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Effects of two offshore gas platforms on soft-bottom benthic communities (northwestern Adriatic Sea, Italy)

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Abstract

The macrozoobenthos living around two offshore gas platforms, Barbara NW (pB) and Calipso (pC) located in the northwestern Adriatic Sea were investigated for three years after their construction to detect eventual effects due to the platforms. The sampling stations were spaced at increasing distance from the platforms up to 1000 m. Both multivariate and univariate analysis showed an initial defaunation (short-term effect) at pB and within a 120 m radius at pC. A general recovery in terms of abundance, species richness and diversity was observed for the benthic communities after one year. During the third monitoring year a mussel mound developed at both the platforms (longer-term effect) extending up to 30 m from pC, whereas similar soft-bottom communities were found at all the other distances. The geographical position play an important role in the “timing” of the above effects. Moreover, despite the different environmental features, a 3-year monitoring plan can be effective to evaluate the potential impact on benthic communities of offshore gas platforms in the north-central Adriatic Sea.

- 1 *Keywords:* Offshore structures, Environmental impact, Zoobenthos, Community composition,
- 2 Adriatic Sea, Mussel mound.

ACCEPTED MANUSCRIPT

1. Introduction

Over the last 50 years, non-renewable resources exploitation has strongly increased to meet the global growing demand for energy. The offshore oil and gas industry plays a leading role in the marine field extraction activity exceeding 14 billion tonnes of oil equivalent (btoe; Ghisel, 1997; Pinder, 2001). In the Mediterranean basin, the Italian production of natural gas was 11.4 million tonnes of oil equivalent (mtoe) in 2004, rising to 0.2 btoe in 2005, the fourth-largest in the EU. About 80% of the total energy comes from this type of activity (Brighenti et al., 2003), and almost half of it is provided from offshore reserves in the Adriatic continental shelf (OGP, 2005). More than 110 offshore gas platforms have been deployed since the 1960s in the northern and central parts of this basin (Maggi et al., 2007), representing the highest concentration of fossil fuel extraction platforms in the Mediterranean area.

It is well known that drilling operations generate waste fluids and cuttings that could cause strong environmental impacts related to drilling mud discharges or hydrocarbons associated waters (Terlizzi et al., 2008). Moreover, the physical structure of the platform may modify local water flow and alter sediment type, affecting the benthic community composition (Wilson-Ormond et al., 2000). Generally, during the installation phase and the drilling operations, benthic communities closer to the platforms show a decrease in diversity and a change in species' abundance, while further away, assemblages may appear more similar to those in the surrounding unaffected area (Grant and Briggs, 2002).

The radius of impact can be different depending on the number of platforms placed in a restricted area, the structures' dimensions and biogeographic/climatic factors. For example, in the North Sea a few studies found effects up to 3,000 m, with more severe impacts within a 500 m radius (Gray et al., 1999; Kingston, 1987; Olsgard et al., 1997). In the Gulf of Mexico the long-term effects of oil-related activities on the benthos were evident up to 200 m from the source and up to 800 m from produced water discharge points (Hernández Arana et al., 2005; Montagna and Harper, 1996; Peterson et al., 1996; Rabalais et al., 1992).

The water-based drill-cuttings, commonly used in the Adriatic Sea, are less toxic than oil-based drilling muds (Cameron et al., 2004; Olsgard and Gray, 1995). Moreover, in most of cases neither drill-cuttings nor formation water are discharged at sea during the drilling operations.

However, structures' installation, drilling operations as well as the associated great occurrence of ships can cause an increase of metals, hydrocarbons and other chemical agents in the environment causing potential impacts to the surrounding physical and biotic compartments.

Some studies highlighted the effects of platforms on benthic communities over the time (Fabi et al., 2007; Frascari et al., 1991, 1992; Spagnolo et al., 2002, 2006; Trabucco et al., 2006). In most of these cases, the more relevant ecological alteration due to the presence of a gas platform was a mussel mound development affecting the surrounding seabed communities within a radius of a few meters.

However, there is still much research to be undertaken to fully understand the gas platforms' potential impacts on the surrounding zoobenthos in the Adriatic Sea. Nevertheless, these platforms are installed in a wide variety of environments, with different types of sediments (from mud to sand) that may be under the influence of rivers such as the Po River representing the main source of fresh water into the northern Adriatic Sea (Cattaneo et al., 2003; Grilli et al., 2005; Marini et al., 2008). This situation, associated with the high drilling activity in the Adriatic basin, makes it difficult to develop general models for prediction of offshore platforms' impact.

The present work compares the possible effects on the surrounding zoobenthic communities of two 4-leg gas platforms (Barbara NW and Calipso) in the northwestern Adriatic Sea installed at similar depth but at different distances from the coastline and different types of seabed. It represents an approach to detect possible common impact patterns both in temporal and spatial terms.

Data were collected in the framework of a wider monitoring programme aimed to evaluate the impacts of the platforms' installation on the different components of the marine environment (i.e. water column, sediments, benthic communities, fish assemblage, ecotoxicological response).

2. Materials and Methods

2.1 Study area

The Adriatic Sea is a small continental shelf about 800 km long in NW-SE direction and about 200 km wide. The northern part of the basin is very shallow, rarely exceeding 46 m depth, while in the central part the depth can reach 80 m. The continental slope located around 600 km from the northern limit separates the central Adriatic from the southern one where the depth reaches 1,200 m. The northern basin receives a high nutrient input from Po River and other minor streams which enhances primary production near the surface and oxygen demand near the bottom (Grilli et al., 2005; Marini et al., 2008). The Po watershed is very large and includes densely populated regions (Crema et al., 1991).

The study was conducted in the northwestern Adriatic Sea. Two 4-leg offshore gas platforms, Barbara NW (hereafter indicated as pB) and Calipso (hereafter indicated as pC), were monitored for three years.

pB is located on a muddy sand seabed at a mean depth of 68.5 m, 56 km off Ancona (De Biasi, unpublished results; Fig. 1). The submerged part of pB was installed in February 1999. The drilling operations finished in June of the same year and the production started soon after. Six field cruises were carried out from 2000 to 2002 (two per year). The main bottom current direction measured during the study period fluctuated between Northwest and Southeast and had a speed sporadically reaching 10 cm s^{-1} (Fabi et al., 2005). Grain size was homogeneous at the different distances from the platform. Heavy metal content in the sediments did not show significant changes at increasing distance from the platform, except for some peaks of cadmium, zinc, mercury, and lead recorded in the surroundings of the structure during the first monitoring year after installation. These anomalies gradually disappeared in the subsequent years (De Biasi et al., 2008; Fabi et al., 2005). Polycyclic Aromatic Hydrocarbon (PAH) levels increased in the second monitoring year (2001) and strongly declined at the end of 2002. However, with only a few exceptions, the values of the above contaminants usually agreed with those reported in other areas of the Adriatic Sea

(Guerzoni et al., 1984; Magi et al., 2002). Organic matter always showed the highest concentrations close to the platform and gradually decreased with increasing distances from it, indicating an intense biological activity around the structure (unpublished results).

