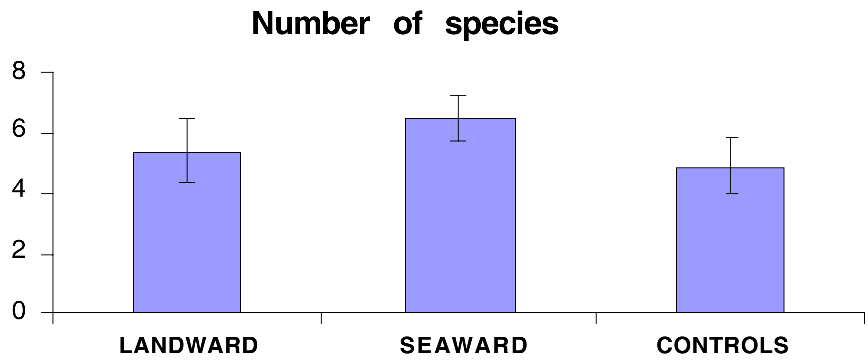


Figure 4 – Number of species between landward, seaward and control areas. No significant differences were found between the sites in the ANOVA.

Table 3 – List of taxa identified in soft-bottom sediments around the LCS at Elmer and their relative contribution (expressed as percentage) to the total abundance and biomass. The biomass of species belonging to the taxa *Bathyporeia* was grouped. In bold are the dominant taxa at each treatment.

	Abundance			**Biomass**		
	Landward	**Seaward**	**Control**	**Landward**	**Seaward**	**Control**
NEMERTEA						
Unknown species	0.09	0.0	0.0	**93.415**	0.000	0.000
POLYCHAETA						
Eteone picta	1.01	2.99	0.76	0.038	1.160	0.367
Phyllodoce mucosa	0.00	1.57	2.29	0.000	0.960	0.067
Glycera sp.	0.37	0.14	0.96	0.049	0.200	1.667
Nephtys sp.	0.09	1.71	0.19	0.096	**18.860**	2.633
Scolelepsis squamata	0.82	0.00	0.19	0.016	0.000	0.033
Spio filicornis	2.56	**38.89**	**23.14**	0.009	1.300	0.967
Spiophanes bombyx	0.09	3.13	0.19	0.005	1.840	0.133
Pygospio elegans	**30.28**	0.00	0.19	0.122	0.000	0.833
Malacoceros fuliginosus	0.18	0.00	0.00	0.122	0.000	0.000
Capitella capitata	7.23	1.57	3.25	0.090	0.200	0.533
Arenicola marina	1.65	0.85	1.72	6.165	**46.080**	**78.033**
CRUSTACEA						
Crangon crangon	0.00	0.28	0.38		4.000	6.667
Mysidae	0.00	0.14	0.00	--	--	--
Amphipods	0.27	0.00	0.00	--	--	--
Urothoe poseidonis	4.85	**17.81**	5.16	0.094	3.620	1.300
Atylus swammerdami	1.01	1.71	0.19	0.056	0.160	0.133
Bathyporeia spp.	0.00	0.14	0.00			
Bathyporeia pilosa	**44.19**	12.54	**35.95**	0.004	0.260	0.033
Bathyporeia sarsi	4.76	2.71	5.54			
Gammaridae	0.18	0.28	0.00	0.061	1.000	0.000
Cumacean	0.09	0.00	0.00	--	--	--
Cumopsis goodsiri	0.27	13.25	19.89	0.002	0.940	1.733
Portunidae	0.00	0.14	0.00	--	--	--!
Carcinus maenas	0.00	0.14	0.00	0.000	20.000	0.000

The contribution of the main taxonomic groups to the abundance and biomass in the different sites is depicted in Figures 5 and 6. Amphipods appeared to be more important in terms of numbers of individuals on the landward and control areas, while Polychaetes were more abundant on the seaward sides of the LCS. The relative importance of these groups changed when considering the biomass. Polychaetes are the dominant group in terms of biomass, as shown by the large portion in the graphs. This is mainly due to the presence in the group of the species *Arenicola marina,* the common lugworm, which can reach considerable dimensions and weight. Amphipods consisted mainly by *Bathyporeia* spp. The individuals of these species, although extremely abundant, are very small in size, therefore the total weight of amphipods was negligible.

However, when considering the total abundance and biomass, no clear patterns were observed (Figure 7a-d). Formal statistical comparison of these community descriptors in the three sites (landward, seaward and controls) did not show significant differences (Table 4). Also Shannon diversity index based on abundance and biomass did not vary between the sites. By contrast, the total abundance and both Shannon index showed highly significant variability between sampling areas within each site (Table 4). This variability at the scale of areas within site was also observed in the environmental variables measured.

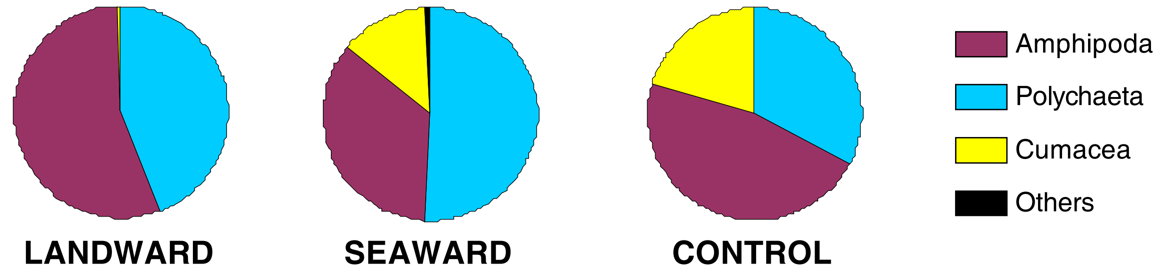


Figure 5 – Abundance contribution of main taxa on the landward (A), seaward (B) and control areas (C). For each site values have been averaged across areas.

