DELIVERABLE 18

Effects of breakwater design on soft-bottom habitat complexity

RESULTS

LCS at Cubelles (Spain)

Low crested structures at Cubelles (Spain) slightly affected the characteristics of the sedimentary bottoms in the surrounding areas. The environmental variables considered in the study (chlorophyll-a, organic matter, silt & clay, mean and median grain size) did not show any statistical difference between the landward, seaward and control sites, with the exception of depth that was significantly lower at the landward site (F = 9.360, p = 0.0063) (Fig. 1).

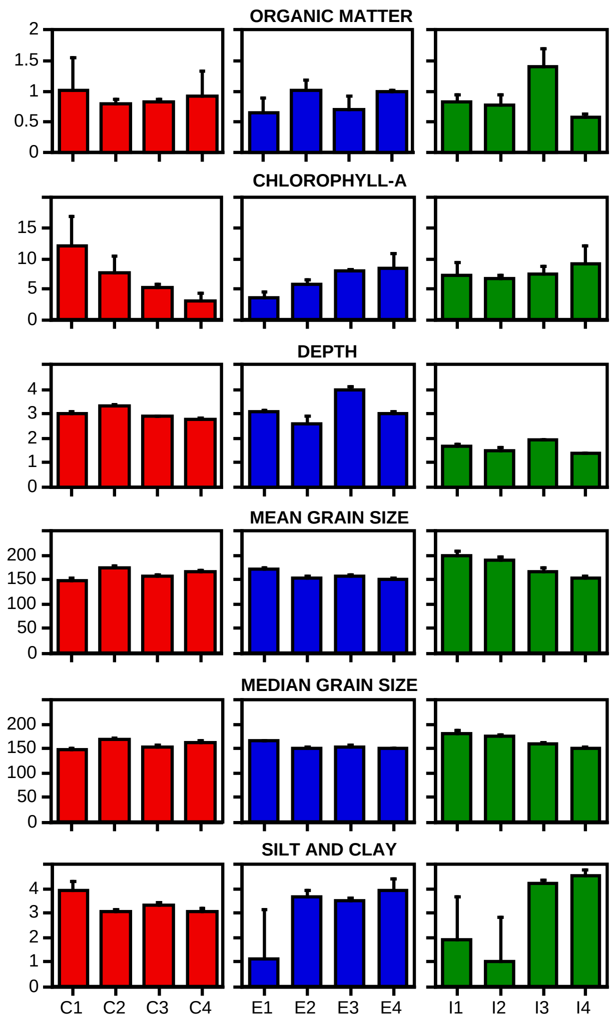

Figure 1.- Variability of the currently studied environmental variables at the Cubelles study site.
RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

Despite the lack of differences in the sites (landward, seaward and controls), all the environmental factors except for the chlorophyll-a showed great variability within each site (Fig. 1) as revealed by the highly significant differences found between areas nested in sites. In order to analyse the amount of variability between landward, seaward and control sites, variances among sampling areas were compared in ANOVA (Fig. 2). Results from this analysis showed no significant differences in the variances between sites. The amount of variability differed significantly only in the median grain size of the sediment ($F = 5.033$, $p < 0.04$). Variability in the grain size appeared to be higher in the landward areas rather than in control and seaward areas. A similar trend was observed also for the mean grain size. Interestingly, although non-significant, the percentage of silt and clay in the sediment was less variable in control areas and successively more variable on the landward and seaward sampling sites (Fig. 2). The variability of the other environmental factors analyzed showed the following trends: Organic matter tended to be more variable on controls, chlorophyll-a tended to be less variable on seaward sites and depth was much more variable on seaward sites.

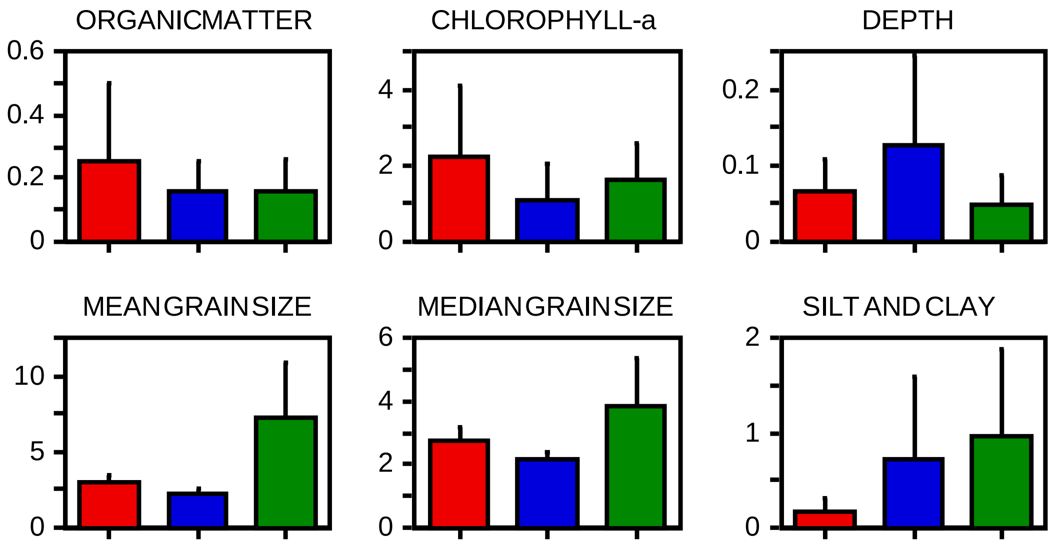

Figure 2.- Variances between areas within site of the environmental variables measured on the seaward and landward and control areas. Bars = S.E. RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

