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A Survey of the Benthic Microfauna of the Marine Ecosystem on IRIS-1 Oil Platform at the Cape Skirring in Casamance, Senegal

Hamet Diaw Diadhiou[1], Mbaye Tine[2*], Anis Diallo[1] and et Mor Sylla[1]

[1]*ISRA /Oceanographic Research Center Dakar-Thiaroye, BP 2241, Dakar, Senegal*

[2]*UFR of Agricultural Sciences, Aquaculture and Food Technologies (UFR S2ATA), Gaston Berger University (UGB), Ngallele Road BP 234 Saint-Louis, Senegal*

***Corresponding author:** Mbaye Tine, UFR of Agricultural Sciences, Aquaculture and Food Technologies (UFR S2ATA), Gaston Berger University (UGB), Ngallele Road BP 234 Saint-Louis, Senegal; E-mail: mbaye.tine@ugb.edu.sn

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Abstract

Long-time suspected as having great natural resources of petroleum, oil was only discovered as recently as 2001 in the West African marine coastal ecosystem. The potential area harboring this offshore oil extends on six countries: Mauritania, Senegal, Gambia, Guinea Bissau, Guinea and Cape Verde. A large Shallow block called AGC Shallow is in offshore area located between Senegal and Guinea Bissau and has an offshore drilling called IRIS-1 drilling, which covers 1,700 km^2. Although these oil reserves are likely to generate significant new economic interests, especially for local communities living along the Senegalese coast to Guinea Bissau, their exploitation must take into account the biological and ecological potential side effects on aquatic ecosystems and their biological diversity. The objective of this study was to characterize the habitat and benthic fauna present in IRIS-1 drilling area. The results showed that the benthic microfauna around the IRIS-1 drilling point has a medium specific diversity of about 44 species with a more or less pronounced spatial variability. Marine mollusks, essentially sessile species, are the most abundant benthic species groups encountered. These organisms are quite sensitive to oil disturbances, which at long-term, may have serious effects on them. We suggest the proposed mitigation and mitigation measures for the IRIS-1 should focus on elements that are at least harmful to the environment and wildlife populations inhabiting the drilling zone. Dispersants may also be used to reduce the toxicity of products discharged into the sea.

Keywords Benthic fauna; IRIS-1 drilling; Oil exploration; Disturbance; Species diversity

Introduction

The West African region has been for long time suspected as having great natural resources of petroleum, but it is only in 2001 that oil was discovered in the West African marine coastal ecosystem [1]. The potential area harbouring this offshore oil covers 3,500 km of coast that extend on six countries: Mauritania, Senegal, Gambia, Guinea Bissau, Guinea and Cape Verde [1]. The extraction of this natural resource of petroleum and all related activities are certainly very beneficial for the six countries in terms of incomes for both governments and indigenous populations, especially those living along the coast [2-4]. However, oil extraction has had severe environmental and social consequences on populations inhabiting areas adjacent oil platforms [1,2,5,6]. The environmental degradations from offshore oil production include degradation of aquatic ecosystems and pollution of both marine air and drinking waters [5,7]. Such environmental degradations constitute a serious stress and health problems for aquatic organisms but also for human populations inhabiting areas surrounding oil platforms [5,7-10]. The ecological disturbances of oil production on aquatic organisms include destruction of habitats, degradation of wildlife and total or sever loss of biodiversity [10,11]. Amongst the adverse impact of oil exploitation is complete destruction of mangroves that are important feeding and spawning areas for fishes [12,13]. The area harbouring the oil resource in West African region corresponds to an important fishing zone with a unique wetland, where the up-welling of deep ocean waters to the surface, creates natural environmental conditions that are suitable for the development of fish species [1]. Many economically important fish species accomplish their entire life cycle in the waters of the six countries harboring this petroleum resources where fisheries is the main source of economic income and social development [14,15]. Along the West African coast, more than 10 millions of people are directly or indirectly dependent on fishing, fisheries and related industrial activities [16,17]. The touristic sector, which is also an important source of incomes, is quite developed in this area [18,19].

Environmental impact assessment studies, including habitat and fauna characterization prior to oil drilling, are necessary to ensure that the area harboring the petroleum reserves is not ecologically important or environmentally sensitive [20-22]. They can, therefore, prevent drilling in such areas [23-25]. Ecologically important areas are environments with high biological diversity that can be damaged by the construction of drilling facilities and related anthropogenetic threats [10,26,27]. Environmental sensitive ecosystems include areas inhabited by endangered species where oil drilling can increase the risk of extinction [1]. Environmental studies can also allow assessing damages caused offshore drilling accidents on aquatic ecosystems and biological diversity [10]. Therefore, initial habitat and fauna characterization is essential since it can help to take appropriate and sustainable environmental management plans for biodiversity restoration when oil drilling accident occurs in the exploitation zone or surrounding areas. Thus, the principal objective of this study was to characterize the habitat and benthic fauna present in IRIS-1 drilling area in Casamance, Senegal. Such an analysis of the benthic fauna is an important element for assessing the impact of oil drilling on the marine environment, especially in the areas where the benthic fauna is likely to be affected by the drilling of an offshore oil well. In fact, benthic fauna, especially sessile organisms, are very sensitive to the effects of pollutants that can annihilate them, degrade natural habitats, and modify trophic relationships between species. Hence, the main focus of this study is the assessment of the oil exploitation impacts on marine habitats and the specific composition of the benthic communities in IRIS-1 drilling area. In addition to these elements, a critical analysis of potential impacts of oil exploitations on benthic organisms and their implication on biodiversity loss was conducted.