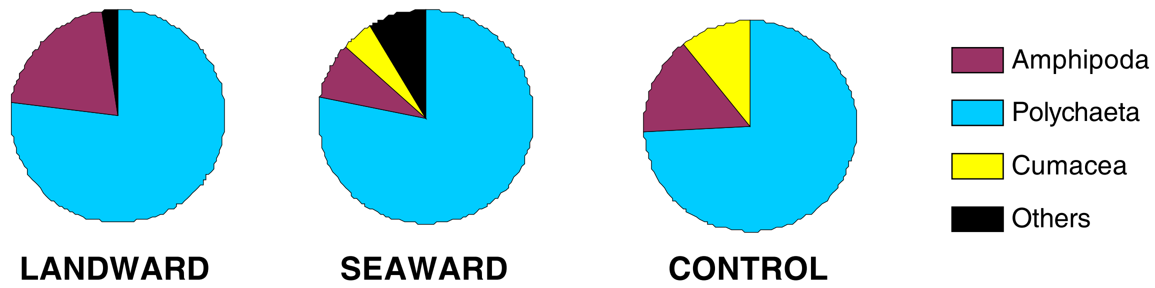


Figure 6 – Biomass contribution of main taxa on the landward (A), seaward (B) and control areas (C). For each site values have been averaged across areas.

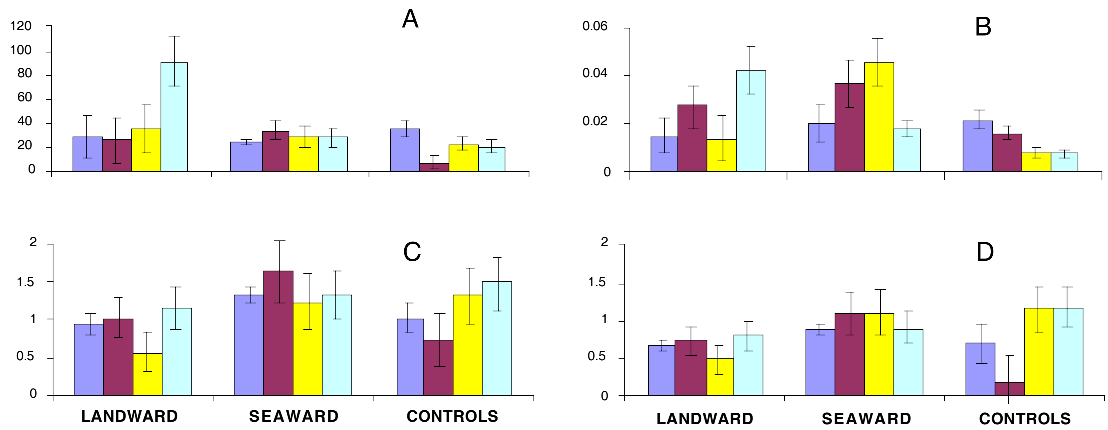


Figure 7a-d – Variation of community descriptors on the landward, seaward and controls areas. A.- Total abundance (N ind.); B.- Total biomass (g); C.- Shannon diversity index (abundance); D.- Shannon diversity index (biomass). Graphs show also the within site variability. ±S.E.

Table 4 – Results from ANOVA to test the effect of LCS on the community descriptors.

	Abundance			Biomass			Shannon (abu)			Shannon (bio)		
Source	MS	F	**P**	MS	F	**P**	MS	F	**P**	MS	**F**	**P**
Site	2.97	2.21	0.17	0.85	1.08	0.38	1.2239	3.09	0.09	0.73	1.43	0.29
Area	1.35	3.58	**<0.001**	0.79	0.97	0.47	0.3963	3.89	**<0.001**	0.51	2.39	**0.02**
RES	0.38			0.81			0.1019			0.21		

The analysis of the infaunal community as a whole gave a clearer picture of the effect of LCS on the surrounding areas, as shown by the MDS plots and ANOSIM results (Figure 8a, b; Table 5). The infaunal community differed significantly between the seaward and landward sides of the LCS. Significant differences in the community structure were also observed between landward and controls, but not between seaward and control areas. Interestingly, these results were consistent when considering in the analysis either the abundance or the biomass. SIMPER procedure attributed most of the differences between landward, seaward and controls to different distribution of the species of Polychaetes and Amphipods, as shown in Tables 6a,b. The different distribution of individuals of *Bathyporeia pilosa* and *Spio flicornis* appeared to be the major discriminator in landward vs. seaward and landward vs. control comparisons. The former species was more abundant in the landward whilst the latter was dominant in the seaward side of the structures. By contrast, when the biomass was considered in the analysis, *Arenicola marina*, *Bathyporeia* sp. and *Nephtys* sp. discriminated the community between the different sites. The total biomass of these species was much higher on the landward than on the seaward sites. More similar values were recorded instead for seaward and control areas.

Once again, great spatial variability was observed in this study. As in the analysis of variance of environmental variables and community descriptors, ANOSIM showed highly significant variation in all the sites at the spatial scale of areas nested in sites (Table 5).

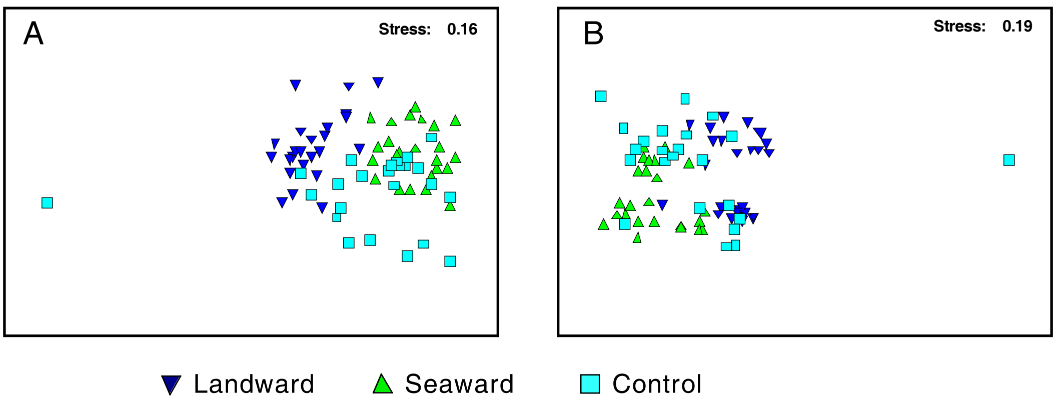


Figure 8a, b- MDS plots of abundance (A) and biomass (B) of infaunal communities on the landward, seaward and control areas.

