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The fouling community as an indicator of fish farming impact in Mediterranean

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Abstract

Fouling species richness, abundance and composition and biomass were chosen as the descriptors of effect of fish farm organic enrichment. The study was carried out in September 2004 in the Gulf of Castellammare (South Tyrrhenian, Mediterranean). The fouling species were sampled from plastic buoys spaced throughout the study area both up- [UP] and down-stream [DOWN]. The results showed that fouling community responded to the chronic input of allochthonous organic matter experiencing local changes more or less significantly with regard to abundance, species composition and general community diversity. Upper fouling would work as a first filter naturally opposed by environment resistance assimilating and facilitating the accommodation of most organic surplus. In highly hydrodynamic and sufficiently deep systems, the transport of organic particles produced from farms would have an effect along the horizontal axis rather than along the vertical axis, involving upper located benthic organisms rather than sedimentary benthic organisms.

Keywords: fouling community, artificial substrata, fish farm organic enrichment, anthropic systems, MED

Introduction

The loading from farming structures may produce detrimental effects on the surrounding environment (Beveridge 1996; Black 2001; Pillay 2004; Sarà, Scilipoti, Milazzo & Modica 2006). In the last two decades, the effects have been recorded both in the water column (Modica, Scilipoti, La Torre, Manganaro & Sarà 2006; Sarà 2006; Sarà *et al.* 2006) and in the underlying sediments (see the review of Kalantzi & Karakassis 2006; Sarà *et al.* 2006). Sediments have been judged as the best systemic memory of disturbance as they are able to record possible detrimental effects on the environment over longer periods of time (Danovaro 2003; Holmer, Perez & Duarte 2003). Similar findings were obtained above all from fish farms located in partially shallow and sheltered areas (Kalantzi & Karakassis 2006). However, currently, most fish farms plants are located in very deep water columns (> 20–30 m) and are characterized by energetic hydrodynamic regime levels (Sarà *et al.* 2006). In these cases, the effects of farming loading should not be researched on the sediments alone because the uneaten feed particles, once produced, are laterally moved (as a function of their settling velocity; Chen, Beveridge & Telfer 1999) rather than vertically transported along the water column (Sarà *et al.* 2006). Thus, sediments may be less affected, considering that lateral drifting forces could be more intense than vertical sedimentation forces. Under similar conditions, local infra-upper-littoral benthic communities can be reliable for recording the effects of pollution (Angel & Spanier 2002). In farming plants, worldwide, the availability of artificial hard surfaces, among buoys and cage structures, is large. They function as attachment substrata for the recruitment of many intertidal benthic organisms, which compose the fouling community (Mook 1981). Recently, several papers have focused on the fouling organisms on many artificial substrata and most of them have pointed out that fouling species can be used as good indicators of environmental disturbance (Calcagno, López Gappa & Tablado 1998) both from organic (Kalaman 2001; Mayer-Pinto & Junqueira 2003) and thermal pollution (Zvyagintsev & Korn 2003). Few papers have focused on fouling in aquaculture polluted systems, although some authors already proposed to use fouling as a natural biofilter for mitigating the impact (Angel & Spanier 2002). Thus, in those environments where lateral drift is more pronounced than sedimentation, fouling descriptors appear to be a promising tool to assess modifications induced by anthropogenic stress. In a similar way, the main aim of the present study was to investigate the effects of fish aquaculture loading on fouling communities through the study of (i) density, species richness and diversity and (ii) biomass of communities in polluted (downstream sites) vs. unpolluted sites (upstream sites).

Material and methods

The study was carried out in the autumn 2004 in the Gulf of Castellammare, on the northern coast of Sicily (latitude 38°02′31″N; longitude 12°55′28″E). The area is seasonally influenced by terrigenous-continental inputs (Sarà, Manganaro, Cortese, Pusceddu & Mazzola 1998; Sarà, Scilipoti, Mazzola & Modica 2004; Modica *et al.* 2006), which originate from nearby streams. Three submersible cages (Farmocean, Sweden; volume = 4500 m^3) and six smaller cages (volume = 1000 m^3) were positioned in the Eastern part of the Gulf (latitude 38°04′53″N; longitude 13°02′04″E) and moored to the bottom at a depth of about 32 m, about 1.2 km off the coastline (Fig. 1). The hydrodynamic regime of the cage area is characterized by a dominant current coming from the third and fourth quadrant (along a west–east axis) for most of the year (Modica *et al.* 2006; Sarà *et al.* 2006). The area where cages were located was not influenced by other discharge types (e.g. sewage from urban areas) but the fish farm deposition could putatively be considered to be the major input (Sarà *et al.* 2006). The cages were stocked with seabass (*Dicentrarchus labrax*) and seabream (*Sparus aurata*) for a total biomass of about 300 tonne produced yearly. Throughout the farming period, the average food conversion ratio was estimated by the owners of the farm to be about 1.9 on average for both species, and the total supplied feed (different types of commercial pelletted feed produced by BioMar, Brande, Denmark and by Hendrix, Verona, Italy) was about 450–500 tonne.