The analysis of the environmental variables as a whole, using PCA procedure, showed a clear pattern in the distribution of the different sampled areas (Fig. 3), with the landward sampled sites being clearly grouped on different quadrants than the control and seawrds sampling sites (which were intermixed in the space defined by the two axis of the PCA).

As a general rule, no apparent relationships between environmental variables were observed within each site. The only significant correlations between some of the sediment descriptors were positive and occurred for silt and clay and chlorophyll-a both in control and seaward sites (Fig. 4) and for depth and organic matter in the landward area (Fig. 5).

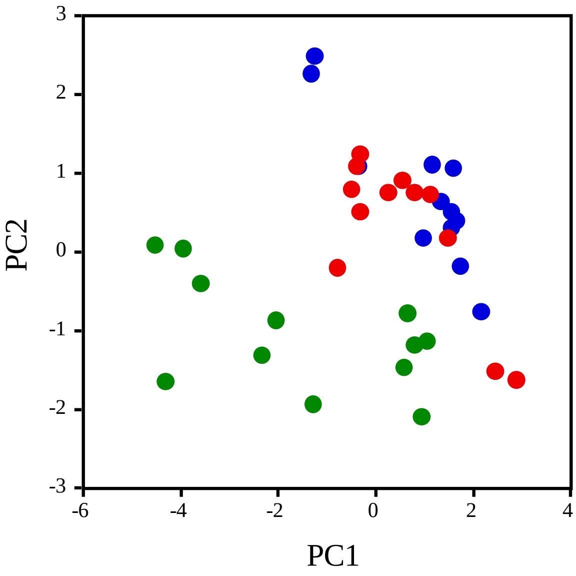

Figure 3.- PCA plot of the environmental variables measured at the Cubelles study site. RED: Control. GREEN: Landward side of the LCS. BLUE: Seaward side of the LCS.

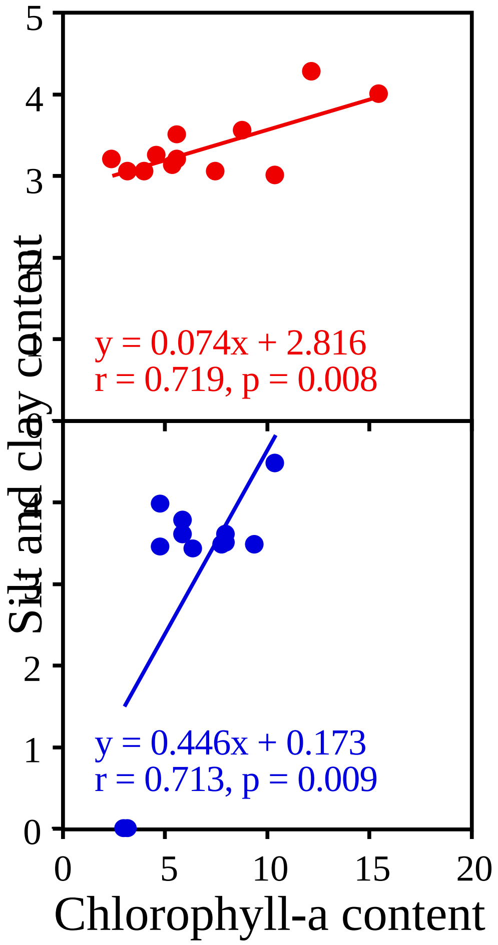

Figure 4.- Correlation between chlorophyll-a and silt and clay contents at two of the sampled locations around the strucures. R is the Pearson's correlation coefficient. RED: Control. BLUE: Seaward side of the LCS.

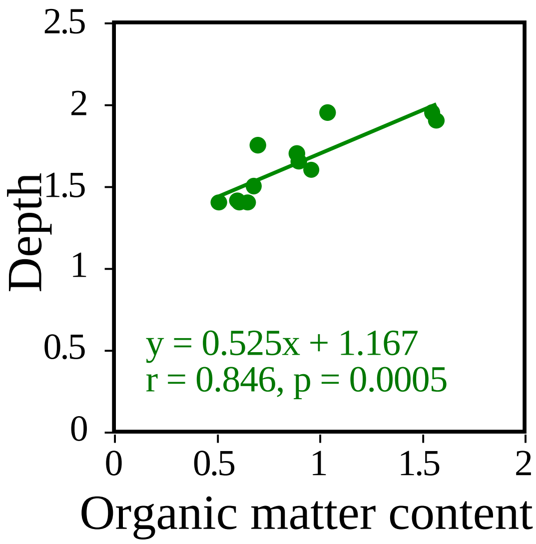

Figure 5.- Correlation between depth and organic matter content at landward side of the strucures. R is the Pearson's correlation coefficient. GREEN: Landward side of the LCS.