Table 5 – Results of a two way nested ANOSIM to test for differences in abundance and biomass of infaunal communities among sites. Significant P values are highlighted in bold.

	Abundance		Biomass	
	R	**P**	**R**	**P**
Variability within site	0.429	**0.001**	0.276	**0.001**
Differences between sites	0.542	**0.001**	0.565	**0.001**
Pairwise tests		**0.03**		
Landward vs. Seaward	1		0.99	**0.03**
Landward vs. Control	0.521	**0.03**	0.417	**0.03**
Seaward vs. Control	0.094	0.23	0.26	0.06

Table 6a, b – Results from SIMPER procedure to analyse which species contributed mostly to the differences observed in the infaunal community between landward, seaward, and controls. a) Analysis based on average abundance; b) Analysis based on average biomass.

b)

Species	**Taxa**	**Landward**	**Seaward**	**Controls**
Bathyporeia pilosa	Amphipods	20.13	3.63	7.83
Spio filicornis	Polychaetes	1.17	11.38	5.04
Urothoe poseidonis	Amphipods	2.21	5.29	1.13
Cumopsis goodsiri	Cumaceans	0.13	3.67	4.33
Capitella capitata	Polychaetes	3.29	0.46	0.71

b)

Species	**Taxa**	**Landward**	**Seaward**	**Controls**
Arenicola marina	Polychaetes	0.016	0.007	0.007
Nephtys sp.	Polychaetes	0.014	0.004	0.001
Bathyporeia sp.	Amphipods	0.004	0.0009	0.002
Crangon crangon	Cumaceans	0	0.001	0.001
Spio filicornis	Polychaetes	0.0007	0.001	0.0005

Results from the trophic function analysis showed less clear patterns (Figure 9). The relative contribution of each trophic group was relatively similar in all three treatments, when abundance data were considered. The group, which dominated the infaunal community in all three locations, was surface deposit feeders. Carnivorous and subsurface deposit feeders were not very abundant whilst filter feeders and mixed feeders were almost absent. Filter feeders, which consist mainly of bivalves, were absent in all the location. Mixed feeders were present only on the landward side and were represented only by the species *Pygospio elegans.* Trophic data based on biomass showed a different pattern. The biomass contribution of each trophic group was minimal, as most of the species were of minimal size. On the landward side, however, total biomass appeared greater then in the other locations, mainly determined by the carnivorous group.

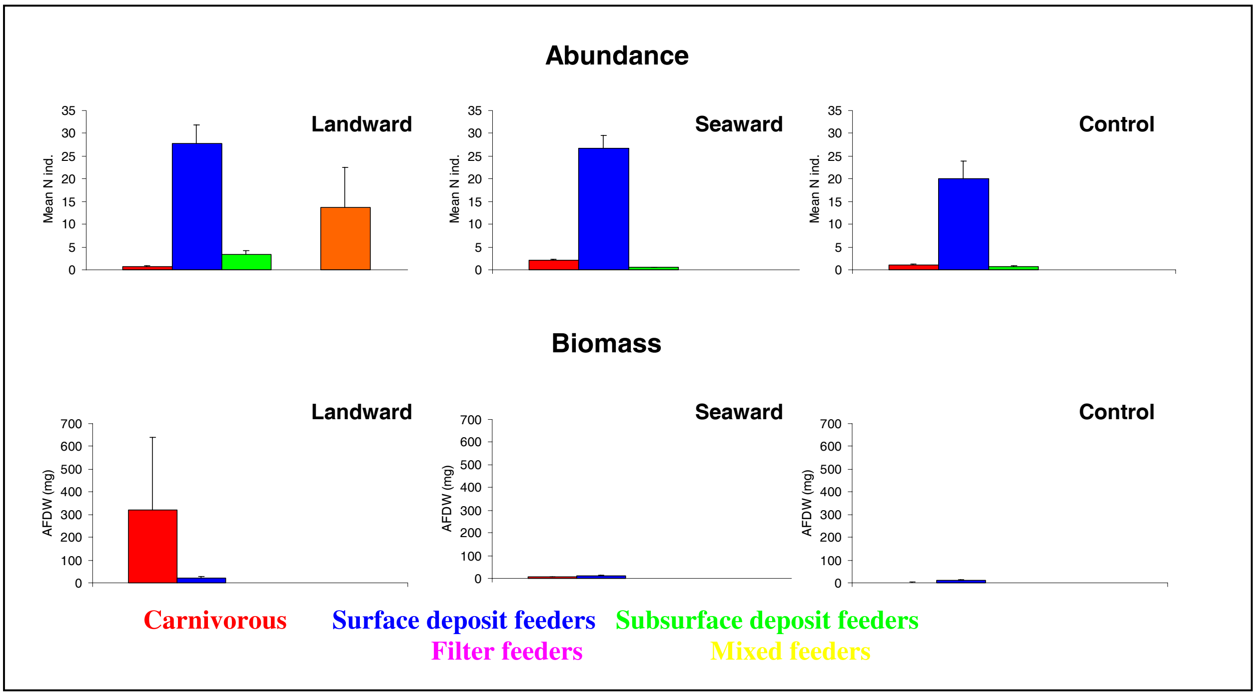


Figure 9 – Relative contribution (expressed as mean value of abundance of individuals and biomass) of trophic groups in each location around LCS at Elmer.