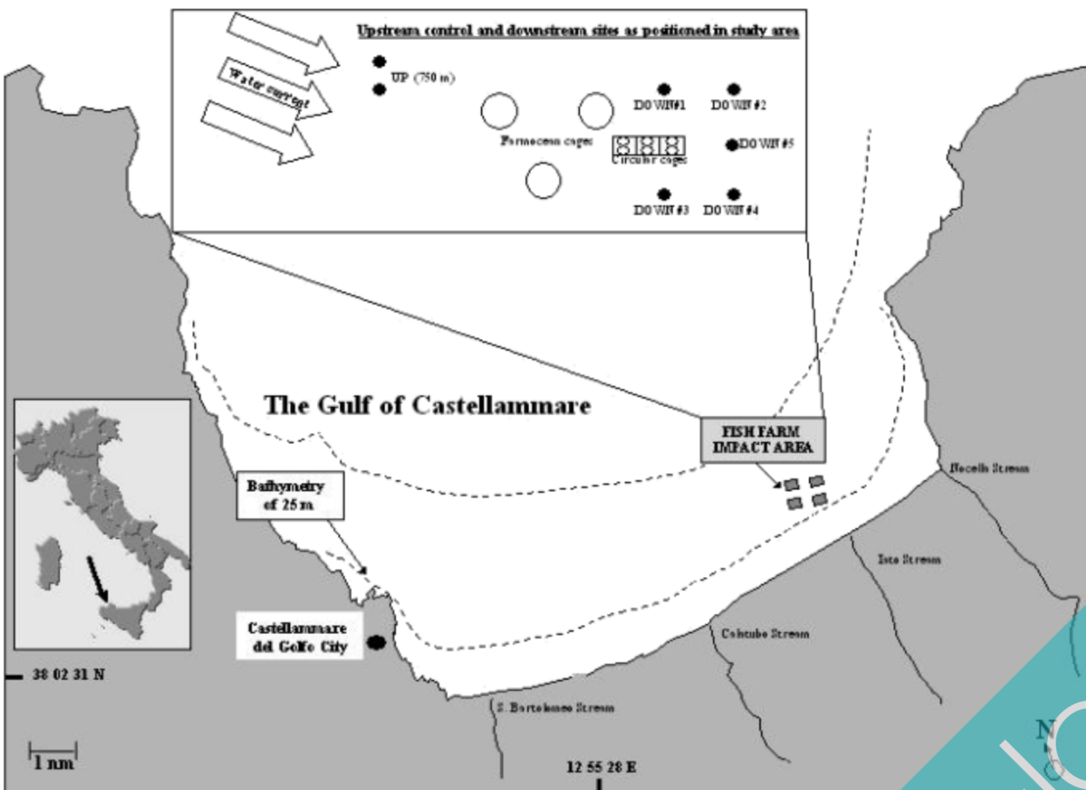

Figure 1 Map of the study area, the Gulf of Castellammare (Sicily, MED, not to scale), showing the location of the fish cages.

