Deep-Sea Research II 106 (2014) 192–197

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Response of benthic macrofauna to an oil pollution: Lessons from the "Prestige" oil spill on the rocky shore of Guéthary (south of the Bay of Biscay, France)

Iker Castège [a,*], Emilie Milon [a], Françoise Pautrizel [b]

[a] Centre de la mer de Biarritz, Plateau de l'Atalaye, 64200 Biarritz, France
[b] Biarritz Océan, Musée de la Mer de Biarritz, Plateau de l'Atalaye, 64200 Biarritz, France

ARTICLE INFO

Available online 3 October 2013

Keywords:
Oil spills
Benthos
Rocky shores
Taxonomic richness
Abundance
Recovery
Bay of Biscay

ABSTRACT

The benthic community on the rocky foreshore of Guéthary (France) has been monitored since 2002. The standardized and quantitative monitoring method counts 20 geographically referenced quadrats spread on three littoral zones: upper mediolittoral, lower mediolittoral and infralittoral zones. The setting up of this monitoring occurred when the "Prestige" sunk close to the Finistere Cape in Galicia (Spain). The oil slick following the shipwreck impacted the Guéthary foreshore in early 2003.

After the "Prestige" oil spill, the taxonomic richness decreased in the studied area with a loss of 16 species – from 57 in 2002 (before the shipwreck) to 41 species in 2004. Two or 3 years later, taxonomic richness increased to a level observed prior to the oil spill.

Along the years, temporal variations in community structure of benthic macrofauna are revealed by detailed analysis. Some polluo-sensitive species disappeared after 2002 and have not reappeared yet (*e.g.*: *Hymeniacidon perlevis*). Some others reappeared two or three years after the spill or even later (*e.g.*: *Amphipholis squamata*, *Botryllus schlosseri*, *Calliostoma zizyphinum*, *Echinus esculentus*, *etc.*). Noteworthy changes were found in 2004 driven by the sudden increase in abundance of grazers. The following years, these abundances went back to a stable level. The benthic community seemed to recover almost 5 years later, although a new composition of macrofauna populations was observed.

In overall aspect, the complexity of the benthic ecosystem response to oil spills confirms the need of regularly updated baselines to assess the impact of pollutions and more generally to maintain marine biodiversity.

1. Introduction

Over the last three decades, the west European coast has experienced many oil spills such as "*Torrey Canyon*" (1967), "*Urquiola*" (1976), "*Amoco Cadiz*" (1978), "*Aegan Sea*" (1992) and "*Erika*" (1999). In 2002, a new oil spill following the "Prestige" shipwreck impacted the French coast.

The "*Prestige*" was an oil tanker that broke in two parts, about 130 nautical miles off Galicia (NW Spain) on November 19, 2002. Of the 77,000 t of heavy fuel carried by the tanker, 63,000 t spilled. Subsequent to the shipwreck, fuel has spread along the north coast of Spain and reached the French and Portuguese shores. Owing to rough weather conditions during that winter, oil mixed with sea water down to some depth within the water column, where sensitive organisms may have been exposed and affected (Sánchez et al., 2006). Furthermore, the oil also deposited on the littoral sea floor as particulate and aggregate forms, thus also affecting the underlying benthic ecosystem.

The "Prestige" accident represents one of the largest environmental catastrophes in the history of European navigation. Owing to its expansion (Garcia-Soto, 2004), magnitude and temporal persistence, the "Prestige" oil spill (POS) is considered as the most important environmental disaster on the northern coast of Spain and one of the most relevant on a worldwide scale (Puente et al., 2009). More than 1000 km of coastline and a huge variety of habitats were affected, ranging from supralittoral, intertidal and sublittoral levels to oceanic and bathyal environments (Penela-Arenaz et al., 2009).

Effects of POS on different marine ecosystems have been well studied during the years following the oil spill, including seabirds (Camphuysen et al., 2002; Velando et al., 2005; Alonso-Alvarez et al., 2007; Castège et al., 2007), plankton (Varela et al., 2006), microfauna (Pascual et al., 2008), fishes (Sánchez et al., 2006; Martínez-Gómez et al., 2009) and benthic communities (Junoy

* Corresponding author. Tel.: +33 559 22 33 34; fax: +33 559 22 75 30.
E-mail address: iker.castege@univ-pau.fr (I. Castège).

0967-0645/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr2.2013.09.035

et al., 2005; Sánchez et al., 2006; Serrano et al., 2006; Puente et al., 2009; *etc.*).

Most benthic communities' studies following the POS have been carried out in various Spanish environments such as deep shelves (Sánchez et al., 2006), estuaries (Puente et al., 2009) and sandy beaches (de la Huz et al., 2005). To our knowledge, no monitoring surveys were dedicated to rocky shores affected by POS.

Assessing the impact of pollution on rocky shores is greatly complicated by a high level of spatial and temporal diversity. According to Hartnoll and Hawkins (1980), the composition of benthic communities may be seasonal, owing to more or less regular annual changes as a result of mortality, recruitment, growth and behavior patterns. Several studies were concluded with caution because their results could not be related to the oil spill but could be explained or masked by climatic variations (Sánchez et al., 2006; Signa et al., 2008).

Furthermore, rocky shore organisms are subject to several natural stresses such as tidal amplitude or wave action (see Raffaelli and Hawkins, 1996; Thompson et al., 2002 for reviews), thus forcing them to be tolerant to a wide range of stresses. Rocky shores are also subject to a variety of human impacts on a wide range of spatial and temporal scales (see Crowe et al., 2000; Thompson et al., 2002 for reviews): pollution (*e.g.* oil spills, eutrophication and toxic alga blooms, endocrine disrupter, *etc.*); food gathering; introduced species; global change (*e.g.* Mieszkowska et al., 2006); modification of coastal processes.