The multivariate analysis of infaunal assemblages based on abundance of trophic groups did not show statistical differences between the different treatments (Figure 10a, Table 7). However, clearer dissimilarities between treatments were observed when biomass data were analysed (Figure 10b, Table7). The community on the landward side was well separated from the seaward side, although control areas did not differ from both exposure sides of the LCS. As observed in the results from ANOSIM analysis based on species, high spatial variability within each treatment was also detected by the analysis based on trophic groups (Table 7).

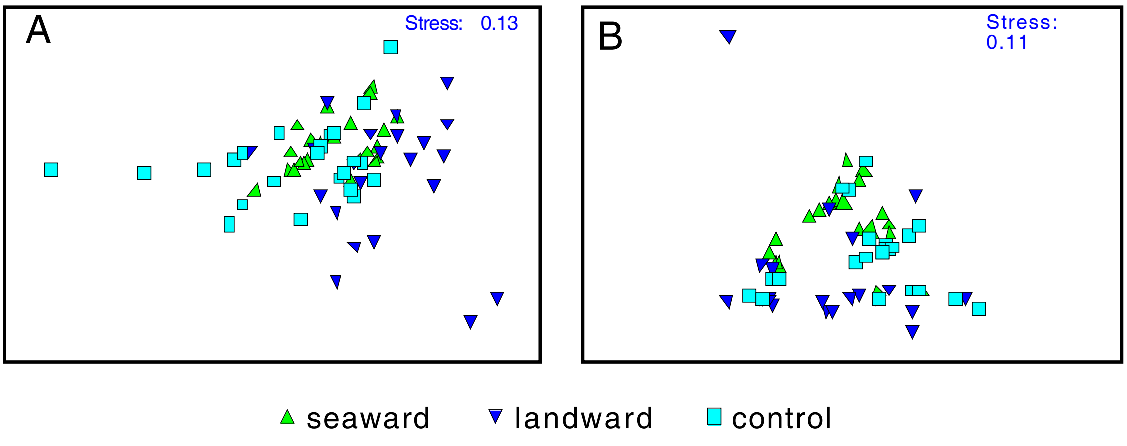


Figure 10 – MDS plots based on abundance (A) and biomass (B) of infaunal trophic groups in the three different locations at Elmer.

Table 7 – Results of a two way nested ANOSIM to test for differences in abundance and biomass of infaunal trophic groups among sites. Significant P values are highlighted in bold.

	Abundance		Biomass	
	R	**P**	**R**	**P**
Variability within site	0.262	**0.001**	0.149	**0.004**
Differences between sites	0.09	0.01	0.331	**0.012**
Pairwise tests				
Landward vs. Seaward	--	**--**	0.625	**0.029**
Landward vs. Control	--	**--**	0.177	0.174
Seaward vs. Control	--	--	0.219	0.086

LCS at Lido di Dante (Italy)

A total of 5040 individuals of macrobenthic organisms were counted for a total biomass of 1243 mg AFDW. 106 species were identified, grouped into 17 major taxa. Analysis of the per cent contributions of the major taxonomic groups to the abundance and biomass (Table 1) in the three experimental treatments (C=Control; L=Landward; S=Seaward) showed that Bivalvia dominated the C and S treatments, instead in the L treatment Bivalvia and Polychaeta co-dominated in the benthic community. As for biomass, Gastropoda, Bivalvia and Polychaeta showed the highest percentage in all treatment; those in the S treatment seemed to be more balanced.

Table 1 - Per cent contribution to the abundance and biomass of major taxonomic taxa found at Lido di Dante (Italy) study site. Bold text indicates the dominant taxa at each treatment.

	Abundances (%)			Biomasses (%)		
TAXON	**C**	**L**	**S**	**C**	**L**	**S**
Anthozoa	0.0	0.0	0.0	0.0	0.1	0.0
Turbellaria	0.0	0.0	0.0	0.0	0.0	0.0
Nemertea	0.1	0.4	0.2	0.4	0.5	2.5
Sipunculida	0.0	0.0	0.0	0.1	0.0	0.0
Gastropoda	0.1	1.1	0.3	**21.4**	**27.8**	**32.1**
Bivalvia	98.3	**50.8**	**91.6**	**59.2**	**62.8**	**31.3**
Polychaeta	1.2	**43.3**	**6.8**	**11.2**	**7.5**	**21.5**
Clitellata	0.0	0.0	0.0	0.0	0.2	0.0
Amphipoda	0.1	**1.3**	**0.4**	0.1	0.1	0.2
Anisopoda	0.0	0.0	0.0	0.0	0.0	0.0
Isopoda	0.0	0.0	0.1	0.0	0.0	0.0
Cumacea	0.2	**2.8**	**0.6**	0.2	0.4	0.3
Mysidacea	0.0	0.0	0.0	0.0	0.0	0.0
Thoracica	0.0	0.0	0.0	0.0	0.1	0.0
Decapoda	0.0	0.1	0.0	**7.4**	**0.5**	**12.2**
Insecta	0.0	0.0	0.0	0.0	0.0	0.0
Echinoderamta	0.0	0.0	0.0	0.0	0.0	0.0

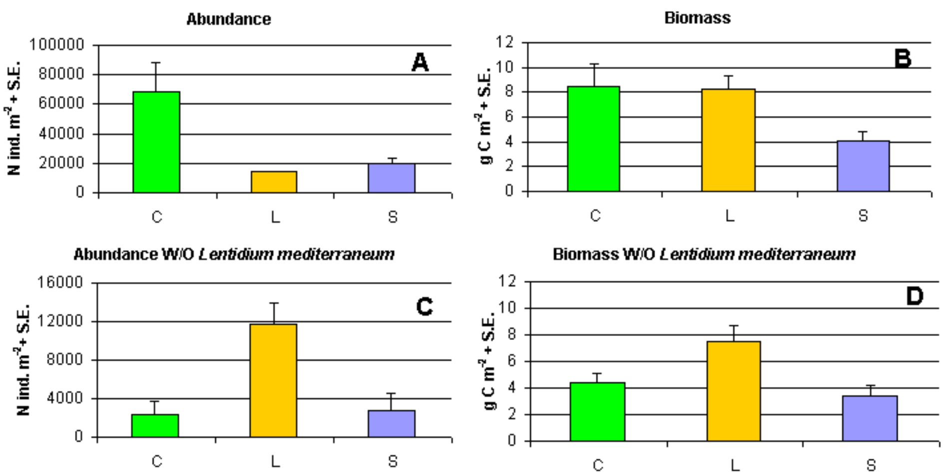


Fig. 1 - Mean values (calculated on areas) of (A) abundance, (B) biomass, (C) abundance after subtracting *Lentidium mediterraenum*, (D) biomass after subtracting *L. mediterraenum* at each treatment.