Sampling and laboratory analysis

To address the question of whether nutrient discharge produced effects recordable by a local fouling community, sites were positioned in order to obtain samples with the highest degree of organic waste deposition coming from the cages. Accordingly, seven sampling sites (#1 to #7) were positioned along the main axis of the water unidirectional current (Modica *et al*. 2006): two (hereafter called UP sites; 1 and 2) were positioned upstream from the farm (at about 750–1000 m) and five (hereafter called DOWN sites; from 3 to 7) downstream (Fig. 1). From each site, sub-surface water samples were collected using a Niskin bottle and analysed for dissolved nutrients (nitrogen and phosphorus). Analyses were carried out according to Liddicoat, Tibbits and Butler (1975), Aminot and Chaussepied (1983), Catalano (1987) for ammonium, Bendschneider and Robinson (1952) for nitrites, Wood, Armstrong and Richards (1967) for nitrates and Murphy and Riley (1962) for orthophosphate. In addition, from the same sites, samples of fouling had been collected solely from artificial substrata from surface buoys used by the owners to mark out their property area and positioned in the water during the same period, about 3 years before. No cleaning operations had ever been carried out on the buoys. Thus, sites of sampling were represented by groups of buoys spaced throughout the study area both up- and downstream. All buoys were of the same size (about 1.4 m in diameter; the submerged sampling area was estimated to be not $<1\,m^2$), shape and material (plastic) and the samples were randomly collected from substrata positioned immediately below the floatation line. The buoys were divided into a sufficient number of different groups in order to pick three plots of buoys randomly. In each plot, we had at least three buoys and from each of them a unique sample from a standardized surface area was collected (using quadrates having $20\,cm \times 20\,cm$ for $400\,cm^2$). Thus, the sampling unit was the plot and standard errors for means were obtained by the average mean of three quadrates per plot. In September 2004, fouling organisms were scraped by means of a putty knife from each quadrate and were brought back to the laboratory where the samples were frozen ($-20\,°C$) or stored in alcohol or formalin as a function of taxa. All specimens from each quadrate were sorted, classified according to species or genera (number of taxa, *S*), counted (abundance, *n*), measured to within 0.1 mm with a digital calliper and the total wet weight (TW, g) of individuals was measured to within 0.1 mg. Animals were dried to a constant weight of 105 °C ($\sim$48 h) and combusted at 500 °C for 24 h to obtain the ash-free dry weight (AFDW, g) to within 0.1 mg. Ash-free dry weight values, in this paper, have been used as a measurement of biomass production.

Experimental design and statistical analysis

A three-way analysis of variance (ANOVA; Underwood 1997) was carried out to test the difference among up and down sites in nutrient concentrations. For this, condition (TREAT; UP vs. DOWN, two levels) was chosen as a fixed factor, and three sites were treated at random and nested in condition. Sampling dates (21 September and 12 October) were chosen as random factors. Three replicates were collected for each of the following variables: ammonium, nitrites, nitrates and ortophosphates. When a significant difference ($P<0.05$) for the main effect was observed, the appropriate means were compared using Student–Newman–Keuls (SNK) tests (Underwood 1997).

To test the difference between up and down sites, a mixed-model permutational multivariate analysis of variance (PERMANOVA, Anderson 2001a) was carried out. In the analysis, treatment (TREAT; UP vs. DOWN, two levels) was the fixed factor, while plot (Plot, three levels) was treated as the random factor. Quadrates in each plot represented replicates ($n = 3$). Species variables were transformed to $y' = \ln(y+1)$ in all analyses to retain information on relative abundances but reduce differences in scale among the variables. The Bray–Curtis dissimilarity measure was used for all analyses, and all *P* values were calculated using 9999 permutations of the residuals under a reduced model (Anderson 2001b). Differences between UP and DOWN were examined in more detail using an analysis of principal coordinates (PCO; Gower 1966; Anderson & Willis 2003).

Results

Up and down sites differed significantly as regards ammonium, nitrates and orthophosphates (ANOVA, $P<0.05$), the concentrations being higher in down than up sites. Nitrites were similar in both conditions (Fig. 2). In the study area, 14 fouling species were collected throughout the study period, accounting for a total of 4612 individuals (Table 1; data are reported excluding polychaetes). The number of total individuals per surface unit significantly differed between the up (data of up sites, not being significantly different from each other in all analyses, were pooled and presented as UP) and the down sites ($P<0.05$; Tables 2a and 2b; Fig. 3). As regards the number of taxa, although there are evidently some subtle differences (PerMANOVA, $P<0.05$) in fouling communities between the various sites, these did not generally provide clear patterns or trends, moving downstream from the farm. Accordingly, species richness remained rather constant throughout the study area, ranging on average 3.9 ± 0.7, irrespective of up and down sites. The fouling community was composed of 6 functional groups, each significantly different as a function of nutrient enrichment (Tables 3a, 3b, 3c). Suspension feeders were the most numerically abundant group. Among them, mollusca Bivalvia (bivalves) represented the most frequent item with five species in the fouling community and a total abundance of 55.0–60.0 ± 30.0%. Crustacea Cirripeda represented the second most important group with a total numerical abundance of about 40.0–45.0 ± 27.0%. The other groups (grazers and predators) accounted for not more than 1% of the total abundance within the community. Barnacles and