Thereby, the need of long-term monitoring is highlighted by many authors to study polluted areas or the variability of natural systems in general (Southward, 1995; Peterson, 2001; Hawkins et al., 2002; Puente et al., 2009). Indeed, recovery after such events may take several years and can only be studied properly over long periods of time, depending on the kind of habitats, the degree of shore cleaning as well as the velocity of recolonization. The latter depends on the time of year, the availability of recolonizing forms, the biological interactions, and climatic and other factors (Crowe et al., 2000; Kingston, 2002).

In the Bay of Biscay, the "Erika" oil spill also confirmed that a reference state must be known in order to assess the impact of an oil spill, particularly in the case of benthic communities (Laubier et al., 2004). Hence, the benthic community has been monitored since 2002 on the rocky foreshore of Guéthary (France).

In this paper, we investigate the temporal change occurring on the benthic community from the rocky shore of Guéthary impacted by the POS. Our ten-year monitoring survey included one sample prior to oil contamination. We focussed more particularly on three changes: (1) global taxonomic richness; (2) temporal variations of community structure and (3) variations in species abundance.

2. Materials and methods

2.1. Study area

The study area is located on the shore of Guéthary (Aquitanian coast, S Bay of Biscay). This is a rocky outcrop exposed to wave action. This area was chosen before the POS because of its singularities. First, it is a protected area where most fishing or other human activities are prohibited. Second, according to a national French inventory, it is classified as a Zone Naturelle d'Intérêt Ecologique, Faunistique et Floristique (ZNIEFF), a natural area considered for its noteworthy fauna and flora.

The standardized monitoring method counted 20 geographically referenced quadrats located on three littoral zones: upper mediolittoral, lower mediolittoral and infralittoral zones. Four of them were placed outside the protected area (Fig. 1).

2.2. Field sampling

Since 2002, each quadrat has been sampled every month between March and May. The number of samples could vary from year to year according to meteorological and tidal conditions: quadrats located on infralittoral zones can only be sampled during low spring tide (which appears once or twice a month). At the end of the fieldwork, each quadrat was sampled between two and four times a year.

The sampling method is standardized, the 20 quadrats' locations were randomly chosen in the three littoral zones and have been permanent since 2002.

The monitoring is based on a 4 m × 4 m quadrat (16 m²). Peterson et al. (2001) pointed out, without giving any size, that a larger area of coverage by sample can achieve better representation. Spreading the sample out on a larger range decreases the effects of natural gradient or spatial heterogeneity.

In each quadrat, all individuals of each macrofauna species were counted and identified at the lowest possible taxonomic level. The abundances of six species (*Balanomorpha*, *Botrylloides leachi*, *Botryllus schlosseri*, *Janua pagenstecheri*, *Mytilus* sp. and *Spirobranchus triqueter*) were specially surveyed due to their high density. However, abundances were not estimated during the first year of the survey; thus only the presence/absence data is available for 2002.

2.3. Data analysis

Temporal variation of the benthic community was assessed using three major analyses. First, the taxa richness was calculated for each year from 2002 to 2011. The Spearman non-parametric test was applied for detecting trends (Legendre and Legendre, 1998) in a number of species over time. All analyses were made with the Statistical Analysis System (CORR procedure), and MapInfo® Software.

To avoid problems with the correct determination of some species, analyses were conducted for data aggregated to a mixed taxonomic level (*e.g.* Smith and Simpson, 1995; Junoy et al., 2005). The validity of this approach is supported by studies suggesting that the effects of pollution are more detectable at high taxonomic levels (Gray et al., 1990; Smith and Simpson, 1993; Gomez Gesteira et al., 2003).

Second, we performed a multivariate analysis to compare the community structure of benthic macrofauna before and after the oil spill. We used a correspondence analysis based on the presence/absence of taxa (matrix 10 years × 110 taxa) conducted by Statbox software (6.4 version).

Third, we investigated the temporal changes in the abundance of benthic macrofauna from 2003 to 2011. Sampling fluctuations around the mean abundances were described by their standard error $SE = SD/\sqrt{n-1}$ (with SD: standard deviation and n: sample size). The analysis was then focused on the most abundant trophic level: the grazers. Indeed, this group alone represents 53% of the abundance of benthic macrofauna on Guéthary's rocky shore. In this feeding group, common taxa were considered such as sea urchins (*Paracentrotus lividus*, *Echinus esculentus* and *Sphaerechinus granularis*), molluscs (*Aplysia* sp., *Calliostoma zizyphinum*, *Diodora* sp., *Gibbula* sp., *Haliotis tuberculata*, *Littorina littorea*, *Littorina neritoides*, *Monodonta lineata*, *Neoloricata*, and *Patella vulgata*) as well as the sea slug *Onchidella celtica*.

Oceano-climatic conditions from the Bay of Biscay varied over the months and years (Hémery et al., 2008; Garcia-Soto and Pingree, 2009, 2012). However seasonality variations are supposed to be negligible in our study since we sampled at the same period each year. Moreover, according to Hartnoll and Hawkins (1980), we eliminated spatial variations in using permanent quadrats.

