Seven years of macroinfauna monitoring at Ladeira beach (Corrubedo Bay, NW Spain) after the *Prestige* oil spill*

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Abstract

The exposed sandy beach of Ladeira (Corrubedo Bay, NW Spain) was sampled during seven years (2003–2009) after the *Prestige* oil spill (winter 2002–03), to determine interannual variations in the macroinfaunal community in two ways: (i) through ecological indices (species richness and abundances, Shannon's diversity and Pielou's evenness) and (ii) through the density of the most representative species. A clear zonation pattern was found, consisting of two zones: (i) the supralittoral, occupied by talitrid amphipods, isopods and insects, and (ii) the intertidal, where marine crustaceans and polychaetes prevailed. The amphipods *Talitrus saltator* and *Talorchestia deshayesii* dominated from the drift line upwards, and isopods (*Eurydice* spp.), polychaetes (*Scolelepis* spp.) and the amphipod *Pontocrates arenarius* dominated the intertidal. Univariate indices remained constant throughout the study period in the supralittoral, but they varied widely in the intertidal zone. Multivariate analysis showed that the *Prestige* oil spill scarcely affected the macroinfaunal community structure during the study period (2003–2009) and its effect was limited just to the first campaign (2003), six months after the *Prestige* accident.

1. Introduction

The *Prestige* oil tanker sank 133 miles off the Galician coast in November 2002. Its cargo, 70 000 tons of fuel oil, spread onto the NW Spanish coast and even to some areas of France. It affected > 300 km of rocky shores and sandy beaches, giving rise to one of the largest oil spills in recent decades (de la Huz et al. 2005, Junoy et al. 2005, Rodríguez et al. 2007, Puente et al. 2009). By May 2003, six months after the oil spill, most of the Galician beaches (98.3%) were clean (Xunta de Galicia 2003), the sediments on many of them were not especially toxic (Fernández Méijome et al. 2006), and clean-up activities (removal of fuel and underlying sand) were limited to removing tar balls that occasionally turned up on the beaches (Junoy et al. 2005). The Ladeira beach is regarded as the one with the highest macroinfauna abundance and diversity of all the Galician beaches as well as the one that was the most seriously impacted by the *Prestige* oil spill (De la Huz et al. 2005, Junoy et al. 2005, Lastra et al. 2006).

Oil spills are the most destructive pollution source impacting sandy beaches (Defeo et al. 2009), causing a significant toxic effect that results in a decrease of many ecological parameters and in the reduction or local extinction of benthic species (Peterson 2001, Kingston 2002, Gómez Gesteira & Dauvin 2005, Veiga et al. 2009). Several studies have analysed their impact on beach macrofauna worldwide (Sanders et al. 1980, Elmgren et al. 1983, Kingston et al. 1995, Gómez Gesteira et al. 2003, de la Huz et al. 2005, Junoy et al. 2005, Fernández Méijome et al. 2006, Viéitez 2007, Puente et al. 2009, Veiga et al. 2009). However, it has been

demonstrated that the persistence of the negative effects of spills can be very variable, depend on many factors (Kingston 2002) and can have long-term consequences on benthic communities (Gómez Gesteira & Dauvin 2003, Peterson et al. 2003, Irvine et al. 2006). It has also been reported that recovery rates of macroinfaunal species can be slow (Dauvin 1998, Gómez Gesteira & Dauvin 2000). In addition, sandy beaches are among the most dynamic habitats worldwide (Brown & McLachlan 1990, McLachlan et al. 1996, Defeo et al. 2009). Macroinfaunal assemblages inhabiting these habitats display a high temporal variability (Junoy et al. 2005) because of the variability in physical factors (beach morphodynamics and exposure, organic matter, grain size, food supply) and biological factors (community dynamics, species life cycle, interspecific competition) (Brown & McLachlan 1990, Jaramillo & McLachlan 1993, Lastra et al. 2006, Defeo et al. 2009).

These statements suggest that carrying out short-term studies on the effects of oil spills on macroinfauna might lead to erroneous conclusions regarding the interpretation and understanding of the consequences of oil spills on the structure and dynamics of sandy beach assemblages. Long-term variations of the structure and dynamics of macroinfaunal communities would provide the appropriate baseline data necessary for a correct evaluation and for interpreting the hypothetical effects induced in these communities by oil spills and other environmental and anthropogenic disasters.

