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The Impacts of Offshore Oil Exploration and Development on Macrobenthos Community：A Case Study in Chengdao Oil Field

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Abstract

Univariate and multivariate methods were used to study macrobenthos collected in October 2012 from the area around a new built offshore oil platform. The univariate parameters and community structure of benthic communities were related to environmental variables. Samples were taken with a 0.1 m^2 Van Veen grab (33×30 ×15 cm) at each station from 15 sampling stations. The mean values of species number, abundance and species diversity (*H'*) were 25 species/grab, 104 animals/grab and 3.12/grab, respectively. A total of 142 species was recorded. Total petroleum hydrocarbons and heavy metal were strongly positively related to species number, abundance and species diversity, suggesting that petroleum hydrocarbons have harmful effects on macrobenthic communities. The BIO-ENV analyses for all stations identified COD, heavy metal and petroleum hydrocarbons as the major environmental variables influencing the infaunal patterns. However, separate analyses for two groups produced stronger correlations and different best-correlated environmental variable combinations.

Keywords: Macrobenthic community, Environmental variable, Offshore platform

1. Introduction

The extraction of fossil fuels from offshore fields largely increased in the last five decades, becoming the leading activity in the exploitation of marine mineral resources (Ghisel, 1997). As a result, thousands of offshore platforms proliferated over the world’s oceans and much more will likely be implemented in the future (DeLuca, 1999; Pulsipher & Daniel, 2000), representing a threat for coastal and deep-sea systems.

Offshore platforms and associated production activities could cause strong environmental impacts related to drilling mud discharges, hydrocarbon associated waters or involved artificial structures (Raimondi et al., 1997; Grant & Briggs, 2002; Holdway, 2002; Schroeder & Love, 2004). As a consequence, the seafloor around platforms could show increased levels of pollutants (e.g., hydrocarbons, heavy metals, organic enrichment), and/or changes in its physical features (e.g., sediment granulometry, sedimentation rates, water movements) (Olsgard & Gray, 1995; Kennicutt et al., 1996; Barros et al., 2001). The magnitude of such perturbations, and the associated effects on benthic assemblages, could vary depending on the complex interactions among local environmental factors and specific features of platforms (e.g., Bakke et al., 1990; Ellis et al., 1996; Wilson-Ormond et al., 2000).

Environmental assessments of offshore platform impact havebeen mostly based on soft-bottom macrofauna assemblages (Kingston, 1987). Generally, benthic assemblages closer to platforms may experience reduced diversity and changes in species’ abundance, whereas, further away, assemblages may return to amore similar, but still detectably different structure, from that in the surrounding unaffected area (Grant & Briggs, 2002). Even though the impact may extend up to 6000 m from the source (Olsgard & Gray, 1995), effects on assemblages have been usually found up to 3000 m from platforms, with the more severe effects within 500 m radius (Kingston, 1987; Olsgard et al., 1997; Gray et al., 1999). Such findings come essentially from studies carried out in the North Sea, whilst elsewhere, such as the Gulf of Mexico, more localized effects, acting within a 200–800 m radius from platforms, have been reported (e.g., Montagna & Harper, 1996).

Approximately 50% of China’s offshore oil and gas production are located in the Bohai bay. Considering large structure only, this area accounts for more than 240active offshore platforms and is likely to represent the Chinese area of greater expansion of offshore activities in the future. To date, to our knowledge, in the Bohai bay no efforts have been paid towards the environmental impact assessment of offshore platforms on the biodiversity and community structure of macrobenthic assemblages. This study is an attempt in this direction.

2. Materials and Methods

2.1 The Survey Site

The study area was located in the Bohai bay, within a oil field off of Dongying (38°20′N, 118°54′E). The offshore platform (hereafter indicated as CBG-110) was placed in this area for gas drilling after our first investigate. The offshore platform had high legs structure and was positioned about 17 km away from the coast, on mud flats at about 20 m depth.

