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Biological impacts of oil pollution and cleaning in the intertidal zone of exposed sandy beaches: Preliminary study of the "Prestige" oil spill

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Abstract

On 13th September 2002, the oil tanker "Prestige" sunk off the Galician coast, causing one of the most important oil spills in history, which affected the entire coastline, particularly the exposed rocky shores and sandy beaches.

Seventeen exposed sandy beaches were analysed along the Galician coast, in May 2003, and results were compared with previous data for September 1995 and 1996. The intertidal areas of the beaches were sampled in four tidal zones along the beach profile: swash, resurgence, retention and dry sand. Six cores of 0.05 m^2 were taken at each level and washed through a 1 mm mesh. Sediment samples were collected at each level for sediment analysis. The species were grouped into six main taxonomic groups: polychaetes, molluscs, marine crustaceans, semi-terrestrial crustaceans, insects and others. The total number of species was calculated in each group before and after the oil spill. The disturbance effect on each tidal level was determined.

A decrease in the species richness was generally observed in all the studied beaches, although this decrease was not homogeneous in all the taxonomic groups. Polychaetes, insects, semi-terrestrial crustaceans and others lost species in all cases, while marine crustaceans did not show this tendency, losing species in some cases and gaining in others. The most affected beaches lost up to 66.7% of the total species richness after the oil spill.

The most disturbed levels were swash, losing most of the polychaetes, and dry sand, with decrease in insects and semi-terrestrial crustaceans in many cases. Dry sand level received a high amount of oil and was more affected by grooming and cleaning activities where fuel and polluted material were removed, including algal wrack that is used by the supratidal macrofauna as food and shelter.

Keywords: oil spill; Prestige; exposed sandy beaches; intertidal macrofauna; northwest Spain

1. Introduction

Exposed beaches are considered poor habitats where wave action and the instability of the sediment limit the development of animals and plant communities, with low productivity compared with other coastal environments (rocky shores, subtidal sediments, saltmarshes ...) (McLachlan, 1983). Sandy beaches were hardly studied until the 1970s, when the importance of the animal communities linked to these beaches was demonstrated.

The biology and the distribution of the species on the beaches are linked with their location in terms of the tide, with a typical layout in all intertidal communities, i.e. zonation or distribution on tidal horizons (Salvat, 1964; Raffaelli et al., 1991; Jaramillo et al., 1993). In temperate latitudes, higher tidal levels of beaches are usually occupied by semi-terrestrial amphipods and isopods (family: Talitridae and Tylidae, respectively) and by numerous species of insects of practically

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unknown biology forming an exclusive community that is linked to the food supply from algal wrack and the tidal organic material (McIntyre, 1963; Craig, 1970; Koop and Field, 1980; Eiroa et al., 1988; Junoy and Viéitez, 1992; McLachlan and Jaramillo, 1995; Jaramillo et al., 2003). Intermediate levels of the beaches are usually occupied by marine isopods (family: Cirolanidae) and polychaetes of the family Spionidae (Perez Edrosa and Junoy, 1991; Junoy and Viéitez, 1992; Borzone et al., 1996; Souza and Borzone, 2000). Lower levels are again occupied by marine isopods, polychaetes and many other species typical of low intertidal and subtidal environments (Dahl, 1952; Jaramillo, 1994; McLachlan and Jaramillo, 1995).

Recent studies have shown the subsidised nature of oceanic beaches (McIntyre, 1963; Koop and Field, 1980). Few significant food resources are present in these environments (McLachlan et al., 1981). Flows of matter and energy depend on the subsidies of planktonic or pelagic materials existing in adjoining ocean areas or imported from nearby coastal ecosystems, algal wrack being the most representative example of this latter case (Griffiths et al., 1983; Stenton-Dozey and Griffiths, 1983; Brown and McLachlan, 1990; Raffaelli and Hawkins, 1996). A direct relationship has been demonstrated between the build up of macroalgal wrack and the biological richness on beaches. As far as macrofauna is concerned, the amphipods (family: Talitridae) are the first colonizers of algal wrack, being the most abundant and with the highest rates of consumption: from 71% to 95% of the biomass of algae (Griffiths and Stenton-Dozey, 1981; Behbehani and Croker, 1982; Marsden, 1991a; Colombini et al., 2000; Adin and Riera, 2003). To a lesser extent, there is the participation of larvae of diptera, isopods of the family Tylidae and the herbivorous coleopters (families Tenebrionidae, Curculionidae, etc.). It is known that cleaning stranded algal wrack negatively affects the infauna. This effect is directly due to the physical removal of macrofauna when cleaning algae (Brown and Odendaal, 1994), or is indirectly due to the removal of food. Recent studies (Dugan et al., 2000) have noted that beach cleaning of this nature has significantly reduced the diversity, abundance and biomass of the macrofauna and of the organisms feeding on it, particularly migratory birds. Alteration of the sedimentary characteristics also occurs and the establishment of dune vegetation and the formation of dunes are inhibited.

The effect of hydrocarbon contamination on beaches is especially detrimental to the upper tidal zones, these generally being near to the base of dunes or cliffs surrounding the beach. The dominant fauna in these areas (isopods and amphipods) display semi-terrestrial ecological and physiological characteristics and direct embryonic development, i.e. they lack the larval phase of dispersion so that females transport embryos until they become individuals morphologically similar to the adults, but smaller in size, remaining in the same habitat as their forebears (Dahl, 1952; Muchmore, 1990; Marsden, 1991b). Thus, the populations of these species affected by contaminant spillage are unable to recover easily from "imported" recruits coming from other more or less neighbouring populations. This highlights the extreme sensitivity of the upper levels of beaches, underlining how important it is to study and to preserve them.

This study sets out to analyse the effect of hydrocarbon spillage from the "Prestige" on the Galician coast, determining the ecological consequences of the artificial removal of macroalgae when cleaning up beaches. Results are compared with data prior to the arrival of the oil.

2. Materials and methods

2.1. Field and laboratory work

Seventeen beaches distributed along the Galician coast were sampled in September of 1995 and 1996 (data prior to the oil spill) (de la Huz, unpublished data), and data collected in May of 2003 (data following the oil spill): América, Lanzada, Corrubedo, Xuño, Louro, Carnota, Rostro, Area Longa, Traba, Seiruga, Baldaio, Barrañán, Doniños, Frouxeira, San Román, Esteiro and Llas (Fig. 1). One transect was extended in the middle of the beach, from the drift line to the swash zone. Four levels based on Salvat's zonation scheme (Salvat, 1964) were sampled during spring low tide: DT, drift line, RT, retention level, RS, resurgence level, and SW, swash level. At each level, six replicates of 0.05 m^2 (1 m apart) were taken using a cylindrical corer, to a depth of 15 cm and sieved through a 1 mm mesh. The residue was preserved in 4% formalin. Macrofauna was sorted from the sediment, identified at the level of species and counted. For the analysis of sediment size and water content, three replicates of sediment were collected at each level with a 3 cm diameter corer to 15 cm depth.