LCS at Elmer (UK)

Low crested structures at Elmer apparently did not affect the characteristics of the sediment in the surrounding areas. All the environmental variables considered in the study (chlorophyll a, organic matter, oxic layer, silt & clay, mean and median grain size) did not show any statistical difference between the landward, seaward and control sites (Tables 1a, b; Figs. 6a-f). However, some variation between sites could be observed in some of the sediment descriptors. The amount of chlorophyll a was slightly higher in the seaward than landward sites and control areas, whilst the thickness of the oxic layer of the sediment was more reduced on the seaward sides. Interestingly, the percentage of silt and clay in the sediment was higher around the rock islands than in control areas, but no clear differences could be observed between the landward and seaward sides of the structures.

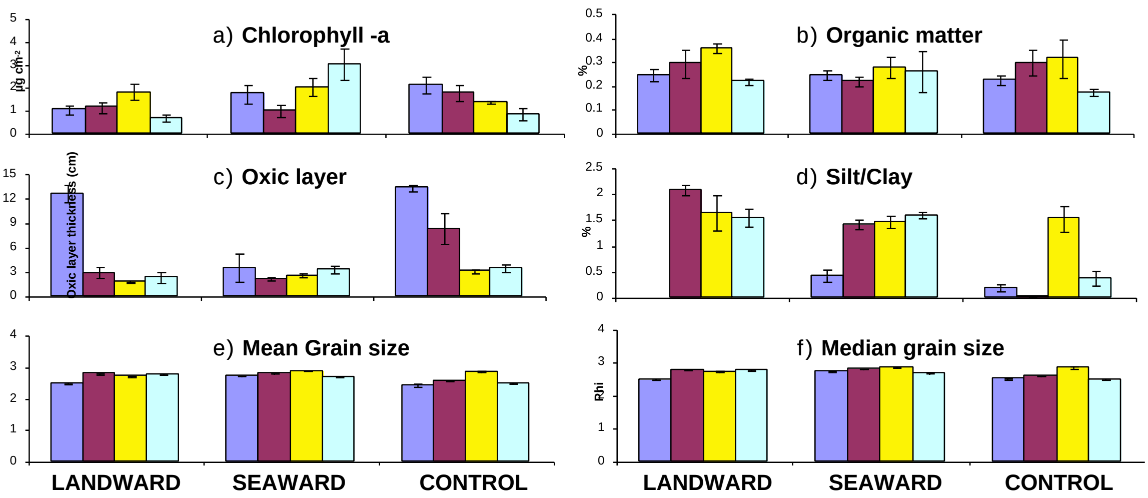

Figure 6a-f - Environmental variables measured on the seaward and landward side of LCS at Elmer and in control areas. For each site 4 stations were randomly selected (represented in different colours). Bars = ± S.E.

Table 1a, b - Results from ANOVA to test the effect of LCS on the environmental variables

a)

	Chlorophyll a			Organic matter			Oxic layer		
Source	MS	F	**P**	MS	F	**P**	MS	F	**P**
Site	0.44	1.32	0.32	0.01	0.32	0.73	116.25	1.14	0.36
Area (Site)	0.33	3.58	**<0.01**	0.02	1.72	0.10	102.06	27.05	**<0.001**
RES	0.09			0.01			3.77		

b)

	Silt & Clay			Mean grain size			Median grain size		
Source	MS	F	**P**	MS	F	**P**	MS	F	**P**
Site	1.41	1.50	0.27	0.21	1.67	0.24	0.16	1.51	0.27
Station(Site)	0.94	17.35	**<0.001**	0.13	31.10	**<0.001**	0.11	68.78	**<0.001**
RES	0.06			0.004			0.002		

Despite the lack of differences in the sites (landward, seaward and controls), all the environmental factors except for the organic matter showed great variability within each site (Figs. 6a-f). Highly significant differences were found between areas nested in site (Tables 1,a, b). In order to analyse the amount of variability between landward, seaward and control sites, variances among sampling areas were compared in ANOVA (Figs. 7a-f; Table 2a,b). Results from this analysis showed no significant differences in the variances between sites. The amount of variability differed significantly only in the median grain size of the sediment. Variability in the grain size appeared to be higher in the control areas rather than around the LCS. A similar pattern was observed also for the mean grain size. The percentage of silt and clay in the sediment was instead more variable on the landward sampling sites.