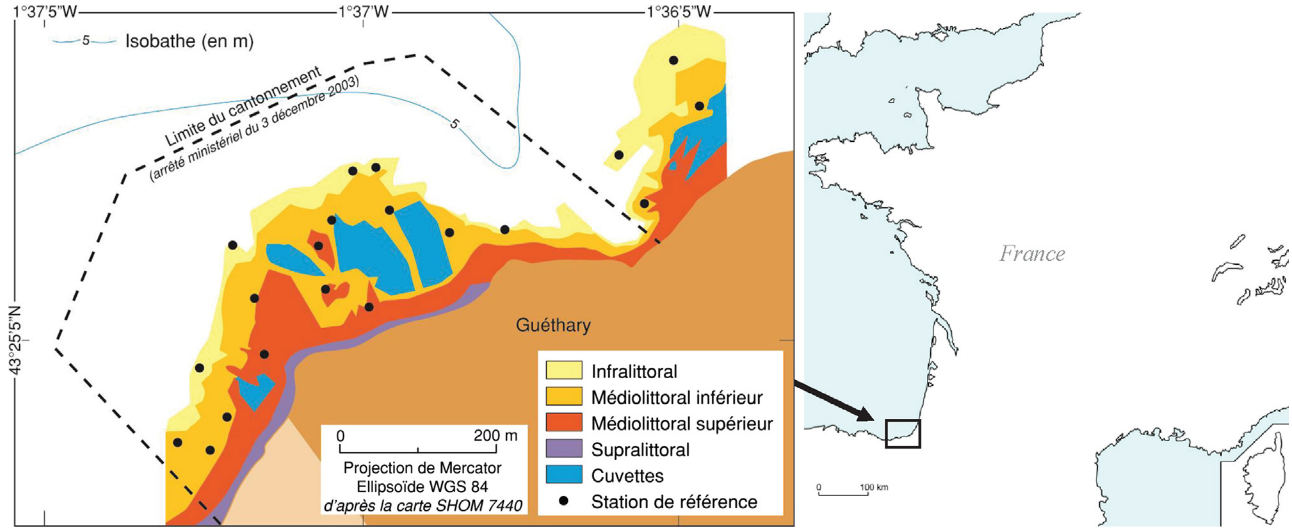

Fig. 1. Location of study area and benthic sample stations (black points) on the rocky foreshore of Guéthary. Quadrats are located in the infralittoral (yellow) and the mediolittoral (orange and red) zones. This map also shows the suppralittoral zone (purple) and the basins (blue). Dotted lines represent the protected zone. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Results

3.1. Changes in taxa richness

Through the 10 years of monitoring, 110 taxa were identified on the rocky shore of Guéthary. The benthic community is dominated by Mollusca (32.7%), Arthropoda (27.3%) and Echinodermata (10.9%). Regarding the trophic group, 42% of taxa are mainly predators, 18% are suspension feeders and 13% are grazers.

Before the oil spill, a total of 57 species were sampled. The "*Prestige*" oil spill began on November 13th, 2002, but our study area was hit on the 31st of December (Daniel et al., 2004). Thus, during the 2003 sampling, this area had been polluted for 3 months. Its taxonomic richness decreased significantly ($p < 0.001$) until it reached the lowest value of 41 species in 2004 (Fig. 2). During the following years, the number of species reached the level observed prior to the oil pollution (around 58 species). Since 2005, taxa richness showed no significant variations ($p = 0.7599$), and stabilized despite some inter-annual variations.

3.2. Temporal variation of the community structure

The Correspondence Analysis (axis 1 and axis 2 explained 39% of the total variance) shows in detail the changes among the community structure of benthic macrofauna (Fig. 3). In 2002, this community was clearly characterized by some species such as *Hymeciadon perlevis* or *Tethya* sp. Then, its structure changed through years with an important loss of taxonomic richness (Fig. 2). After 2006, its taxa richness was similar to the level observed prior to the oil contamination, but with a new faunal composition of the community.

The fauna collected in the study area could be classified in four groups of species: (1) taxa sampled every year (*e.g. Actinia equina*, *Anemonia viridis*, *Asterina gibbosa*, *Athanas nitescens*, *Carcinus maenas*, *Eriphia spinifrons*, *Galathea squamifera*, *Gibbula* sp., *Holothuria* sp.); (2) "rare" taxa sampled from time to time (*e.g. Clavelina lepadiformis*, *Doriopsilla areolata*, *Lepidonotus squamatus*, *Rostanga rubra*, *O. celtica*); (3) taxa that disappeared after the oil spill and reappeared 2–5 years later (*e.g. Amphipholis squamata*, *B. schlosseri*, *C. zizyphinum*, *E. esculentus*, *L. littorea*, *Psammechinus miliaris*), and (4) taxa that never reappeared after 2002 (*e.g. H. perlevis*, *Tethya* sp.).

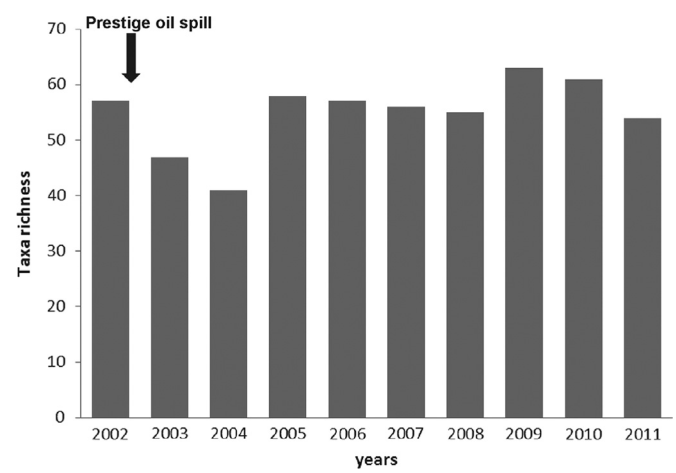

Fig. 2. Fluctuations of taxa richness in the benthic community of Guéthary's rocky shore between 2002 and 2011. The vertical arrow shows the occurrence of the oil spill after the Prestige shipwreck.