There are no data on hydrocarbon concentration in the sediment of the beaches studied, thus data on hydrocarbon contents in the water column and coastal sediment by the IEO (Instituto Español de Oceanografía, Spanish Oceanographic Institute), were used to classify the extent to which the beaches studied were contaminated. Data from the accident (13 November 2002) on the number of days and persons working on grooming activities to the sample date were used as an index of human impact during the cleaning and fuel removal on the studied beaches. With these two data, a disturbance level was made with four levels: 1, beach apparently clean, no cleaning activity; 2, beach slightly polluted, low intensity of cleaning activity; 3, beach

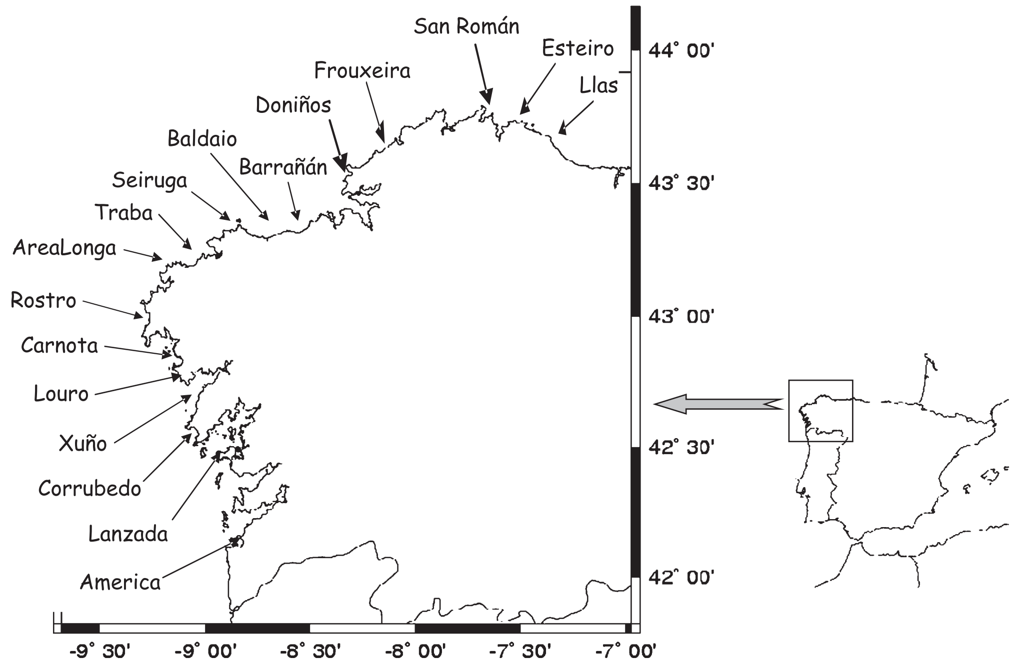

Fig. 1. Location of the studied beaches.

medium polluted, medium intensity of cleaning activity; and 4, beach highly polluted, high cleaning activity (many days, many people and use of heavy machinery on the beach) (Table 1).

Species richness and abundance of individuals per m^2 were calculated for each level of the beaches. Numbers of species of the six main taxonomic groups of macrofauna were calculated: marine crustaceans (exclusive species of the intertidal area), semi-terrestrial crustaceans (located on the upper part of the beach), polychaetes, molluscs, insects and others. Crustaceans were grouped into marine and semi-terrestrial in order to distinguish between the crustaceans that live on the marine environment and stay burrowed in the intertidal sand during the low tide, and the crustaceans that live in the dry sand, on the limit of the high tide, shifting to the

Table 1
Summary table describing the locations and the prinicipal characteristics of the beaches studied (width and length in metres; MGS (mean grain size) in μm). Disturbance grade: 1, beach apparently clean, no cleaning activity; 2, beach slightly polluted, low intensity of cleaning activity; 3, beach medium polluted, medium intensity of cleaning activity; and 4, beach highly polluted, high cleaning activity (many days, many people and use of heavy machinery on the beach)

Beaches	Sampling data		Location		Width	Length	MGS		Disturbance grade
	Before	After	Latitude	Longitude			Before	After	
América	26/09/1996	13/05/2003	42° 08′ N	8° 49′ W	104	2300	257–470	240–370	1
Lanzada	07/09/1995	13/05/2003	42° 28′ N	8° 51′ W	128	2400	254–529	200–1570	2
Corrubedo	09/09/1995	14/05/2003	42° 32′ N	9° 01′ W	139	2900	289–406	210–460	3
Xuño	29/09/1996	14/05/2003	42° 41′ N	9° 01′ W	108	2700	457–835	460–1380	3
Louro	12/09/1995	14/05/2003	42° 43′ N	9° 03′ W	115	1470	363–480	380–560	3
Carnota	10/09/1995	14/05/2003	42° 49′ N	9° 07′ W	133	7000	298–331	210–410	4
Rostro	11/09/1995	14/05/2003	42° 58′ N	9° 12′ W	125	2070	407–591	380–490	4
Area Longa	01/09/1996	15/05/2003	43° 10′ N	9° 11′ W	185	310	449–866	450–770	4
Traba	28/09/1995	15/05/2003	43° 11′ N	9° 09′ W	98	2630	432–667	350–810	4
Seiruga	31/08/1996	15/05/2003	43° 18′ N	8° 52′ W	91	530	531–710	340–540	4
Baldaio	27/09/1995	16/05/2003	43° 17′ N	8° 41′ W	163	3650	308–703	370–1290	4
Barrañan	30/09/1996	16/05/2003	43° 18′ N	8° 32′ W	140	1200	456–556	430–550	4
Doniños	27/09/1996	16/05/2003	43° 28′ N	8° 18′ W	154	1700	477–508	480–1070	3
Frouxeira	26/09/1995	16/05/2003	43° 35′ N	8° 10′ W	215	3000	296–336	350–1070	2
San Román	25/09/1995	17/05/2003	43° 44′ N	7° 37′ W	153	910	326–400	330–390	1
Esteiro	29/08/1996	17/05/2003	43° 43′ N	7° 34′ W	185	400	326–442	360–430	1
Llas	28/08/1996	18/05/2003	43° 35′ N	7° 16′ W	69	760	324–416	300–370	1

intertidal zone at low tide in search of food. The change in the community characteristics was analysed to check for general change or to see if any taxonomic groups were more affected than others. Levels were grouped into two zones: intertidal (swash, resurgence and retention) and supratidal (drift line), because of the very different physical characteristics of these environments. The relationship between the number of species and individual abundance per tidal level, and medium grain size, was tested using the Pearson correlation coefficient. The non-parametric Wilcoxon test was applied to test for significant differences between the data before and after the oil spill. The non-parametric Kruskal–Wallis test was applied to check for differences in the number of species, depending on the level of pollution and disturbance (Table 1). The sediment grain size was analysed with the Wilcoxon matched-pair test, to check for significant changes in the sediment before and after the oil spill. SPSS software was used to perform the above analyses.