The aims of this study were (1) to interpret the long-term effects of the *Prestige* oil spill on the Ladeira beach, (2) to analyse the long-term variations of macroinfauna on the study beach, and (3) to provide baseline data of a long-term study of macroinfauna from a Spanish sandy beach.

2. Material and methods

Ladeira beach is an exposed sandy beach 1200 m long located in the northern part of Corrubedo Bay, on the Galician coast (NW Spain; 43°34′N, 9°03′W). It is a protected area belonging to the Corrubedo Natural Park (Parque Natural del Complexo dunar de Corrubedo e lagoas de Carregal e Vixán) (Figure 1). It is a dissipative beach subject to a semidiurnal mesotidal regime (Rey et al. 2004), as the tidal range may reach 4.1 m during spring tides and l.35 m during neap tides (Vilas et al. 1991). The sediment consists of fine to medium sands with a small admixture of silt, clay and organic matter (0.8–2.75%) (Junoy et al. 2005).

The beach was affected by the *Prestige* oil spill on November 2002, and it was classified as having been heavily polluted (Junoy et al. 2005). Sampling was carried out once a year (April or May) during the spring low tides during
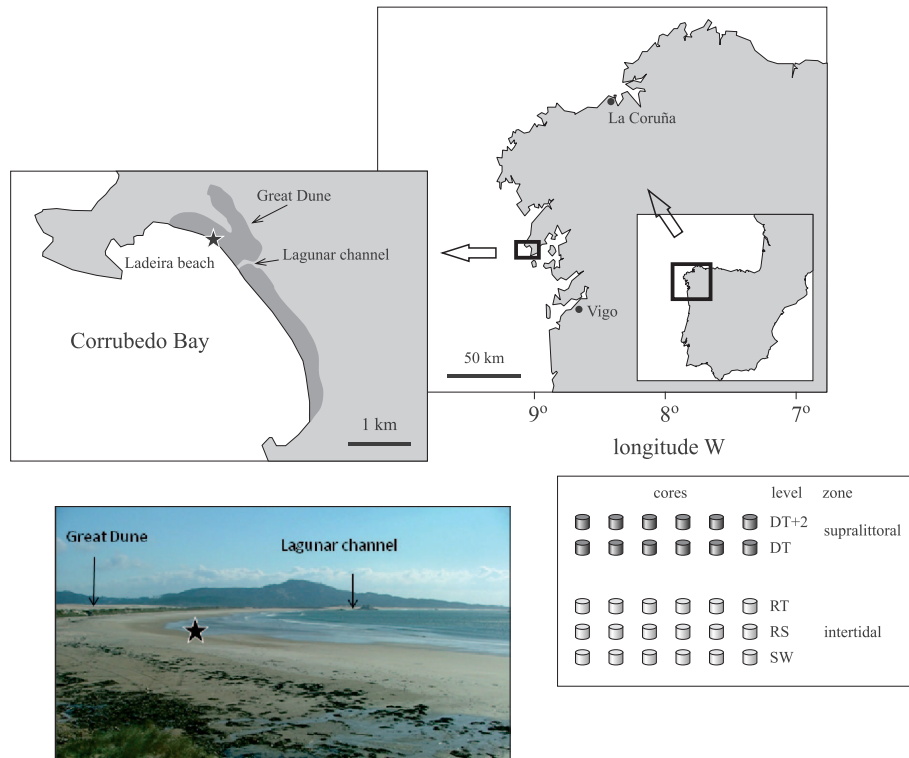
Figure 1. Map of the study area; the asterisk indicates the sampling site. Lower right, sampling design; the six cores on each level are 1 m apart

seven years, from 2003 (six months after the *Prestige* oil spill event) to 2009. In the center of the beach, five levels according to Salvat's zonation scheme (Salvat 1964, 1967), with modifications by Pollock & Hummon (1971), were sampled: two supralittoral levels – 2 m above the drift line (DL+2) and the drift line itself (DL) – and three intertidal levels – the retention level (RT), the resurgence level (RS) and the swash zone (SW). At each level, six replicates (1 m apart) of 0.05 m^2 were taken with a cylindrical core to a depth of 30 cm and sieved through a 1 mm mesh. The residue was preserved in 4% formalin and the macroinfauna was sorted, identified and counted.