3.3. Changes in the abundance of some trophic groups

Most notably, the total mean abundance of the fauna significantly increased in 2004 with a sharp peak (176 ± 30 ind m^{-2}) but decreased in 2005 to a value of 63 ± 30 ind m^{-2}, slightly higher than the 2003 value. The following years, the total mean abundance showed no significant variations ($p = 0.2152$) and slightly fluctuated between 68 ± 14 ind m^{-2} (2006) and 36 ± 4 ind m^{-2} (2011).

Fig. 4 shows that total mean abundance is explained by grazers abundance, mainly in 2004 (138 ± 28 ind m^{-2}, 78% of the total abundance). Total mean abundances and grazers mean abundances are strongly correlated ($p = 0.0016$) whereas the relationship between total abundances and abundances of other taxa (*i.e.* excepted grazers) is not significant ($p = 0.0671$). It should be noted that total mean abundances without grazers seemed relatively stable from 2003 to 2011 with no significant trend ($p = 0.3807$).

4. Discussion

Our results suggest that the macrofauna community on Guéthary's rocky shore was impacted by the "Prestige" oil spill.

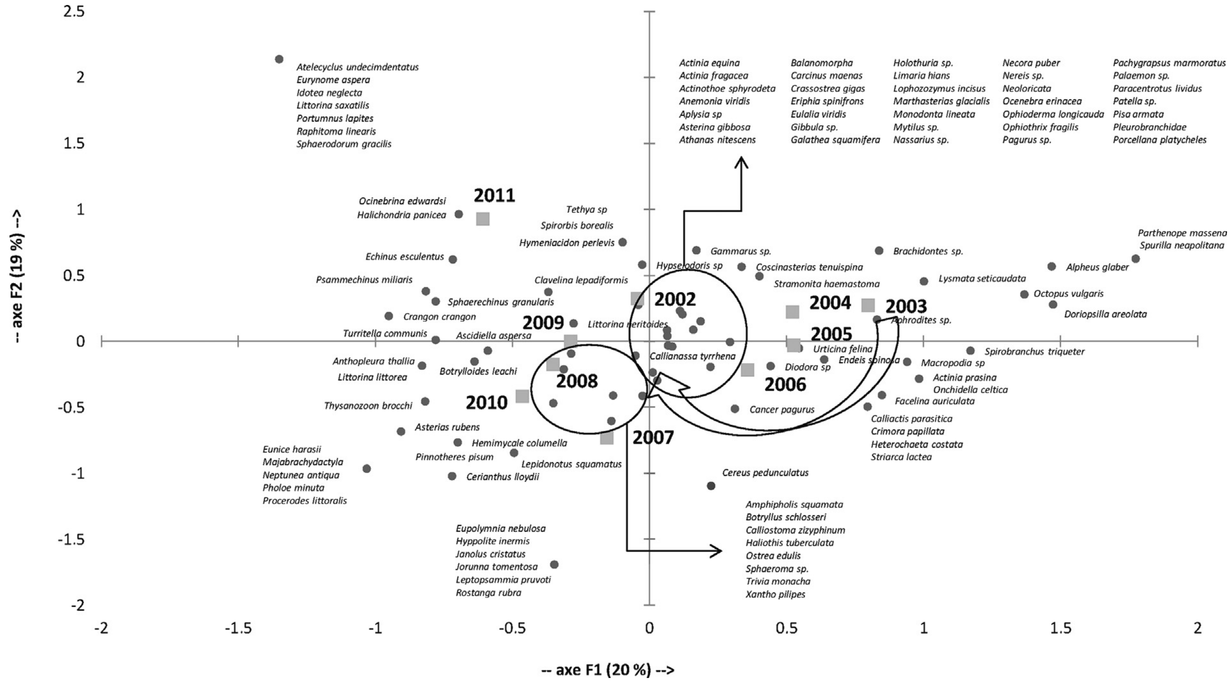

Fig. 3. Correspondence Analysis (matrix 10 years × 110 taxa; presence/absence data) showing the temporal variations occurring in 2002–2011 in the community structure of Guéthary's rocky shore.

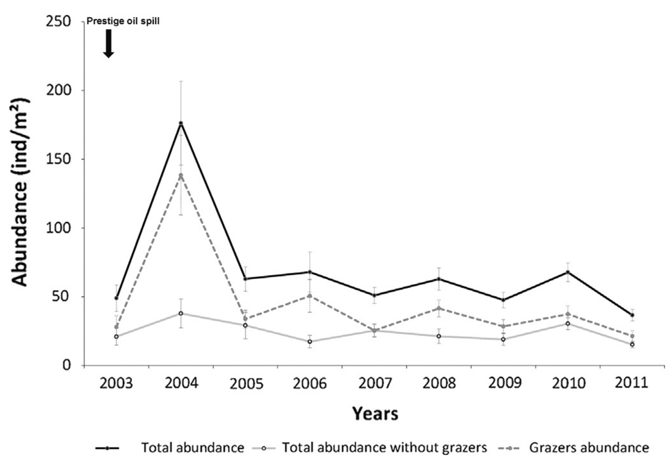

Fig. 4. Fluctuations in mean total abundances, mean abundances without grazers and mean grazers abundances between 2003 and 2011 in the benthic community of Guéthary's rocky shore. Vertical bars represent standard errors.