Multidimensional scaling (MDS) and analysis of similarities (ANOSIM) were used to compare the situation of the macrofauna community before and after the spill. For these analyses, the data matrix, consisting of total abundance of species at each level in each beach was fourth root transformed and then converted to a similarity matrix of pairs of sites using the Bray–Curtis similarity index. Variability among samples was analysed using multi-dimensional scaling ordination (MDS) that maps the samples (usually in two dimensions) in such a manner that the distances between pairs of samples reflects their relative (dis)similarity in species composition. ANOSIM is built on a simple non-parametric permutation procedure, which is applied to the similarity matrix underlying the ordination or classification of samples (Clarke, 1993). PRIMER (Plymouth Marine Laboratory, 1996) software was used to perform the above analyses.

Variation in macrofauna composition between before (September 1996) and after the spill (May 2003) might be due to normal temporal variation, i.e. seasonal, between September and May. To test that observed differences were not due to this seasonal component, data from a previous study of temporal variation of three beaches (América, Carnota and Llas) were used. Species richness and abundance of individuals per m^2 were calculated for each level of the beaches. The non-parametric Wilcoxon test was applied to test for significant differences between the spring and summer time. If no temporal variation occurred between June 1997 and September 1997, variation of macrofaunal composition could be attributed to the oil spill.

2.2. Characteristics of the oil spill

On 19th September 2002, the oil tanker "Prestige", with 77,000 MT of heavy oil, sunk at 42° 15′ N, 12° 08′ W, 130 miles off the Galician coast to a depth of 3500 m. Sixty thousand tonnes of oil affected 300 km of the Galician, North Spanish and French coasts (Fig. 2a,b).

The oil carried by the "Prestige" was heavy oil. The main composition was: carbon (86.8%), hydrogen (11.0%), sulphur (2.28%) and nitrogen (0.69%). It was composed of saturated hydrocarbons (22%), aromatic hydrocarbons (50%) and resins and asphaltens (28%). The density (0.99 g/cm^3) and viscosity (615 centiStoks at 50 °C and 30,000 centiStoks at 15 °C) were high, as well as its persistence in the environment due to its low dissolution (maximum 1%), evaporation (maximum 5% after 3–4 months) and biodegradation rate (maximum 1% after 4–5 months) (Centro Superior de Investigaciones Científicas, personal communication).

The highest levels of oil pollution in the sediments of the continental platform were observed in the area known as "Costa da Morte" and "Coruña" (Fig. 3) (IEO, personal communication). The most disturbed

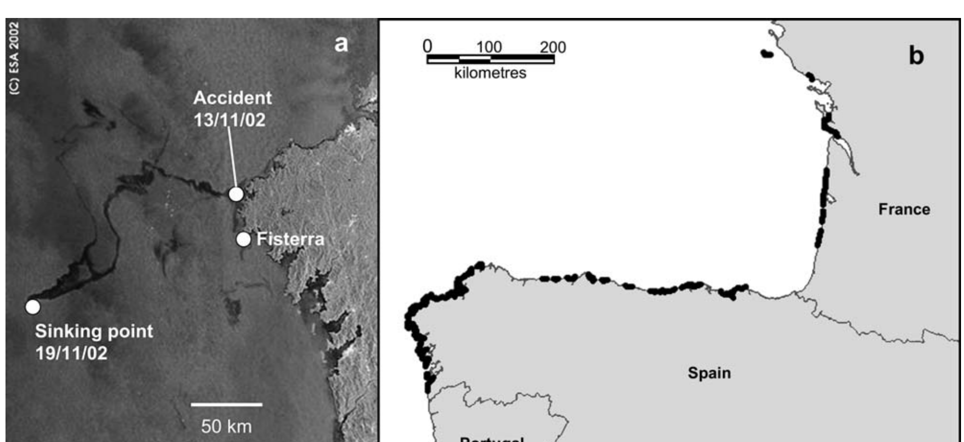

Fig. 2. (a) Accident point and sinking point of the tanker "Prestige". Oil spill left by the tanker during manoeuvring away from the coast. (b) Affected coast.

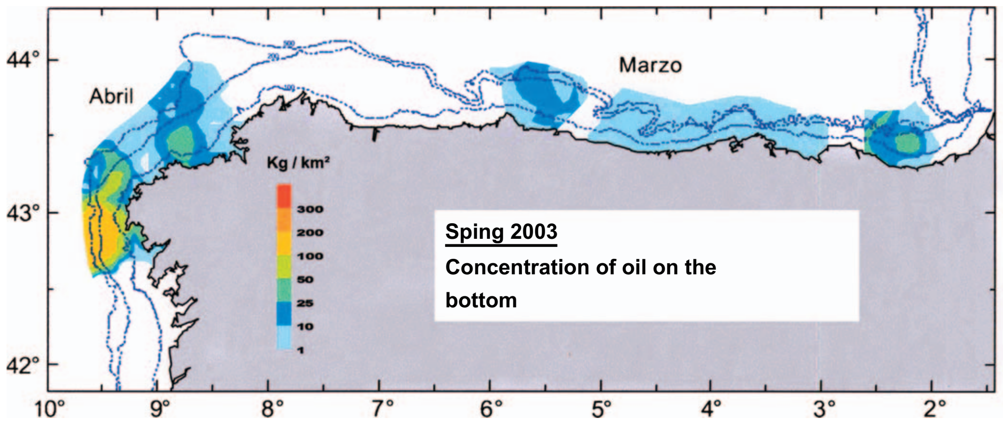

Fig. 3. Concentration of oil on the platform of Galicia and Bay of Biscay (kg/km^2) (source: Spanish Institute of Oceanography).

beaches either by the oil or by the cleaning activities were those located on the Atlantic margin of the Galician coast, from Louro Point (42° 43′ N, 9° 03′ W) to Coruña (43° 18′ N, 8° 32′ W), namely the beaches of Louro, Carnota, Rostro, Area Longa, Traba, Seiruga, Baldaio and Barrañán. During the studies conducted by the Spanish Oceanographic Institute 1 year after the oil spill, a reduction of the hydrocarbons in the water column and coastal sediments was observed.