pC is located on a muddy seabed approximately 35 km off Ancona in 75 m of water (De Biasi et al., 2007; Fig. 1). The structure was installed in May 2002 and the drilling operations started in the following month and finished in October 2002. Production began immediately thereafter. Again, six field cruises were carried out from 2003 to 2005 (two per year). During the study period the main current at the sea bottom flowed from Northwest towards Southeast, following the basin topography with a speed of 5-10 cm s⁻¹ sporadically reaching 20 cm s⁻¹ (Paschini, unpublished results). The sediment texture was homogeneous at the different distances from the platform in the overall study period. A gradual decrease of heavy metal content was observed from the first to the last monitoring year. Nevertheless, some anomalies for copper, lead, barium and zinc were recorded during the overall monitoring period. During the first two years after installation PAH concentrations were higher around the structure compared with those recorded at the farther distances, but they decreased in 2005 (De Biasi et al., 2006, 2007). Also in this case the recorded contaminant levels were comparable with those reported in other Adriatic areas (Guerzoni et al., 1984; Magi et al., 2002). Organic matter content was homogeneous in the overall area, showing a consistent increase in the second monitoring year which persisted until the end of 2005 (De Biasi et al., 2007).

At both platforms water-based muds were used for the drilling operations and neither cuttings nor formation waters were discharged at sea. Moreover, no water is discharged during the production phase.

2.2 Sampling design and analyses

The sampling design was planned according to the 'gradient design' approach that is particularly useful when a stressor or disturbance attenuates with the distance from the point source of impact (Ellis and Schneider, 1997).

For each platform, four sampling sites (about 20 m apart) were randomly selected at 5 m, 30 m, 60 m, 120 m, and 1000 m from the structure. At each site three samples were collected using a Van-Veen grab (capacity = 13 L and width = 0.105 m²), for a total of 12 samples for each selected distance.

The overall 720 biological samples (60 samples x 2 platforms x 6 surveys) were sieved *in situ* through a 0.5 mm mesh and all organisms retained were preserved in 5% buffered formalin. In the laboratory, macrofauna was sorted through a stereomicroscope and a binocular microscope, identified and classified to the species level when possible using standard nomenclature, quantified, and weighted.

2.3 Data analysis

Multivariate analyses were performed to identify spatial and temporal changes in the composition and abundance of macrofauna communities using PRIMER™ ecological software package developed by the Plymouth Marine Laboratory (Clarke, 1993; Clarke and Warwick, 2001). Prior to any analysis, the species abundance data were fourth-root transformed to reduce the contribution of prevalent taxa and therefore increase the importance of less abundance species. Afterwards, species contributing at least 10% of the total community abundances were selected and the Gower exc 0-0 similarity matrix was calculated. Gower coefficient is well-suited for quantitative abundance data excluding double-zeros from comparison (Legendre and Legendre, 1998). The differences among macrofauna assemblages at increasing distance from platforms during the three monitoring years were tested by means of a permutation analysis of variance. This method allowed testing of the general multivariate hypothesis of differences in the composition and/or relative abundances of organisms of different species in samples from different groups (Anderson, 2001; McArdle and Anderson, 2001). In the 3-way PERMANOVA, Distance (five levels fixed factor), Year (three levels fixed factor) and Platform (two levels random factor orthogonal to the other two factors) were considered. Since the test results were significant for the factor Platform, pB and pC were investigated separately and independently from each other.

For both pB and pC, multivariate patterns of variation among distances and years were tested by PERMANOVA and the significant terms were investigated using pair-wise comparisons. Successively, similarity percentage breakdown procedure (SIMPER; Clarke and Warwick, 2001) was used to determine the contribution of individual taxa towards the dissimilarity between and similarity within the two distance and year groups.

Univariate measures such as species abundance (N), species richness (S_m) and Simpson index (λ ; Simpson, 1949) were calculated on benthic abundance data for each sampling site at each distance for the three sampling years. Changes in these biological indices were examined using the same statistical design previously described for PERMANOVA. The random factor Platform and/or the interactions between Platform and the other terms showed again significant differences. Therefore a 2-way ANOVA was conducted separately for each platform considering Distance and Year as fixed factors. In the case of significant interactions, a one-way ANOVA was employed for each temporal factor level to compare the distance. Prior to performing statistical analyses, normal distribution and heterogeneity of variances were evaluated through the Kolmogorov–Smirnov and Bartlett tests, respectively (Lindman, 1992). When the latter was significant, the relationship between means and the respective standard deviations was analysed to check whether the ANOVA assumptions were effective at any rate. Based on the tests, total abundance data (N) were log-transformed. The Tukey HSD test for balanced samples was used to make comparisons across all pairs of group means when corresponding ANOVA tests were significant. Levels of significance were set at $p \leq 0.01$ (highly significant) and $p \leq 0.05$ (significant).

3. Results

3.1 Overview

A total of 206 taxa were recorded at pB. This group included 92 polychaetes, 52 crustaceans, 41 molluscs, 8 echinoderms, 5 cnidarians, 3 sipunculids, 1 ascidian, 1 nemertean, 1

nematod, 1 platelmint and 1 tunicate, for a total of 1,369 ind 0.105 m⁻². The community mostly consisted of both limicoulus and sandy organisms.

On the other hand, a total of 139 taxa were found at pC. Of these, polychaete worms made up again the greatest proportion of the macroinvertebrate population with 67 taxa, followed by 32 crustaceans, 26 molluscs, 6 echinoderms, 4 cnidarians, 2 sipunculids, 1 nemertean and 1 platelmint, for a total of 1,481 ind 0.105 m⁻². Limicoulus species dominated the community.

Although at both pB and pC sites most taxa were typical of soft-bottom communities, close to the platforms, hard-bottom species were also found, especially crustaceans (e.g., *Pilumnus hirtellus*, *Galathea intermedia*) and molluscs (e.g., *Mytilus galloprovincialis*, *Neopycnodonte cochlear*, *Hiatella arctica*). Although the number of these species was initially very low in all the sampling sites, it increased by the end of the monitoring (during the third year) at both pB and pC.

3.2 Multivariate patterns

The 3-way PERMANOVA highlighted a significant difference in the abundance of macrobenthos between pB and pC (Table 1). Moreover, significant interactions among Distance, Year and Platform were shown by PERMANOVA (Table 1). Analyzing separately the two platforms, significant differences among distances and years were found for both pB and pC (Table 2), indicating a potential effect of the platforms on the spatial and temporal variation of zoobenthic communities. Pair-wise test revealed that 5 m sites for pB were different from all the other distances during the overall sampling period (Table 2), while the 1000 m sites were different from all the others only during the first sampling year. A spatial gradient was determined by the presence of the platform from sites nearest to the platform to those furthest away. The macrofauna assemblages evolved in the second and third year. The communities became similar at all distances with the exception of 5 m sites. On the other hand, as regards pC, pair-wise tests pointed out a temporal evolution of 5 m sites which became completely different from all the other sites in the last sampling year (Table 2).