2.2 Experimental Design

There cruises was taken during the exploration. The survey area is a rectangle, and the platform is in the center of this area. 15 stations were set up in this area，the distance of every 2 adjacent stations was 1 km (Figure 1). Stations are located using a recently GPS system. A total of 15boxcores were taken at each station during each cruise. At each station samples were taken with a Van Veen Grab（$0.1m^2$）with 2 replicates for analyses of macrobenthos and 3 replicates for analyses of sediment variables. The biological samples were extracted using 1 mm mesh sieves and the material fixed in formalin and analyzed in the laboratory. For physical and chemical analyses subsamples were taken from the top of the grab, using the upper 5cm for physical and chemical analyses. Upon retrieval, 50 ml of sediment was sampled from each replicates, and particle size determined by a dry sieve method. Samples for metal analyses were placed directly in PVC containers and frozen at -20℃. The following heavy metal were routinely determined: Cu, Zn, Cd, Sr, Hg, As. Samples for hydrocarbons were wrapped in aluminium foil and frozen at -20℃ for subsequent analyses of total hydrocarbon content (THC).

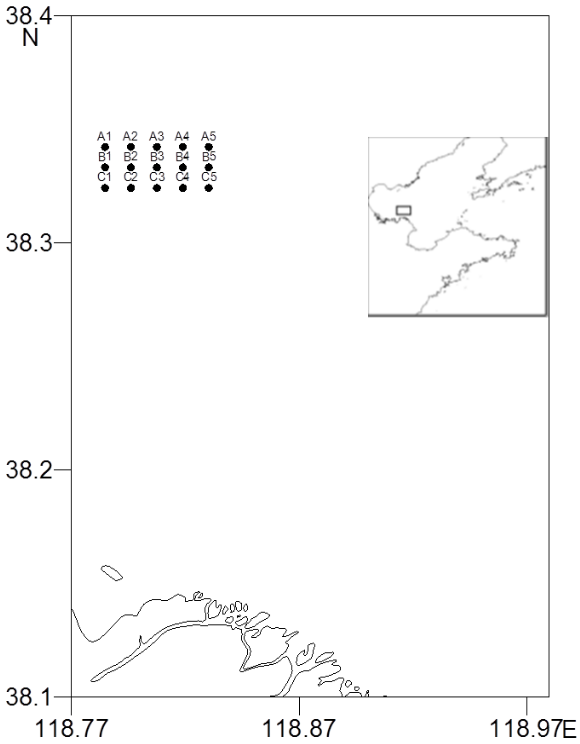

Figure 1. Area of survey with the locations of 15 sampling stations

2.3 Date Processing

Dominant species in each sampling were identified by rank-score analysis (Fager, 1957). The ten most abundant species were ranked with the most abundant species receiving the highest numerical rank. Biological Index (BI) for each species was calculated by summing the values of each replicate for each sampling.

Species diversity of each sample was calculated using Shannon–Wiener's index (H') (Shannon & Weaver, 1963):

$$H' = -\sum_{i=1}^{S} \frac{N_i}{N} log_2 \left(\frac{N_i}{N_i}\right),$$

where S=the number of species in the sample, N= the total number of individuals, and N_i=the number of individuals in the ith species (i=1 to S).

Evenness of each sample was calculated using Pielou's index (J) (Pielou, 1966):

$$J' = \frac{H'}{log_2 S}$$

where *H'*= Shannon-wiener's index and *S*= the number of species.

Mapping of environmental and biological variables in the studied area was executed with the Surfer v.7 software, using kriging as the griding method. Hierarchical clustering with group-average linking was applied to abiotic and biotic data. For sediment characteristics, Normalised Euclidean Distances were used and data were ln-transformed. For species abundance, Bray–Curtis similarities were used and data were 4th root transformed. The software PRIMER (Clark & Warwick, 1994) was used in this analysis. Other multivariate methods available in this software package, such as PCA and MDS, were applied to the data set, but no clearer interpretation could be inferred.

Spearman rank coefficient (ρs) was used to establish correlations between biological parameters and sediment characteristics. This is one method to test for the significance of association between two variables that do not conform to a bivariate normal distribution (Sokal & Rohlf, 1995). This analysis was done using the software Statistic0.99 edition.

BIO-ENV procedure enable the selection of the abiotic variable subset that maximises the rank correlation (ρ) between biotic and abiotic (dis)similarity matrices. In this study, combinations of the eight-environment variables were considered at steadily increasing levels of complexity, i.e. k variables at a time (k=1,2,3,. . .,8), yielding the best matches of biotic and abiotic (dis)similarity matrices for each k, as measured by Spearmanrank coefficient (s). The software PRIMER (Clark & Warwick, 1994) was used in this analysis.