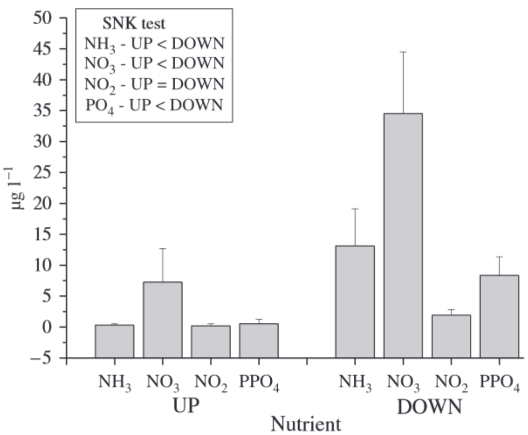

Figure 2 Nutrient concentrations (± SE) in the comparison among UP and DOWN sites.

Table 2a Mixed-model permutational multivariate analysis of variance (PerMANOVA) on the basis of Bray–Curtis dissimilarities carried out for comparing controls vs. impacts for (a) abundances of all taxa (14 species) and (b) species (*S*) and total abundance (*n*) (two variables)

	d.f.	MS	*F*	*P*
(a)				
Treatment (Tr)	6	5597.81	4.45	***
Plot (Tr)	14	1256.93	0.83	NS
Residual	42	1513.90		
(b)				
Treatment (Tr)	6	760.62	3.03	**
Plot (Tr)	14	250.83	0.94	NS
Residual	42	268.15		

Data were transformed to ln(x+1); no standardization.

Table 1 Fouling species as collected throughout the study area, in controls and impacts

	UP		DOWN 1		DOWN 2		DOWN 3		DOWN 4		DOWN 5	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
N species	3.39	1.54	4.22	1.86	3.89	1.05	3.11	1.45	3.89	1.17	5.11	1.76
Abundance	25.92	19.42	42.67	15.71	78.78	48.21	51.78	34.66	109.67	106.04	177.67	102.26
Balanus perforatus	7.28	7.67	23.11	14.21	26.11	12.51	15.56	17.54	6.67	4.69	15.44	5.64
Chthamalus stellatus	14.25	21.03	4.11	8.61	0.00	0.00	14.00	18.54	8.56	16.15	15.22	35.92
Balanus trigonus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.56	6.78
Pachygrapsus marmoratus	0.67	1.28	0.56	0.73	0.33	0.50	0.11	0.33	0.00	0.00	0.44	0.73
Eriphia verrucosa	0.11	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.78	1.64	0.11	0.33
Acanthonyx lunulatus	0.44	1.20	0.11	0.33	0.11	0.33	0.11	0.33	0.33	0.71	0.33	0.71
Patella coerulea	0.06	0.24	0.67	0.87	0.11	0.33	0.22	0.44	0.11	0.33	0.00	0.00
Thais haemastoma	0.00	0.00	0.22	0.67	0.11	0.33	0.00	0.00	0.22	0.44	0.00	0.00
Ostrea edulis	0.94	1.16	0.00	0.00	0.22	0.67	0.56	0.73	0.78	1.30	4.00	3.39
Arca noae	0.11	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mytilaster minimus	1.83	3.70	12.44	8.75	49.89	44.99	20.67	39.92	91.00	105.35	134.56	93.63
Mytilus galloprovincialis	0.22	0.55	0.89	1.05	0.11	0.33	0.33	0.50	0.33	0.71	0.22	0.44
Brachidontes pharaonis	0.00	0.00	0.33	0.71	0.56	1.33	0.11	0.33	0.78	1.39	1.44	1.74
Arbacia lixlula	0.00	0.00	0.22	0.44	1.22	0.83	0.11	0.33	0.11	0.33	0.33	0.71
Polychaeta (ND)	NP	–	p	–	p	–	p	–	p	–	p	–

Polychaeta have not been considered in any analysis throughout the present paper.
± SE, standard errors for means; ND, not determined; NP, not present; p, present in the quadrate but representing a negligible component.