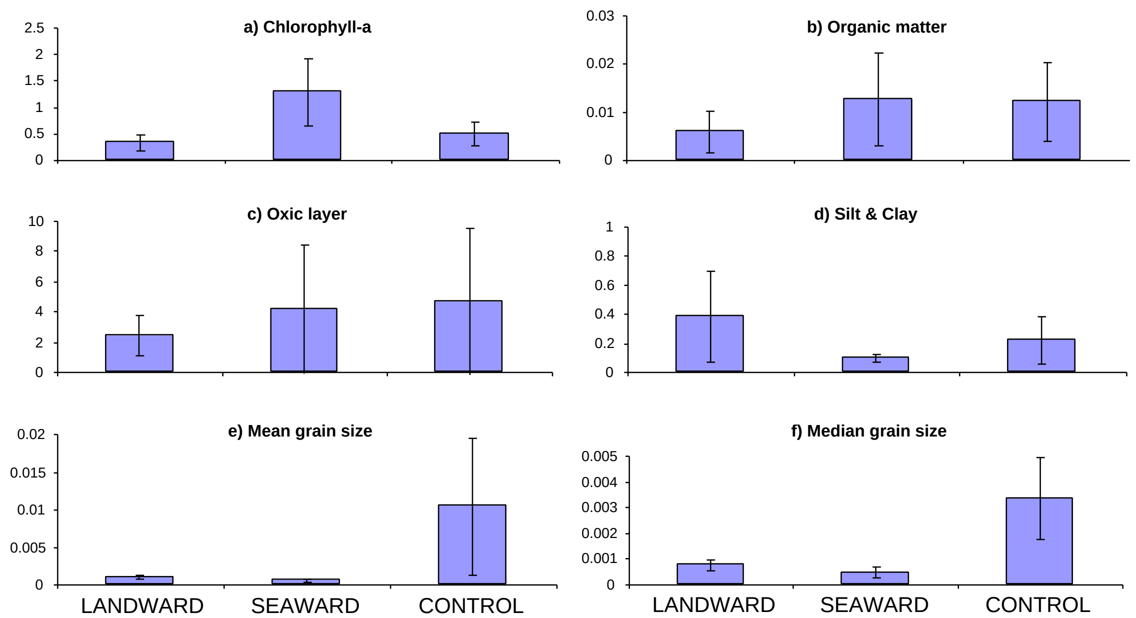

Figure 7a-f – Variances between areas within site of the environmental variables measured on the seaward and landward and control areas. Bars = ±S.E.

The analysis of the environmental variables as a whole, using PCA procedure, did not show more clear patterns between the different sites (Fig. 8). No apparent relationship between environmental variables was observed within each site. Significant correlations between some of the sediment descriptors were found only on the landward side of the structures and in the control areas. On the landward side the thickness of the oxic layer in the sediment was negatively correlated with the chlorophyll a and positively correlated with the organic matter (Figs. 9a, b). In control areas, the oxic layer was negatively correlated only with the percentage of silt and clay in the sediment (Fig. 10).

Table 2a, b - Results of ANOVA to test for differences in variances between sites.

a)

	Chlorophyll a			Organic matter			Oxic layer		
Source	MS	F	**P**	MS	F	**P**	MS	F	**P**
Site	0.26	2.57	0.13	0.0001	0.32	0.74	5.44	0.13	0.88
RES	0.09			0.0002			43.33		

b)

	Silt & Clay			Mean grain size			Median grain size		
Source	MS	F	**P**	MS	F	**P**	MS	F	**P**
Site	0.09	0.69	0.53	0.0001	1.49	0.28	3.90	4.25	**0.05**
RES	0.12			0.0001			0.92		