This impact was expressed by a global decrease in taxa richness with a loss of 16 species between 2002 (prior to the spill) and 2004. The increase of taxa richness in the following years reveals a process of recovery of the ecosystem. Ten years after the oil spill, taxa richness seems to remain stable. It took 3 years to reach a level similar to the reference value of 58 taxa observed before the oil spill.

Noteworthy, changes in the community structure were revealed by the multivariate analysis. Some species never reappeared on the shore after the POS (*e.g.* Sponges *H. perlevis* and *Tethya* sp.), whereas others were present during the whole monitoring survey. Moreover, some species disappeared just after the spill and reappeared few years later (most of them between 2 and 5 years). This last group gathers species known for their sensibility to pollution, such as *A. squamata*, *C. zizyphinum* and *P. miliaris* (Grall and Glémarec, 1997; Borja et al., 2000; Barillé-Boyer et al., 2004). The first axis scans the temporal gradient, highlighted by the arrow, suggesting a recovery of the ecosystem (Fig. 3).

Although the taxa richness went back to its “normal level” in 2005 with 58 species, multivariate analysis indicated that the recovery process is more complex because benthic communities vary among time. Indeed, the recovery process seems to take almost 5 years before reaching a macrofaunal composition similar to the structure observed prior to the spill. However, as pointed out by Crowe et al. (2000), recovery measurements remain difficult to estimate, because interpretation of time-scale recovery is known to be affected by survey design (Peterson et al., 2001).

Our results are in accordance with previous studies on the impact of oil spills on worldwide rocky shores which reported a recovery of initial communities around 3–4 years after the event (Kingston, 1999; Crowe et al., 2000; Kingston, 2002; Barillé-Boyer et al., 2004; Penela-Arenaz et al., 2009). Sell et al. (1995) reviewed 27 oil spill cases in which the recovery rate of rocky shores has been studied and they found that only four cases showed a recovery delayed beyond three years. Their study also showed that recovery times ranging from 3 to 4 years for a rocky shore exposed to wave action to over 12 years for a sheltered shore.

Nevertheless, recovery of a polluted area can be delayed by cleaning operations. Guéthary's rocky shore was partially cleaned using high pressure hot water washing. According to Sell et al. (1995), cleanup appears to have delayed the re-establishment of the biota and also the recovery process. Such detrimental effects presumably arise because the cleaning operations sterilize the substratum by removing or killing any biota that have survived the initial effect of oiling. For example, as a result of the *Torrey Canyon* oil spill in Cornwall, the major damage was not caused by the tons of oil that came ashore, but by excessive treatment with over 10,000 t of dispersants (Smith, 1968). These dispersants were later shown to be very toxic to marine life (Corner et al., 1968). They killed the grazer *P. vulgata*, and, to a lesser extent, other herbivores such as *M. lineata* and *Littorina* spp. The negative effects of high pressure or hot water cleaning procedure on rocky shore ecosystems have also been demonstrated by Broman et al. (1983), Peterson (2001) and Le Hir and Hily (2002). Both oil slick and cleanup effects could explain why some sensitive species attached on the rocks never reappeared (*e.g. H. perlevis* and *Tethya* sp.).

Despite some inter-annual variation, the total mean abundances revealed very interesting data about the response of this ecosystem. Three months after the POS, the total mean abundance of the community was 49 ± 9 ind m^{-2} but 1 year later (2004), its value reached a peak of 176 ± 30 ind m^{-2}. During the following years, abundance stabilized around a value of 60 ind m^{-2}. As grazers alone represent 53% of the total abundance, we focused our analysis on this trophic group. It appears that most of the total mean abundance of the community is explained by the density of grazers.

From this perspective, we can link this phenomenon with the study of Barillé-Boyer et al. (2004) also located in the Bay of Biscay. These authors emphasized the importance of changes in percent cover of the two species of macrophytes, *Ulva* sp. and *Grateloupia doryphora* after the “Erika” oil slick. The significant correlation between the decrease in algal cover and the rise in herbivore density illustrated the pressure of grazing exerted by the return of the herbivores in the area. Even if we did not measure algal cover, according to the literature, we can suggest that the maximum of herbivore density could illustrate a variation of algal abundance. Indeed, the proliferation of macrophytes, caused by the immediate death of the herbivores after an oil spill, is well described in studies of oil tanker accidents (Marchand, 1981; Newey and Seed, 1995; Crump et al., 1999; Barillé-Boyer et al., 2004). In 2005 (i.e. 3 years after the POS), the density of grazers in the studied area decreased and then seemed to stabilize. This phenomenon could reveal the balance between herbivore and algal communities after a period of perturbation.

The effects of the “Prestige” oil spill on the marine ecosystem were studied at different community levels, from plankton to seabirds. Despite contrasting results, most studies have shown the actual impact of the oil contamination on some populations: decrease in the species richness and abundance of the macroinfauna in sandy beaches with the disappearance of rare species (de la Huz et al., 2005; Junoy et al., 2005); and reduction in the abundance of shrimp, lobster and megrim on outer shelf (Sánchez et al., 2006); indirect impact for European shags through a reduction of the availability of preys (Velando et al., 2005). Generally, these studies indicated a strong initial impact during the first year after the oil spill, mainly on intertidal communities and fishing resources, with the recovery of communities by 2004 (Penela-Arenaz et al., 2009). Peterson et al. (2003) revealed that cascades of indirect effects can be as important as direct trophic interactions in structuring communities. In the present study, we also measured a strong initial impact (loss of taxa richness, changes in community structure, proliferation of grazers). The recovery of the community took between 3 (number of taxa) to almost 5 years (community structure).