Mean values of total abundance (Fig. 1A) and biomass (Fig. 1B) showed no significant difference among treatments (F=2.05, p=0.184; F1.19, p=0.349, respectively) but a significant within-treatments variability (F=66.27, p=0.0001; F=11.27, p=0.0001 respectively). Even if not significant, seemingly higher average density was recorded in the C site.

The above results were due to the density extreme variability of *Lentidium mediterraneum*, a typical North-Adriatic small bivalve. In fact, when ANOVA was performed on abundance after subtracting *L. mediterraneum* (Fig. 1C), a treatment effect was detected (F=47.74, p<0.001) with significantly higher density at L treatment (SNK test). The same did not occur when *L. mediterraneum* values were subtracted from total biomass (Fig. 1D), owing to its small size and trifling weight, no difference was detected among treatment biomass values (F=3.30, p=0.08).

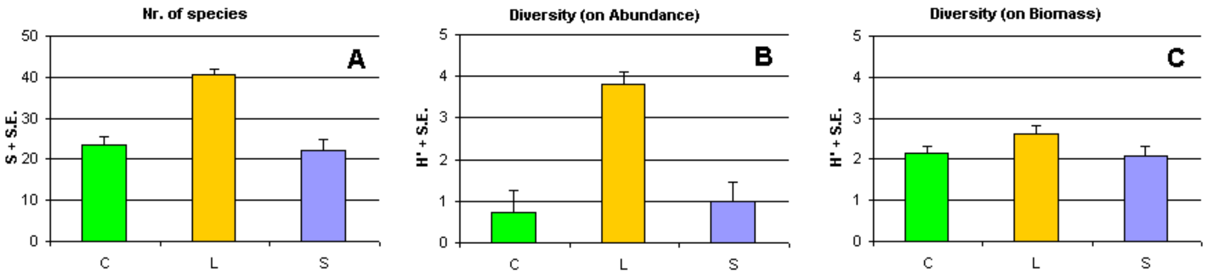


Fig. 2 - Mean values (calculated on areas) of (A) number of species, (B) Diversity on abundance data, (C) Diversity on biomass data, at each treatment.

When structural and functional aspects were considered, by using univariate and multivariate analyses the LCS effect was much more clearly detected.

In particular number of species and diversity, the latter based on abundance data, showed significant differences among treatments (F=9.45 p=0.006; F=65.47 p=0.0001) with higher values recorded at L but not different between C and S treatment (SNK test) (Fig.2A, 2B). On the contrary, diversity calculated on biomass data showed no statistically significant treatment effect (F=1.05, p=0.39) (Fig. 2C).

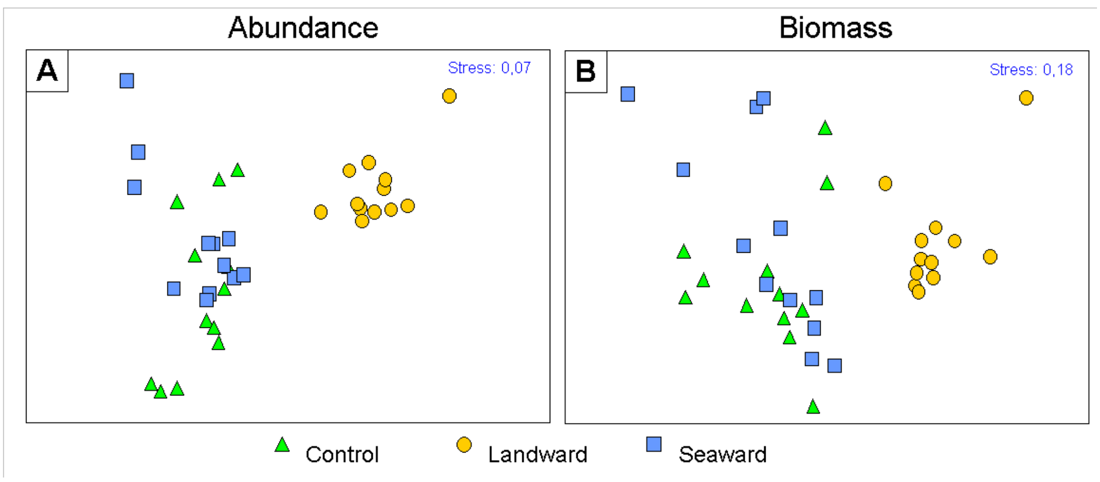


Fig. 3 - nMDS plot of macrobenthic communities based on (A) Abundance data and (B) Biomass data.

Table 2 - Results of Two-way Nested ANOSIM based on abundance and biomass data. Pairwise results are also shown, after detecting significant effect of the treatment factor.