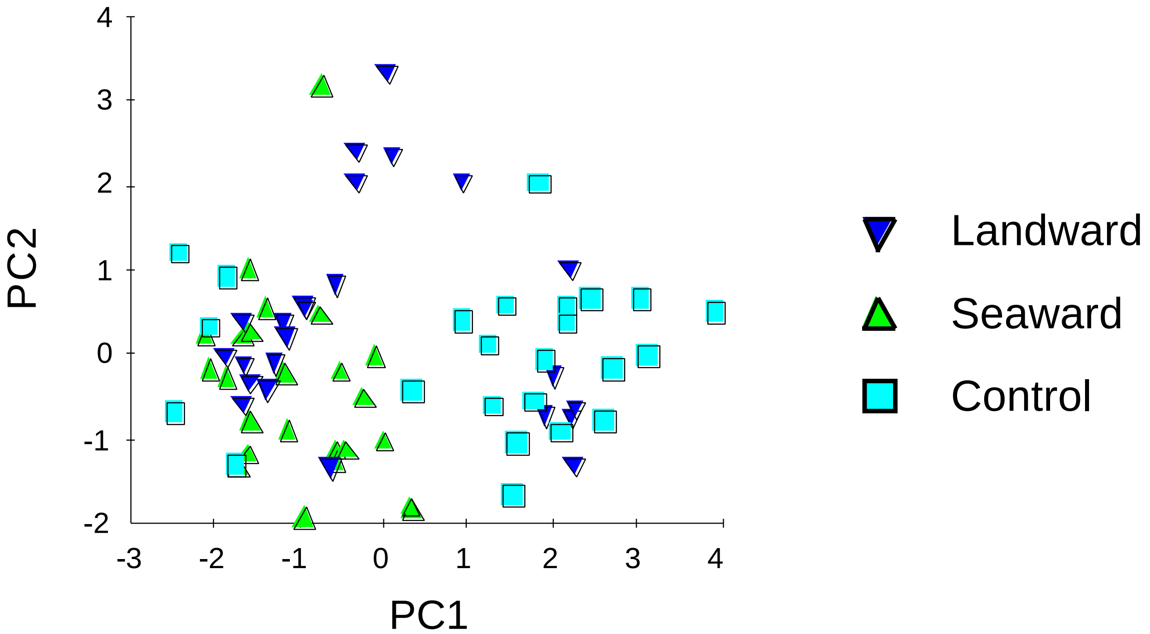

Figure 8 – PCA plot of the environmental variables measured on the landward, seaward sides of the LCS and control areas. No significant patterns could be observed between the sites. BIO-ENV procedure showed no correspondence between patterns in the environmental variables and the infaunal communities.

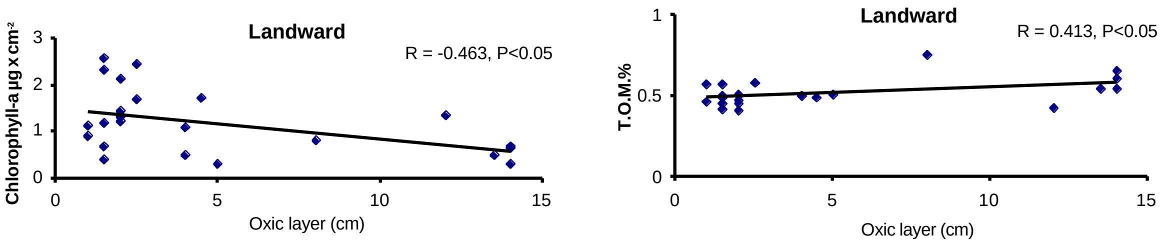

Figure 9a, b – Correlation between chlorophyll a, oxic layer and T.O.M. on the landward sides of the structures. R is the Pearson's correlation coefficient.

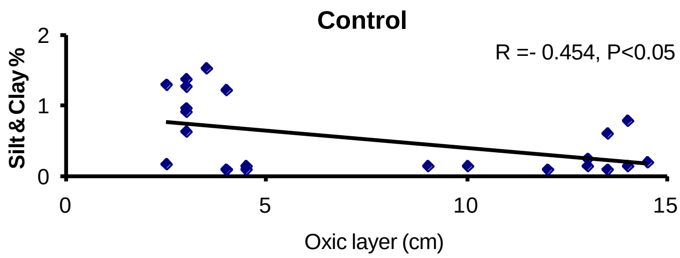

Figure 10 – Correlation between silt & clay and the oxic layer on the seaward sides of the structures. R is the Pearson's correlation coefficient.

LCS at Lido di Dante (Italy)

Low crested structures at Lido di Dante (Italy) slightly affect the characteristics of the sediment in the surrounding areas. In particular variables such as silt-clay content, organic matter and chlorophyll a did not show any statistical difference between control, landward and seaward sites (Table 3, Figs. 11a, c, d). Significant differences between the three sites at concern were obtained only for depth and shell debris variables (Table 3). As expected, depth resulted significantly lower in the landward site respect to both control and seaward sites (Fig. 11e). As for shell debris, SNK test showed higher amount in the landward compared to that measured at the seaward site (Fig. 11b). However large variability within each site was observed, with the exception of the chlorophyll a (Table 3). To analyse the amount of variability between landward, seaward and control sites, variances among sampling areas were compared in ANOVA (Figs. 12 a-e). Results from this analysis showed no significant differences in the variances between sites.

Table 3.- Results from ANOVA to test the effect of LCS on the environmental variables. * = p<0.05; ** = p<0.01;*** = p<0.001

Source of variation	**df**	Silt / clay		Shell debris		TOM		Chlorophyll *a*		Depth	
		MS	**F**	**MS**	**F**	**MS**	**F**	**MS**	**F**	**MS**	**F**
Sites	2	218.562	1.86	**5,0610**	**4,34***	14.666	1.18	0.569	1.82	**1.967**	**9.38****
Areas (Sites)	9	**117.385**	**7.62*****	**1,1650**	**11,62*****	**12.407**	**11.28*****	0.312	0.60	**0.209**	**3.63****
Residual	24	15.403		0.100		1.100		0.518		0.05	
Transformation		none		Ln(x+1)		Arcsin(x)		Ln(x+1)		none	

The analysis of the environmental variables as a whole, using PCA procedure, showed a recognizable pattern of the site characteristics (Fig. 13). The first principal component (37.1% of the explained variance) points out the habitat gradient between control and seaward. Coefficients in the linear combinations of the variables making up PC's show that the most important variables determining the above pattern are higher silt-clay content and lesser amount of shell debris associated with seaward site (Fig. 11).