SIMPER analysis showed the highest dissimilarities between 5 m sites and all the other distances for both pB and pC (Table 3). The crustacean *Callinassa subterranea*, together with the polychaetes *Nephtys hysiricis*, *Capitella capitata*, and *Paralacydonia paradoxa* were not collected in 5 m sites for pB and were the major contributors to these dissimilarities.

On the other hand, the decrease of abundant polychaete species such as *Caulleriella caputesocis*, *Sternaspis scutata*, and *Prionospio cirrifer* was associated with a greater contribution of the polychaetes *Marphysa bellii*, *Lumbrineris impatiens*, of the gastropod *Hyala vitrea*, and of *C. subterranea* at increasing distance from the platform. These species were the major ones responsible for the differences at pC.

On temporal scale (year groups, Table 3) the dissimilarity was slightly higher between the second and third years rather than between the first and the second ones for pB, while highly decreased for pC.

3.3 Univariate patterns

As in the multivariate analysis, also the 3-way ANOVA highlighted highly significant interactions among the three considered factors (Distance, Year, and Platform; Table 4). Therefore, the analysis was again computed separately for pB and pC.

As regards pB, S_m , N, and λ showed different spatial trends in each sampling year causing a significant interaction between Distance and Year (Table 5). During the first year the benthic community was represented everywhere by a low number of both species and individuals. S_m (Fig. 2) changed from 4.63 ± 1.03 (5 m) to 14.50 ± 3.37 (1000 m; one-way ANOVA, $p < 0.01$). A significant increment ($p < 0.05$) was observed from 5 m to 30 m, which showed a value of 13.38 ± 1.64 similar to all the other distances. No differences among distances were recorded for N, varying from 12.00 ± 1.55 ind 0.105 m^{-2} (5 m) and 27.38 ± 5.16 ind 0.105 m^{-2} (60 m; Fig. 2). In contrast, the λ value at 5 m (0.38 ± 0.030) was significantly higher than the others ($p < 0.01$) due to the dominance of the polychaete *Prionospio malmgreni*. In the second year, S_m and N were characterized by similar trends (Fig. 2). The lowest S_m and the highest λ (11.63 ± 7.13 and 0.16 ± 0.10 respectively) were still

recorded at 5 m. The difference was significant only for S_m in respect to 30 m (19.13 ± 1.55 ; $p < 0.05$). At the end of the second monitoring year, a mussel mound started to develop close to the platform hosting a varied macrobenthic community composed by both soft- and hard-bottom species. As a consequence, during the third year, S_m and N reached the highest values (23.25 ± 6.74 and 104.00 ± 31.25 ind 0.105 m^{-2} respectively) at 5 m, showing significant differences with the other distances. λ was similar everywhere due to the high number of species with low dominance.

S_m , N , and λ showed different spatial trends in each year also for pC, making significant the interaction between Distance and Year (Table 5). In the first sampling year the benthic community living just close to the platform up to 1000 m was very poor in terms of number of both individuals and species. The highest value of λ was recorded at 5 m (0.55 ± 0.39) and the lowest at 1000 m (0.16 ± 0.05 ; Fig. 2). The only significant differences ($p < 0.05$) were observed between 5 m and 1000 m for both S_m (3.38 ± 0.98 and 11.50 ± 2.95 respectively) and N (7.50 ± 1.65 ind 0.105 m^{-2} and 36.88 ± 15.44 ind 0.105 m^{-2} respectively). During the second year all the three indices did not show any spatial trend and all the values were similar to each other (Fig. 2). Also in this case a mussel mound developed at the end of the second monitoring year but differently from pB, it extended up to 30 m from the platform. As a consequence, S_m and N increased within this area in the last sampling period. Some hard-bottom species (e.g., *N. cochlear*, *Ostrea edulis*, *Modiolarca subpicta*), not observed at the other distances, in fact, were recorded in addition to the typical soft-bottom taxa. The values of S_m obtained within a 30 m radius were similar to each other (5 m: 23.00 ± 3.32 ; 30 m: 22.13 ± 2.10) and significantly higher than those observed from 120 up to 1000 m ($p < 0.05$; Fig. 2). The greater occurrence of *M. galloprovincialis* at 5 m caused a very high N value close to the platform (243.50 ± 33.15 ind 0.105 m^{-2}), which was statistically different from the other distances ($p < 0.01$). Also the 30 m value (87.00 ± 9.87 ind 0.105 m^{-2}) was significantly higher than those recorded at the further distances ($p < 0.01$). Finally, λ index was significantly higher at 5 m (0.20 ± 0.06) in comparison to 30 m and 60 m ($p < 0.01$ and $p < 0.05$ respectively).

4. Discussion

The Adriatic Sea is largely affected by many different human activities (e.g., tourism, fishing, open-sea aquaculture), and the extraction of natural gas represents one of the most important. The quantification and interpretation of the environmental effects of offshore gas platforms can be difficult and hard to generalize. Although the physical presence of the structure is a common characteristic to all the platforms, several local abiotic and biotic variables, especially in the Adriatic Sea, influence the effects of each platform in a unique and different way. In fact, the peculiar physiography of this long, narrow, shallow water basin with many fresh water inputs, enhances the effects of nutrients and oxygen concentration, salinity, temperature, turbidity, currents, primary and secondary production (Grilli et al., 2005; Marini et al., 2008).

The natural sea bottom in most areas proposed for offshore gas platforms in the Adriatic shelf consists of soft sediments ranging from coastal mud to offshore coarse sand inhabited by an adapted fauna. Many benthic organisms are sessile, and can hardly escape natural and anthropogenic disturbances. In addition, several species are known to be susceptible to disturbances or environmental changes. Due to their sessile character and ability to “integrate” environmental influences over longer time scales, these species are commonly regarded as good indicators for environmental impacts (Underwood, 1996), as well as for long-term changes in the ecosystem (Kröncke, 1995).

This study assesses and compares the possible effects of two gas platforms located in the north-western Adriatic Sea on the surrounding benthic communities. The aim is to find a common pattern in the populations’ response to the installation of Adriatic offshore structures and identify the ecological features mostly leading the macrofauna changes. The two platforms are quite similar in shape and dimensions, but located at different distances from the coast. Consequently, according to grain size distribution maps (George et al., 2007; Harris et al., 2008) and water circulation pattern in the northwestern Adriatic basin, they are situated on different sediment types (De Biasi, unpublished results; De Biasi et al., 2007) and subjected to different environmental variables.

Bottom currents, river plumes, and turbidity, for example, tend to decrease from the coast towards offshore (Boldrin et al., 2009).

