A temporal study of the macroinfauna of the beach most affected by the Prestige oil-spill (O Rostro, NW Spain)

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Exposed beaches are considered poor habitats where wave action and sediment instability limit the development of biological assemblages, with low productivity compared with other coastal environments (McLachlan, 1983). In temperate latitudes, supralittoral levels of beaches are usually occupied by an assemblage constituted by semi-terrestrial amphipods, isopods and insects that are linked to the food supply from algal wrack and the tidal organic material. Intertidal levels are usually occupied by marine amphipods, isopods and polychaetes.

Oil-spills are considered one of the most important environmental disasters on coastal areas and particularly, the "Prestige" oil-spill (autumn 2002 to spring 2003) was particularly harmful due to its magnitude. An important scientific effort was done in intertidal beaches and estuaries affected by the oil-spill, with special emphasis on macroinfaunal assemblages (Junoy *et al*. 2005; de la Huz *et al.* 2005; Puente *et al*. 2008, 2009). Medium and long-term studies are suitable to discern between the rates of natural and/or anthropogenic disturbances, however, these studies are scarce on sandy beaches.

In the present study, a before-after environmental study was conducted in O Rostro beach (42º58´N- 9º15´W, Figure 1), the most affected beach by the "Prestige" oil-spill and pristinely characterized by low macroinfaunal abundances and diversity (Junoy *et al*. 2005; Lastra *et al*. 2006). The morphodynamic of the beach is well known after the monitoring plan and studies developed with occasion of the "Prestige" catastrophe (Bernabeu *et al*. 2006; CEPRECO, 2006; González *et al*. 2009).

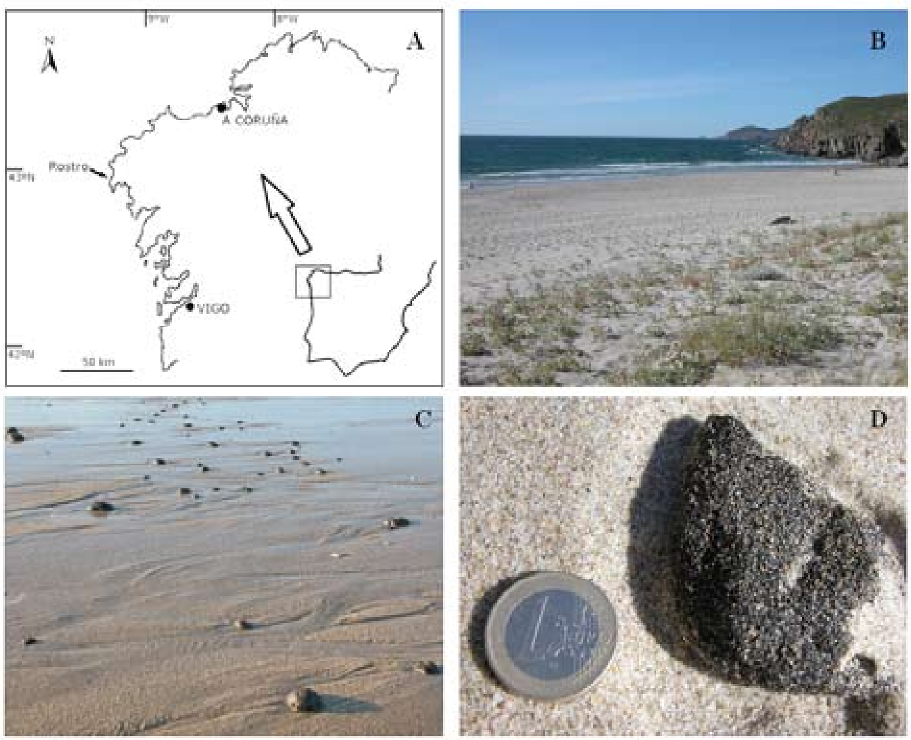

Figure 1. A) Location of the O Rostro beach; B) Photo of the north end of the O Rostro beach at high tide on May 2003; C) Tar balls (15-30 cm diameter) observed at the intertidal on first campaign (May 2003); D) Small pellets still present at O Rostro beach at the last campaign (May 2007).

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This beach was sampled in six sampling campaigns: before oil-spill (September 1995), six months after the oil-spill (May 2003) and after, in yearly campaigns (May 2004, May 2005, May 2006 and May 2007). Big tar balls (15-30 cm diameter) were obvious on the sediment in May 2003 (Fig. 1c); moreover small pellets about 1-2 cm were collected at the end of the sampling period, in May 2007 (Fig. 1d). In each sampling campaign 6 transects were extended from above the drift line (supralittoral level) to below the swash line. Beach division was based on Salvat's zonation scheme (Salvat, 1964, 1967) adding an extra supralittoral level (Pollock & Hummon, 1971): (1) 2 m above the drift line, (2) drift line, (3) retention, tidal level (3-2 m); (4) resurgence, tidal level 2-1 m, and (5) saturation, tidal level 1-0 m. At each level six 0.05 m^2 replicates (1 m apart each other) were taken and sieved through a 1 mm sieve, it is extensively used in former studies in the Galician beaches because of their sediment grain size. The residue was preserved in 7% formalin; the macroinfauna was later sorted from the sediments, identified, and counted. At each level, one yearly sediment sample was collected for grain size analysis and organic matter content.