bivalves significantly changed between up and down sites. Barnacles dominated in the up sites (Tables 3a, 3b, 3c), while once the effect of nutrient loading increased, bivalve specimens became numerically the most abundant group in the down sites (~ 70%), and barnacles remained constant. This was confirmed from the Shannon index, which showed an initial increment in value from up to first down sites (DOWN #1 and #2), but successively decreased, reaching the impact sites further away (Fig. 4). Also biomass (Table 4) varied as a function of different nutrient loading as evidenced by the PERMANOVA results presented in Table 5. Biomass (as expressed by the AFDW) was on average twofold higher in down (32.8 ± 12.4 g per 400 cm^2) than in up sites (17.2 ± 29.7 g per 400 cm^2) (Fig. 5). Barnacles, although numerically less abundant than bivalves, represented the main producer of organic matter in the study area, accounting for about 62.2 ± 12.9% of the total both in the up and the down sites (9.2 ± 9.5 g per 400 cm^2 and 20.7 ± 9.0 g per 400 cm^2 respectively). By contrast, bivalves represented about 30.7 ± 14.6% of the total biomass.

Table 2b Pair-wise a posteriori comparison tests for a) abundances of all taxa and (b) species (*S*) and total abundance (*n*)

	UP 1	UP 2	DOWN 1	DOWN 2	DOWN 3	DOWN 4	DOWN 5
(a)							
UP 1	–						
UP 2	NS	–					
DOWN 1	**	*	–				
DOWN 2	***	*	NS	–			
DOWN 3	*	NS	NS	*	–		
DOWN 4	*	NS	NS	*	NS	–	
DOWN 5	*	*	*	*	*	*	–
(b)							
UP 1	–						
UP 2	NS	–					
DOWN 1	*	NS	–				
DOWN 2	*	NS	NS	–			
DOWN 3	*	NS	NS	NS	–		
DOWN 4	*	NS	NS	NS	NS	–	
DOWN 5	**	NS	**	NS	**	*	–

Data were transformed to ln(*x*+1); no standardization.

Discussion

Fish-farm biodeposition causes changes in the chemical environment. In the study area up and down sites were significantly different as regards the nutrient profile, similar to the changes observed in other Mediterranean areas (Pitta, Karakassis, Tsapakis & Zivanovic 1999; Pitta, Apostolaki, Giannoulaki & Karakassis 2005). This may induce changes in the characteristics of the mediolittoral benthic environment. These results are also in line with one of the best-documented impacts of net pen fish farms (i.e. alteration of community dynamics and changes in biodiversity of local fauna; Weston 1990; Yokoyama,

Table 3a Fouling groups as collected throughout the study area in controls and impacts: (a) species richness and (b) total units for each group

	UP		DOWN 1		DOWN 2		DOWN 3		DOWN 4		DOWN 5	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
(a)												
N species	3.39	1.54	4.22	1.86	3.11	1.45	3.89	1.05	3.89	1.17	5.11	1.76
Crustacea Cirripeda (SUSP)	1.72	0.46	1.33	0.50	1.33	0.50	1.00	0.00	1.44	0.53	2.00	0.87
Crustacea Decapoda (CARN)	0.56	0.92	0.56	0.73	0.22	0.44	0.44	0.53	0.56	0.73	0.67	0.87
Mollusca Gasteropoda (GRAZ)	0.06	0.24	0.44	0.53	0.22	0.44	0.11	0.33	0.11	0.33	0.00	0.00
Mollusca Gasteropoda (CARN)	0.00	0.00	0.11	0.33	0.00	0.00	0.11	0.33	0.22	0.44	0.00	0.00
Mollusca Bivalvia (SUSP)	1.06	0.94	1.56	1.13	1.22	1.39	1.44	0.53	1.44	1.01	2.44	0.73
Echinodermata Echinoidea (GRAZ)	0.00	0.00	0.22	0.44	0.11	0.33	0.78	0.44	0.11	0.33	0.22	0.44
(b)												
Abundance	25.92	19.42	42.67	15.71	51.78	34.66	78.78	48.21	109.67	106.04	177.67	102.26
Crustacea Cirripeda (SUSP)	21.53	19.43	27.22	9.88	29.56	17.40	26.11	12.51	15.22	16.01	36.22	39.18
Crustacea Decapoda (CARN)	1.22	2.18	0.67	1.00	0.22	0.44	0.44	0.53	1.11	1.76	0.89	1.36
Mollusca Gasteropoda (HERB)	0.06	0.24	0.67	0.87	0.22	0.44	0.11	0.33	0.11	0.33	0.00	0.00
Mollusca Gasteropoda (CARN)	0.00	0.00	0.22	0.67	0.00	0.00	0.11	0.33	0.22	0.44	0.00	0.00
Mollusca Bivalvia (SUSP)	3.11	4.52	13.67	9.12	21.67	40.78	50.78	45.66	92.89	106.23	140.22	94.63
Echinodermata Echinoidea (HERB)	0.00	0.00	0.22	0.44	0.11	0.33	1.22	0.83	0.11	0.33	0.33	0.71

