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Effects of the 'Prestige' oil spill on macroalgal assemblages: Large-scale comparison

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Abstract

An assessment of the effects of the 'Prestige' oil spill on intertidal, macroalgal assemblages was carried out comparing abundance data obtained before and after the spill. Four zones in the North and Northwest coast of Spain were sampled, one of them located at the immediate vicinity of the spill, the zone most heavily oiled. Macroalgal assemblages had similar structure between years. Neither critical decrease in abundance of the dominant macroalgae, nor increase in opportunistic species were found. Some differences in abundance were observed, but they did not show any pattern, being more likely the result of the natural variability of the assemblage. Extensive, but not intense fuel deposition on the shores and a limited use of aggressive cleanup methods are suggested as possible causes for the lack of the effects in these assemblages after the 'Prestige' oil spill.

Keywords: 'Prestige' oil spill; Macroalgal assemblages; Community structure; Species distribution; Pollution; North of Spain

1. Introduction

In November 2002, the 'Prestige' oil tanker sank at ca. 130 nautical miles off the Galician coast, carrying more than 77,000 tons of heavy fuel oil M-100. This fuel is characterized by its low solubility and volatility, which makes it very persistent over time (Markarian et al., 1993). After the wreckage, the 'Prestige' released more than 10,000 tons of fuel oil, which were carried by prevailing winds and ocean currents and reached extensive areas of the Cantabrian coast, North of Spain (Montero et al., 2003; García-Soto, 2004; Acuña et al., in press). After sinking, the 'Prestige' gradually released the rest of its fuel during ca. 4 months, causing a series of oil waves, which mainly affected the Galician coast, Northwest of Spain (Acuña et al., in press). Except for most oiled areas located at the "Costa da Morte" (Galicia, Fig. 1), oil deposition on the Atlantic and Cantabrian Spanish coasts was extensive, but not very intense, affecting mainly a 100 km coastal zone East of Cape Peñas (Acuña et al., in press; Fig. 1).

To date, moderate to negligible effects of the 'Prestige' oil spill have been documented on benthic (Serrano et al., 2006) and planktonic (Varela et al., 2006; Bode et al., 2006; Salas et al., 2006) communities, and on cell and tissue condition biomarkers in mussel, hake and anchovy (Marigómez et al., 2006). This is consistent with low fuel contents measured during the winter 2002–2003 in shelf sediments and in the water column off the Cantabrian coast (IEO http://www.ieo.es/prestige/resultados.htm; González et al., 2006). Therefore, the most likely target to detect any significant ecological effect should be the shoreline, where much of the spilled fuel was deposited (Acuña et al., in press).

Proper assessment of the ecological effects of disturbances requires baseline time-series studies, documenting the situation before the impact (e.g. for application of a BACI sampling design, Underwood, 1992). Information of the natural variability of the ecosystem is essential to

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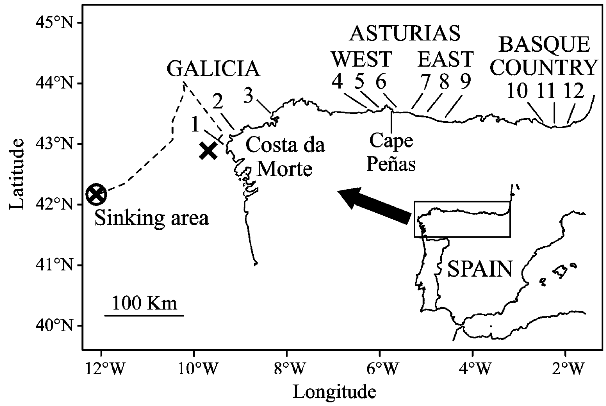

Fig. 1. Sampled locations in the study area (N and NW Spanish coast). The dotted line shows the 'Prestige' course since it started to leak oil on November 13th (×) until the sinking on 19th (⊗) 2002. (1) Muxía; (2) Lobeiras; (3) Lobadiz; (4) Novellana; (5) Artedo; (6) Aramar; (7) Rodiles; (8) La Griega; (9) Vidiago; (10) Sakoneta; (11) Zumaia; (12) Igeldo.

differentiate and evaluate the effects of anthropogenic impacts. In spite of the remarkable recurrence of oil spills in certain areas, including the Galician coast, baseline studies with adequate replication for hypothesis testing are rarely available (Teal and Howarth, 1984). During 2000 and 2002, right before the 'Prestige' oil spill, we conducted a survey to characterize the structure of macroalgal assemblages at the mid and low rocky intertidal in the northern Spanish coast (Galicia, Asturias and Basque Country, Fig. 1). Hierarchical sampling allowed us to partition variance in community structure among different spatial scales (from kilometers to meters). After the 'Prestige' disaster we decided to repeat the same sampling program to evaluate the effects of oil spill on these assemblages. Coincidentally, our study included locations from the most affected area in Galicia to the eastern affected coast in the Basque Country. Although these data lacked temporal replication before and after the spill, they allowed us to test of hypothesis concerning differences in macroalgal community structure after the 'Prestige' oil spill.