Multivariate analyses of sample data were performed using PERMANOVA (Anderson 2001) and SIMPER (Clarke, 1993). Furthermore a level and a yearly analysis were studied by cluster and CAP (Anderson & Robinson 2003, Anderson & Willis 2003). PERMANOVA was used to study the differences between the yearly and spatial-temporal variation, it was performed in a 2 factors model design. The factors employed in the model were level and year, both were considered as fixed and crossed. Permutation of residuals under a reduced model was the permutation method chosen by 9999 permutations; moreover Monte Carlo test was used. The samples were studied through main test and pair-wise test. Further subsequent one-way SIMPER analyses were done on the fauna matrix to check the fauna variables which note the differences among the samples with significant results from PERMANOVA pair-wise test. Canonical discriminant analyses were performed through CAP analyses to check the differences among the different years for each level.

The dominant sedimentary type was medium sands (0.2-0.5 mm diameter) throughout the study period in both tidal levels (supralittoral and intertidal). Gravel and, silt and clay are scarce (< 1.3%). Organic matter content was characterized by low values (< 1.2%). Beach index (BI) ranged from 2.23 (2004) to 2.61 (2005). Dean´s parameter (Ω) estimated at the sampling times (May) ranging from 3.2 (2007) to 3.8 (2004). However, the beach slope (1/x) varied largely in O Rostro beach, from 21.85 (2004) to 48 (2006). These observations are in concordance with the data of CEPRECO (2006) and González *et al*. (2009). These authors noted that the modal state of the beach corresponds with the Rhytmic Bar and Beach; however the beach exhibits a great temporal distribution of morphodynamic states, from Transversal Bar and Rip to Longhsore Bar and Trough.

The overall macroinfaunal abundances varied largely throughout the study period, ranging from 74 ind (2005) to 423 ind (2007). These differences were mainly due to the abundance variations of crustaceans, the dominant taxonomic group (Table 1, Figure 2). Species richness remained with slight variations throughout the study period, with the exception of 2003 campaign, six months after the spill that showed the lowest richness (5 taxa). Supralittoral levels were characterized by low macroinfaunal abundances throughout the study period, ranging from 25 ind (2005) to 166 ind (2007). The most abundant taxa were Oligochaeta (114 ind), the isopod *Tylos europaeus* (158 ind) and the talitrid amphipods *Talitrus saltator* (174 ind) and *Talorchestia brito* (77 ind). The remaining species were scarce (< 20 ind). Intertidal levels varied largely throughout the study period, ranging from only one specimen six months after the spill (2003) to a maximum of 291 before it (1995). The most abundant species were the isopods *Eurydice naylori* (257 ind) and *E. pulchra* (247 ind), and the amphipod *Pontocrates arenarius* (256 ind), followed by the mysid *Gastrosaccus roscoffensis* (89 ind).

Table 1. Mean abundances (± SE) of macroinfaunal species from O Rostro beach throughout the study period. * Data kindly provided by Dr. Mariano Lastra, Universidad de Vigo.