3. Result

3.1 Macrobenthic Community Structure

Cluster analysis, based on the species abundance, allowed the identification of three groups of stations, at the similarity level of 40% (Figure 2). Group Acombines five stations close to the platform, presenting medium to low numbers of individuals belonging to a low number of species. These stations indicate lower diversities and dominance. Group B, characterized by high numbers of individuals and species, includes 8 stations mainly away from the central zone of the platform. Group C includes only one station characterized by a very low number of individual and species. The MDS plot also shows the differences between sites (Figure 3).

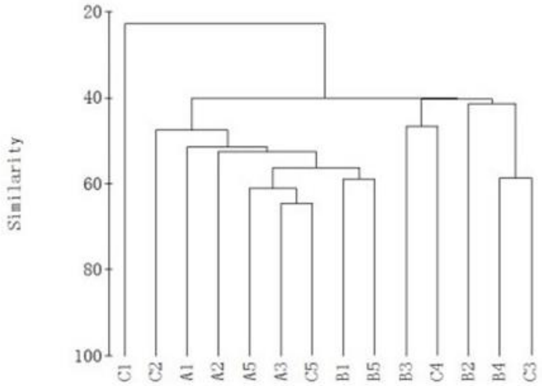

Figure 2. Dendrogram for hierarchical clustering, showing similarities of macrobenthic samples during the studyperiod

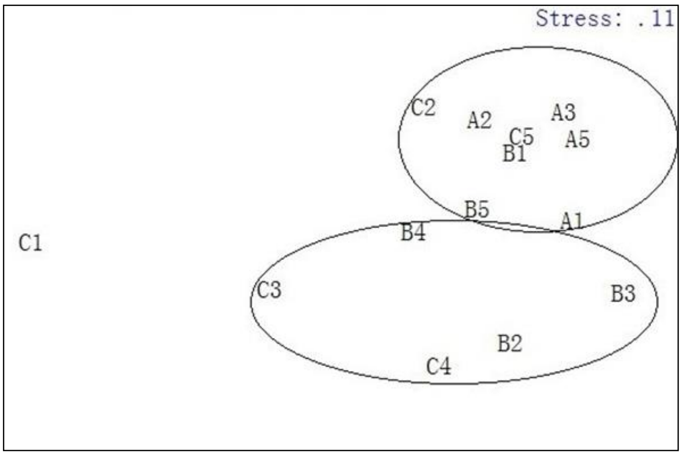

Figure 3. Non-metric MDS configuration of macrobenthic samples (stress = 0.11)

3.2 Abundance and Species Number

The total of 4032 specimens collected were characterized as 142 taxa of Mollusca (1803 individuals, 71 taxa), Polychaeta (807 individuals, 21 taxa), Crustacea (707 individuals, 24 taxa), Sipuncula (621 individuals, 19 taxa), Echinodermata (86 individuals, 6 taxa) and Nemertea (8 individuals, 1 taxon).

The ten most dominant species in each group, as identified by IRI, are shown in Table 1. In Group A, all the dominant species, except *Moerellairidescens*, Tanaidae, *Macomapraetexta*, were polychaets. Compared with Group A, the dominance of Polychaets decreased in Group B. Five taxa of macrobenthos dominant the sediment in Group B during the survey period.

Table1. The top 10 IRI in two different groups

Group A			Group B		
Taxa	Species name	IRI	Taxa	Species name	IRI
Ploychaetes	*Paralacydoniaparadoxa*	128	Ploychaetes	*Paralacydoniaparadoxa*	115
Nemertea	*Nemertinea*	108	Echinofrtmata	*Ophiuroidea*sp.1	83
Ploychaetes	*Paraprionospiopinnata*	87	Nemertea	*Nemertinea*	70
Ploychaetes	*Laonicecirrata*	75	Ploychaetes	*Sternaspisscutata*	53
Ploychaetes	*Sthenoiepis japonica*	62	Crustacea	Tanaidae	52
Ploychaetes	*Pseudopolydorakempi*	49	Mollusca	Bivalvia sp.	48
Echinofrtmata	*Ophiuroidea*sp.1	46	Crustacea	*Cirolanajaponensis*	45
Ploychaetes	*Cossurellaaciculata*	30	Ploychaetes	*Pseudopolydorakempi*	44
Mollusca	Bivalvia sp.	28	Ploychaetes	*Cossurellaaciculata*	43
Ploychaetes	*Spiomartinensis*	28	Ploychaetes	*Laonicecirrata*	42