2. Materials and methods

2.1. Sampling

We sampled 12 localities along Galicia (Muxía, Lobeiras, and Lobadiz), West Asturias (Novellana, Artedo, and Aramar), East Asturias (Rodiles, La Griega, and Vidiago), and the Basque Country (Sakoneta, Zumaia, and Igeldo) coasts (Fig. 1). West and East Asturias localities were sampled in August 2000 and 2003, and Galicia and Basque Country localities in September 2002 and 2003. Six sites were randomly chosen at each locality, three at "lower" (between 0.4 and 0.7 m above the Lowest Astronomical Tide) and three at "upper" (between 0.9 and 1.3 m) intertidal zone. One 15 m transect parallel to the coastline was sampled at each site. Five, 50 × 50 cm quadrats were randomly placed in each transect and photographed. Algae were identified to species, or assigned to higher taxonomic categories when species identification was not possible (e.g. Order Ceramiales). Abundance (as percentage cover) of each taxon was estimated in the laboratory by the point-contact method (Hawkins and Jones, 1992). A grid of 100 regularly spaced points was superimposed over the digitized pictures of the quadrats and interceptions for each taxon were counted. This technique reduces sampling time at the low intertidal level, but overestimates canopy species in multilayered assemblages (Meese and Tomich, 1992; Dethier et al., 1993).

2.2. Data analysis

Percentage cover data were analyzed using both univariate and multivariate techniques. Spatio-temporal differences of most abundant taxa from each intertidal level (comprising more than 75% of total cover) were analyzed. These taxa were *Fucus* spp. (including *Fucus spiralis* L. and *Fucus vesiculosus* L., difficult to distinguish on photographs), *Fucus serratus* L., *Mastocarpus stellatus* (Stack.) Guiry, *Corallina elongata* J. Ellis & Sol., *Ralfsia verrucosa* Aresch., and Ceramiales (mainly *Ceramium* spp. and *Callithamnion* spp.) for the "upper" level; and *Bifurcaria bifurcata* R. Ross, *Himanthalia elongata* (L.) S.F. Gray, *C. elongata*, Ceramiales, *Stypocaulon scoparium* (L.) Kütz., and *Cladostephus spongiosus* (Hudson) C. Agardh for the "lower" level. In addition, species of *Ulva* spp. were included due to their importance as colonizers on open substrata. Hypothesis of absence of spatio-temporal differences of these taxa was tested using univariate analysis of variance (ANOVA). Separate analyses were done for the "upper" and "lower" tidal levels. "Time" (fixed, with two levels, Before and After spillage), "Zone" (fixed, with four levels, GAL (Galicia), ASTw (West Asturias), ASTe (East Asturias), and BC (Basque Country) coasts), "Locality" (random and nested in Zone, with three levels), and "Site" (random and nested in the "Time × Locality (Zone)" interaction, with three levels and five replicates) were the factors considered in the *C. elongata*, Ceramiales, *R. verrucosa*, and *Ulva* spp. analyses. Different designs were used for the other species, as they were absent in some of the zones. Factor zone with three levels was used for *Fucus* spp., and *M. stellatus,* because they did not appear in the Basque Country, and for *S. scoparium*, and *C. spongiosus*, since they were not present in samples from Galicia. For *H. elongata*, only present in Galicia and West Asturias, factor Zone had two levels. Variances were homogeneous (Cochran's test, $P > 0.05$) for *B. bifurcata* and, after arcsine transformation for *S. scoparium*, and $\ln(x+1)$ transformation for the rest of the taxa. Despite heterogeneity of variances for *Fucus* spp., *H. elongata*, and *C. elongata*, ANOVA was used because of its robustness and validity in large and balanced designs (Underwood, 1997). When significant Time × Zone interaction was found, Student–Newman–Keuls (SNK) *a posteriori* test was applied.

Multivariate analyses were used to examine changes in the community structure before and after the oil spill. Percentage cover estimates of all taxa (29 and 28 in the "upper" and "lower" levels, respectively) were included in the analyses. All non-metric multivariate approaches were performed on the basis of a Bray–Curtis dissimilarity matrix (Bray and Curtis, 1957) calculated from the untransformed data. Differences in the macroalgal community were tested using distance-based permutational multivariate analysis of variance (PERMANOVA, Anderson, 2001). The full design described for univariate data was used, and each term in the analysis was tested using 9999 random permutations. Significant terms of interest were investigated using *a posteriori* pairwise comparisons with the PERMANOVA *t*-statistic, and *p*-values were obtained using a Monte Carlo random sample from the asymptotic permutation distribution because there were not enough permutable units to get a reasonable test by permutation (Anderson and Robinson, 2003).

Hierarchical clustering analysis (CLUSTER) and multidimensional scaling (MDS) were used to visualize multivariate patterns of the macroalgal assemblages of each Zone and Time. A similarity percentage analysis (SIMPER) was used to determine the contribution of each taxon to dissimilarities between groups obtained from CLUSTER and MDS. PERMANOVA was performed with the computer programme PERMANOVA (Anderson, 2001), and the rest of multivariate analyses with the PRIMER statistical software package (Clarke and Warwick, 1994). For univariate analyses, GMAV5 for Windows (Underwood et al., 1998) was used.