Data analysis was performed using PRIMER-E (Clarke & Warwick 2001). Species composition, density [indiv. m^{-2}], Pielou's evenness (J') and Shannon's diversity (H') were calculated for each level and year. SIMPER analysis based on all replicated samples was used to identify the contribution of each species to the averaged similarity and dissimilarity within and between both zones. To visualize affinities in the macroinfauna

assemblage structure, nm-MDS (non-metric multidimensional scaling) was carried out on $\log(x + 1)$ transformed abundance data via the Bray-Curtis similarity index. The temporal variability of assemblage descriptors was tested through one-way ANOVA and whenever necessary, data were log-transformed. Differences in the macroinfaunal assemblage structure between tidal zones (supralittoral and intertidal) throughout the study period (7 years: 2003–2009) were tested by means of a permutational MANOVA (PERMANOVA) that included two fixed factors 'Tide level' and 'Year'. A two-way ANOVA with these factors was done for overall macroinfauna abundances. Even though the variances remained heterogeneous in all cases, we reduced the increase in type I errors by reducing the α value to the 0.01 level (Underwood 1991); ANOVA is robust to such departures for balanced studies. These analyses were performed with STATGRAPHICS 5.1 and PRIMER 6.0 and PERMANOVA+ statistical package.

3. Results

Fifty-five species and a total of 8 119 individuals were collected throughout the study period (2003–2009). Crustaceans were the most diverse group (27 species, 45% of overall richness), followed by polychaetes (16 species, 27%) and insects (11 species, 18%). The most abundant species were the isopod *Eurydice affinis* (16.06% of overall abundance), the polychaete *Scolelepis squamata* (14.11%), the cumacean *Cumopsis fagei* (11.12%) and the amphipods *Talitrus saltator* (8.36%) and *Pontocrates arenarius* (8.14%). In terms of frequency, the amphipods *Talitrus saltator*, *Talorchestia deshayesii* and Tabanidae larvae were constant taxa in the supralittoral zone throughout the study period. The species collected on each sampling occasion in the intertidal were the polychaetes *Scolelepis squamata*, *S. mesnili* and *Nephtys cirrosa*; the amphipod *P. arenarius*; the isopods *Eurydice affinis*, *E. naylori*, *Lekanesphaera teissieri* and *L. weilli*; the cumacean *Cumopsis fagei* and the mysid *Gastrosaccus roscoffensis*.