3. Results

3.1. Physical characteristics of the area studied

The beaches studied were exposed beaches according to the McLachlan classification (1980), with exposure rates ranging from 10 (America, exposed) to 19 (Rostro, very exposed). Mean grain size varied from very fine sands (0.21 mm swash zone of Corrubedo "after"), to very coarse sands (1.38 mm resurgence zone of Xuño "after"), medium sands predominating (Table 1). The distribution of the sediment along the intertidal area was, in general, homogeneous, with low and medium areas of the intertidal zone being characterized by fine and medium grain sizes, and the higher level by medium and coarse sand. No significant differences were noted in the sediment size before and after the oil spill ($Z = -0.732$, $p = 0.464$). Pearson correlations between sediment size vs. density (ind/m^2) and species richness per tidal level were applied. In the tidally affected zone (swash, resurgence and retention), a trend towards an increased density of individuals and species richness was observed when the sediment grain size decreased; this was valid both before and after the oil spill ($R = -0.325$, $p = 0.007$ and $R = -0.476$, $p = 0.000$, respectively), but in the semi-terrestrial zone this tendency was not observed (Table 2).

3.2. Effect of the oil spill on the macrofauna

A decrease in the species number was observed in all studied beaches, except in San Roman (Fig. 4). The percentage of species lost or gained was calculated (Table 3). On the group of mollusc, none of the two species found before oil spill, *Donax trunculus* and *Angulus tenuis*, were found on samples after the accident. However in previous studies on oil spill a marked decrease in the population of *D. trunculus* was observed, for reasons unknown, so that this group was not considered in the statistical analysis. The group of polychaetes was the most sensitive, losing a greater number of species than other studied groups. Non-parametric Wilcoxon test was applied. The data did not follow a normal distribution, even after they were transformed. Significant differences were obtained for the total species number in the beaches before and after the oil spill ($Z = -3.5$, sig = 0.000), for polychaetes ($Z = -2.85$, sig = 0.004) and insects ($Z = -2.78$, sig = 0.005). The analysis of the number of species per level showed significant differences in all tidal zones

Table 2
Correlation between the mean grain size (MGS) and the biotic variables of the different zones, before and after the oil spill

	Before spill				After spill			
	MGS intertidal		MGS supratidal		MGS intertidal		MGS supratidal	
	R	sig	*R*	sig	*R*	sig	*R*	sig
Abundance/m^2	−0.286	0.040	0.342	0.180	−0.373	0.01	0.070	0.790
No. spp.	−0.403	0.003	−0.117	0.653	−0.510	0.00	−0.346	0.174

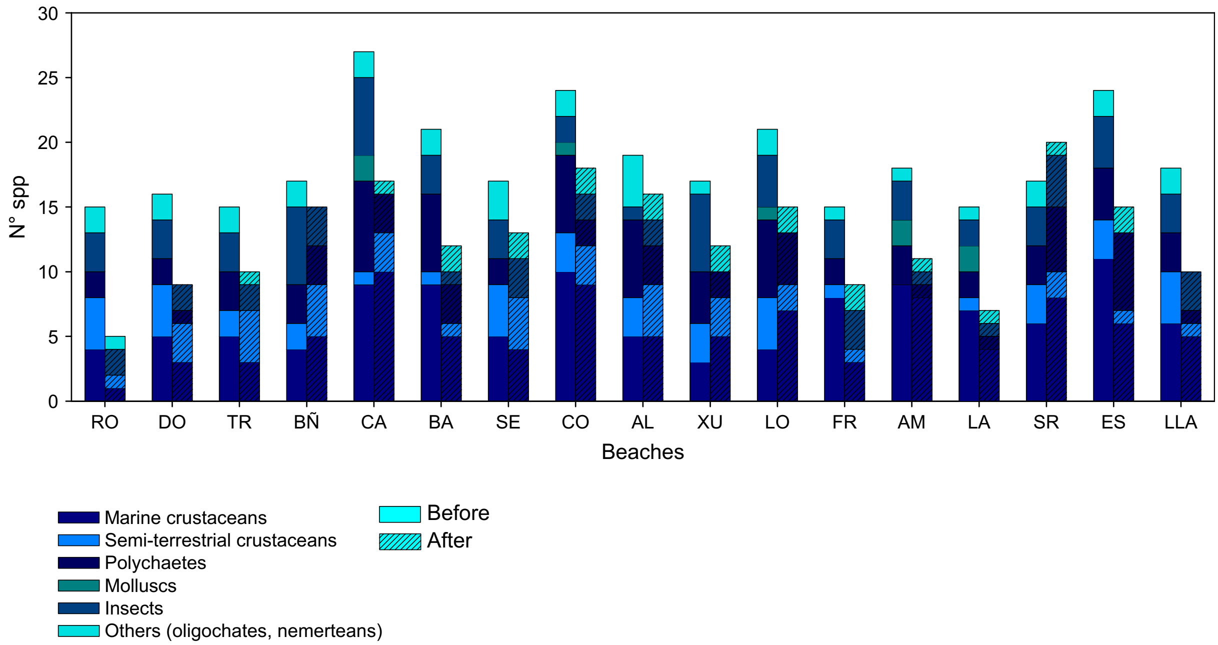

Fig. 4. Number of species of the main groups of macrofauna on the studied beaches, before and after the oil spill.

(SW = 0.009, RS = 0.002, RT = 0.007 and DL = 0.000), indicating a significant loss of species in all levels sampled. Abundance m^{-2} was calculated at each of the four sampled levels (Table 4) and a significant difference was only noted at the retention zone. This apparently low effect of the oil on the abundance of macrofauna in the dry zone and swash, is due to the fact that some species have reduced their abundance or have disappeared (especially polychaetes and insects), while others have increased the abundance. All species of polychaetes decreased as well as abundances of the mysid *Gastrosaccus sanctus* and the cumacean *Cumopsis fagei* increased in the swash level. Polychaetes and the isopod *Sphaeroma rugicauda* reduced their abundance in the resurgence level, while the amphipod *Pontocrates arenarius* and the isopods *Eurydice affinis* and *Eurydice pulchra* showed a marked increase in the same tidal zone. Abundance of all species decreased in the retention zone, and *Scolelepis squamata*, a polychaete characteristic of this level, practically disappeared. The drift line showed a clear reduction in the presence of insects and an increase in the oligochaetes. The Kruskal–Wallis non-parametric test showed no significant differences for the total number of species and for the species of each taxonomic group, depending on the disturbance level on the beaches.