3. Results

3.1. Abundance of dominant taxa

Abundance of main taxa in the two tidal levels did not show any critical change after the spill in the zones studied (Figs. 2 and 3). A west–east gradual variation of dominant taxa was observed. The "upper" level was dominated by Fucaceae, mainly *F. spiralis* and *F. vesiculosus*, in GAL, ASTw and ASTe, and by *C. elongata* and Ceramiales in BC (Fig. 2). *M. stellatus*, abundant in GAL, gradually decreased to the east. *R. verrucosa* and *Ulva* spp. showed very low percentages in all of the samples and, in most cases, *Ulva* spp. were epiphytes. The $T \times Z$ interaction was significant for *Ulva* spp. (Table 1A), being more abundant in pre-spill BC samples than in the other $T \times Z$ combinations (SNK, Table 1B). Factor Zone was significant for Ceramiales, and marginally significant for *C. elongata* (ANOVA, $P = 0.052$). Differences in *Fucus* spp. and *M. stellatus* abundance among zones were assumed, as they were not present in the BC zone (Fig. 2). ANOVA did not detect differences among zones where these species were present (Table 1A). Abundance of *R. verrucosa* did not vary spatially but it was large after the oil spill (significant Time effect). *F. serratus* appeared just in one West Asturias locality, where it was dominant, and decreased significantly from 2000 to 2003 (ANOVA, $F = 17.33$, $P < 0.01$). The $T \times L(Z)$ interaction was significant for *C. elongata* and Ceramiales, indicating differences in some localities without a clear pattern that were not reflected at the Zone level.

Similar results were found at the "lower" level, where the dominant taxa were *H. elongata* in GAL, *B. bifurcata*

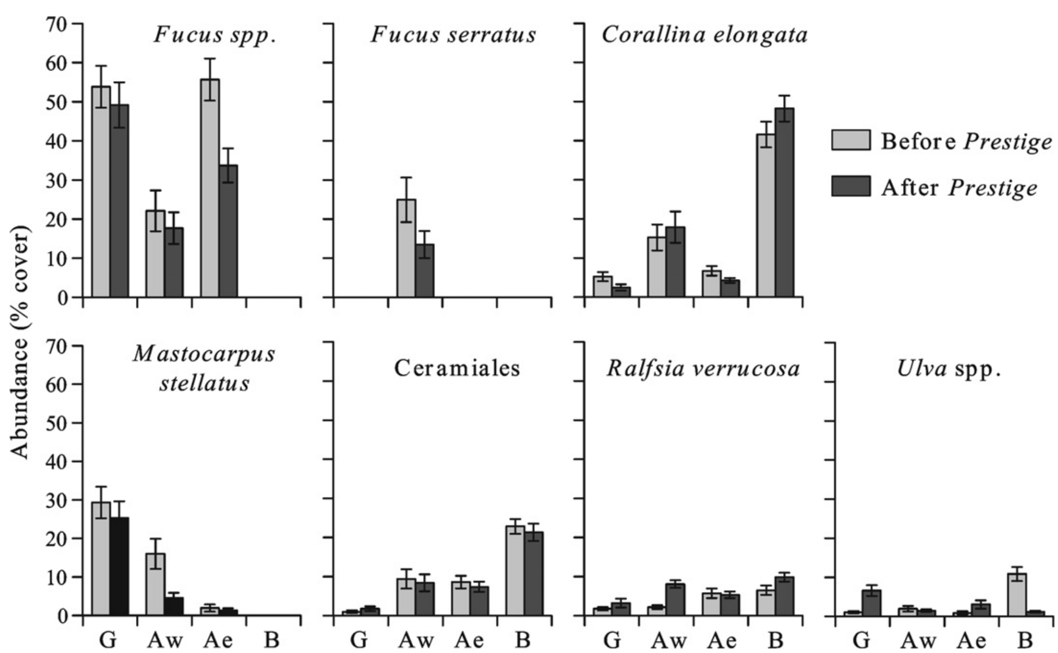

Fig. 2. Abundance (% cover, mean ± SE) of the most abundant taxa in the "upper" intertidal in the zones sampled before (light grey bar) and after (dark grey bar) the 'Prestige' oil spill. G = Galicia; Aw = West Asturias; Ae = East Asturias; B = Basque Country.