3.3 Species Diversity

Species diversity was estimated based on Species number, *S*Margalef,*d*Pielou's index, *J*and Shannon-Wiener, *H'* ($\log_e$) indices. In Group B, S,d values, H'are significantly greater than these in group A. (Table 2).

Table 2. Biodiversity of macrobenthos indexs at different community

Group	*S*	*H’*	*d*	*J’*
Group A	18.60	3.90	2.70	0.93
Group B	32.75	4.54	4.21	0.90

3.4 Relations between Environmental and Biological Variables

Comparing dendograms for hierarchical clustering of environmental and biological variables enables the establishment of some relationships.

The same dis/similarity matrices used in cluster analysis, were used in the BIO-ENV procedure to select the combinations of environmental variables that best associates the stations in a consistent manner with the macrobenthic community structure. The single variable that best matches biological pattern was organic matter (s=0.30), followed by Hg (s=0.27) and Cu (s=0.24). The combination of these three variables constituted the overall optimum (s=0.37).

4. Discussion

At present, oceans are affected by many different human activities, but the understanding of how different stressors combine to impact marine ecosystems is very low (Halpern et al., 2008). The quantification and the interpretation of ecological impacts in human dominated landscape can be difficult especially when appropriate reference conditions are of difficult identification (Bulleri et al., 2007), as in this case.

Different contaminants may have distinct toxic modes of action and may, therefore, elicit very different, sometimes opposite, ecological responses. The study of Montagna and Harper (1996) in the Gulf of Mexico showed that the density of deposit-feeding polychaetes and nematodes increases (indicating organic enrichment), while the density of amphipods and harpacticoides decreases (indicating toxicity of contaminants, e.g., heavy metals and petroleum hydrocarbons) around three gas platforms. In the present experiment, the abundance and species number in Group A were significantly lower than those Group B, indicating that industrial wastes retarded the settlement and growth of juveniles of macrobenthic infauna. The higher abundance in the industrial-contaminated sediment in August 1996 may be explained by species-specific responses.

Total petroleum hydrocarbons were significantly relatively correlated with species number, abundance and diversity, suggesting harmful effects from petroleum hydrocarbons on macrobenthic communities in survey area. Petroleum hydrocarbons have long been known to be toxic to benthos, and they are persistent in sediments (Rudling, 1976). Hartwick et al. (1982) found that crude oil had harmful effects on the behavior of a bivalve. Lower densities and species numbers were found in defaunated sediment contaminated with petroleum hydrocarbons in experimental studies (Berge, 1990; Lu, 1999). Olsgard and Gray (1995) found that contamination of oil-based drill-cuttings in Norway caused reduction in key components of the benthic communities, and the impact persisted several years after cessation of drill-cutting discharge. Poulton et al. (1997) reported a decrease of macrobenthic diversity during an 18-month study following a crude oil spill and demonstrated the persistent effects of oil on the benthic community.

Analysis of correlation between macrobenthic communities and environmental variables for all the stations yielded low values of the rank correlation coefficient for the best single correlated variable (<0.3) and the best-correlated variable combination (<0.5), suggesting that the environmental variables affecting the benthic community structure may be different in different areas. Separate analyses of correlation for the two groups show higher values of ρ_w and difference in the best-correlated variable combinations. Heavy metal were among the major factors that best “explained” the pattern of macrobenthic infauna in Group A, while organic chemicals were dominant in the best-correlated variable combination even though there was considerable variation in sediment characteristics in Group B. No single mechanism has been able to explain faunal patterns observed across many different environments, and at any given location, a number of different interacting factors will be involved (Snelgrove & Butman, 1994). Total petroleum hydrocarbons were the only common factor in both areas, showing the importance of oil contamination in determining community structure of benthic infauna in survey area.

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