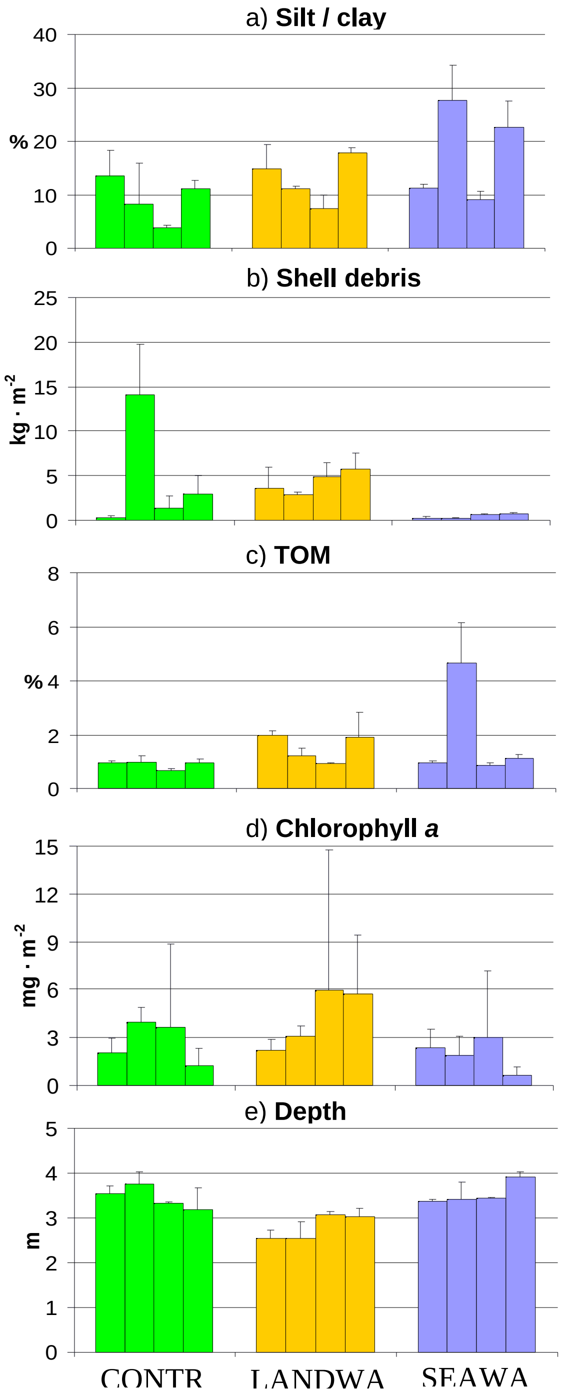

Figure 11 – Mean values (n = 3) of the silt/clay fraction (a), shell debris (b), total organic matter (c), chlorophyll *a* (d) and depth (e) referred to experimental areas randomly nested in sites. Bars = S.D.

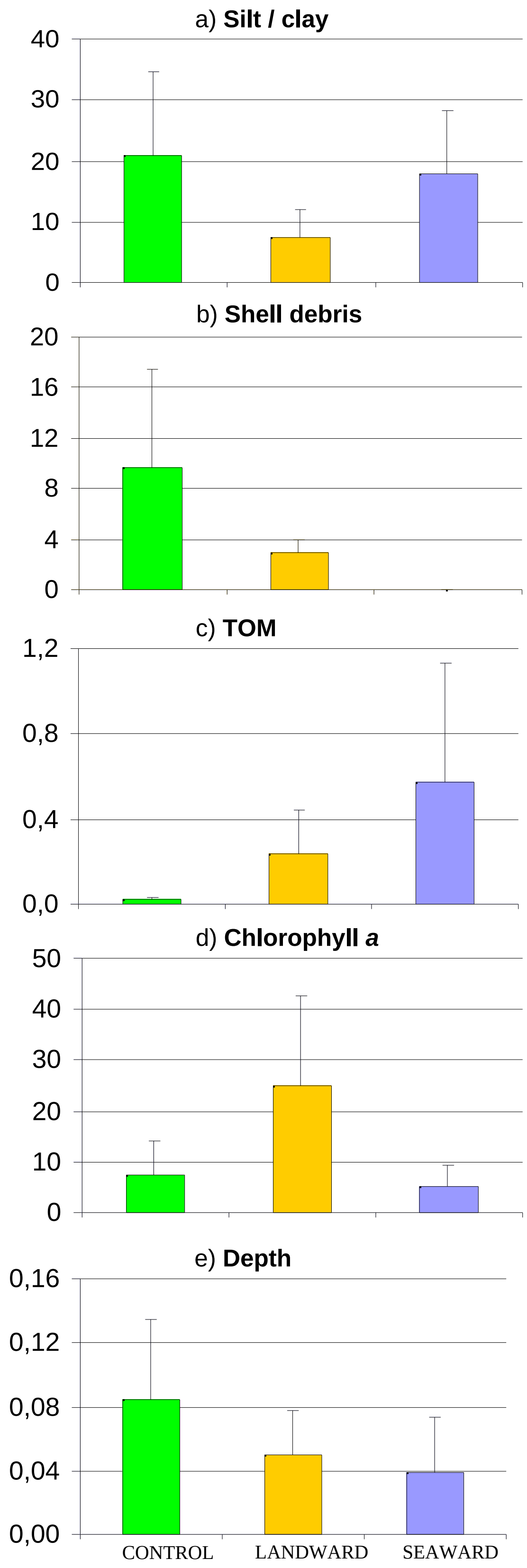

Figure 12 – Variances between areas within sites of the environmental variables measured on the seaward and landward and control areas. Bars = S.E.