	Abundance		Biomass	
	R	**p**	**R**	**p**
Treatment (Tr)	0.66	<0.001	0.549	0.001
Area (Tr)	0.626	<0.001	0.455	0.001
Pairwise				
C vs L	0.927	<0.05	0.906	<0.05
C vs S	-0.016	n.s.	0.01	n.s.
S vs L	0.938	<0.05	0.708	<0.05

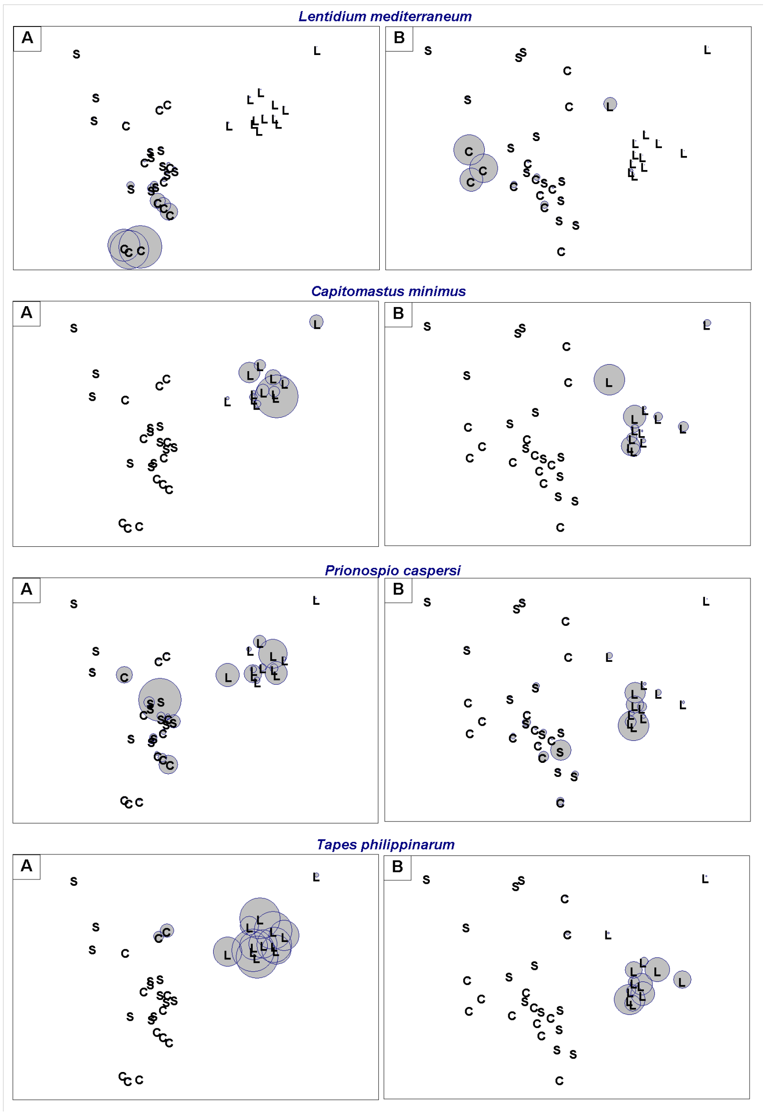


Fig. 4 - nMDS plot of macrobenthic communities based on (A) Abundance data and (B) Biomass data with superimposed bubble whose size mirror the abundance or biomass of the indicated species. The larger the bubbles are, the larger the values of superimposed variable are.

The MDS plot based on abundance (Fig. 3A) revealed a marked effect of LCS on the composition and structure of macrobenthic communities. In fact, sample-points of the L treatment grouped close together and clearly separated from the cluster of the S and C treatments. That indication was confirmed by ANOSIM results and pairwise comparisons (Table 2). A similar pattern was obtained with biomass data (Fig. 3B; Table 2), even if sample-points appeared a little more scattered.

These results seems to be due to the different contributions which single species gave to the abundance and biomass at the different treatments, as shown in the MDS plots with superimposed circles indicating increasing abundance (Fig. 4A) or biomass (Fig. 4B) data. The Bivalve *Lentidium mediterraneum* was present in the C and S treatments with very high densities in comparison with L treatment. On the contrary, polychaetes *Capitomastus minimus* and *Prionospio caspersi* were present with higher abundance and biomass in the L treatment. Moreover, the first species seemed to be typical of the L treatment. In fact, only few specimens were recorded in the C and S treatments. An other discriminating species seemed to be *Tapes philippinarum* mainly present in the L treatment and completely absent in the S one.