± SE, standard errors for means; SUSP, suspensivores; CARN, carnivorous; GRAZ, grazers.

Table 3b Mixed-model permutational multivariate analysis of variance (PERMANOVA) on the basis of Bray–Curtis dissimilarities carried out for comparing controls vs. impacts for (a) abundances of all taxa (14 variables) and (b) species (*S*) and total abundance (*n*) (two variables)

	d.f.	MS	*F*	*P*
(a)				
Treatment (Tr)	6	5597.81	4.45	***
Plot (Tr)	14	1256.93	0.83	NS
Residual	42	1513.90		
(b)				
Treatment (Tr)	6	760.62	3.03	**
Plot (Tr)	14	250.83	0.94	NS
Residual	42	268.15		

Data were transformed to ln(*x*+1); no standardization.

Table 3c Pair-wise a posteriori comparison tests for (a) abundances of all taxa and (b) species (*S*) and total abundance (*n*)

	UP 1	UP 2	DOWN 1	DOWN 2	DOWN 3	DOWN 4	DOWN 5
(a)							
UP 1	–						
UP 2	NS	–					
DOWN 1	**	*	–				
DOWN 2	***	*	NS	–			
DOWN 3	*	NS	NS	*	–		
DOWN 4	*	NS	NS	*	NS	–	
DOWN 5	*	*	*	*	*	*	–
(b)							
UP 1	–						
UP 2	NS	–					
DOWN 1	*	NS	–				
DOWN 2	*	NS	NS	–			
DOWN 3	*	NS	NS	NS	–		
DOWN 4	*	NS	NS	NS	NS	–	
DOWN 5	**	NS	**	NS	**	*	–

Data were transformed to ln(*x*+1); no standardization.

Abo, Toyokawa, Toda & Yamamoto 1997). To date, biofouling of hard artificial substrata and fish-cage netting has been studied only as a negative factor affecting aquaculture productivity (Hodson, Burke & Bissett 2000). The fouling community responded to the chronic input of allochthonous organic matter (fish waste and uneaten food), exhibiting local changes more or less consistently with regards to abundance, species composition, biomass and general community diversity. The total abundance in up sites was significantly lower than in down sites. In aquatic environments, under anthropogenic disturbance, such us organic enrichment, the local first re-

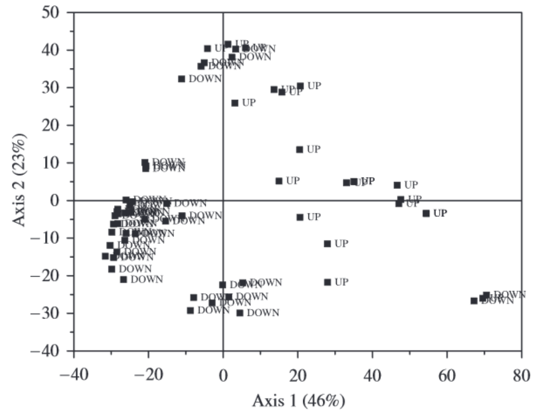

Figure 3 Principal coordinates [metric Multi Dimensional Scaling (MDS)] ordination on the basis of Bray–Curtis dissimilarities carried out for comparing total abundance for 14 fouling species among controls and impacts. Percentage variabilities explained by the principal coordinate axes are given on the plot.