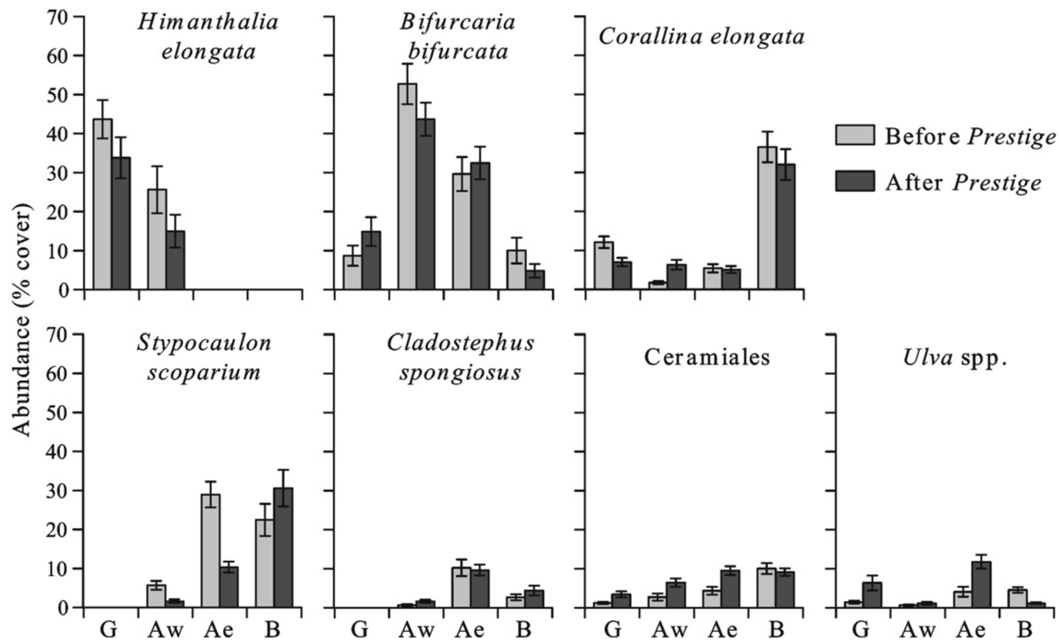

Fig. 3. Abundance (% cover, mean ± SE) of the most abundant taxa in the "lower" intertidal in the zones sampled before (light grey bar) and after (dark grey bar) the 'Prestige' oil spill (abbreviations as in Fig. 2).

Table 1
A. ANOVA of macroalgal abundance in the "upper" intertidal ($n = 5$). B. SNK tests of the significant Time x Zone interaction. Variables were ln $(x + 1)$ transformed to homogenize variances. Variances were still heterogeneous for *Fucus* spp.

A. ANOVA

		Fucus spp.		*M. stellatus*			*C. elongata*	
Source of variation	df	MS	F	MS	F	df	MS	F
Time = T	1	7616.1	2.51^{ns}	8.60	2.67^{ns}	1	54.4	0.05^{ns}
Zone = Z	2	20767.9	0.96^{ns}	89.44	3.14^{ns}	3	31824.8	3.97^{ns}
$T \times Z$	2	2190.4	0.72^{ns}	3.12	0.97^{ns}	3	361.3	0.35^{ns}
Locality = $L(Z)$	6	21525.5	12.27**	28.46	10.66**	8	8021.9	29.8**
$T \times L(Z)$	6	3036.6	1.73^{ns}	3.22	1.21^{ns}	8	1030.1	3.83**
Site = $S(T$ x $L(Z))$	36	1754.2	4.38**	2.67	2.97**	48	269.2	4.39**
Residual	216	400.5		0.90		288	61.3	
Transformation		None		ln$(x + 1)$			None	
Cochran's Test		0.128*		0.095^{ns}			0.076^{ns}	

		Ceramiales		*R. verrucosa*		*Ulva* spp.		
Source of variation	df	MS	F	MS	F	MS	F	F versus
Time = T	1	1.14	0.13^{ns}	21.32	8.2*	10.40	0.00^{ns}	$T \times L(Z)$
Zone = Z	3	93.15	4.56*	19.75	2.12^{ns}	3.25	3.20^{ns}	$L(Z)$
$T \times Z$	3	1.21	0.14^{ns}	5.87	2.26^{ns}	0.00	4.40*	$T \times L(Z)$
Locality = $L(Z)$	8	20.45	10.08**	9.31	7.45**	1.89	1.72^{ns}	$S(T \times L(Z))$
$T \times L(Z)$	8	8.64	4.26**	2.60	2.08^{ns}	19.59	2.35*	$S(T \times L(Z))$
Site = $S(T \times L(Z))$	48	2.03	4.78**	1.25	2.14**	4.45	4.45**	Residual
Residual	288	0.42		0.58		0.43		
Transformation		ln$(x + 1)$		ln$(x + 1)$		ln$(x + 1)$		
Cochran's Test		0.069^{ns}		0.065^{ns}		0.059^{ns}		

B. SNK of "Time × Zone" interaction in *Ulva* spp.

Factor	Level		Factor	Level	
Time	Before	GAL = ASTw = ASTe < BC	Zone	GAL	Before = After
	After	GAL = ASTw = ASTe = BC		ATSw	Before = After
				ASTe	Before = After
				BC	Before > After

GAL = Galicia; ASTw = West Asturias; ASTe = East Asturias; BC = Basque Country.
* $P < 0.05$; ** $P < 0.01$; ns, not significant.