Table 3
Percentage of species of the principal macrofaunal groups lost after the oil spill (the positive values correspond to cases where species were gained)

Beaches	Total	Marine crustaceans	Semiterrestrial crustaceans	Polychaetes	Mollusc	Insects	Others
América	−38.8	−11.1	0.0	−66.7	−100.0	−66.7	−66.7
Lanzada	−46.7	−42.9	−100.0	−50.0	−100.0	−50.0	50.0
Corrubedo	−25.0	−10.0	0.0	−66.7	−100.0	−66.7	−50.0
Xuño	−29.4	66.7	0.0	−50.0	−100.0	−100.0	50.0
Louro	−28.6	75.0	−50.0	−33.3	−100.0	−100.0	−66.7
Carnota	−37.0	10.0	30.0	−62.5	−100.0	−100.0	−50.0
Rostro	−66.7	−75.0	−75.0	−100.0	−100.0	−33.3	−50.0
Area Longa	−15.8	0.0	25.0	−50.0	−100.0	100.0	−66.7
Traba	−33.3	−60.0	50.0	−100.0	−100.0	−66.7	−66.7
Seiruga	−23.5	20.0	0.0	−100.0	−100.0	−66.7	−50.0
Baldaio	−42.9	−44.4	0.0	−50.0	−100.0	−66.7	−66.7
Barrañan	−11.8	20.0	50.0	0.0	−100.0	−50.0	−100.0
Doniños	−43.8	−40.0	−25.0	−50.0	−100.0	−33.3	−100.0
Frouxeira	−40.0	−62.5	0.0	−100.0	0.0	−66.7	−66.7
San Roman	17.6	33.3	−33.3	33.3	−100.0	33.3	−50.0
Esteiro	−37.5	−45.5	−66.7	33.3	−100.0	−100.0	50.0
Llas	−44.4	−33.3	−50.0	−66.7	−100.0	−66.7	−100.0

Table 4
Abundance/m^2 in the different levels of the studied beaches, before and after the oil spill (SW, swash; RS, resurgence; RT, retention; DR, dry zone)

Beaches	Before spill				After spill			
	Intertidal			Supratidal	Intertidal			Supratidal
	SW	RS	RT	DR	SW	RS	RT	DR
América	166.6	295.8	3039.6	30.9	197.2	261.8	394.4	0.0
Lanzada	102.0	153.0	4110.6	25.5	130.2	980.9	0.0	132.2
Corrubedo	438.6	622.2	1380.4	260.1	578.0	197.2	282.2	232.8
Xuño	193.8	57.8	95.2	78.2	238.0	142.4	284.8	1856.4
Louro	159.8	183.6	115.6	102.0	47.6	258.4	68.0	51.0
Carnota	462.4	428.4	1278.4	142.8	550.8	238.0	115.6	62.9
Rostro	74.8	139.4	754.8	141.1	3.4	0[a]	0[a]	165.7
Area Longa	88.4	210.8	289.0	923.1	229.1	197.2	51.0	604.1
Traba	112.2	149.6	108.8	617.1	326.4	244.8	0[b]	268.6
Seiruga	57.8	139.4	489.6	3988.2	61.2	0[a]	104.0	970.7
Baldaio	265.2	350.2	377.4	154.7	465.8	47.6	81.6	5.1
Barrañan	125.8	23.8	57.8	329.8	197.2	0[a]	57.8	98.6
Doniños	149.6	115.6	163.2	328.1	125.8	163.2	61.2	538.9
Frouxeira	360.4	136.0	217.6	73.1	238.0	61.2	0.0	20.4
San Roman	268.6	231.2	1822.4	113.9	258.4	540.6	146.2	45.9
Esteiro	265.2	74.8	329.8	170.0	302.6	102.0	119.0	28.9
Llas	142.8	207.4	68.0	98.6	210.8	115.6	71.4	149.6
Mean	202.0	207.0	864.6	445.7	244.7	253.6	122.5	307.8

[a] Level impossible to sample.
[b] 0.05 m^2 sampled.

MDS analysis was conducted with the four tidal levels of the studied beaches before and after the oil spill, to identify (dis)similarity between communities (Fig. 5). A low value of stress was found in all cases ≤ 0.05, and, in most cases, two groups of levels were observed, one grouping the intertidal levels (sw, rs, rt) and the other, the supratidal levels (dl). ANOSIM was applied to identify the similarity between the samples of the two groups (intertidal vs supratidal) (Table 5). Significant differences between the levels of the intertidal zone of most of the beaches were observed, though R values were low, while on the supratidal zone R values were high and significant differences were observed on all beaches (except América and Llas), this area being the one presenting the most variation in community composition.

There were no significant differences in abundances between seasonal samples, i.e. June 1997 and September 1997 (Wilcoxon test, sig > 0.05 in the four levels) except for the retention level of América that presented significant differences in abundances of intertidal isopods (*Eurydice affinis*, *Eurydice pulchra* and *Sphaeroma rugicauda*) between the two seasons. Neither number of species varied significantly between seasons, i.e. June 1997 and September 1997 (Wilcoxon test, sig > 0.05 in the four levels).

4. Discussion

There has been a change in the macrofaunal composition in the intertidal and supratidal zones, although these changes did not correspond with that found in other oil spills. Species sensitive to hydrocarbons—crustaceans and specially amphipods—rapidly disappear and present a high mortality at the start of the pollution (Sanders et al., 1980; Elmgren et al., 1983; Dauvin, 1987; Gómez Gesteira and Dauvin, 2000). A marked decrease in the number of polychaete species and a reduction in their abundance were observed, with no presence of opportunistic species, such as F. Capitellidae. The polychaetes adapted to inhabit exposed beaches, such as *Scolelepsis squamata* or *Nepthys cirrosa*, are seen to be linked to meso- and low intertidal levels, requiring clean fine to coarse sands and high hydrodynamic conditions (Clark, 1962; Laborda, 1986; Junoy and Viéitez, 1992). An increase of oligochaetes was noted in the retention and dry sand levels, where higher concentrations of hydrocarbons were observed, that constitute organic matter (Gómez Gesteira and Dauvin, 2000). Apart from the disappearance of some rare species of amphipods, some of the most abundant, such as *Bathyporeia pelagica* and *Haustorius arenarius*, were only present in the low intertidal of the beaches (swash and resurgence), possibly because of avoidance of the higher concentrations of fuel in the higher levels. Similar results were observed in species of *Eurydice*, which concentrate on the low tidal areas and *Sphaeroma rugicauda* that had decreased or disappeared from most of the beaches. A large increase of cumaceans and mysids, *Gastrosaccus* spp., in the swash zone was observed; they were concentrated on the lower shore