A general trend was observed in both supralittoral and intertidal species; abundances at the beginning of the study period (2003) were always lower than in the remaining years (Figure 2). Talitrid amphipods showed significant differences in the supralittoral. *T. saltator* (One-way ANOVA, $F = 10.62$, $p < 0.001$) did not follow a clear temporal pattern, almost disappearing in 2005. *T. deshayesii* ($F = 12.39$, $p < 0.001$) increased its density gradually during the first three years, then decreased. Significant differences were found in the abundances of insects (one-way ANOVA, $F = 2.51$, $p = 0.028$) with a lower density in the first two
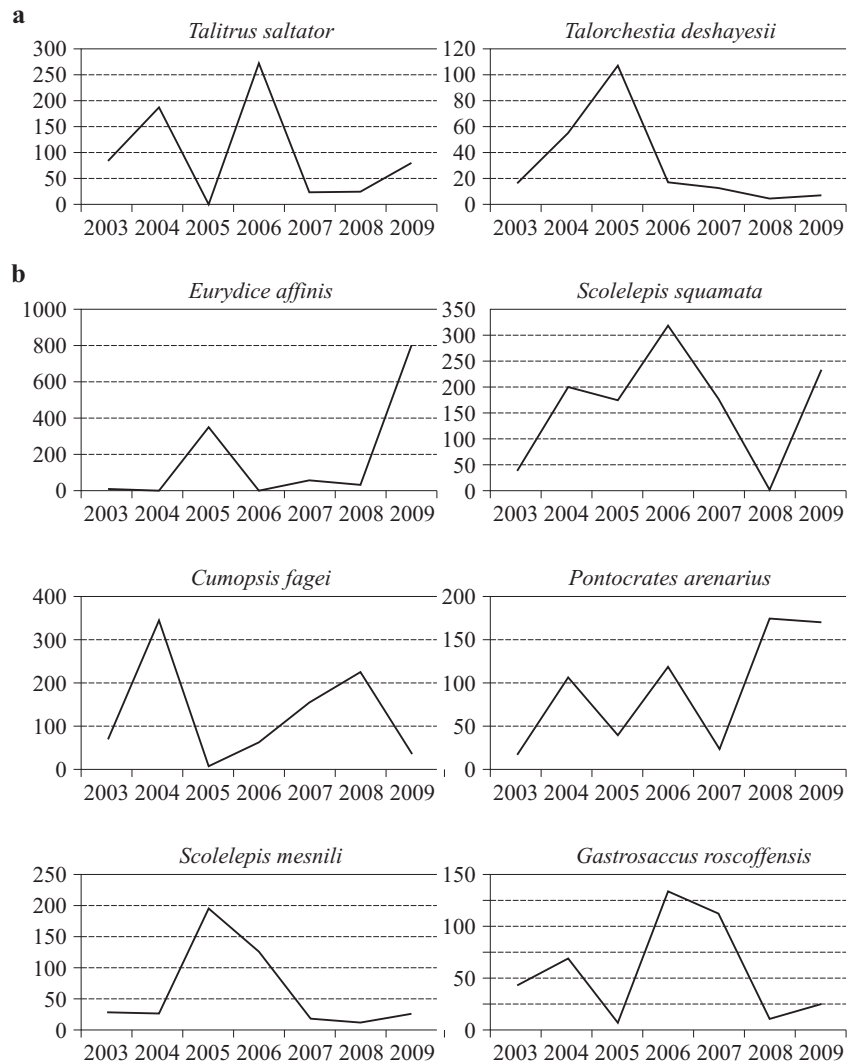
a

b

Figure 2. Abundances of the main species during the seven year study in the a) supralittoral and b) intertidal zones

years than in the last three. The intertidal species exhibited the lowest densities in 2003 and 2008. The polychaete *N. cirrosa* was present in low densities during the first years (2003–2006), but the polychaete *S. squamata* displayed the opposite trend, increasing gradually from 2003 to 2006. The amphipod *Haustorius arenarius* remained quite constant during the first four years (2003–2006), after which it increased, except in 2008 when it did not occur in the intertidal. *P. arenarius* occurred in high-density blooms in alternate years. The cumacean *C. fagei* increased gradually from 2003 to

2004 and from 2005 to 2008. The mysid *G. roscoffensis* followed a similar pattern in the first three years, reaching maximum abundances in 2006 and 2007. *E. affinis* achieved its highest abundances in 2009, after a maximum in 2005.

Table 1. Biological descriptors (mean $\pm$ SE) of macrofaunal assemblages throughout the study period

Year	Tide level	No. of species	Overall abundance	Pielou's evenness (J')	Shannon's diversity (H')
2003	supra	2.17 ± 0.34	11.17 ± 3.69	0.54 ± 0.12	0.54 ± 0.12
	inter	4.83 ± 0.55	17.55 ± 3.26	0.86 ± 0.03	1.24 ± 0.07
2004	supra	2.25 ± 0.25	21.00 ± 6.81	0.67 ± 0.10	0.56 ± 0.82
	inter	5.67 ± 0.49	45.39 ± 12.47	0.63 ± 0.04	1.05 ± 0.08
2005	supra	2.83 ± 0.37	43.83 ± 21.49	0.48 ± 0.09	0.44 ± 0.11
	inter	5.94 ± 0.37	56.22 ± 9.40	0.74 ± 0.04	1.29 ± 0.08
2006	supra	3.25 ± 0.18	26.08 ± 6.65	0.55 ± 0.07	0.64 ± 0.08
	inter	9.33 ± 0.58	59.11 ± 7.47	0.71 ± 0.04	1.57 ± 0.11
2007	supra	2.00 ± 0.35	4.50 ± 1.28	0.62 ± 0.13	0.55 ± 0.13
	inter	8.94 ± 0.63	67.94 ± 10.14	0.76 ± 0.03	1.65 ± 0.09
2008	supra	2.08 ± 0.52	5.08 ± 1.11	0.67 ± 0.10	0.58 ± 0.10
	inter	5.06 ± 0.46	35.17 ± 6.34	0.60 ± 0.05	0.98 ± 0.09
2009	supra	2.17 ± 0.72	11.16 ± 13.15	0.53 ± 0.07	0.62 ± 0.15
	inter	6.28 ± 0.48	81.00 ± 19.47	0.67 ± 0.04	1.22 ± 0.10