Some differences in the composition of the benthic communities recorded in the surroundings of the two platforms may be associated with the diverse sediment texture. Limicoulus organisms, indeed, were found around pC, whereas a mix of sandy and limicoulus species characterized pB. These differences in the benthic communities living in the natural habitats as well as the distance from the coast and other abiotic features (i.e. currents, river plumes, and turbidity) could explain the different response to the impacts caused by the platforms' installation and drilling operations. Distance from the coast was found to be one of the main factors affecting metal distribution around offshore platforms in the western Adriatic Sea (De Biasi et al., 2008). In addition, a strong relationship between changes in benthic communities and decreasing gradients of contaminants' concentration at increasing distance from the platforms was reported by Olsgard and Gray (1995). As regards pC and pB, the results of sediment analysis did not show significant levels of contamination, suggesting a minor role of chemical pollution in determining the observed gradients of variation in benthic assemblages (De Biasi et al., 2006, 2007, 2008). Similar findings were also reported by Terlizzi et al. (2008) for inshore and offshore platforms located in the Ionian Sea.

The zoobenthos close to pB was different from that living at the various distances from the platform in the overall survey period. During the first year, indeed, just after the end of the drilling operations, the community at 5 m was very poor especially in terms species number and strongly dominated by the opportunistic polychaete *P. malmgreni*, typical of defaunated, organic matter enriched areas, and also living in polluted habitats (Lu and Wu, 2000; Pearson and Rosenberg, 1978). The great occurrence of this species agreed with the high level of organic matter observed at that time close to the platform (unpublished results). From 30 m to 120 m apart some soft-bottom species not observed at 1000 m were found. Some of these taxa were suspension- or deposit feeders (e.g., *Onuphis conchilega*), likely attracted to this area by detritus and microparticulate matter made

available by the bottom mixing due to the drilling operations. Other taxa were carnivorous (e.g., *Alpheus glaber*) foraging on the above mentioned species. This scenario indicates a more severe effect just close to the platform and a slight influence on the surrounding seabed restricted to 120 m, likely due to the weak bottom currents characterizing the area (Fabi et al., 2005).

A different situation was observed for pC where an initial defaunation in terms of number of species and individuals was observed up to 120 m. This wider spreading out of the impact may be attributed to the more intensive bottom currents compared to pB (Paschni, unpublished results). Some opportunistic species were found within 120 m of radius (e.g., *C. caputesocis*, *P. cirrifera*) acting as pioneers in defaunated bottoms and preparing the substrate for other organisms' colonization which have more elaborate settlement needs (Pearson and Rosenberg, 1978).

In the second sampling year the benthic communities living close to the platforms showed a recovery from the previous defaunation. The appearance and/or the abundance increase of some common soft-bottom species (e.g., *O. conchilega* for pB and *H. vitrea*, *M. bellii* for pC) were recorded at all the distances. Moreover, in the case of pB a reduction of *P. malmgreni* was observed. However, this recovery process seemed to be faster at pC compared with pB, where the number of species close to the platform was still lower than those recorded at the further distances.

At the end of the second monitoring year a mussel mound developed close to both the platforms, extending up to 30 m in case of pC. Again, this spatial difference between the two platforms may be related to the higher hydrodynamics characterizing pC. Specimens of *M. galloprovincialis* fell down from the submerged parts of the platforms providing natural hard substrates and forming new habitat for marine epifaunal organisms which rarely occur in soft-bottom communities. For example, hard-bottom molluscs such as *N. cochlear*, *Anomia ephippium*, and *H. arctica* as well as crustaceans such as *P. hirtellus* and *G. intermedia* were observed only at 5 m for pB and up to 30 m for pC. This process made 5 m for both platforms and 30 m for pC again different from the other distances in terms of either number of species, number of organisms and community structure. Some mobile species use the living mussels as a food source, and the shells of

dead specimens as shelter (Kneib and Weeks, 1990; Warburg and Schwartz, 1993; Zariquiey Alvarez, 1968). Some sessile species, instead, settle on the mussel shells utilizing them as substrate. As a consequence of above, hard bottom organisms, attracted by the mussels, enrich the community (Bomkamp et al., 2004; Page et al., 1999; Thayer et al., 1997; Wolfson et al., 1979). This scenario is common in the northern and central Adriatic Sea and it was already observed at other offshore platforms located at different depths and distances from the coastline (Fabi et al., 2007; Spagnolo et al., 2002, 2006; Trabucco et al., 2006, 2008). Formation of mussel mounds, increased substrate heterogeneity, and development of hard bottom communities close to the offshore platforms have been also reported in southern California (Love et al., 1999; Page et al., 1999; Wolfson et al., 1979), in the southern Arabian Gulf (Stachowitsch et al., 2002), and in the south-eastern Australia (Currie and Isaacs, 2005). An enrichment of the benthic macrofauna up to 100 m from the platform, mainly due to the increase of deposit-feeding polychaetes, was also observed by Montagna and Harper (1996) in the Gulf of Mexico.

In conclusion, two main typologies of effects on soft-bottom benthic communities were observed for both pB and pC. An initial short-term (~ one year), localized effect, consisting in the defaunation, may be attributed to the installation of the platforms and drilling operations. A following longer-term effect bound to the physical presence of the structures started at the end of the second year after installation and consisted of the development of mussel mounds and the subsequent macrofauna enrichment/diversification close to the platforms.

Geographical position likely plays an important role in the “timing” of the above effects. In the case of platforms placed in shallower water close to the western Adriatic coast (less than 20 km), all the potential effects appeared accelerated. In fact, the recovery of natural soft-bottom communities from the initial defaunation and the mussel mound’s development started 7-8 months and about 1.5 years after the drilling operations, respectively (Fabi et al., 2005, 2007; Spagnolo et al., 2002, 2006). The higher variability of the environmental parameters and the frequent sediment mixing due to sea storms and currents typical of these near shore areas seem to be the main factors

1 that induced a major population dynamic reducing all the effects' duration. As a matter of fact, a
2 slight difference in the time of recovery was also highlighted between pC and pB, located at similar
3 depth but 35 km and 56 km offshore respectively.

4 The homogeneity observed from 30 m up to the farther distances from the platforms during
5 the third sampling year after installation agrees with what was previously reported for other
6 offshore structures located in the same area (Fabi et al., 2005, 2007; Spagnolo et al., 2002, 2006)
7 and indicates that, despite the different environmental features, a 3-year monitoring planning can be
8 effective to evaluate the potential impact on benthic communities of offshore gas platforms in the
9 north-central Adriatic Sea.

10 From the ecological point of view, the increased seabed heterogeneity due to shells,
11 fragments and dead organisms falling for natural dislodgement or structure cleaning, associated to
12 the physical extension along the water column, make the platforms a unique habitat. Many aquatic
13 organisms, indeed, can settle on these substrates or gather around them either for orientation,
14 protection and/or greater food availability (e.g., Bomkamp et al., 2004; Fabi et al., 2004; Neira,
15 2005; Page et al., 1999, 2007; Stanley and Wilson, 1997; Wolfson et al., 1979). As a consequence,
16 after the first impact caused by the installation and drilling operations, the offshore platforms can
17 play an important ecological role in areas characterized by flat soft bottoms and relatively small
18 amount of natural reef habitat like the Adriatic Sea, inducing a diversification and an enrichment of
19 both the natural benthic and finfish communities.