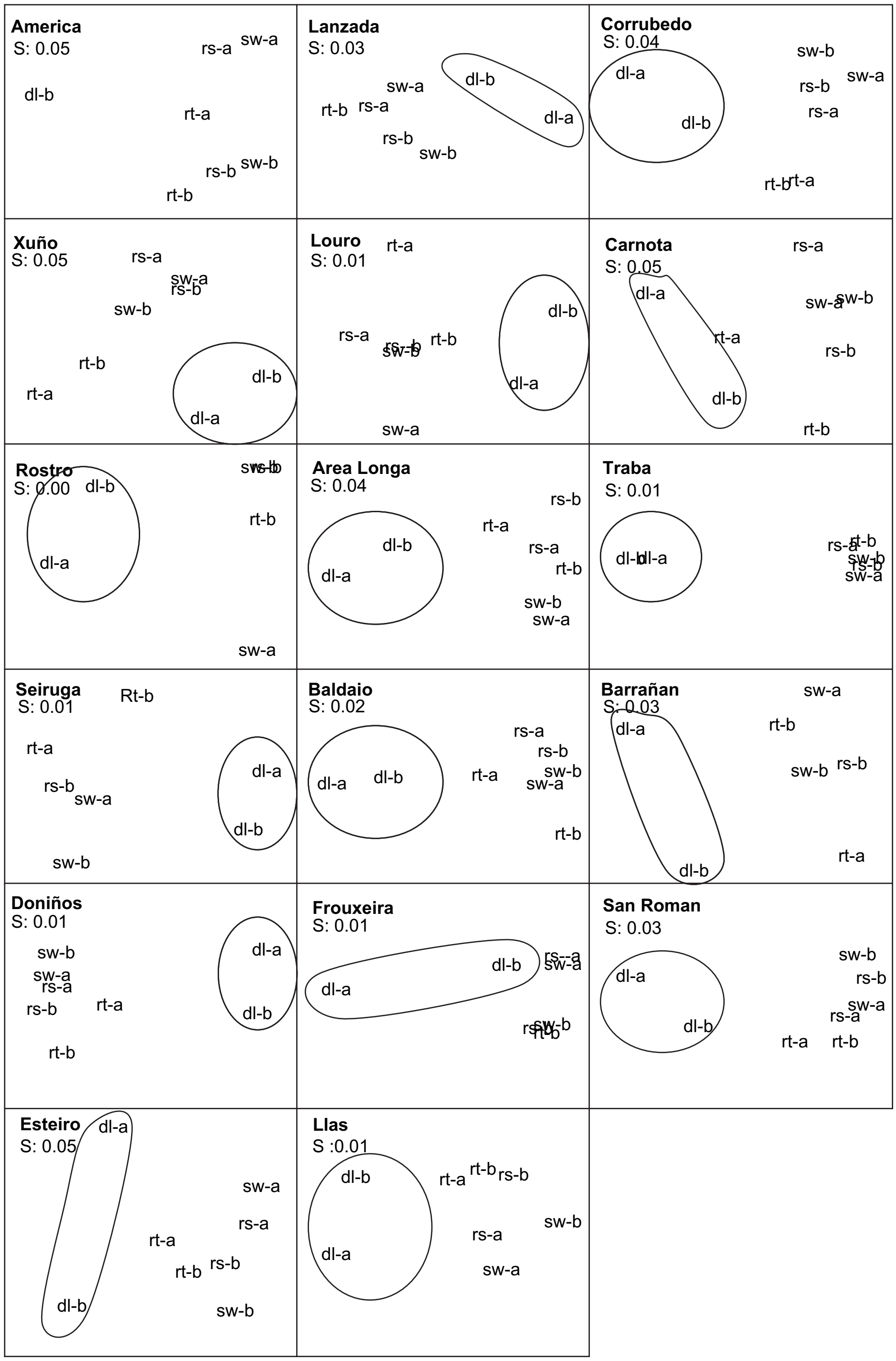

Fig. 5. MDS ordinations of species data for the four levels sampled at each beach. sw-b, swash zone before the accident; sw-a, swash zone after the accident; rs-b, resurgence zone before; rs-a, resurgence zone after; rt-b, retention zone before; rt-a, retention zone after; dl-b, drift line before; dl-a, drift line after.

and not along the intertidal zone, as was observed in previous samples for *Gastrosaccus sanctus* (de la Huz, unpublished data). This situation is similar to that found in June 1997 and September 1997. For example, on América and Llas beaches, there were no significant differences of species along the intertidal zone before and after the oil spill, as occurred in June 1997 and September 1997. In contrast, on Carnota beach, the composition of macrofauna between June 1997 and September 1997 revealed a similar pattern to that found in September 1996, before spill. The polychaete *S. squamata* occurred all along the intertidal area (SW,

Table 5
Summary of ANOSIMs comparing macrofaunal community before and after the oil spill (supratidal level of América after the spill was impossible to sample)

Beaches	Intertidal		Supratidal	
	R	sig	*R*	sig
América	0.41	0.001	–	–
Lanzada	0.18	0.013	−0.07	0.571
Corrubedo	0.06	0.065	0.90	0.002
Xuño	0.03	0.168	0.73	0.002
Louro	0.52	0.001	0.32	0.019
Carnota	0.52	0.001	0.74	0.002
Rostro	0.51	0.012	0.89	0.002
Area Longa	0.10	0.015	0.32	0.006
Traba	0.40	0.013	0.86	0.002
Seiruga	0.28	0.004	0.94	0.002
Baldaio	0.34	0.001	0.51	0.024
Barrañan	0.12	0.038	0.77	0.002
Doniños	−0.01	0.498	0.92	0.002
Frouxeira	0.72	0.001	0.77	0.004
San Roman	0.17	0.013	0.74	0.002
Esteiro	0.19	0.001	0.94	0.002
Llas	0.14	0.010	0.00	0.247

RS and RT levels) in June and September 1997, showing a high abundance at the retention level. Oligochaetes abundance was lower than that found in May 2003. The amphipods *B. pelagica* and *H. arenarius* occurred across the whole intertidal area, not being restricted to a narrower zone as shown after the spill. Insects were distributed at the drift line in both seasons. Carnota beach was highly impacted by arrival of fuel and cleaning activities, especially in the supratidal level (Ministerio de Medio Ambiente, personal communication), whereas América and Llas beaches were not affected. Thus the high variation between samples from before and after oil spill, could not be attributed to a simple temporal variation, i.e. seasonal.

Results of MDS analysis showed two zones in this study: one intertidal with exclusively marine species influenced by the hydrodynamic and sedimentary characteristics of the area, and the other, a semi-terrestrial zone or the transition between the littoral and the terrestrial zone. The latter has species that develop their life cycle outside the water but are still dependent on the marine environment, specially the algal wracks that give food and shelter (Dugan et al., 2003). This reduction in zonation levels as established by Salvat (1964) has already been observed in exposed sandy beaches on the North coast of Spain (Rodil and Lastra, 2004). Considering the relationships between the macrofauna and the physical variables analysed, especially sediment grain size, its effect on the intertidal fauna has been shown by other authors (Jaramillo and McLachlan, 1993; McLachlan et al., 1993; Brazeiro, 2001), but not on the supratidal macrofauna (Dugan et al., 2003).