The second principal component (23.7% of the explained variance) points out instead the gradient between landward site and the other two (Fig. 13). Variables determining this pattern are higher Chlorophyll a concentration and shallower depth in the landward site (Fig. 11).

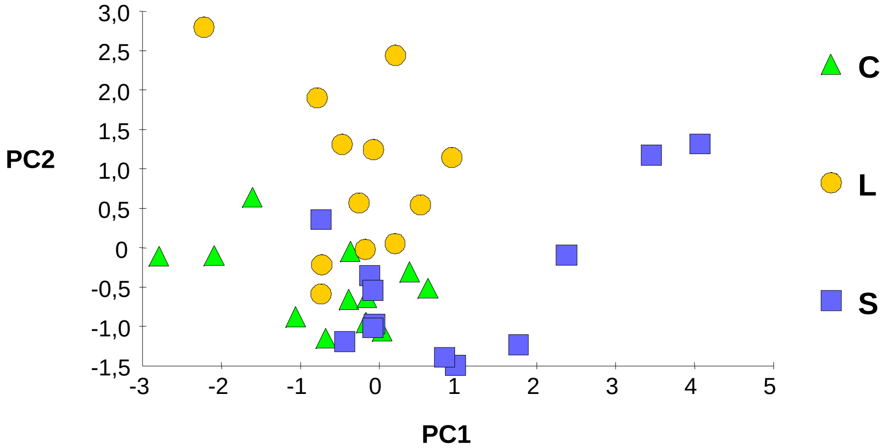

Figure 13 – PCA plot of the environmental variables measured at the Lido di Dante study site. Green symbols = control site; yellow symbols = landward side of the LCS; blue symbols = seaward side of the LCS.

Significant positive correlations between silt-clay and TOM were observed in all the three sites (Figs. 14, 15, 16). Positive correlations were found also between depth and shell debris in control and seaward sites (Figs. 14, 15).

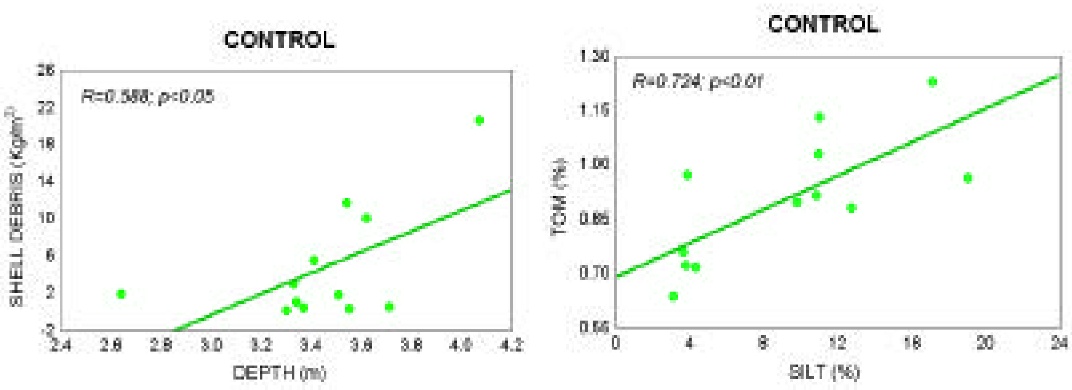

Figure 14 – Correlation between shell debris and depth (on the left) and between silt and TOM (on the right) at the control site. R is the Pearson's correlation coefficient.

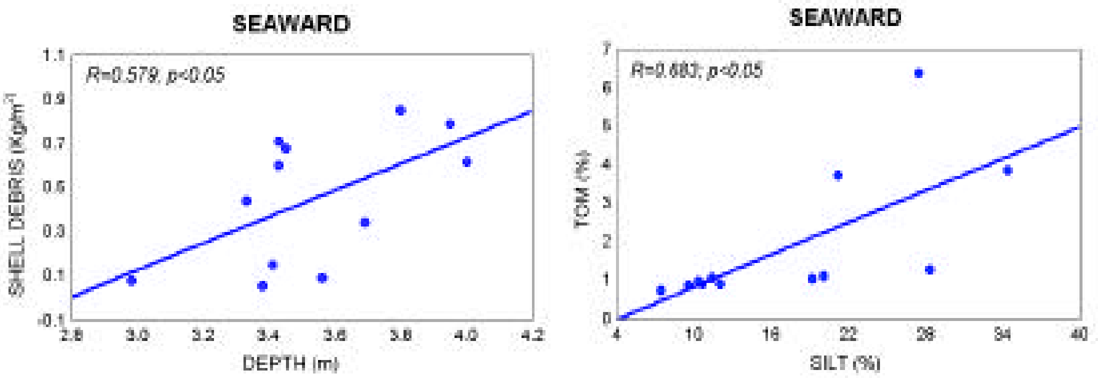

Figure 15 – Correlation between shell debris and depth (on the left) and between silt and TOM (on the right) at the seaward site. R is the Pearson's correlation coefficient.