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References

- Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance. *Australian Ecology* 26, 32–46.
- Anderson, M.J., Willis, T.J., 2003. Canonical analysis of principal coordinates: a useful method of constrained ordination for ecology. *Ecology* 84, 511-525.
- Boldrin, A., Carniel, S., Giani, M., Marini, M., Bernardi Aubry, F., Campanelli, A., Grilli, F., Russo, A., 2009. Effects of bora wind on physical and biogeochemical properties on stratified waters in the northern Adriatic. *Journal of Geophysical Research* 114, C08S92, doi:10.1029/2008JC004837.
- Bomkamp, R.E., Page H.M., Dugan, J.E., 2004. Role of food subsidies and habitat structure in influencing benthic communities of shell mounds at sites of existing and former offshore oil platforms. *Marine Biology* 146, 201-211.
- Brighenti, G., Macini, P., Mesini, E., 2003. Environment and sustainable management of hydrocarbons. *Proc. 4th European Congress on Regional Geoscientific Cartography and Information Systems I*, 69-71.
- Cameron, C., Florence, A., Temple, C., 2004. Water-based drilling fluid helps achieve oil-mud performance. *American Association of Drilling Engineers*, 1-6.
- Cattaneo, A., Correggiari, A., Langone, R., Trincardi, F., 2003. The late-Holocene Gargano subaqueous delta Adriatic shelf: sediment pathways and supply fluctuations. *Marine Geology* 193, 61-91.

- Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure. *Australian Journal of Ecology* 18, 117-143.
- Clarke, K.R., Warwick, R.M., 2001. Change in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, UK.
- Crema, R., Caselli, A., Prevedelli, D., 1991. Long term eutrophication effects on macrofaunal communities in Northern Adriatic Sea. *Marine Pollution Bulletin* 22, 503-508.
- Currie, D.R., Isaacs, L.R., 2005. Impact of exploratory offshore drilling on benthic communities in the Minerva gas field, Port Campbell, Australia. *Marine Environmental Research* 59, 217-233.
- De Biasi, A.M., Pacciardi, L., Fabi, G., 2008. Effetti di alcune variabili nominali sui metalli pesanti di otto piattaforme estrattive nel Mar Adriatico. *Biologia Marina Mediterranea* 15(1), 416-417.
- De Biasi, A.M., Fabi, G., Pacciardi, L., Puletti, M., 2007. Heavy metals and polycyclic aromatic hydrocarbons near an offshore gas-platform (Adriatic Sea): a 3 year monitoring study. *Atti Società Toscana Scienze Naturali, Memorie, Serie B* 114, 23-33.
- De Biasi, A.M., Fabi, G., Pacciardi, L., Spinelli, O., Micheli, R., Puletti, M., De Ranieri, S., 2006. Metalli pesanti e idrocarburi policiclici aromatici in prossimità di una piattaforma di estrazione: 3 anni di osservazioni (Adriatico settentrionale). *Biologia Marina Mediterranea* 13(2), 332-333.
- Ellis, J.I., Schneider, D.C., 1997. Evaluation of a gradient sampling design for environmental impact assessment. *Environmental Monitoring Assessment* 48, 157-172.
- Fabi, G., Ausili, S., Campanelli, A., De Biasi, A., Fornasiero, P., Grati, F., Grilli, F., Marini, M., Panfili, M., Paschini, E., Puletti, M., Scarcella, G., Spagnolo, A., 2005. Evaluation of the ecological impact of gas platforms in the Adriatic Sea. *Libro de Ponencias II Congreso Internacional de Ciencia y Tecnología Marina - Oceanos III Millennium Tomo I*. Editorial C.P.D., Madrid, 127-139.

- Fabi, G., Da Ros, L., De Biasi, A.M., Manoukian, S., Nasci, C., Puletti, M., Punzo, E., Spagnolo, A., 2007. Environmental impact of gas platforms in the Northern Adriatic Sea: a case study. *Rapport de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 38, 471.
- Fabi, G., Grati, F., Puletti, M., Scarcella, G., 2004. Effects on fish community induced by the installation of two gas platforms in the Adriatic Sea. *Marine Ecology Progress Series* 273, 187-197.
- Fascari, F., Rosso, G., Bortoluzzi, G., Barbanti, A., Ravaioli, M., Bonvicini Pagliai, A.M., Crema, R., Castelli, A., Mauri, M., Zunarelli, R., Orlando, E., Prevedelli, D., Ceffa, L., Ratti, S., 1991. Uno studio sull'impatto dell'attività di perforazione in ambiente marino. *Atti della Società Italiana di Ecologia (S.It.E.)* 12, 761-767.
- Fascari, F., Rosso, G., Bortoluzzi, G., Barbanti, A., Bonvicini Pagliai, A.M., Crema, R., Castelli, A., Mauri, M., Zunarelli, R., Orlando, E., Prevedelli, D., Ceffa, L., Ratti, S., 1992. Environmental impact of water based drilling muds and cuttings in a northern Adriatic Sea site. *Bulletin de l'Institut Océanographique, Monaco* 11, 305-324.
- George, D.A., Hill, P.S. and Milligan, T.G., 2007. Flocculation, heavy metals (Cu, Pb, Zn) and the sand-mud transition on the Adriatic continental shelf, Italy. *Continental Shelf Research* 27, 475-488.
- Ghisel, R.G., 1997. *Years of Offshore Oil, Gas Development*. Hart Publications, Houston.
- Grant, A., Briggs, A.D., 2002. Toxicity of sediments from around a North Sea oil platform: are metals or hydrocarbons responsible for ecological impacts? *Marine Environmental Research* 53, 95-116.
- Gray, J.S., Bakke, T., Beck, H.J. Nilssen, I., 1999. Managing the environmental effects of the Norwegian oil and gas industry: from conflict to consensus. *Marine Pollution Bulletin* 38, 525-530.