sponse adopted by the system to the unnatural enhancement of food availability is a change in the total number of individuals *per* surface unit (Angel & Spanier 2002). Thus, if the attachment surface (i.e. space) is not limiting (Dayton 1971), the main result is an increase in recruitment of new specimens that in turn leads to an increase in abundance. Nevertheless, the increase in total abundance was not followed by an increase in species richness. Indeed, the total number of species did not vary between up and down sites, remaining constantly up to three to four species per surface unit. Similar values of species richness were in line with natural patterns observed on Southern Mediterranean coasts (Riggio, D'Anna & Sparla 1992) where the upper-infra-littoral community is generally observed to be depauperate with respect to other Mediterranean (Solis-Weiss, Aleffi, Bettoso, Rossin, Orel & Fonda-Umani 2004) and White Sea communities (Kalaman 2001). Thus, under the study area hydrodynamics, the input of organic matter could be assimilated by the system while not causing any impact on the number of species. On the other hand, the first stage of the ecological response to anthropogenic stress is the modification of species abundance, while the energetic threshold a system requires to change the species richness equilibrium must be greater due to resistance opposed by the system itself. Moreover, species composition varied. Barnacles are usually the dominant group in Mediterranean hard natural sites (Lipkin & Safriel 1971) with *Chthamalus* sp., which

Table 4 Biomass as estimated by means the AFDW (g per 400 cm^2) by fouling groups in controls and impacts

	UP		DOWN 1		DOWN 2		DOWN 3		DOWN 4		DOWN 5	
	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE	Mean	± SE
T-P (g per 400 cm^2)	17.2	29.7	33.1	24.0	12.6	18.4	41.7	17.3	32.5	16.2	44.0	18.2
I-P (T-P/n)	16.5	18.7	17.3	8.2	17.1	18.6	13.1	7.8	19.6	21.4	38.5	37.9
Crustacea Cirripeda (SUSP)	9.2	9.5	24.6	19.6	9.0	18.4	30.3	19.8	13.7	6.8	26.0	10.5
Crustacea Decapoda (CARN)	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.2	0.3	0.1	0.1
Mollusca Gasteropoda (GRAZ)	0.1	0.5	0.5	0.8	0.2	0.5	0.0	0.0	0.1	0.3	0.0	0.0
Mollusca Gasteropoda (CARN)	0.0	0.0	0.0	0.1	0.0	0.0	1.8	5.5	2.0	5.0	0.0	0.0
Mollusca Bivalvia (SUSP)	7.8	28.3	6.0	8.1	2.9	4.1	5.4	4.2	15.2	12.5	16.8	10.9
Echinodermata Echinoidea (GRAZ)	0.0	0.0	1.9	3.8	0.4	1.3	4.2	3.7	1.4	4.1	1.2	2.8

± SE, standard errors for means; T-P, total biomass in grams per 400 cm^2 as estimated in each site; I-P, individual biomass in grams per 400 cm^2; SUSP, suspensivores; CARN, carnivorous; GRAZ, grazers; AFDW, ash-free dry weight.

Table 5a Mixed-model permutational multivariate analysis of variance (PerMANOVA) on the basis of Bray–Curtis dissimilarities carried out for comparing controls vs. impacts for (a) total biomass (AFDW; grams per 400 cm^2) and (b) individual biomass (AFDW; grams per 400 cm^2)

	d.f.	MS	*F*	*P*
(a)				
Treatment (Tr)	6	3758.37	3.31	***
Plot (Tr)	14	1136.72	1.19	NS
Residual	42	955.97		
(b)				
Treatment (Tr)	6	5455.85	2.45	**
Plot (Tr)	14	2224.62	1.13	NS
Residual	42	1968.05		

Data were transformed to ln(x+1); no standardization.
AFDW, ash-free dry weight.

Table 5b Pair-wise a posteriori comparison tests for (a) total biomass production (AFDW; grams per 400 cm^2) and (b) individual biomass production (AFDW; grams per 400 cm^2)

	UP 1	UP 2	DOWN 1	DOWN 2	DOWN 3	DOWN 4	DOWN 5
(a)							
UP 1	–						
UP 2	NS	–					
DOWN 1	NS	NS	–				
DOWN 2	*	*	NS	–			
DOWN 3	NS	NS	NS	*	–		
DOWN 4	*	NS	NS	*	*	–	
DOWN 5	**	*	NS	*	*	NS	–
(b)							
UP 1	–						
UP 2	NS	–					
DOWN 1	NS	NS	–				
DOWN 2	**	*	NS	–			
DOWN 3	NS	NS	NS	*	–		
DOWN 4	NS	NS	NS	*	NS	–	
DOWN 5	NS	NS	NS	NS	NS	NS	–