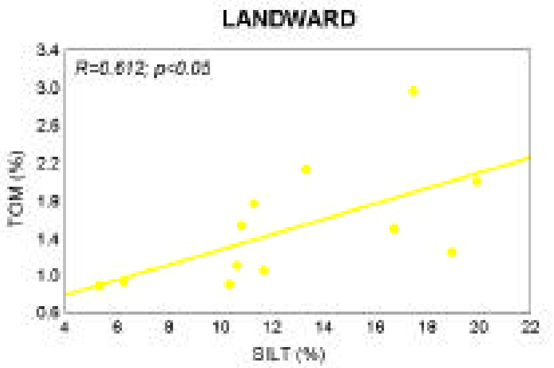

Fig. 16 – Correlation between silt and TOM at the landward site. R is the Pearson's correlation coefficient.

Discussion

The effect of LCS on the habitat complexity at the three study sites was very low, as most of the environmental variables measured did not vary significantly between landward, seaward and control areas. The high variability among areas within sites tends also to mask differences of single sediment characteristics between sites. However, some indications of a recognizable distinctiveness of the compared sites (control, landward and seaward) emerge from the multivariate analysis performed on the combined data of all measured variables.

As revealed by the PCA, the different design of the LCS (Fig. 17) give rise to different levels of response in the influence of LCS on the surrounding sediments. At the Spanish site, the landward stations clustered together and were clearly separated from the landward and control ones, while there was a remarkable absence of clear patterns both at the UK and Italians sites. Around the Cubelles LCS, depth was significantly lower landward than seaward. Thus, the sediments apparently tended to accumulate in the protected landward zones. The fact that seaward and control sites tends to function in a similar way is pointed out by the positive correlation between chlorophyll-a and silt and clay contents at both sites, which did not occur at landward. Moreover, the accumulation of sediments landward gives rise to the formation of a tombolo between the structure and the beach. This fact can be supported by the significant increase in the organic matter content at the deepest landward stations (i.e. those which are far from the tombolo), as well as by the highest variability detected in grain size.

At Elmer, there was not a direct effect on the habitat complexity of the area around the LCS. Although some variation was observed in the amount of chlorophyll-a, the thickness of the oxic layer in the sediment and the percentage of silt and clay, these slightly differences could not be clearly explained. There is, however a slight but interesting higher sit and clay content around the LCS (both at landward and seaward) with respect to the controls. Also, no apparent relationship was found between the sediment descriptors considered. Therefore the areas around and far away from structures appeared relatively homogeneous. The influence of tidal regime may be the responsible of this lack of clear differences. Moreover, the sediment unexpectedly consisted mainly of sand, as it was shown by very low values in the silt and clay component. This is in contrast from preliminary observations of the sediment composition between seaward and landward sides of other coastal defences in UK. In general, the sediment in the landward sides, where hydrodynamics is much reduced, had a much higher silt and clay content than in the seaward side. It might be possible that the absence of core at the centre of the rock islands allows more flow between the two sides and therefore more hydrodynamics occurs also on the landward side.

Apart an obvious correlation between silt-clay and organic content of the sediment, the major role in determining the observed pattern at Lido di Dante seems to be played by the interaction of both depth and shell debris variables. Their positive correlation in control and seaward site is reasonably explained by the tendency of shall debris to accumulate in deeper waters characterized by lesser turbulence in the course of time. This is apparently contradicted by the situation in the landward site where, notwithstanding the shallowest depth, the amount of shell debris is the highest (Table 3, SNK test). However also this result can be ascribed to the reduced turbulence caused by the presence of the low crested structures. In turn, the increase of shell debris content in the sediment could play an important role in structuring macrobenthic communities of the sublittoral areas behind breakwaters.

The most surprising characteristic shared by the three study sites is, however, that a great variability was estimated at smaller spatial scale, within landward, seaward and controls. Highly significant differences between areas within each site were found in most of the variables considered. This spatial variation might have made difficult to detect finer differences at higher level, i.e. between sites (landward, seaward and controls). Further investigations will be carried out in Year 2 to verify the results obtained in Year 1, which will also allow to estimate the extent of the impact of LCS in the surrounding areas. The effect of LCS on habitat complexity will be tested again at the three study sites either, but the new comparisons between landward, seaward sides and control areas will be made between zones located at increasing distances from the structures. The possibility of improving the resolution of the analysis by using a higher replication (bigger sample size) will be explored at Elmer. Additionally, similar studies will be also repeated on selected LCS in Liverpool (UK) and Altafulla (Spain), where more contrasting differences in the sediment characteristics were preliminary observed in Year 1.

To explore the coupling between the different environmental factors that may influence the soft bottoms around the LCS emerged as one of the main necessities for the second year of the project. Among them, the links between hydrodynamics, sediment dynamics and sediment patterns will be explored as we expect they would certainly help to explain the patterns observed when analysing the distribution of the infauna around the structures.