We consider that our study is free of seasonal variability since all our samples were conducted in the same season (spring). Thus, the natural variations that could occur within these 3 months of sampling can be related to background noise. However we cannot exclude some other natural variabilities such as climatic variation, which could mask possible effects induced by the oil spill (Signa et al., 2008). Human impacts are negligible because quadrats are settled in a protected area.

The meaning of the word “recovery” can vary according to authors (*e.g.* Ganning et al., 1984; Sell et al, 1995) because recolonization processes may take different forms depending on the nature of the oil spill damage. Kingston (2002) offered the following possible definition: “Recovery of an ecosystem is characterized by the re-establishment of a biological community in which plants and animals characteristic of that community are present and functioning normally”. Thereby, the multivariate analysis that revealed community structure seems to be more suitable.

We agree with Elmgren et al. (1983) who consider that ecosystems are better indicators of oil pollution than single species even if several orders seem to be in some cases polluo-sensitive, *e.g.* the Amphipoda (Bellan-Santini, 1980; Gomez Gesteira and Dauvin, 2000; de-la-Ossa-Carretero et al., 2012). Our study suggests taking into account further elements (*e.g.* taxa richness variation and multivariate analysis) to assess the recovery of benthic ecosystems after pollution.

5. Conclusion

The “Prestige” oil spill impacted taxonomic richness, species abundances and structure of the benthic macrofaunal community on Guéthary's rocky shore.

Although the taxonomic richness went back to “normal level” in 2005 (3 years after the oil spill), the multivariate analysis indicates that recovery processes are more complex because benthic communities vary along time. Indeed, the recovery processes seem to take more time (almost 5 years) before reaching a composition comparable to the community observed prior to the oil spill. Moreover, the proliferation of grazers suggests a perturbation of the benthic ecosystem.

These results confirm the complexity of recovery on impacted ecosystems and that true assessment of oil spill impact needs long monitoring surveys, at least 5 years after the accident. Globally, long-term study of marine biodiversity proves to be necessary for the understanding and the conservation of marine ecosystems. From this perspective, the monitoring of the area will be extended to observe the next steps in the ecological successions.

Acknowledgments

This study is part of the regional research program ERMMA “Environnement et Resources des Milieux Marins Aquitains”. Different public or private organizations contributed significantly to this study: the “Mairie de Guéthary”, the “Centre de la Mer de Biarritz”, the “Musée de la Mer de Biarritz” and the “Université de Pau et des Pays de l'Adour”. The authors wish to thank greatly the different members of the communal services of Guéthary, mainly Albert Larrousset and Jean Choignard. Many thanks go also to the biologists working since 2002, unfortunately too numerous to be cited individually in this paper (Yves-Marie Guenier, Mathieu Libier, Sébastien Irola, Tatiana Lacamoire, Olivia Raphanel, Samuel Saez, Simon Clavier, Jeanne Gautier, Erwan Peru, Emilie Lamarque, Mickaël Kauffmann, Piero Rouget, Marie Berdoulay, Bruno Landabure, Jonathan Dix, Florence Henry, Sébastien Chouinard, Claire Papot, Elsa Malagnoux, Audrey Aragües, Théo Huguet, Magali Cazemajou-Tourne and Maxime Remazeilles). We thank Marie-Noelle de Casamajor, Gaël Arnaud, Yann Lalanne, Mikaël Vezinet and Mathilde Cordero for their helpful advices on the manuscript, along with Carlos Garcia-Soto (lead guest editor) and two anonymous reviewers. This work was funded in part by the “Conseil Général des Landes”, the “Conseil Général des Pyrénées-Atlantiques”, the “Observatoire de la Côte Aquitaine” and the “Conseil Régional d'Aquitaine”.

References

Alonso-Alvarez, C., Munilla, I., López-Alonso, M., Velando, A., 2007. Sublethal toxicity of the Prestige oil spill on yellow-legged gulls. Environment International 33, 773–781.
Barillé-Boyer, A-L., Gruet, Y., Barillé, L., Harin, N., 2004. Temporal changes in community structure of tide pools following the “Erika” oil spill. Aquatic Living Resources 17, 323–328.
Bellan-Santini, D., 1980. Relationship between populations of amphipods and pollution. Marine Pollution Bulletin 11 (8), 224–227.
Borja, A., Franco, J., Pérez, V., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin 40 (12), 1100–1114.