Table 2
ANOVA of macroalgal abundance in the "lower" intertidal ($n = 5$)

ANOVA Source of variation	df	*H. elongata* MS	*H. elongata* F	df	*C. spongiosus* MS	*C. spongiosus* F	*S. scoparium* MS	*S. scoparium* F	F versus
Time = T	1	5611.3	2.87^{ns}	1	4.424	4.37^{ns}	706.99	0.95^{ns}	$T \times L(Z)$
Zone = Z	1	14346.9	0.52^{ns}	2	41.78	5.13^{ns}	8155.1	1.49^{ns}	$L(Z)$
$T \times Z$	1	1.606	0.01^{ns}	2	0.216	0.21^{ns}	2317.7	3.11^{ns}	$T \times L(Z)$
Locality = $L(Z)$	4	27684.1	20.67^{**}	6	8.147	3.28^{*}	5470.5	9.37^{**}	$S(T \times L(Z))$
$T \times L(Z)$	4	1957.0	1.46^{ns}	6	1.013	0.41^{ns}	745.78	1.28^{ns}	$S(T \times L(Z))$
Site = $S(T \times L(Z))$	24	1339.3	3.83^{**}	36	2.485	4.6^{**}	583.75	11.24^{**}	Residual
Residual	144	349.88		216	0.541		51.95		
Transformation		None			$\ln(x+1)$		arcsine (%)		
Cochran's test		0.122^{**}			0.072^{ns}		0.088^{ns}		

Source of variation	df	*C. elongata* MS	*C. elongata* F	Ceramiales MS	Ceramiales F	*B. bifurcata* MS	*B. bifurcata* F	*Ulva* spp. MS	*Ulva* spp. F
Time = T	1	43.40	0.13^{ns}	36.72	7.31^{*}	47.67	0.02^{ns}	9.932	1.92^{ns}
Zone = Z	3	16840.5	4.35^{*}	27.11	2.53^{ns}	31040.9	5.14^{*}	16.863	3.33^{ns}
$T \times Z$	3	388.93	1.17^{ns}	4.011	0.8^{ns}	1396.3	0.64^{ns}	15.835	3.06^{ns}
Locality = $L(Z)$	8	3875.8	21.6^{**}	10.72	6.48^{**}	6044.5	4.38^{**}	5.067	2.7^{*}
$T \times L(Z)$	8	331.52	1.85^{ns}	5.022	3.04^{**}	2171.6	1.57^{ns}	5.170	2.76^{*}
Site = $S(T \times L(Z))$	48	179.41	1.68^{**}	1.654	3.7^{**}	1381.2	4.68^{**}	1.875	4.59^{**}
Residual	288	106.60		0.447		295.12		0.408	
Transformation		None		$\ln(x+1)$		None		$\ln(x+1)$	
Cochran's test		0.208^{**}		0.050^{ns}		0.070^{ns}		0.074^{ns}	

Variables were $\ln(x+1)$ or arcsine (%) transformed to homogenize variances. Variances were still heterogeneous for *H. elongata,* and *C. elongata.* $^{*}P < 0.05$; $^{**}P < 0.01$; ns, not significant.

in ASTw and ASTe, and *C. elongata* and *S. scoparium* in BC (Fig. 3). No significant $T \times Z$ interactions were detected (Table 2). *B. bifurcata*, *C. elongata*, and *C. spongiosus* abundances showed significant differences among zones (ANOVA for *C. spongiosus*, $P = 0.0503$). Differences in *H. elongata* (absent in ASTe and BC) and *S. Scoparium* (absent in GAL) abundance among zones were assumed. ANOVA did not detected differences among the zones in which these species were present. Ceramiales increased slightly after the 'Prestige' oil spill. $T \times L(Z)$ interaction was significant for Ceramiales and *Ulva* spp., which increased or decreased in some localities but any pattern could be observed.

3.2. Assemblage structure

Macroalgal assemblage structure at the "upper" intertidal level varied in some localities between years as evidenced by the significant $T \times L(Z)$ interaction term (Table 3), but this change was not reflected at the zone level (non-significant $T \times Z$ interaction), indicating that communities of each zone after the 'Prestige' oil spill were very similar to those before (Table 3). Assemblages varied spatially (significant Zone term), and pairwise comparisons revealed significant differences between GAL and BC, and between ASTe and BC communities.

Samples were clearly grouped according to their spatial distribution along the west–east gradient, not by sampling date, in both classification analyses. The CLUSTER grouped pre-spill and post-spill samples of the same zone, resulting in four groups coincident with the levels of factor Zone (Fig. 4A). MDS ordination showed similar results, being samples of the same zone (before and after Prestige) closer than samples of different zones (Fig. 4B).

Table 3
A. PERMANOVA of macroalgal assemblages (29 taxa) in the "upper" intertidal ($n = 5$); B. Pairwise *a posteriori* comparisons of levels of factor Zone (abbreviations as in Table 1)

A. PERMANOVA Source of variation	df	MS	F	P	F versus
Time = T	1	16838.79	2.712	0.067	$T \times L(Z)$
Zone = Z	3	118738.3	3.174	**0.019**	$L(Z)$
Locality = $L(Z)$	8	37411.59	14.894	**0.000**	$S(T \times L(Z))$
$T \times Z$	3	6931.68	1.116	0.364	$T \times L(Z)$
$T \times L(Z)$	8	6208.72	2.472	**0.001**	$S(T \times L(Z))$
Site = $S(T \times L(Z))$	48	2511.90	3.868	**0.000**	Residual
Residual	288	649.48			
Total	359				

B. Pairwise comparisons of Zones

Groups	t	P (MC)	Unique values
GAL, ASTw	1.205	0.269	10
GAL, ASTe	1.543	0.144	10
GAL, BC	3.515	**0.006**	10
ASTw, ASTe	1.015	0.406	10
ASTw, BC	1.384	0.189	10
ASTe, BC	2.844	**0.016**	10

Each test was done using 9999 random permutations. P (MC) = p-values obtained using 9999 Monte Carlo samples from the asymptotic permutation distribution. Bold numbers indicate significant values.