Species richness ranged from 2 ± 0.35 (2007) to 3.25 ± 0.18 (2006) in the supralittoral and from 4.83 ± 0.55 (2003) to 9.33 ± 0.58 (2006) in the intertidal (Table 1). One-way ANOVA revealed significant differences among the years in the intertidal ($F = 14.49$, $p < 0.001$), indicating that species richness was the highest in both tide zones in 2006 and 2007.

Shannon's diversity ranged from 0.44 ± 0.11 (2005) to 0.64 ± 0.09 (2006) in the supralittoral and from 0.98 ± 0.09 (2008) to 1.65 ± 0.09 (2007) in the intertidal (Table 1). Consistent differences were found in the intertidal zone (one-way ANOVA, $F = 7.91$, $p < 0.001$), with the maximum diversity in 2006 and 2007, and the minimum in 2008. Evenness ranged from 0.54 ± 0.12 (2003) to 0.71 ± 0.10 (2008) in the supralittoral and from 0.60 ± 0.05 (2008) to 0.86 ± 0.03 (2003) in the intertidal (Table 1), with significant differences throughout the study period in this zone (one-way ANOVA, $F = 4.83$, $p < 0.001$).

Overall macroinfauna abundances ranged from 4.5 ± 1.28 indiv. m^{-2} (2007) to 43.83 ± 21.49 indiv. m^{-2} (2005) in the supralittoral and from

17.55 ± 3.26 indiv. m^{-2} (2003) to 81 ± 19.47 indiv. m^{-2} (2009) in the intertidal (Table 1).

The results confirmed the zonation of the two-groups (supralittoral vs. intertidal) in terms of assemblage structure ('Tide level', $F = 110.77$, $p = 0.001$), with a clear differentiation between both tide zones (the supralittoral on the left-hand side and the intertidal on the right). The same pattern occurs with regard to the univariate descriptors, such as macroinfaunal abundance ($F = 26.82$, $p = 0.0001$) and species richness ($F = 147.2$, $p = 0.0001$) (Table 2). The SIMPER test showed a high dissimilarity between both zones (99.52%) owing to the different species found and their contribution to the similarity in each of them: semi-terrestrial amphipods (86.39%) and insects (9.12%) in the supralittoral, and marine crustaceans (75.8%) and polychaetes (33.86%) in the intertidal.

The macroinfauna community assemblage varied significantly throughout the study period between the supralittoral and intertidal zones (PERMANOVA, 'Year' $\times$ 'Tide zone', $F = 4.77$, $p = 0.001$). The same pattern was found in the overall abundances (two-way ANOVA, 'Year' $\times$ 'Tide zone', $F = 4.92$, $p = 0.0001$). These differences were due to the spatial ('Tide zone') and temporal ('Year') variability in the macroinfaunal assemblages throughout the study period (Table 2, Figure 3). SIMPER analysis confirmed that three species – *T. saltator* (46.67–82.35% similarity), *T. deshayesii* (17.65–85.29% similarity) and Tabanidae larvae (< 20%) – were responsible for > 95% of similarity in the supralittoral. The amphipod *T. saltator* was by far the most abundant species in this zone throughout the study period, except in 2005, when oligochaetes reached their highest abundances. In the supralittoral, the differences from 2003 to 2006 were due to variations in the abundances of *Talitrus saltator*, *Talorchestia deshayesii*, *T. brito* and Tabanidae larvae; however, from 2006 to 2009 the differences were due to the presence of species previously not collected (Coleoptera larvae, *Phaleria cadaverina*, Diptera larvae sp. (A), *Hyppocacus dimidiatus* and isopods Oniscidea).