Broman, D., Ganning, B., Lindblad, C., 1983. Effects of high pressure, hot water shore cleaning after oil spills on shore ecosystems in the Northern Baltic proper. Marine Environmental Research 10 (3), 173–187.
Camphuysen, C.J., Heubeck, M., Cox, S.L., Bao, R., Humple, D., Abraham, C., Sandoval, A., 2002. The Prestige oil spill in Spain. Atlantic Seabirds 4, 131–140.
Castège, I., Lalanne, Y., Gouriou, V., Hémery, G., Girin, M., D'Amico, F., Mouchès, C., D'Elbée, J., Soulier, L., Pensu, J., Lafitte, D., Pautrizel, F., 2007. Estimating actual seabirds mortality at sea and relationship with oil spills: lesson from the "Prestige" oil spill in Aquitaine (France). Ardeola 54, 289–307.
Corner, A.D.S., Southward, A.J., Southward, E.C., 1968. Toxicity of oil-spill removers ("detergents") to marine life: an assessment using the intertidal barnacle *Elminius modestus*. Journal of Marine Biological Association of United Kingdom 48, 29–47.
Crowe, T.P., Thompson, R.C., Bray, S., Hawkins, S.J., 2000. Impacts of anthropogenic stress on rocky intertidal communities. Journal of Aquatic Ecosystem Stress and Recovery 7, 273–297.
Crump, R.G., Morley, H.S., Williams, A.D., 1999. West Angle Bay, a case of study. Littoral monitoring of permanent quadrats before and after "Sea Empress" oil spill. Field Studies 9, 497–511.
Daniel, P., Josse, P., Dandin, P., Lefevre, J.-M., Lery, G., Cabioc'h, F., Gouriou, V., 2004. Forecasting the Prestige oil spills. In: Proceedings of the Interspill 2004 conference, Trondheim, Norway.
de-la-Ossa-Carretero, J.A., Del-Pilar-Ruso, Y., Giménez-Casalduero, F., Sánchez-Lizaso, J.L., Dauvin, J.-C., 2012. Sensitivity of amphipods to sewage pollution. Estuarine, Coastal and Shelf Science 96, 129–138.
Elmgren, R., Hansson, S., Larsson, U., Sundelin, B., Boehm, P.D., 1983. The "Tsesis" oil spill: acute and long-term impact on the Benthos. Marine Biology 73, 51–65.
Ganning, B., Reish, D.J., Straughan, D., 1984. Recovery and restoration of rocky shores, sandy beaches, tidal flats, and shallow subtidal bottoms impacted by oil-spills. In: Cairns Jr., J., Buikema Jr., A.L. (Eds.), Restoration of Habitats Impacted by Oil Spills. Arbor Science Book, Sydney, pp. 7–36.
Garcia-Soto, C., 2004. 'Prestige' oil spill and Navidad flow. Journal of Marine Biological Association of United Kingdom 84, 297–300.
Garcia-Soto, C., Pingree, R.D., 2009. Spring and summer blooms of phytoplankton (SeaWiFS/MODIS) along a ferry line in the Bay of Biscay and western English Channel. Continental Shelf Research 29, 1111–1122.
Garcia-Soto, C., Pingree, R.D., 2012. Atlantic Multidecadal Oscillation (AMO) and sea surface temperature in the Bay of Biscay and adjacent regions. Journal of Marine Biological Association of United Kingdom 92, 213–234, http://dx.doi.org/10.1017/S0025315410002134.
Gomez 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.
Gomez Gesteira, J.L., Dauvin, J.C., Salvande Fraga, M., 2003. Taxonomic level for assessing oil spill effects on soft-bottom sublittoral benthic communities. Marine Pollution Bulletin 46, 562–572.
Grall, J., Glémarec, M., 1997. Using biotic indices to estimate macrobenthic community perturbations in the Bay of Brest. Estuarine, Coastal and Shelf Science 44 (Suppl. A), 43–53.
Gray, J.S., Clarke, K.A., Warwick, R.M., Hobbs, G., 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series 66, 285–299.
Hartnoll, R.G., Hawkins, S.J., 1980. Monitoring rocky-shore communities: a critical look at spatial and temporal variation. Helgoländer Meeresunters 33, 484–494.
Hawkins, S.J., Gibbs, P.E., Pope, N.D., Burt, G.R., Chesman, B.S., Bray, S., Proud, S.V., Spence, S.K., Southward, A.J., Langston, W.J., 2002. Recovery of polluted ecosystems: the case for long-term studies. Marine Environmental Research 54, 215–222.
Hémery, G., d'Amico, F., Castège, I., Dupont, B., d'Elbée, J., Lalanne, Y., Mouchès, C., 2008. Detecting the impact of oceano-climatic changes on marine ecosystems using a multivariate index: the case of the Bay of Biscay (North Atlantic-European Ocean). Global Change Biology 14, 27–38.
de la Huz, R., Lastra, M., Junoy, J., Castellanos, C., Viéitez, J.M., 2005. Biological impacts of oil pollution and cleaning in the intertidal zone of exposed sandy beaches: preliminary study of the "Prestige" oil spill. Estuarine, Coastal and Shelf Science 65, 19–29.
Junoy, J., Castellanos, C., Viéitez, J.M., de la Huz, R., Lastra, M., 2005. The macroinfauna of the Galician sandy beaches (NW Spain) affected by the Prestige oil-spill. Marine Pollution Bulletin 50, 526–536.
Kingston, P.F., 1999. Recovery of the marine environment following the Braer spill, Shetland. In: Proceedings 1999 Oil Spill Conference.
Kingston, P.F., 2002. Long-term environmental impact of oil spills. Spill Science & Technology Bulletin 7, 53–61.
Laubier, L., Le Moigne, M., Flammarion, P., Thybaud, E., Cossa, D., 2004. The monitoring programme of the ecological and ecotoxicological consequences of the "Erika" oil spill. Aquatic Living Resources 17 (3), 239–241.