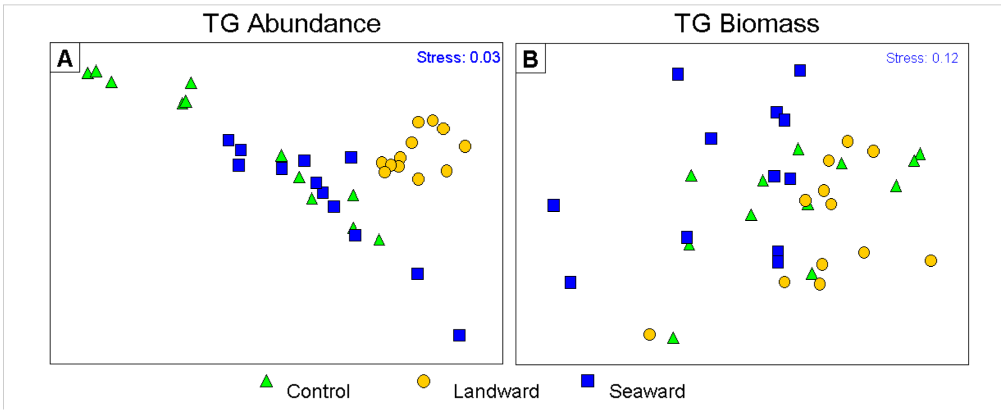


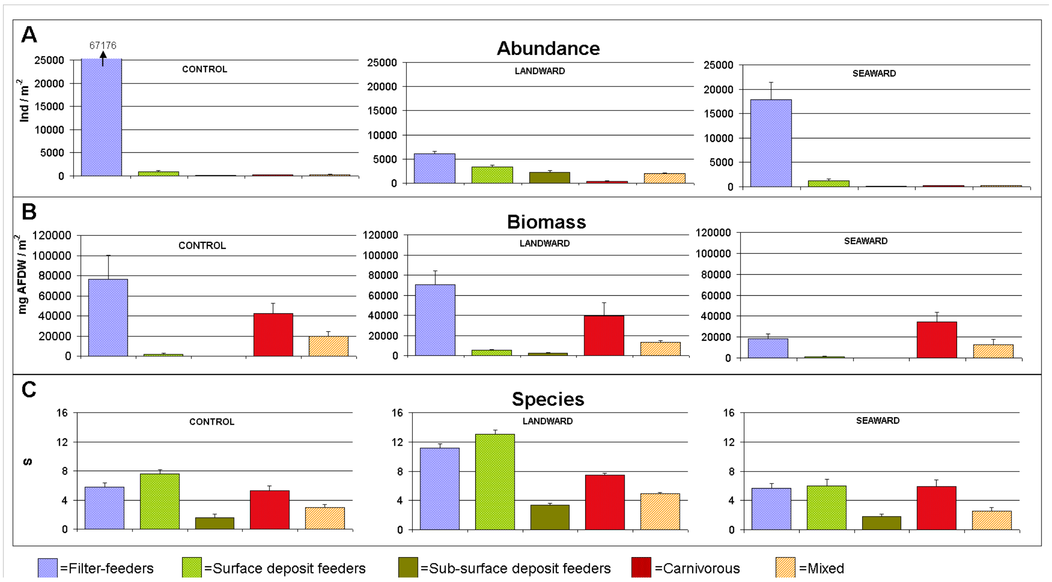
Fig. 5 - MDS plot of macrobenthic communities based on (A) Trophic group (TG) Abundance data and (B) Trophic group Biomass data

Table 3 - Results of Two-way Nested ANOSIM based on abundance and biomass data of trophic groups (TG). Pairwise results are also shown, after detecting significant effect of the treatment factor

	TG Abundance		TG Biomass	
	R	**p**	**R**	**p**
Treatment (Tr)	0.377	<0.05	0.016	n.s.
Area (Tr)	0.604	<0.001	0.498	<0.001
Pairwise				
C vs L	0.583	<0.05	-	-
C vs S	-0.083	n.s.	-	-
S vs L	0.635	< 0.05	-	-

The MDS and ANOSIM analyses performed on trophic groups showed that, in terms of abundance, significant differences occurred among treatments with L different from both C and S as expected (Table 3; Fig 5A). This result seems to be due to the marked dominance of Filter feeders in the C and S treatments and to a more even distribution of individuals among all trophic groups in the L treatment (Fig. 6A). Once again, these was due to the extremely high abundance of *Lentidium mediterraneum* in the C and S treatments which, in some way masks the importance of the other trophic groups. In fact, when the same analysis was performed on trophic group biomass data, MDS plot shows all sample points interspersed, without distinctive patterns of trophic structure among treatments (Fig. 5B; Fig. 6B; Table 3).

Fig. 6 - Mean values (calculated on areas) of trophic group based on (A) abundance, (B) biomass, (C) number of species data at each treatment.



Only when the number of species in each trophic group (Fig. 6C) is considered, surface deposit feeder species were slightly more represented than other groups in all treatments. In the L treatment an higher number of both filter feeders and surface deposit feeders species occurred in comparison with C and S treatments.

To investigate the possible disturbing effect of LCS structure on surrounding community, ABC curve method was also utilised (Fig. 7). A clear disturbed pattern, with abundance curve laying over that of biomass, was evidenced in the C and S treatments. Instead, in the L treatment, the two curves run side by side, indicating a more balanced community structure, not dominated by abundance and/or biomass of a few species. This pattern could be interpreted as representing a level of intermediate disturbance, which means, in turn, that there was ameliorative effect of the LCS on the benthic community inhabiting the area between the structure and the shoreline.

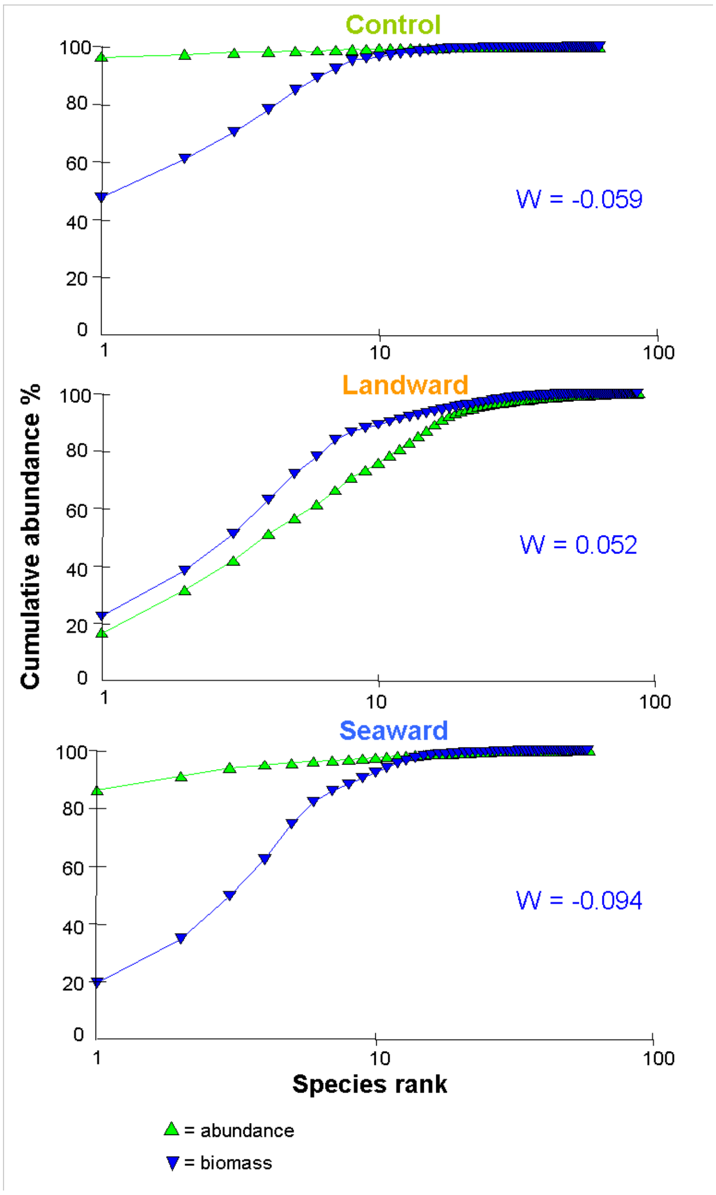


Fig. 7 - ABC plots over the three treatments.