Species	1995*		2003		2004		2005		2006		2007	
	Supra-	Inter-	Supra-	Inter-	Supra-	Inter-	Supra-	Inter-	Supra-	Inter-	Supra-	Inter-
Spio martinensis	0	1 ± 1.4	0	0	0	0	0	0	0	0	0	0
Oligochaeta	2 ± 2.8	0	0.5 ± 0.7	0	32 ± 38.1	0	2.5 ± 3.5	0	16.5 ± 23.3	0	2.5 ± 3.5	0
Pontocrates arenarius	0	0	0	0.5 ± 0.7	0	26.5 ± 33.2	0	42 ± 28.2	0	26.5 ± 33.2	0	42 ± 28.2
Talitrus saltator	3.5 ± 0.7	0	0	0	18 ± 19.7	0	58.5 ± 82.7	0	6.5 ± 9.1	0	58.5 ± 82.7	0
Talorchestia brito	11 ± 0	0	0	0	0	0	13.5 ± 6.3	0	4 ± 5.6	0	13.5 ± 6.3	0
Talorchestia deshayesii	7 ± 0	0	0	0	0.5 ± 0.7	0	0.5 ± 0.7	0	0	0	0.5 ± 0.7	0
Eurydice affinis	0	0.5 ± 0.7	0	0	0	0	0	0	0	0	0	0
Eurydice naylori	0	0	0	0	0	1 ± 1.4	0	37 ± 31.1	0	1 ± 1.4	0	37 ± 31.1
Eurydice pulchra	0	119.5 ± 169	0	0	0	0	0	0	0	0	0	0
Tylos europaeus	8.5 ± 2.1	0	47 ± 66.4	0	1 ± 1.4	0	3.5 ± 4.9	0	14.5 ± 19.0	0	3.5 ± 4.9	0
Gastrosaccus roscoffensis	0	14 ± 19.8	0	0	0	0.5 ± 0.7	0	8.5 ± 0.7	0	0.5 ± 0.7	0	8.5 ± 0.7
Cafius xantholoma	0	0	0	0	0	0	0	0	0.5 ± 0.7	0	0	0
Hypocaccus dimidiatus	0	0	1 ±1.4	0	0	0	0	0	1.5 ± 2.1	0	0	0
Coccinelidae	0	0	0	0	0	0	0	0	0.5 ± 0.7	0	0	0
Tabanidae	4 ± 5.6	0	0.5 ± 0.7	0	0	0	2 ± 2.8	0	0	0	2 ± 2.8	0
Diptera sp	2 ± 2.8	0	0	0	0	0	2.5 ± 2.1	0	0	0	2.5 ± 2.1	0
Aracnea	0.5 ± 0.7	0	0	0	0	0	0	0	0	0	0	0
Carinomidae	0	0	0	0	0	1 ± 1.4	0	0	0	1 ± 1.4	0	0

In 2003, post oil-spill conditions, macroinfaunal assemblages were only represented by only one intertidal specimen of the amphipod *Pontocrates arenarius* and four supralittoral taxa: Oligochaeta, the tabanidae (Diptera) larvae, the coleopteran *Hypocaccus dimidiatus maritimus* and the isopod *Tylos europaeus. T. europaeus* dominated overwhelmingly (94 ind. 94.94% overall abundance). To lesser extent, some differences can be discerned between before (1995) and after oil-spill (2003 onwards). In 1995, some species were well-represented (the amphipod *Talorchestia deshayesii*, Diptera sp. and the polychaete *Scolelepis squamata*) and posteriorly their densities abruptly decreased or even disappear after the oil-spill episode. In contrast, several species were important components of macroinfauna assemblages during recent campaigns (2006-2007) (*Talitrus saltator* and *Pontocrates arenarius*). Discrepancies with the *Eurydice* species collected, *E. pulchra* in 1995 and *E. naylori* after the spill, are related with the description in 1997 of the latter species (Jones & Pierpoint, 1997).

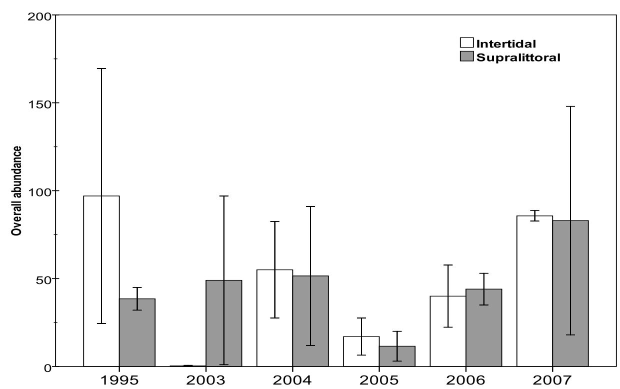

Figure 2. Overall macroinfaunal abundances (± SE) in intertidal and supralittoral stations throughout the study period (oil-spill: winter 2002).

Pair-wise test from PERMANOVA showed that the years 1995, 2004, 2006 and 2007 didn't have significant differences between them in reference to richness and abundances, in contrast the years 2003 and 2005 which had noticeable differences with the rest of years. Cluster analysis presented an aggregation of the two years with less abundance, 2003 (six month after the spill) and 2005, moreover to highlight a different behaviour between intertidal and supralittoral levels (Fig.3)

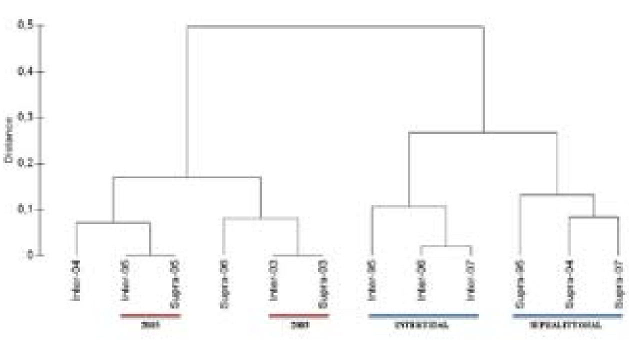

Figure 3. Cluster analysis of levels (Supra: supralittoral; Inter: intertidal) and years (95: 1995; 03... 07: 2003... 2007).