The macroinfauna in the intertidal zone was more diverse than in the supralittoral and was dominated by marine crustaceans (21 spp., 47.7% overall richness) and polychaetes (16 spp., 36.4%). Characteristic species were isopods of the genera *Eurydice* and *Lekanesphaera*, polychaetes of the genus *Scolelepis*, the cumacean *C. fagei*, the amphipod *P. arenarius*, the mysid *G. roscoffensis*, the amphipod *H. arenarius* and the polychaete *N. cirrosa*. These species made up 70.54% of the overall abundance. The polychaete *Spiophanes bombyx* was a very common species, absent only during the six months following the spill (2003) and reaching its maximum dominance in 2007.

Table 2. Results of multi- and univariate ANOVA testing for differences in the macrofaunal (multivariate) assemblage structure, overall macrofaunal abundance and species richness ('Tide level', fixed factor) throughout the study period ('Year' fixed factor). Significant differences ($p < 0.01$) are highlighted in bold. Results of pairwise comparisons between years are included as a result of a significant interaction between 'Tide level' and 'Year'

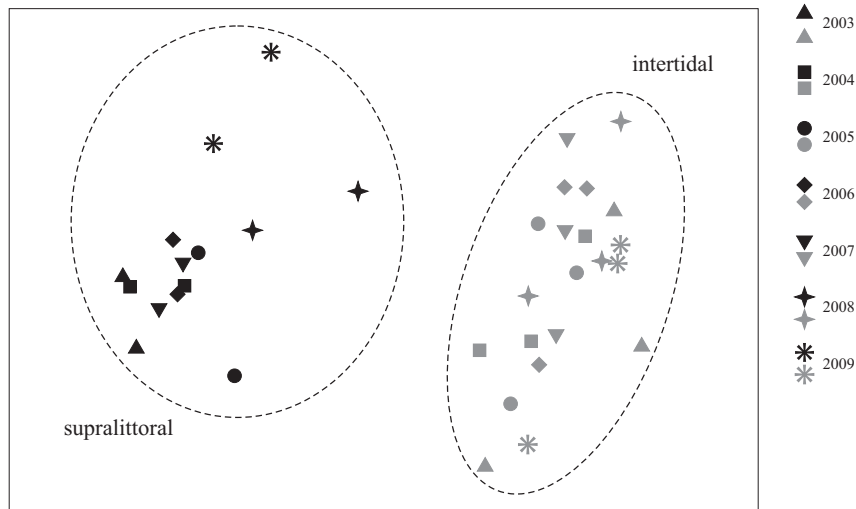| Source of variation	df	Assemblage structure			Overall abundance			Species richness		
		MS	F	p	MS	F	p	MS	F	p
Year (Y)	6	9 124.9	5.38	**0.001**	6 865	3.27	**0.0040**	39 122.00	4.78	**0.0001**
Tide level (T)	1	18 796.0	110.77	**0.001**	53 417	26.82	**0.0001**	85.73	147.20	**0.0001**
Y × T	6	8 096.6	4.77	**0.001**	8 846	4.92	**0.0001**	89.33	23.83	**0.0001**
Residual	196	33 257.0			285.6			324.1		

Figure 3. Ordination plot (nm-MDS, stress = 0.08) showing similarities in the macrofaunal assemblage structure in the supralittoral (black) and intertidal (grey) zones throughout the study period (2003–2009)

4. Discussion

The macroinfaunal community at Ladeira beach (Corrubedo Bay) exhibited considerable temporal variability and was represented mainly by three taxonomic groups: crustaceans, polychaetes and insects. Few oil-spill effects were noted during the study period, and were only really conspicuous during the first campaign (2003), six months after the *Prestige* accident.

In the present study, a clear zonation pattern consisting of two distinctive zones was found: (1) the supralittoral, corresponding to the upper zone of the beach, and (2) the intertidal, i.e. the mid-low shore zone. The former was dominated by air-breathing amphipods *Talitrus saltator* and *Talorchestia deshayesii* and Tabanidae larvae. The intertidal was more diverse, being characterized by marine species such as isopods (*Eurydice* and *Lekanesphaera* spp.), polychaetes (*Scolelepis* spp.), the amphipod *Pontocrates arenarius* and the cumacean *Cumopsis fagei*. Other typical species of European sandy beaches (Dexter 1988, 1990), such as the mysid *Gastrosaccus roscoffensis*, the amphipod *Haustorius arenarius* and the polychaete *Nephtys cirrosa* were also present but in lower abundances.