- 1 Grilli, F., Marini, M., Degobbis, D., Ferrari, C.R., Fornasiero, P., Russo, A., Gismondi, M.,
2 Djakovac, T., Precali, R., Simonetti, R., 2005. Circulation and horizontal fluxes in the
3 northern Adriatic Sea in the period June 1999–July 2002. Part II: Nutrients transport. *Science*
4 *of the Total Environment* 353, 115–125.
- 5 Guerzoni, S., Frignani, M., Giordani, P., Frasari, F., 1984. Heavy metals in sediments from different
6 environments of a northern Adriatic Sea area, Italy. *Environmental Geology and Water*
7 *Sciences* 6, 111-119.
- 8 Harris, C.K., Sherwood, C.R., Signell, R.P., Bever, A.J. and Warner, J.C., 2008. Sediment dispersal
9 in the northwestern Adriatic Sea. *Journal of Geophysical Research* 13, C11S03, 1-18.
- 10 Hernández Arana, H.E., Warwick, R.M., Attrill, M.J., Rowden, A.A., Gold-Bouchot, G., 2005.
11 Assessing the impact of oil-related activities on benthic macrofauna assemblages of the
12 Campeche shelf, southern Gulf of Mexico. *Marine Ecology Progress Series* 289, 89-107.
- 13 Kingston, P.F. 1987. Field effects of platform discharges on benthic macrofauna. *Philosophical*
14 *Transactions of Royal Society London* B316, 545-555.
- 15 Kneib, R.D., Weeks, C.A., 1990. Intertidal distribution and feeding habits of the mud crab *Eurytium*
16 *limosum*. *Estuaries* 13, 462-468.
- 17 Kröncke, I., 1995. Long-term changes in North Sea benthos. *Senckenbergiana Maritima* 26, 73-80.
- 18 Legendre, P., Legendre, L., 1998. *Numerical Ecology: Developments in Environmental Modelling*
19 20 (2nd Edition). Elsevier Science B.V., The Netherlands.
- 20 Lindman, H.R., 1992. *Analysis of variance in experimental design*. Springer-Verlag, New York.
- 21 Love, M.S., Caselle, J., Snook, L., 1999. Fish assemblages on mussel mounds surrounding seven oil
22 platforms in the Santa Barbara Channel and Santa Maria Basin. *Bulletin of Marine Science*
23 65, 497-513.
- 24 Lu, L., Wu, R.S.S., 2000. An experimental study on recolonization and succession of marine
25 macrobenthos in defaunated sediment. *Marine Biology* 136, 291-302.
- 26 Maggi, C., Trabucco, B., Mannozi, M., Manfra, L., Gabellini, M., Di Mento, R., Nonnis, O., Virno

Lamberti, C., Cicero, A.M., 2007. A methodology approach to study the environmental impact of oil and gas offshore platforms. *Rapport de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée* 38, 688.

Magi, E., Bianco, R., Ianni, C., Di Carro, M., 2002. Distribution of polycyclic hydrocarbons in the sediments of the Adriatic Sea. *Environmental Pollution* 119, 91-98.

Marini, M., Jones, B.H., Campanelli, A., Grilli, F., Lee, G.M., 2008. Seasonal variability and Po River plume influence on biochemical properties along western Adriatic coast. *Journal of Geophysical Research* 113, C05S90, doi:10.1029/2007JC004370.

McArdle, B.H., Anderson, M.J., 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* 82, 290-297.

Montagna P., Harper D.E. Jr., 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. *Canadian Journal of Fishery and Aquatic Sciences* 53, 2567-2588.

Neira, F.J., 2005. Summer and winter plankton fish assemblages around offshore oil and gas platforms in south-eastern Australia. *Estuarine, Coastal and Shelf Science* 63, 589-604.

OGP. 2005. Facts, figures and expectations for the Green Paper on a European Maritime Policy. www.ogp.org.uk.

Olsgard, F., Gray, J.S., 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Marine Ecology Progress Series* 122, 277-306.

Olsgard, F., Somerfield, P.J., Carr, M.R., 1997. Relationships between taxonomic resolution and data transformations in analyses of a macrobenthic community along an established pollution gradient. *Marine Ecology Progress Series* 149, 173-181.

Page, H.M., Dugan, J.E., Dugan, D.S., Richards, J.B., Hubbard, D.M., 1999. Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. *Marine Ecology Progress Series* 185, 47-57.

- 1 Page, H.M., Dugan, J.E., Schroeder, D.M., Nishimoto M.M., Love, M.S., Hoesterey, J. C., 2007.
2 Trophic links and condition of a temperate reef fish: comparisons among offshore oil platform
3 and natural reef habitats. *Marine Ecology Progress Series* 344, 245-256.
- 4 Pearson, T.H., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and
5 pollution of the marine environment. *Oceanography and Marine Biology. An Annual Review*
6 16, 229-311.
- 7 Peterson, C.H., Kennicutt, M.C., Green, R.H., Montagna, P., Harper, D.E., Powell, E.N., Roscigno,
8 P.F., 1996. Ecological consequences of environmental perturbations associated with offshore
9 hydrocarbon production: a perspective on long-term exposures in the Gulf of Mexico.
10 *Canadian Journal of Fishery and Aquatic Sciences* 53, 2637-2654.
- 11 Pinder, D., 2001. Offshore oil and gas: global resource knowledge and technological change. *Ocean*
12 *and Coastal Management* 44, 579-600.
- 13 Rabalais, N.N., McKee, B.A., Reed, D.J., Means, J.C., 1992. Fate and effects of produced water
14 discharges in coastal Louisiana, Gulf of Mexico, USA. In: Ray, J.P., Engelhart, F.R. (Eds.),
15 *Produce water*. Plenum Press, New York, pp. 355-369.
- 16 Simpson, H.E., 1949. Measurement of diversity. *Nature* 163, 688.
- 17 Spagnolo, A., Panfili, M., Giampieri, A., Spegne, R., Trovatelli, L., 2002. Cambiamenti indotti sulla
18 comunità bentonica di fondo mobile da una piattaforma estrattiva offshore (Adriatico
19 settentrionale). *Biologia Marina Mediterranea* 9, 191-198.
- 20 Spagnolo, A., Ausili, S., Fabi, G., Manoukian, S., Puletti, M., 2006. Realizzazione di una
21 piattaforma estrattiva offshore: effetti sul macrozoobenthos di fondo mobile. *Biologia Marina*
22 *Mediterranea* 13, 60-61.
- 23 Stachowitsch, M., Kikinger, R., Herler, J., Zolda, P., Geutebrück, E., 2002. Offshore oil platforms
24 and fouling communities in the southern Arabian Gulf (Abu Dhabi). *Marine Pollution*
25 *Bulletin* 44, 853–860.
- 26 Stanley, D.R., Wilson, C.A., 1997. Seasonal and spatial variation in the abundance and size

- distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. Canadian Journal of Fishery and Aquatic Sciences 54, 1166–1176.
- Terlizzi, A., Bevilacqua, S., Scuderi, D., Fiorentino, D., Guranieri, G., Giangrande, A., Licciano, M., Felling, S., Fraschetti, S., 2008. Effects of offshore platforms on soft-bottom macrobenthic assemblages: A case study in a Mediterranean gas field. Marine Pollution Bulletin 56, 1303-1309.
- Thayer, S.A., Haas, R.C., Douglas Hunter, R., Kushler, R.H., 1997. Zebra mussel (*Dreissena polymorpha*) effects on sediment, other zoobenthos, and the diet and growth of adult yellow perch (*Perca flavescens*) in pond enclosures. Canadian Journal of Fishery and Aquatic Sciences 54, 1903-1915.
- Trabucco, B., Cicero, A.M., Gabellini, M., Virno Lamberti, C., Di Mento, R., Bacci, T., Moltedo, G., Tomassetti, P., Panfili, M., Marusso, V., Cornello, M., 2006. Studio del popolamento macrozoobentonico di fondo mobile in prossimità di una piattaforma offshore (Adriatico centrale). Biologia Marina Mediterranea 13, 659-662.
- Trabucco, B., Bacci, T., Marusso, V., Lomiri, S., Vani, D., Marzialetti, S., Cicero, A.M., Di Mento, R., De Biasi, A.M., Gabellini, M., Virno Lamberti, C., 2008. Studio della macrofauna attorno alle piattaforme oo-shore in Adriatico centrale. Biologia Marina Mediterranea 15, 141-143.
- Underwood, A.J., 1996. Detection, interpretation, prediction and management of environmental disturbances: Some roles for experimental marine ecology. Journal of Experimental Marine Biology and Ecology 200, 1-27.
- Warburg, M.R., Schwartz, Y., 1993. Intra- and interspecific relationships within a crab community of the intertidal rocky shore in the Eastern Mediterranean. Proceedings of the fourth Colloquium Crustacea Decapoda Mediterranea. Bios, Macedonia, Greece 1, 33-47.
- Wilson-Ormond, E.A., Elliss, M.S., Powell, E.N., Kim, Y., Li S-I., 2000. Effects of gas-producing platforms on continental shelf megafauna in the Northwest Gulf of Mexico: reproductive status and health. Int. Rev. Hydrobiologia 85, 299-323.