In the supratidal, variation in macrofaunal composition was greater after the spill than that observed before the spill (data for 1995 and 1996), with the practical disappearance of the insects, and in some cases, with an enormous increase in oligochaetes concentration. The talitrid amphipods and the semi-terrestrial isopod *Tylos* showed a clear reduction in numbers. The upper levels of the beaches were affected by massive arrival of oil, followed by cleaning of polluted material, especially algal wrack, and the upper centimetres of sediment were removed. Talitrids and *Tylos* are more adapted to burrowing than insects, being able to escape the pollution and cleaning activities, unlike the insects that occur over the algal wrack and sand surface. It was observed that *Tylos europaeus* can burrow to 20 cm (Giordani Soika, 1954), showing a zonation that varies over the year: during the winter months they are farther from the coast than during the spring and summer time (Fallaci et al., 1996). Species of the Talitridae family move to the intertidal zone during the night for feeding activity, going up to the dry zone or dunes to burrow during the day time (Behbehani and Croker, 1982; Marsden, 1991a,b; Scapini et al., 1992, 1996; Jaramillo et al., 2003). Many of the beach's typical insects feed on talitrids, moving with them in their migrations, or waiting semi-burrowed for their prey (Craig, 1970). This surface activity could make the insects more vulnerable to oil pollution and cleaning activities, as they would be removed with the sediment and the wrack. Numerous authors have shown that after an accident of these characteristics, the disturbance caused by the cleaning activities can be more damaging than the oil (Whitfield, 2003). This was the case of the "Exxon Valdez" oil spill, where the affected beaches that were cleaned had a longer recovery time than those not cleaned (Peterson, 2001).

The reduction in macrofauna abundance in the supratidal (Table 4) as opposed to the intertidal zone, was similar to that found in rocky shores (Besteiro, personal communication). On the rocky shore, the upper tidal levels were the most affected, especially the areas where hydrocleaning machines were used (Besteiro, personal communication).

The apparently small negative effect of this spill on the intertidal macrofauna, compared with other accidents, could be related to the physical-chemical characteristics of the "Prestige" oil that degrade slowly. Also the season of the year, in this case winter, with low temperatures that makes the oil denser and less toxic (Peterson, 2001) could have helped in the quick removal of the fuel from the beaches affected. The characteristic storms of the season facilitate natural cleaning of the polluted areas. It seems that the effect of the hydrocarbons on the intertidal sediments does not show the same patterns as observed in subtidal sediments (Mora et al., 1996; Gómez Gesteira and Dauvin, 2000). One explanation could be related to coarse intertidal sediment in exposed sandy beaches. Larger interstitial space and porosity could facilitate faster degradation of oil pollution.

These results are initial and a temporal study is required to observe long term recolonization of the lost species or for recovering the zonation observed before the oil spill.

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References

Adin, R., Riera, P., 2003. Preferential food source utilization among stranded macroalgae by *Talitrus saltator* (Amphipod, Talitridae): a stable isotopes study in the northern coast of Brittany (France). Estuarine, Coastal and Shelf Science 56, 91–98.

Behbehani, M.I., Croker, R.A., 1982. Ecology of beach wrack in Northern New England with special reference to *Orchestia platensis*. Estuarine, Coastal and Shelf Science 15, 611–620.

Borzone, C.A., Souza, J.R.B., Soares, A.G., 1996. Morphodynamic influence on the structure of inter- and subtidal macrofaunal communities of subtropical sandy beaches. Revista Chilena de Historia Natural 69, 565–577.

Brazeiro, A., 2001. Relationship between species richness and morphodynamics in sandy beaches: what are the underlying factors? Marine Ecology Progress Series 224, 35–44.

Brown, A.C., McLachlan, A., 1990. Ecology of Sandy Shores. Elsevier, Amsterdam, pp. 197–226.

Brown, A.C., Odendaal, F.J., 1994. The biology of oniscid Isopoda of the genus Tylos. Advances in Marine Biology 30, 89–153.

Clark, R.B., 1962. Observations on the food of Nepthys. Limnology and Oceanography 7, 380–385.

Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal Ecology 18, 117–143.

Colombini, I., Aloia, A., Fallaci, M., Pezzoli, G., Chelazzi, L., 2000. Temporal and spatial use of stranded wrack by the macrofauna of a tropical sandy beach. Marine Biology 136, 531–541.

Craig, P.C., 1970. The behaviour and distribution of the intertidal sand beetle *Thinopinus pictus* (Coleoptera: Staphylinidae). Ecology 51, 1012–1017.

Dahl, E., 1952. Some aspects of the ecology and zonation of the fauna on sandy beaches. Oikos 4, 1–27.

Dauvin, J.C., 1987. Evolution à long terme (1978–1986) des populations d'amphipodes des sables fins de la Pierre Noire (Baie de Morlaix, Manche Occidentale) après la catastrophe de l'*Amoco Cadiz*. Marine Environmental Research 21, 247–273.

Dugan, J.E., Hubbard, D.M., Martin, D.L., Engle, J.M., Richards, D.M., Davis, G.E., Lafferty, K.D., Ambrose, R.F., 2000. Macrofauna communities of exposed sandy beach on the Southern California Mainland and Channel Islands. In: Browne, D.R., Mitchell, K.L., Chaney, H.W. (Eds.), Proceedings of the 5th California Islands Symposium. Santa Barbara Museum of Natural History, pp. 339–346.

Dugan, J.E., Hubbard, D.M., McCrary, M.D., Pierson, M.O., 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of Southern California. Estuarine, Coastal and Shelf Science 58S, 25–40.

Eiroa, E., Novoa, F., González, J., 1988. La entomofauna de las dunas de la playa de Barra (Cangas-Pontevedra). III Coleoptera. Boletín Asociación Española de Entomología 12, 301–317.

Elmgren, E., Hansson, S., Larsson, U., Sundelin, B., Boehm, P.D., 1983. The 'Thesis' oil spill: acute and long term impact on the benthos. Marine Biology 73, 51–65.

Fallaci, M., Colombini, I., Taiti, S., Chelazzi, L., 1996. Environmental factors influencing the surface activity and zonation of *Tylos europaeus* (Crustacea: Oniscoidea) on a Tyrrhenian sandy beach. Marine Biology 125, 751–763.

Giordani Soika, A., 1954. Ecologia, sistematica, biogeografia ed evoluzione del *Tylos latreillei* Auct. (IFOP. Tylidae). Bolletino Museo civico di storia Naturale Venezia 7, 63–83.

Gómez Gesteira, J.L., Dauvin, J.-C., 2000. Amphipods are good bioindicators of the impact of oil spills on soft-bottom macrobenthic communities. Marine Pollution Bulletin 40, 1017–1027.