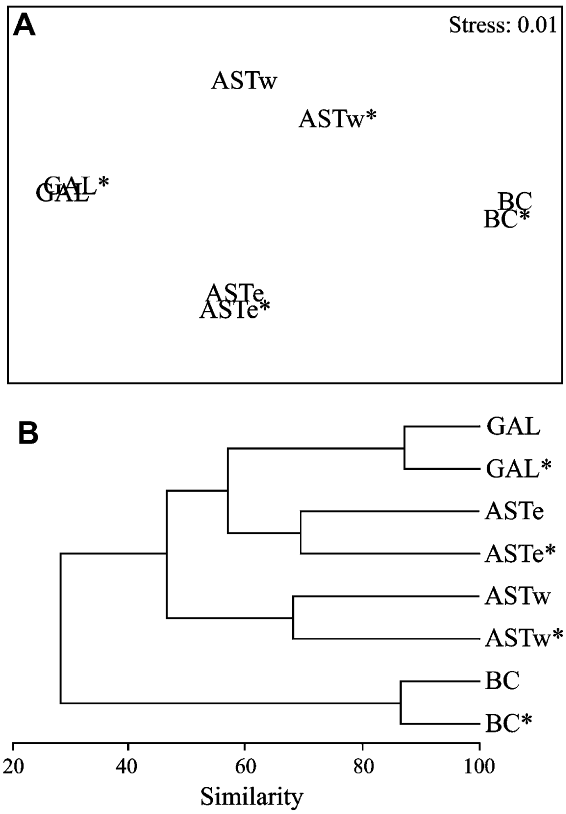

Fig. 4. (A) MDS ordination plot and (B) dendrogram of CLUSTER analysis of the macroalgal assemblages in the "upper" intertidal of each Zone and Time. GAL = Galicia; ASTw = West Asturias; ASTe = East Asturias; BC = Basque Country. * samples taken after 'Prestige'.

This indicates that communities of each Zone were more similar between years than among zones. The main taxa responsible of the dissimilarity between Zones were *Fucus* spp., *M. stellatus*, and *C. elongata* (SIMPER, Table 4). The GAL samples were characterized by greater abundance of *Fucus* spp., and *M. stellatus,* whereas *C. elongata* was more abundant in BC samples. ASTw differed from ASTe by the presence of *F. serratus*, and the lower abundance of *Fucus* spp.

Similar results were found at the "lower" level. $T \times L(Z)$ interaction was significant indicating a variation of the community in some localities (Table 5). However, the $T \times Z$ interaction term was not significant, showing that communities at the zone level did not change after the spill. A significant spatial variation between zones was found (pairwise comparisons, Table 5), being four of the six possible comparisons statistically different (GAL–ASTe; GAL–BC; ASTw–BC; and ASTe–BC).

Table 5
A. PERMANOVA of macroalgal assemblages (28 taxa) in the "lower" intertidal ($n = 5$); B. Pairwise *a posteriori* comparisons of levels of factor Zone (abbreviations as in Table 1)

A. PERMANOVA

Source of variation	df	MS	*F*	*P*	*F* versus
Time = T	1	10982.09	1.837	0.119	$T \times L(Z)$
Zone = Z	3	116265.1	3.673	**0.002**	$L(Z)$
Locality = $L(Z)$	8	31650.69	9.400	**0.000**	$S(T \times L(Z))$
$T \times Z$	3	8916.56	1.491	0.158	$T \times L(Z)$
$T \times L(Z)$	8	5980.02	1.776	**0.008**	$S(T \times L(Z))$
Site = $S(T \times L(Z))$	48	3366.94	4.091	**0.000**	Residual
Residual	288	823.08			
Total	359				

B. Pairwise comparisons of Zones

Groups	*t*	*P* (MC)	Unique values
GAL, ASTw	1.527	0.151	10
GAL, ASTe	2.627	**0.013**	10
GAL, BC	2.158	**0.031**	10
ASTw, ASTe	1.365	0.192	10
ASTw, BC	1.948	**0.044**	10
ASTe, BC	1.920	**0.070**	10

Each test was done using 9999 random permutations. *P* (MC) = *p*-values obtained using 9999 Monte Carlo samples from the asymptotic permutation distribution. Bold numbers indicate significant values.