- 1 Wolfson, A., VanBlaricom, G., Davis, N., Lewbel, G.S., 1979. The marine life of an offshore oil
- 2 platform. Marine Ecology Progress Series 1, 81-89.
- 3 Zariquiey Alvarez, R., 1968. Crustáceos decápodos ibéricos. Investigación Pesquera 32, 1-510.

1 **Figure captions**

2 **Fig. 1.** Study area and position of the two investigated gas platforms, Barbara NW (pB) and Calipso
3 (pC).

4 **Fig. 2.** Univariate indices of macrofaunal communities at each distance (5, 30, 60, 120, and 1000 m)
5 for both pB and pC during the three monitoring years. S_m = mean species richness (number of
6 species $\pm$ SD); N = mean abundance (number of specimens $0.105 \text{ m}^{-2} \pm$ SD); λ = mean Simpson
7 index ($\pm$ SD).

Table 1

PERMANOVA analyzing differences among assemblages at increasing distance from platforms during the three monitoring years based on Gower exc 0-0 similarity

Source of variability	d.f.	SS	MS	<i>F</i>	<i>p</i>
Distance = Di	4	15937.00	3984.20	0.94852	0.5665
Year = Ye	2	22416.00	11208.00	1.05590	0.5356
Platform = Pl	1	44032.00	44032.00	30.77900	0.0001
Di x Ye	8	15807.00	1975.90	1.00670	0.4865
Di x Pl	4	16802.00	4200.40	2.93610	0.0001
Ye x Pl	2	21230.00	10615.00	7.41980	0.0001
Di x Ye x Pl	8	15702.00	1962.70	1.37190	0.0008
Residual	210	3.0043E5	1430.60		

not significant $p > 0.05$; significant $0.05 \geq p > 0.01$; highly significant $p \leq 0.01$

Table 2

PERMANOVA analyzing separately differences among assemblages at increasing distance from each platform during the three monitoring years

Source of variability	d.f.	SS	MS	F	p
pB					
Distance = Di	4	26528.00	6632.00	3.25000	0.0001
Year = Ye	2	17769.00	8884.40	4.35380	0.0001
Di x Ye	8	25227.00	3153.40	1.54530	0.0001
Residual	105	2.1426E5	2040.60		
<i>Pair-wise tests for term Di x Ye</i>					
Ye 1	Ye 2	Ye 3			
5 m ≠ 30 m = 60 m = 120 m	5 m ≠ 30 m = 60 m = 120 m	5 m ≠ 30 m = 60 m = 120 m = 1000 m			
5 m ≠ 1000 m ≠ 30 m = 60 m = 120 m	5 m ≠ 1000 m ≠ 30 m				
	60 m = 120 m = 1000 m				
Source of variability	d.f.	SS	MS	F	p
pC					
Distance = Di	4	9140.50	2585.10	1.49010	0.0010
Year = Ye	2	26919.00	13459.00	8.78270	0.0001
Di x Ye	8	14601.00	1825.10	1.19100	0.0203
Residual	105	1.6091E5	1532.50		
<i>Pair-wise tests for term Di x Ye</i>					
Ye 1	Ye 2	Ye 3			
5 m = 30 m = 60 m = 120 m = 1000 m	5 m = 30 m = 60 m = 120 m = 1000 m	5 m ≠ 30 m = 60 m = 120 m = 1000 m			

not significant $p > 0.05$; significant $0.05 \geq p > 0.01$; highly significant $p \leq 0.01$

Table 3

Summary of SIMPER analysis for pB and pC

Species	Avg. ab.	Contr. %	Cum. %	Avg. dis. %	Species	Avg. ab.	Contr. %	Cum. %	Avg. dis. %		
Distances across years pB					Distances across years pC						
5 m					5 m						
<i>Prionospio malmgreni</i>	0.51	12.15	12.15	5 m vs 30 m	88.13	<i>Caulleriella caputesocis</i>	1.25	11.25	11.25	5 m vs 30 m	65.98
<i>Naticarius hebraeus</i>	0.52	9.50	21.65	5 m vs 60 m	88.52	<i>Marphysa bellii</i>	0.81	9.52	20.77	5 m vs 60 m	69.49
<i>Solemya togata</i>	0.57	8.15	29.80	5 m vs 120 m	89.57	<i>Sternaspis scutata</i>	0.80	8.38	29.15	5 m vs 120 m	70.44
<i>Myrtea spinifera</i>	0.72	6.83	36.63	5 m vs 1000 m	89.74	<i>Prionospio cirrifera</i>	0.67	7.43	36.58	5 m vs 1000 m	71.06
<i>Galathea intermedia</i>	0.56	5.88	42.51	30 m vs 60 m	61.20	<i>Hyala vitrea</i>	0.70	6.78	43.36	30 m vs 60 m	57.64
<i>Onuphis conchilega</i>	0.53	5.72	48.23	30 m vs 120 m	64.21	<i>Cirratulus filiformis</i>	0.73	6.64	50.00	30 m vs 120 m	58.67
30 m					30 m						
<i>Callianassa subterranea</i>	0.88	10.28	10.28	30 m vs 1000 m	65.47	<i>Marphysa bellii</i>	1.33	23.49	23.49	30 m vs 1000 m	58.42
<i>Capitella capitata</i>	0.89	9.75	20.73	60 m vs 120 m	59.86	<i>Hyala vitrea</i>	1.07	10.62	34.11	60 m vs 120 m	57.85
<i>Onuphis conchilega</i>	0.91	8.92	28.95	60 m vs 1000 m	60.00	<i>Lumbrineris impatiens</i>	0.68	8.37	42.48	60 m vs 1000 m	58.09
<i>Paralacydonia paradoxa</i>	0.79	7.68	36.63	120 m vs 1000 m	62.38	<i>Tharyx marioni</i>	0.81	6.80	49.29	120 m vs 1000 m	56.49
<i>Nephtys hystricis</i>	0.79	6.74	43.37								
<i>Alpheus glaber</i>	0.66	6.64	50.01								
60 m					60 m						
<i>Callianassa subterranea</i>	1.12	13.46	13.46			<i>Marphysa bellii</i>	1.27	27.18	27.18		
<i>Nephtys hystricis</i>	1.13	13.39	26.85			<i>Hyala vitrea</i>	1.00	13.51	40.69		
<i>Capitella capitata</i>	0.94	8.38	35.23			<i>Callianassa subterranea</i>	0.71	8.57	49.26		
<i>Paralacydonia paradoxa</i>	0.94	8.09	43.32								
<i>Onuphis conchilega</i>	0.85	7.62	50.95								
120 m					120 m						
<i>Callianassa subterranea</i>	1.12	13.46	13.46			<i>Marphysa bellii</i>	1.13	21.25	21.25		
<i>Nephtys hystricis</i>	1.13	13.39	26.85			<i>Hyala vitrea</i>	1.10	16.21	37.45		
<i>Onuphis conchilega</i>	0.94	8.38	35.23			<i>Lumbrineris impatiens</i>	0.61	9.31	46.76		
<i>Paralacydonia paradoxa</i>	0.94	8.09	43.32			<i>Callianassa subterranea</i>	0.66	8.55	55.31		
<i>Capitella capitata</i>	0.85	7.62	50.95								
1000 m					1000 m						
<i>Nephtys hystricis</i>	1.39	23.54	23.54			<i>Marphysa bellii</i>	1.10	15.58	15.58		
<i>Callianassa subterranea</i>	1.31	19.88	43.42			<i>Hyala vitrea</i>	1.20	11.23	26.81		
<i>Capitella capitata</i>	0.83	10.13	53.54			<i>Lumbrineris impatiens</i>	0.73	10.57	37.38		
						<i>Callianassa subterranea</i>	0.93	10.14	47.52		
						<i>Cirratulus filiformis</i>	0.67	7.37	54.89		