Materials and Methods

Oil platform

The petroleum exploration in West African region started in the 1960 and 1970's and targeted the tops of certain domes in the Casamance salt basin. This prospection has resulted to the discovery of large heavy oil accumulation in the Tertiary-aged carbonates but also to significant light oil (~33° API) that was encountered in the Cretaceous Maastrichtian sandstones [1]. A large Shallow block located between Senegal and Guinea Bissau where oil and gas exploitation is controlled and regulated by the AGC (Agence de Gestion et de Cooperation avec le Senegal et la Guinee Bissao). It was then adware to Oryx Petroleum Corporation Limited Company in October 2011 for an initial four year of exploration period. This Shallow block called AGC Shallow is in offshore area and has an offshore drilling called IRIS-1 drilling, which covers 1,700 km^2 AGC Shallow [1]. Although these oil reserves are likely to generate significant new economic interests along the coast Senegal to Guinea Bissau, their exploitation must take into account the potential biological and ecological side effects on aquatic ecosystems and their biological diversity. Thus, an environmental and social impact assessment study was recommended inside the block AGC Shallow awarded to the Oryx Petroleum Corporation Limited consortium.

The study area: characteristics and fisheries activities

Cape Skirring, the mouth of Casamance River in Senegal-Guinea-Bissau border, covers an area of approximately 23 kilometres on the Atlantic coast. The sandy sea coasts are more frequent. The vase is present at the mouth of Casamance River and a little at the border with Guinea-Bissau. The climate is tropical and is characterized by a long dry season from November to Jun and a short rainy season from July to October. The annual precipitations are overall significant; with an average of 1400 mm. The tropical divergence oscillates within a range of latitudes concerning the Cape Skirring sector. The amplitude of these variations is high and the inter-annual variability is significant. Such a situation is due to the large-scale of meteorological and ocean balances. Supplementary Table 1 shows changes in salinity and temperature of water surface. From January to March, the salinity is largely stable at around 30 psu and is around 35 psu the rest of the year. Salinity varies slightly around that of ocean water. Decreases in water salinity often occur in the mixing zones at the mouths of rivers during and/or at the end of the rainy season. The surface water temperature, by contrast, depends on local climate, wind and water circulation in the area. The lowest values were observed between December and April.

Phylum	Species
Annelids	*Neanthes kerguelensis*
	Aphroditidea sp
	Serula narconensis
	Lumbrinerídea sp
	Oligochaetes
Chaetognaths	*Chaetognathe sp*
Crustaceans	*Euphausiids*
	Decapods sp
	Copepods
	Coryceaus
	Cumacea sp
	Larvae of crustaceans
Arthropods	*Serilis sp*
	Pedunculata sp
	Natatolana sp
Tanaids	*Tanaidacea sp*
	Apseudomorpha sp
Gastropod mollusks	*Cerithiopsidea sp*
	Buccinidea sp
	Turridea sp
	Cancellariidea sp
	Nassariidae sp
	Epitoniidea sp
	Gasteropodea sp
	Enixotiophan sp
	Epoitonidea sp
	Fissurellidea sp
Bivalve mollusks	*Crassatellidea sp*
	Nuculana sp
	Bivalvia sp
	Crasostrea gasar
	Kidderia sp
	Euciroa sp
	Opistotranchia sp
	Cyaniidae sp
	Galeommatidea sp
	Limopsidea sp
	Cardiidea
	Gouldiopa sp
Nematodes	*Priapulidea sp*

	Sipunculidea sp
	Pennatulacea sp
	Platyhelminthes sp
Broken eggs	*Fish?*
Turbelleria	*Turbellerea sp*
Chordate	*Sea squirts*
Bryozoa	*Lagunenchara lyrulan*

Table 1: List of species found in benthic wildlife harvesting in IRIS-1 drilling area.

The continental shelf of Cape Skirring like the rest of the Casamance maritime domain is very broad. The 200 meter isobaths is very far from shore, up to 100 km in the extreme south, toward the border with Guinea-Bissau. The vast majority of oceans seabed is tangible. The vase is visible in certain locations. Muddy with the bottom trawling. The majority of vast allows and fine sands account for a significant proportion. The rocks are scattered and may interfere algal cover of Cape Skirring area. The tide is semi-diurnal and the average tidal range is moderate (about one meter). The sea swell is generally low. A swell, current "long shore current" of around 1 ms^{-1} is observed in the area.