A specific abundance study through CAP, subsequently to the oil spill, revealed a difference between years in the first canonical axe: i) 2003 ii) 2005 and iii) 2004, 2006 and 2007. The second canonical axe shows the difference between the two levels, supralittoral and mediolittoral, except for the first sampling campaign, 2003 (Fig. 4)

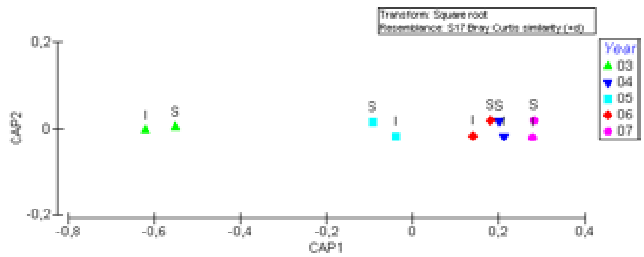

Fig.ure4. CAP analysis. S: supralittoral levels; I: intertidal levels; year 2003 (left) and 2005 are separated from 2004, 2006 and 2007.

The main problem for the assessment of the ecological effects of the "Prestige" oil spill was the lack of the baseline studies in many of the ecosystems affected. Fortunately, the former data (1995) from Galician beaches make possible to compare data from before and six months after the oil-spill (2003). In this context, a long-term spatial analysis with many beaches sampled has proved to be useful to detect the general impact in an 11 short term before-after analyses (De la Huz *et al*. 2005; Junoy *et al*. 2005). A reduction of macroinfaunal abundances and species richness was encountered six months after the spill. These shifts were particularly accentuated in scarce species, represented by low abundances at the studied beaches, which were eliminated. These authors showed changes in macroinfaunal composition in the intertidal and supralittoral zones. In supralittoral, macroinfaunal variations consisted of the disappearance of insects, and in some cases, a sharp increase of oligochaetes. This increase was related with the oil deposit at upper beach levels. Talitrid amphipods and the isopod *Tylos europaeus* showed a clear reduction in their assemblages. In the intertidal, they observed a marked decrease of polychaetes (*Scolelepis*) and isopods abundances (*Eurydice*) and the increase of abundances of the amphipod *Pontocrates arenarius*. The "Prestige" oil-spill did not markedly affect macroinfaunal diversity and richness (De la Huz *et al*. 2005; Serrano *et al*. 2006; Puente . 2009), like occurred in other oil-spills (Kingston . 1995; Feder & Blanchard 1998; Fukuyama . 1998).

However, an expected macrofaunal recovery was observed but within natural variability. In contrast, a significant effect was observed in other spills (Pielou 1975; Gómez-Gesteira . 2003). Other accident oil-spills enhanced the abundance of opportunistic species, mainly polychaetes, and a sharp decrease of sensitive species, mainly amphipods (Gómez-Gesteira & Dauvin 2000, 2005; Peterson 2001). This smaller effect of the oil-spill could be explained by the physico-chemical characteristics of the oil, season of the spill (winter), rough seas, sea temperature and quick removal of oil from most of the beaches (de la Huz . 2005; Junoy . 2005). The present study extends the beach macroinfaunal comparison to five years after the oil-spill, and the results are in contrast with the previous studies on Galician beaches. At short-time study, O Rostro beach suffer a reduction in macroinfaunal abundance and species number (1995 *vs* 2003, six months after the spill). Significant differences were found according to abundance and richness along the 2003-2007 periods. Ecological studies on interannual variations are scarce in Spanish coasts, and are crucial to determine the temporal variations of the macroinfaunal assemblages. Ganning . (1984) showed the importance to conduct studies in order to define natural variability in the ecosystems; this is particularly noticeable in intertidal exposed sandy beaches where constant ecological variations occur throughout the year (McLachlan & Brown 2006).

Green & Montagna (1996) showed that natural disturbances have possibly hindered the identification of the generalised effects of oil-related activities on macrofauna assemblages. Thus, the responses of opportunists to natural and anthropogenic disturbances are not easily distinguishable (Clark 1982; Spies 1987). One possible explanation for the present data is that the oil-spill changed macrofaunal assemblages in the short-term (weeks or even months) but a mobile sandflat is recovered very quickly as expected. Thus, a naturally highly mobile and variable environment makes rather difficult the detection of anthropogenic stress. Moreover, it has been observed that the temporal response of faunal impoverishment and the peak of opportunistic species are still driven mainly by the presence or absence of natural disturbances.

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