Data were transformed to ln(x+1); no standardization.
AFDW, ash-free dry weight.

represents a key species of the upper-infra-littoral, and bivalves that are only occasionally present (genus *Mytilaster*; Lipkin & Safriel 1971). Similarly, in the up sites of the study area, barnacles represented the most important group, and bivalves were only occasional as in the Western Baltic fouling communities (Durr & Whal 2004) in unpolluted sites. By contrast, in the down buoys of the study area, mussels were observed to be dominant on the barnacles. This is explained by the capacity of the competitive dominance of the mussel community (Durr & Whal 2004) under the small scale of the environmental disturbance (Petraitis & Latham 1999). Similarly, under conditions of intermediate physical stress but where trophic availability was not a limiting factor (i.e. eutrophic waters), mussels dominated or co-occurred with barnacles (Dayton 1971; Dean & Hurd 1980; Harms & Anger 1983; Wootton 1994; Durr & Whal 2004; Sarà 2007). However, in the study area physical conditions (e.g. temperature and salinity) did not differ between up and down sites, but differed only as regards food availability. Moreover, the trophic factor would function similar to physical factors (tide, currents, temperature, space and so on) as a structuring factor, able to induce changes in species composition. Consequently, the recruitment rate of mussels was higher in down than up sites, while that of barnacles remained rather constant or declined slightly. If the low–moderate environmental changes did not produce effects on species richness, it induced deviation from natural patterns of the trophic web structure. Substantially, the number of trophic levels appeared to be fairly constant among

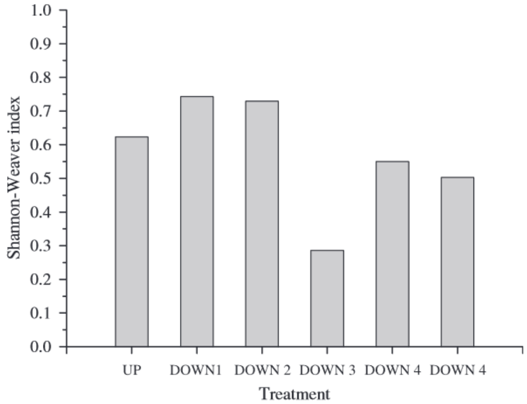

Figure 4 Pattern of diversity as estimated by the Shannon index (*H′*; Magurran 1988) of functional groups in the fouling of controls and impacts.

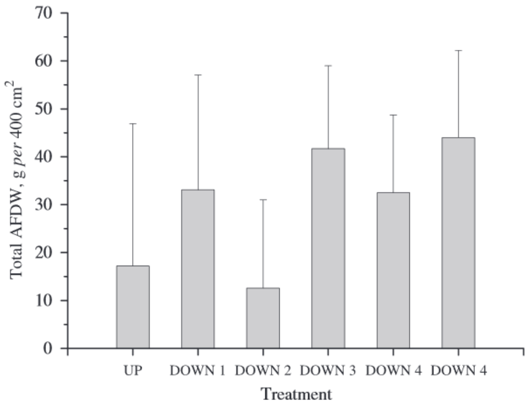

Figure 5 Biomass [ash-free dry weight (AFDW), g per 400 cm^2] as estimated by the AFDW technique of fouling in controls and impacts.

up and down sites, even though primary consumers like suspensivores changed significantly when nutrient loading was present. The last difference was also evident by the difference among up and down sites with regard to biomass of the fouling community. Indeed, biomass was twofold higher in down than in up sites. This suggested that nutrient loading was efficiently exploited by the fouling along the horizontal axis of the system thanks to the lateral drifting movements. Significant differences in biomass in polluted and unpolluted sites were also measured on other occasions (Mayer-Pinto & Junqueira 2003). In the current literature, there is only evidence about the exploitation of loading coming from farming by sedimentary communities and moreover along the horizontal axis of the system (Kalantzi & Karakassis 2006). Thus, in sufficiently deep systems, the transport of organic particles produced from farms should mostly be verified along the horizontal axis rather than along the vertical axis, involving above all upper located benthic organisms. According to recent models of waste dispersal (Cromey, Nickell & Black 2002; Cromey, Nickell, Black, Provost & Griffiths 2002) considering hardness, friability, settling velocity, relationship with salinity and temperature of pelletted food (Chen *et al*. 1999), the hypothesis of a major effect on the water column surface rather than deeper layers can be corroborated.

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