Table 4
SIMPER analysis of macroalgal contributions to dissimilarity between the Zones (abbreviations as in Table 1) in the "upper" intertidal

Taxa	GAL–ASTw $\delta = 77.4$				GAL–ASTe $\delta = 65.2$				GAL–BC $\delta = 91.2$			
	X_{GAL}	X_{ASTw}	δ/SD	δ%	X_{GAL}	X_{ASTe}	δ/SD	δ%	X_{GAL}	X_{BC}	δ/SD	δ%
Fucus spp.	51.5	19.9	**1.41**	29.8	51.5	44.7	**1.39**	30.8	51.5	0.0	1.46	28.2
M. stellatus	27.3	10.3	1.09	17.7	27.3	1.7	1.04	20.5	27.3	0.0	1.03	15.0
C. elongata	3.9	16.6	0.76	11.0	3.9	5.5	0.96	4.9	3.9	44.9	**1.87**	22.7
F. serratus	0.0	19.2	0.61	12.4	–	–	–	–	–	–	–	–
Ceramiales	1.4	8.9	0.63	6.0	1.4	8.0	0.88	6.1	1.4	22.1	1.57	11.5

Taxa	ASTw–ASTe $\delta = 75.55$				ASTw–BC $\delta = 75.3$				ASTe–BC $\delta = 79.3$			
	X_{ASTw}	X_{ASTe}	δ/SD	δ%	X_{ASTw}	X_{BC}	δ/SD	δ%	X_{ASTe}	X_{BC}	δ/SD	δ%
Fucus spp.	19.9	44.7	**1.33**	27.5	19.9	0.0	0.65	13.2	44.7	0.0	1.32	28.2
M. stellatus	10.3	1.7	0.56	7.2	10.3	0.0	0.51	6.8	–	–	–	–
C. elongata	16.6	5.5	0.8	11.4	16.6	44.9	**1.66**	21.5	5.5	44.9	**1.81**	25.1
F. serratus	19.2	0.0	0.61	12.7	19.2	0.0	0.61	12.8	–	–	–	–
Ceramiales	8.9	8.0	0.9	8.0	8.9	22.1	0.88	6.1	8.0	22.1	1.4	11.1

X= average abundance, δ = average dissimilarity between groups, SD = standard deviation of the δ, δ% = percentage contribution of each taxon to the overall dissimilarity. Only main contributors to the overall dissimilarity between groups are shown. Bold numbers indicate best discriminating taxon between groups (major δ/SD ratio).

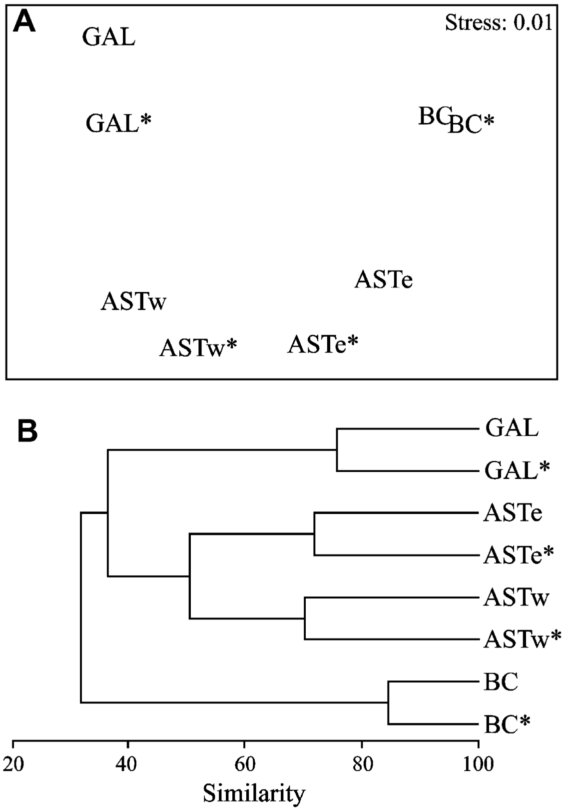

Fig. 5. (A) MDS ordination plot and (B) dendrogram of CLUSTER analysis of the macroalgal assemblages of the "lower" intertidal of each Zone and Time (abbreviations as in Fig. 4). * samples taken after 'Prestige'.

Both CLUSTER and MDS ordination grouped samples according to the levels of factor Zone. Pre- and post-spill samples of the same zone were closer than those of different zones, reflecting a similar macroalgal structure (Fig. 5). SIMPER analysis (Table 6) revealed that *B. bifurcata*, *H. elongata*, and *C. elongata* were the main contributors to Zone differences. *H. elongata* explained most of the dissimilarity between GAL and the other Zones. *C. elongata* and, secondly, *S. scoparium*, were the most important macroalgae in BC. ASTw communities were characterized by the presence of *H. elongata*, and higher abundance of *B. bifurcata* than in ASTe communities, where *S. scoparium* was also very abundant.

4. Discussion

Along the coast of Northern Spain, from west to east, there is a replacement of cold-temperate species (*Fucus* spp., *H. elongata*, *M. stellatus*, and *B. bifurcata*) by warm-temperate ones (*C. elongata*, *S. scoparium*, and *C. spongiosus*). This spatial variation was detected in this study by both univariate (abundance of these species significantly different among zones) and multivariate (different community structure among zones) techniques. This transition has been previously documented (Fischer-Piette, 1957; Anadón and Niell, 1981; Anadón, 1983; Arrontes, 1993), and is probably related to a summer upwelling centred on the westernmost Spain, Galician coast (Fraga et al., 1982; Botas et al., 1990), which a decreased influence towards the east.