Legendre, P., Legendre, L., 1998. Numerical Ecology, 2nd edition Elsevier, Amsterdam, p. 870.
Le Hir, M., Hily, C., 2002. First observations in a high rocky-shore community after the Erika oil spill (December 1999, Brittany, France). Marine Pollution Bulletin 44, 1243–1252.
Marchand, M. 1981. Amoco Cadiz Bilan du colloque sur les conséquences d'une pollution acid,entelle par hydrocarbures Brest – Novembre 1979. Centre océanologique de Bretagne, CNEXO, Rapports Scientifiques et Techniques no. 44.
Martínez-Gómez, C., Fernández, B., Valdés, J., Campillo, J.A., Benedicto, J., Sánchez, F., Vethaak, A.D., 2009. Evaluation of three-year monitoring with biomarkers in fish following the Prestige oil spill (N Spain). Chemosphere 74 (5), 613–620.
Mieszkowska, N., Kendall, M.A., Hawkins, S.J., Leaper, R., Williamson, P., Hardman-Mountford, N.J., Southward, A.J., 2006. Changes in the range of some common rocky shore species in Britain – a response to climate change? Hydrobiologia 555, 241–251.
Newey, S., Seed, R., 1995. The effects of the "Braer" oil spill on rocky intertidal communities in south Shetland, Scotland. Marine Pollution Bulletin 30, 274–280.
Pascual, A., Rodriguez-Lazaro, J., Martín-Rubio, M., Jouanneau, J-M., Weber, O., 2008. A survey of the benthic microfauna (foraminifera, Ostracoda) on the Basque shelf, southern Bay of Biscay. Journal of Marine Systems 72, 35–63.
Penela-Arenaz, M., Bellas, J., Vázquez, E., 2009. Chapter five: effects of the Prestige Oil spill on the Biota of NW Spain: 5 years of learning. Advances in Marine Biology 56, 365–396.
Peterson, C.H., 2001. The "Exxon Valdez" oil spill in Alaska: acute, indirect and chronic effects on the ecosystem. Advances in Marine Biology 39, 1–103.
Peterson, C.H, McDonald, L.L., Green, R.H., Erickson, W.P., 2001. Sampling design begets conclusions: the statistical basis for detection of injury to and recovery of shoreline communities after the 'Exxon Valdez' oil spill. Marine Ecology Progress Series 210, 255–283.
Peterson, C.H., Rice, S.D., Short, J.W., Esler, D., Bodkin, J.L., Ballachey, B.E., Irons, D.B., 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302, 2082–2086.
Puente, A., Juanes, J.A., Calderón, G., Echavarri-Erasun, B., García, A., García-Castrillo, G., 2009. Medium-term assessment of the effects of the Prestige oil spill on estuarine benthic communities in Cantabria (Northern Spain, Bay of Biscay). Marine Pollution Bulletin 58, 487–495.
Raffaelli, D., Hawkins, S., 1996. Intertidal Ecology. Chapman and Hall, London, UK.
Sánchez, F., Velasco, F., Cartes, J.E., Olaso, I., Preciado, I., Fanelli, E., Serrano, A., Gutierrez-Zabala, J.L., 2006. Monitoring the Prestige oil spill impacts on some key species of the Northern Iberian shelf. Marine Pollution Bulletin 53, 332–349.
Sell, D., Conway, L., Clark, T., Picken, G.B., Baker, J.M., Dunnet, G.M., McIntyre, A.D., Clark, R.B., 1995. Scientific criteria to optimize oil spill cleanup. In: Proceedings of 1995 International Oil Spill Conference. American Petroleum Institute, Washington, DC, pp. 595–610.
Serrano, A., Sánchez, F., Preciado, I., Parra, S., Frutos, I., 2006. Spatial and temporal changes in benthic communities of the Galician continental shelf after the Prestige oil spill. Marine Pollution Bulletin 53, 315–331.
Signa, G., Cartes, J.E., Solé, M., Serrano, A., Sánchez, F., 2008. Trophic ecology of the swimming crab *Polybius henslowii* Leach, 1820 in Galician and Cantabrian Seas: influences of natural variability and the Prestige oil spill. Continental Shelf Research 28, 2659–2667.
Smith, J.E. (Ed.), 1968. A Report by the Plymouth Laboratory of the Marine Biological Association of the United Kingdom. Cambridge University Press, Cambridge.
Smith, S.D.A., Simpson, R.D., 1993. Effects of pollution on holdfast macrofauna of the kelp Eklonia radiata: discrimination at different taxonomic levels. Marine Ecology Progress Series 96, 199–208.
Smith, S.D.A., Simpson, R.D., 1995. Effects of the "Nella Dan oil-spill on the fauna of Durvillaea antarctica holdfast". Marine Ecology Progress Series 121, 73–89.
Southward, A.J., 1995. The importance of long time-series in understanding the variability of natural systems. Helgoländer Meeresunters 49, 329–333.
Thompson, R.C., Crowe, T.P., Hawkins, S.J., 2002. Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. Environment Conservation 29 (2), 168–191.
Varela, M., Bode, A., Lorenzo, J., Álvarez-Ossorio, M.T., Miranda, A., Patrocinio, T., Anadón, R., Viesca, L., Rodríguez, N., Valdés, L., Cabal, J., Urrutia, A., García-Soto, C., Rodríguez, M., Álvarez-Salgad, X.A., Groom, S., 2006. The effect of the "Prestige" oil spill on the plankton of the N–NW Spanish coast. Marine Pollution Bulletin 53, 272–286.
Velando, A., Munilla, I., Leyenda, P.M., 2005. Short-term indirect effects of the 'Prestige' oil spill on European shags: changes in availability of prey. Marine Ecology Progress Series 302, 263–274.