Griffiths, C.L., Stenton-Dozey, J., 1981. The fauna and rate of degradation of stranded kelp. Estuarine, Coastal and Shelf Science 12, 645–653.

Griffiths, C.L., Stenton-Dozey, J.M.E., Koop, K., 1983. Kelp wrack and the flow of energy through a sandy beach ecosystem. In: McLachlan, A., Erasmus, T. (Eds.), Sandy Beach as Ecosystems. W. Junk, The Hague, pp. 547–556.

Jaramillo, E., 1994. Patterns of species richness in sandy beaches of South America. South African Journal of Zoology 29, 227–234.

Jaramillo, E., McLachlan, A., 1993. Community and population responses of the macroinfauna to physical factors over a range of exposed sandy beaches in South-central Chile. Estuarine, Coastal and Shelf Science 37, 615–624.

Jaramillo, E., McLachlan, A., Coetzee, P.S., 1993. Intertidal zonation patterns of the macroinfauna over a range of exposed sandy beaches in South-central Chile. Marine Ecology Progress Series 101, 105–118.

Jaramillo, E., Contreras, H., Duarte, D., Avellanal, M.H., 2003. Locomotor activity and zonation of upper shore arthropods in a sandy beach of north central Chile. Estuarine, Coastal and Shelf Science 58S, 177–197.

Junoy, J., Viéitez, J.M., 1992. Macrofaunal abundance analysis in the ría de Foz (Lugo, Northwest Spain). Cahiers de Biologie Marine 33, 331–345.

Koop, K., Field, J.G., 1980. The influence of food availability on population dynamics of a supralittoral isopod, *Ligia dilatata* (Brandt). Journal of Experimental Marine Biology and Ecology 48, 61–72.

Laborda, A.J., 1986. Distribución espacial de una comunidad de *Tellina* (Pelecypoda: Tellinidae) en la playa de Covas (NO de España). Investigaciones Pesqueras 50, 43–55.

Marsden, I.D., 1991a. Kelp – sandhopper interactions on a sand beach in New Zealand. I. Drift composition and distribution. Journal of Experimental Marine Biology and Ecology 152, 61–74.

Marsden, I.D., 1991b. Kelp – sandhopper interactions on a sand beach in New Zealand. II. Populations dynamics of *Talorchestia quoyana* (Milne-Edwards). Journal of Experimental Marine Biology and Ecology 152, 75–90.

McIntyre, R.J., 1963. The supra-littoral fringe of New Zealand sand beaches. Transactions of the Royal Society of New Zealand 1, 89–103.

McLachlan, A., 1980. The definition of sandy beaches in relation to exposure: a simple rating system. South African Journal of Science 76, 137–138.

McLachlan, A., 1983. Sandy beach ecology: a review. In: McLachlan, A., Erasmus, T. (Eds.), Sandy Beach as Ecosystems, W. Junk, The Hague, pp. 321–380.

McLachlan, A., Erasmus, T., Dye, A.H., Wooldridge, T., van der Horst, G., Rossouw, G., Lasiak, T.A., McGwynne, L., 1981. Sand beach energetics: an ecosystem approach towards a high energy interface. Estuarine, Coastal and Shelf Science 13, 11–25.

McLachlan, A., Jaramillo, E., Donn, T.E., Wessels, F., 1993. Sandy beaches macrofauna communities and their control by the physical environment: a geographical comparison. Journal of Coastal Research 15, 27–38.

McLachlan, A., Jaramillo, E., 1995. Zonation on sandy beaches. Oceanography and Marine Biology 33, 305–335.

Mora, J., Garmendia, J.M., Gómez-Gesteira, J.L., Parada, J.M., Abella, F.E., Sánchez-Mata, A., García Gallego, M., Palacio, J., Currás, A., Lastra, M., 1996. Seguimiento mensual del bentos infralitoral de la ría de Ares y Betanzos antes y después de la marea negra del 'Aegean Sea'. In: Ros, J. (Ed.), Seguimiento de la Contaminación Producida por el Accidente del Buque Aegean Sea, Ministerio de Medio Ambiente, Serie Monografías. Madrid, pp. 137–150.

Muchmore, W.B., 1990. Terrestrial isopoda. In: Dindal, D.L. (Ed.), Soil Biology Guide, John Wiley & Sons, New York, pp. 805–817.

Perez Edrosa, J.C., Junoy, J., 1991. Macrofauna intermareal de las playas de Area Longa, Peizas, Anguieira y Altar (Lugo, NW España). Thalassas 9, 37–48.

Peterson, Ch.H., 2001. The "Exxon Valdez" oil spill in Alaska: acute indirect and chronic effects on the ecosystem. Advances in Marine Biology 39, 1–103.

Raffaelli, D., Karakassis, I., Galloway, A., 1991. Zonation scheme on sandy shores: a multivariate approach. Journal of Experimental Marine Biology and Ecology 148, 241–253.

Raffaelli, D., Hawkins, S., 1996. Intertidal Ecology. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 190–213.

Rodil, I.F., Lastra, M., 2004. Environmental factors affecting benthic macrofauna along a gradient of intermediate sandy beaches in northern Spain. Estuarine, Coastal and Shelf Science 61, 37–44.

Salvat, B., 1964. Les conditions hydrodynamiques interstitielles des sédiment meubles intertidaux et la repartition verticale de la jenne endogée. Comptes Rendus de l'Academie des Sciences (Paris) 259, 1576–1579.

Sanders, H.L., Grassel, J.F., Hampson, G.R., Morse, L.S., Garner-Price, S., Jones, C.C., 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge '*Florida*' off West Falmouth, Massachusetts. Journal of Marine Research 38, 265–280.

Scapini, F., Chelazzi, L., Colombini, I., Fallaci, M., 1992. Surface activity, zonation and migrations of *Talitrus saltator* on a Mediterranean beach. Marine Biology 112, 573–581.

Scapini, F., Fallaci, M., Mezzetti, M.C., 1996. Orientation and migration in *Talitrus saltator*. Revista Chilena de Historia Natural 69, 553–563.

Stenton-Dozey, J.M.E., Griffiths, C.L., 1983. The fauna associated with kelp stranded on sandy beach. In: McLachlan, A., Erasmus, T. (Eds.), Sandy Beaches as Ecosystems. The Hague, W. Junk, pp. 133–144.

Souza, J.R.B., Borzone, C.A., 2000. Population dynamics and secondary production of *Scolelepis squamata* (Polychaeta: Spionidae) in an exposed sandy beach of Southern Brazil. Bulletin of Marine Science 67, 221–233.

Whitfield, J., 2003. How to clean a beach. Nature 422, 464–466.