SUMMARY OF KEY FEATURES

Cubelles (Catalunya, Spain)

Polychaetes and amphipods are the major contributors to the abundance in all treatments (higher percentage for the amphipods around the LCS and for the polychaetes in the control). As for the biomass, the major contributors (in order of importance) are: (a) polychaetes, gastropods and amphipods at the seaward side; (b) polychaetes, bivalves and amphipods at the landward side; (c) bivalves, decapods and polychaetes in the controls.

The origin of the differences found around the LCS can be attributed to three characteristic patterns: (a) an abundance lower in the landward side than in the control and seaward; (b) a biomass higher in the control than around the LCS; (c) a biomass diversity higher in the seaward side than in the control and landward.

There was also a characteristically high within-treatment variability among the infaunal communities around the LCS. However, independently of this trend, there were significant differences between seaward, landward and control treatments, with the biomass data being particularly discriminating.

The trophic functional approach indicates that surface deposit feeders clearly dominate in all treatments, followed by the carnivorous, in terms of abundance. Moreover, deposit feeders were clearly more abundant in control sites and had intermediate values at seaward and the lowest values at landward. When based on biomass, the pattern was markedly different. Control sites were dominated by filter feeders (mainly bivalves), followed (with much lower biomasses) by the carnivorous. Conversely, this last group was dominant at landward and, particularly, at seaward.

The infaunal community around the LCS and in the control were basically the same, with some species contributing to increase the similarity between treatments by having a more or less homogeneous distributional pattern. However, other species showed characteristic patterns of distribution, which allowed to define the differences observed among treatments. Some species were only present in the control, landward and seaward sides, respectively while some others allowed to characterize a particular situation by their absence. For instance, the high presence of some species like *Capitella capitata*, which may be related with a relatively high degree of stress at landward side of the LCS. This seems to indicate that this side may have the most delicate environmental situation, which would probably derive to a stressed one if the hydroclimatic do not facilitate enough water circulation around the LCS.

LCS at Elmer (West Sussex, UK)

The study carried out around the LCS located at Elmer, UK showed that this type of sea defences directly affect the structure of the infaunal community living in the surrounding soft-bottoms. Significant differences were detected when either species abundance of individuals or biomass was considered in the analysis, showing consistency of the patterns observed.

A different pattern, however, was observed when the analysis was based on infaunal trophic groups classification. In this case, only trophic data based on biomass showed significant dissimilarities between the infaunal community on the landward and seaward side. By contrast, the relative contribution of trophic groups in each location was very similar.

Considerable spatial variation was also observed in the infaunal community. The univariate analysis of total abundance, biomass and diversity indexes did show significant differences between areas within treatment, but not at level of site. High spatial variability at small scale was also detected by the multivariate analysis, although in this case differences between sites resulted significant. This can be explained by the fact that this type of statistical approach can cope better with situation of great variability and heterogeneity of variances, which represent a serious problem when using the analysis of variance.

The small differences observed between the soft-bottom system nearby the structures and in the control areas might be attributed to the scarce distance between the two sites. Control areas were selected around 100 m far from the rock islands, therefore the effect of LCS could still be present, even partially, to these zones.

Lido di Dante (Italy)

The presence of LCS proved to affect the benthic assemblages in the surrounding soft bottoms. Highly significant differences in abundance and composition have been observed between Landward communities and those of both Seaward and Control areas which, on the contrary, did not show marked structural differences between them.

The Control and Seaward areas were almost completely dominated by *Lentidium mediterraneum* (96% and 86%, respectively), a species known to be well adapted to energetically dynamic habitats. The occurrence of this species suggests that the simplified macrobenthic assemblages inhabiting these two habitats are mainly structured by the strength of physical factors.

On the contrary, the more structured community settled at Landward is characterised by an higher number of species and an higher diversity, while the presence of *Lentidium mediterraneum* is highly reduced. In accordance, a substantial presence of Capitellidae and Spionidae species, seems to indicate a typical pattern of stiller water.

In the Landward area, owing to the slackened water circulation caused by the presence of LCS, biotic interactions seem to favour an increasing structuring of the benthic community and improving the overall biodiversity of species assemblages, at least in the conditions of Lido di Dante.

CONCLUSIONS

In conclusion, this study provided useful insights in the effects of LCS on the surrounding soft-bottoms, showing a more complex and dynamic system than previously expected.

The observation of similar trends in the soft bottoms around the LCS at the three study sites in Spain, Italy and UK are probably the most relevant conclusion. These trends can be summarized as:

1) The existence of a high within-treatment variability for all variables analysed to describe the infaunal assemblages, this indicating also a high heterogeneity of the bottoms surrounding the LCS.

2) The existence of marked differences between the infaunal assemblages at seaward and those at landward, independently of the tidal range (macrotidal in UK, microtidal in Italy and no tides in Spain), this indicating the strong influence of the presence of LCS in the surrounding assemblages.

3) The existence of significant differences between the landward assemblages and those in control sites.

In spite of these common trends, some differences occurred between the three study sites. The main one was that the infaunal communities seemed to be more densely populated and had higher diversity at the seaward side of the LCS at the Spanish site, while the pattern was inverted at the Italian site and, at the UK site, there were no significant differences among treatments.

The most reliable explanation seems to be a different exposition to water circulation, as the Spanish site is an open system with no tides, the Italian one is laterally closed by two submerged barriers and has a microtidal regime and the UK site is an open system submitted to macrotidal regime.

Consequently the degree of exposition and the hydrodynamic regime at the landward side, and the influence of the LCS on them, seems to be one of the key features we have been able to identify, among those that influence the diversity of the soft bottoms around the LCS, which could be incorporated into design guidelines.