Table 3

Continue

Species	Avg. ab.	Contr. %	Cum. %	Avg. dis. %		Species	Avg. ab.	Contr. %	Cum. %	Avg. dis. %	
Years across distances pB						Years across distances pC					
1 st year						1 st year					
<i>Callianassa subterranea</i>	0.83	12.78	12.78	1 st vs 2 nd year	69.90	<i>Marphysa bellii</i>	0.86	30.44	30.44	1 st vs 2 nd year	78.41
<i>Nephtys hystricis</i>	0.75	12.47	25.25	1 st vs 3 rd year	76.05	<i>Labidoplax digitata</i>	0.53	13.05	43.49	1 st vs 3 rd year	79.03
<i>Onuphis conchilega</i>	0.87	11.04	36.29	2 nd vs 3 rd year	71.24	<i>Hyala vitrea</i>	0.62	11.45	54.94	2 nd vs 3 rd year	60.37
<i>Alpheus glaber</i>	0.52	6.44	42.74								
<i>Paralacydonia paradoxa</i>	0.60	6.38	49.12								
<i>Sternaspis scutata</i>	0.48	6.12	55.30								
2 nd year						2 nd year					
<i>Nephtys hystricis</i>	1.08	12.62	12.62			<i>Marphysa bellii</i>	1.19	24.58	24.58		
<i>Callianassa subterranea</i>	1.09	11.99	24.61			<i>Lumbrineris impatiens</i>	0.90	15.40	39.98		
<i>Onuphis conchilega</i>	1.16	11.33	35.95			<i>Callianassa subterranea</i>	0.80	11.01	50.99		
<i>Capitella capitata</i>	0.89	9.06	45.01			<i>Hyala vitrea</i>	0.69	6.75	57.74		
<i>Paralacydonia paradoxa</i>	0.72	5.69	50.70								
3 rd year						3 rd year					
<i>Callianassa subterranea</i>	0.89	16.10	16.10			<i>Hyala vitrea</i>	1.73	15.48	15.48		
<i>Nephtys hystricis</i>	0.83	13.35	29.45			<i>Cirratulus filiformis</i>	1.55	13.13	28.61		
<i>Capitella capitata</i>	0.84	11.38	40.83			<i>Marphysa bellii</i>	1.33	11.76	40.38		
<i>Onuphis eremita</i>	0.74	8.24	49.07			<i>Caulleriella caputesocis</i>	1.55	10.82	51.20		
<i>Paralacydonia paradoxa</i>	0.72	7.51	56.58								

Average abundances (Avg. ab.), % contribution (Contr.), and % cumulative contribution (Cum.) to the average similarity are given for each species within distance groups and year groups. Only species reaching the cumulative contribution of about 50% are reported. % average dissimilarities (Avg. dis.) between distance and year groups are also pointed out.

Table 4

Summary of 3-way ANOVA applied to mean values of mean species richness (S_m), mean abundance (N), and mean Simpson index (λ) per each distance during the three monitoring years

Source of variability	d.f.	S_m			N			λ		
		MS	F	p	MS	F	p	MS	F	p
Distance = Di	4	56.16	1.66968	0.3158	0.33	2.72861	0.1772	0.09	4.5624	0.0015
Year = Ye	2	1005.65	2.74148	0.2673	4.14	1.87247	0.3481	0.34	16.4272	0.0001
Platform = Pl	1	250.10	6.86101	0.0095	0.07	1.15466	0.2838	0.47	22.4301	0.0001
Di x Ye	8	219.69	3.93937	0.0348	0.61	7.12767	0.0059	0.07	3.4380	0.0010
Di x Pl	4	33.64	0.92271	0.4516	0.12	1.97517	0.0995	0.01	0.5387	0.7074
Ye x Pl	2	366.83	10.06308	0.0001	2.21	36.66851	0.0000	0.11	5.4710	0.0048
Di x Ye x Pl	8	55.77	1.52983	0.1484	0.09	1.40891	0.1942	0.02	0.8098	0.5946

not significant $p > 0.05$; significant $0.05 > p > 0.01$; highly significant $p < 0.01$

Table 5

Summary of 2-way ANOVAs for pB and pC applied to mean values of mean species richness (S_m), mean abundance (N), and mean Simpson index (λ) per each distance during the three monitoring years

Source of variability	d.f.	S _m			N			λ		
		MS	F	P	MS	F	P	MS	F	P
pB										
Distance = Di	4	24.62	0.53140	0.7130	0.07	1.25200	0.2936	0.064	5.8516	0.0003
Year = Ye	2	158.31	3.41730	0.0365	0.54	9.49700	0.0002	0.036	3.2701	0.0419
Di x Ye	8	183.33	3.95740	0.0004	0.26	4.56700	0.0001	0.023	2.1459	0.0377
pC										
Distance = Di	4	65.18	2.45220	0.0505	0.37	5.80900	0.0003	0.04	1.3678	0.250
Year = Ye	2	1214.18	45.68040	0.0000	5.82	90.44400	0.0000	0.42	13.7004	0.001
Di x Ye	8	95.12	3.4659	0.0014	0.43	6.73900	0.0000	0.06	2.1160	0.041

(Log +1) transformation for N

not significant $p > 0.05$; significant $0.05 > p > 0.01$; highly significant $p < 0.01$

>> highly significant; > significant