Dahl (1952) and Salvat (1964, 1967) respectively divided the intertidal beach into two or three zones. Similar results were obtained by other authors (Brown & McLachlan 1990, Raffaelli et al. 1991, Rodil & Lastra 2004, De la Huz et al. 2005, Rodil et al. 2006, Pérez-Domingo et al. 2008). Raffaelli (1991) recognized only a rigorous scheme of two zones (Brown & McLachlan

1990): a high-shore assemblage of air-breathers, and a low-shore assemblage consisting exclusively of water-breathers. Defeo & McLachlan (2005) considered that the zonation is highly dynamic and not sharply defined; so faunal tide levels depend on the beach type in an ecosystem that is subject to spatial and temporal changes.

In the supralittoral, diversity, richness and evenness did not vary during the study period, not even in 2003, six months after the oil spill; with the exception of insects, richness and abundance increased from 2003 to 2006 and in 2008. These findings are consistent with earlier reports comparing the Ladeira macroinfauna before and after the *Prestige* oil spill (De la Huz et al. 2005, Junoy et al. 2005, Viéitez 2007; in this last reference the beach is referred to as the Corrubedo beach), with very few insects and a reduction of overall richness. However, in the present study, the effects of the *Prestige* oil spill were recorded exclusively in 2003, six months after the oil spill. Thus, the recovery period was found to be less than 18 months in duration, in agreement with previous studies (Fernández Méijome et al. 2006).

In the intertidal, all the parameters varied throughout the study period, and these variations cannot be associated with the oil spill. The species number and diversity did not vary during the first three years, showing low values; higher values were recorded in 2006 and 2007, when evenness also reached its maximum values. However, the heavy rainfall that occurred during the sampling campaign of 2008 triggered a significant decrease in macroinfaunal abundances and richness. More than 50% of the species disappeared from the intertidal, and those that remained decreased abruptly in abundance (with the exception of the amphipod *P. arenarius*, the isopod *Lekanesphaera* spp. and the cumacean *C. fagei*).

The apparently minimal effect of the spill on the supralittoral could be related to the fact that the amount of hydrocarbons reaching the supralittoral sediments was less than that in the intertidal (Veiga et al. 2009). Although such chemicals have low degradation rates (Díez et al. 2007) and long-term toxic consequences on macroinfauna (Peterson et al. 2003), the nature of well-aerated sandy sediments ensures a short residence time. Large interstitial spaces and substantial porosity could accelerate the degradation of oil pollutants (de la Huz et al. 2005). In fact, the sediments did not show a high degree of toxicity six months after the oil spill, not even just a few weeks afterwards (Fernández Méijome et al. 2006). Moreover, seasonal storms during the spill period (winter) could have speeded up the dissemination of any oil that persisted in the sediments (Owens et al. 2008).

Temporal variability in the supralittoral was due mainly to talitrid amphipods and to a lesser extent, to insects. *Talitrus saltator* and *Talorchestia deshayesii* dominated the zone, especially between 2003 and 2006. There

are reports that assemblages of talitrid amphipods and isopods (*Tylos*) were reduced six months after the *Prestige* spill (de la Huz et al. 2005, Junoy et al. 2005, Viéitez 2007) as well as in other oil-spills (Sanders et al. 1980, Kingston et al. 1995, Gómez Gesteira & Dauvin 2000), owing to their sensitivity to hydrocarbons and the cleaning of polluted material that provide them food and refuge (Borzone & Rosa 2009). However, talitrid amphipods display a behavioural plasticity that is considered a key factor in surviving stressful conditions that make them useful bioindicators of anthropogenic impacts such as oil spills (Scapini et al. 1996, Gómez Gesteira & Dauvin 2000, 2003, Fanini et al. 2005).

Long-term studies are necessary to understand the ecosystem functioning of macroinfaunal intertidal assemblages on beaches. Anthropogenic (*Prestige* oil spill) and natural (heavy rainfall) events can have short-term effects on intertidal assemblages, such as shifts in assemblage structure, and abrupt decreases in abundance and species richness. However, they recover after a relatively short period of time (< 18 months) to pre-disturbance levels, and the assemblage structure now even includes species previously not present.

Acknowledgements

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