After the "Prestige" oil spill, we though that as in other similar disasters strong changes in the structure of rocky shore assemblages would be expected: mass mortality of macroalgae and invertebrates, habitat loss and alteration of trophic interactions (Topinka and Tucker, 1981; Hawkins and Southward, 1992; Peterson, 2001; Peterson et al., 2003). But none of these effects were observed. No relevant changes were found neither in the structure of the assemblage nor in the biomass of dominant macroalgal species.

The structure of the macroalgal assemblages in the zones studied did not change noticeably after the 'Prestige'. Some temporal differences in community structure and in

Table 6
SIMPER analysis of macroalgal contributions to dissimilarity between the Zones (abbreviations as in Table 1) in the "lower" intertidal

Taxa	GAL–ASTw $\delta = 76.9$				GAL–ASTe $\delta = 85.9$				GAL–BC $\delta = 86.2$			
	X_{GAL}	X_{ASTw}	δ/SD	δ%	X_{GAL}	X_{ASTe}	δ/SD	δ%	X_{GAL}	X_{BC}	δ/SD	δ%
B. bifurcata	11.7	48.3	**1.47**	28.2	11.7	31.1	**1.19**	17.6	11.7	7.3	0.71	9.2
H. elongata	38.9	20.4	1.25	26.1	38.9	0.0	1.16	22.6	38.9	0.0	1.16	22.6
C. elongata	9.6	4.0	1.08	5.9	9.6	5.3	1.07	5.0	9.6	34.2	**1.17**	16.1
Ceramiales	2.3	4.6	0.81	3.3	2.3	7.1	1.04	4.0	2.3	9.6	**1.17**	5.0
S. scoparium	–	–	–	–	0.3	19.1	1.05	11.0	0.3	26.7	0.92	15.4
	ASTw–ASTe $\delta = 68.9$				ASTw–BC $\delta = 84.9$				ASTe–BC $\delta = 73.5$			
	X_{ASTw}	X_{ASTe}	δ/SD	δ%	X_{ASTw}	X_{BC}	δ/SD	δ%	X_{ASTe}	X_{BC}	δ/SD	δ%
B. bifurcata	48.3	31.1	**1.42**	26.7	48.3	7.3	**1.49**	26.5	31.1	7.3	1.18	20.7
H. elongata	20.4	0.0	0.59	14.8	20.4	0.0	0.59	12.0	–	–	–	–
C. elongata	4.0	5.3	0.83	4.2	4.0	34.2	1.25	18.4	5.3	34.2	**1.21**	20.5
Ceramiales	4.6	7.1	1.09	5.5	4.6	9.6	1.19	5.1	7.1	9.6	0.66	6.3
S. scoparium	3.7	19.1	1.02	12.8	3.7	26.7	0.96	15.3	19.1	26.7	1.19	18.2

X = average abundance, δ = average dissimilarity between groups, SD = standard deviation of the δ, δ% = percentage contribution of each taxon to the overall dissimilarity. Only main contributors to the overall dissimilarity between groups are shown. Bold numbers indicate best discriminating taxon between groups (major δ/SD ratio).

abundance of the main macroalgae were found in various localities; however, they did not exhibit a clear spatial trend. Some taxa increase in some and decrease in others. Although lacking a time series prior to the oil spill, the magnitude of these observed changes in abundance of some macroalgae could be considered within the range of natural variability, which would render statistical significant differences between years (see Mathieson et al., 1976 for an example in Fucaceae).

When localities were grouped by zones neither significant change in community structure nor reduction in the abundance of the main macroalgae after the 'Prestige' oil spill were found. Only *Ulva* spp. in the "upper" intertidal level of the Basque Country decreased significantly after the disaster. However, this trend is opposite to the expected result, because these opportunistic algae rapidly colonize the newly available surface after the removal of the canopy-forming algae by intense oil deposition (Houghton et al., 1996; Southward and Southward, 1978; Floc'h and Diouris, 1980; Kingston et al., 1997, respectively) but no destruction of the algal canopy was observed in any of the localities studied.

What may be the reason for the lack of significant effects of the 'Prestige' oil spill on macroalgal assemblages? The degree and persistence of damage from oil spills depends on several factors like type of fuel, quantity and duration of the spill, oceanographic and meteorological conditions, and the type of cleanup treatments used (Clark and Finley, 1977). In this case, the tanker sank carrying most of its cargo far from the coast, releasing the fuel in several pulses which impacted a large area of the coast. This generated extensive but not intense fuel deposition (Acuña et al., in press) but the most likely causes for the absence of severe impacts were fuel dilution due to intense winter mixing and advection during the wreckage period (García-Soto, 2004; Acuña et al., in press) and limited use of aggressive cleanup methods, that sometimes cause more damage to organisms than fuel itself, delaying recovery of the ecosystem for several years (Southward and Southward, 1978; Houghton et al., 1996).

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