A total number of 78 species or groups of species, height of which covers more than 80% of the annual captures, are caught in Cape Skirring area. Supplementary Table 2 shows the relative importance of the main groups of species. Of the five types of fishing gear operating in Cape Skirring port, two represent nearly 99% of the total annual fishing effort. This includes fixed nets of soles (96%) and lobster (3%). A number of canoes based in Cape Skirring operate in Guinea-Bissau (Bijagos Archipelago). The annual landings from this country represented almost 30% of fish landed in this port in 1998. This percentage has certainly doubled due to the current scarcity of fisheries resources in Senegal. The southern part of Cape Skirring used by industrial fishing based in Dakar. Many fishing vessels targeting demersal fish operate in this area rich in fisheries resources.

Selection of sampling stations and sampling equipment

Ten sampling stations starting from the drilling point were selected for the sampling of benthic fauna (Figure 1). These sampling locations are positioned as a star at one km, then 5 km around the drilling zone. Supplementary Table 3 shows the geo-referenced coordinates. A conical dragging system of 160 cm^3 was used. It was preferred over the Van Veen grab, which by the nature of funds (soft mud), loses its contents during the ascent phase. The craft boarded a large canoe of Saint-Louis (Senegal) twenty meters long with two outboard motors (40 HP and 30 HP, respectively) allowed to scrape the surface of the background with the inhabiting organisms. To ensure proper operation of the dredge, a huge stone weighing one kg was used to weight the machine.

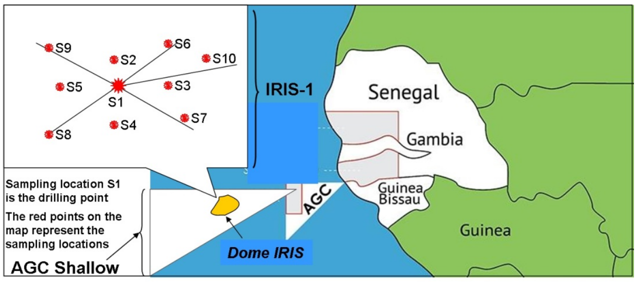

Figure 1: Sampling locations in IRIS-1 drilling zone.

Collection, sorting and counting of benthic fauna samples

The benthic fauna samples were collected in Jun 2014 at ten different stations of the IRIS-1 drilling zone. At least two replicas per station were carried out in each sampling campaign; the filtered samples are then stored in bottles and/or plastic bags and conserved in 95% alcohol and stored at 4°C in a fridge. The type of soil is described from samples taken and by visual observation during screenings (Supplementary Table 3). Laboratory analyses were conducted on all collected samples. Rose Bengal solution (protein dye) 1 g/l was added to the samples to allow a clear staining of individuals (biological tissue). This makes the counting easier and allows clear identification operations. All replicas are treated at biovolume measurements for each station. Each sample was split using the Matoda box to obtain aliquots and each sub-sample part was placed in a Dolfus cuve for counting and determination of individuals under a binocular microscope. Empty shells, debris, stones were not counted. Their percentage in the whole sample was estimated from the volume of organisms in the collected sediment. The species present in the different sediment samples collected in the studied sites are determined and classified by order, gender and family using benthic fauna identification key [28,29].

Diversity and evenness indices

The Shannon-Wiener Index (H') is commonly used as diversity index in benthic ecological analyses [30]. The Shannon diversity was used in this study to estimate the diversity of benthic fauna present in IRIS-1 drilling area. This index, that is dependent on sample size, was used for assessing the heterogeneity of the environment in term of benthic organism composition. The Shannon index was calculated using the logarithm for a base 2, using the following formula:

$$H' = -\sum pi \ln (pi) \qquad (1)$$

Where pi is the proportion of individuals found in species "i" in terms of abundance. This proportion can be estimated as pi=ni/N, where ni is the number of individuals in species "i" and N is the total number of individuals in the sampled community.

Pielou's index, which is a measure of species evenness, was used in this study to assess species distribution over all sampling stations [31]. It is defined as a diversity index, a measure of biodiversity, which quantifies how equal the community is numerically. Pielou's index was calculates using the following formula:

$$J = H'/\ln(S) \qquad (2)$$

Where H' is Shannon Weiner diversity and S is the total number of species in a sample, across all samples in dataset. Multiple comparisons were conducted using Kruskal-Wallis nonparametric test to compare the diversity and evenness indices between sampling stations.

A principal components analysis (PCA) of the distribution patterns of the species encountered at the ten stations (44 species x 10 stations) was done to identify an overall structure of identified benthic fauna. PCA is an ordination method that uses linear equations of variables to explain the variation in an environmental data set by finding the dominant gradient(s). PCA assumes a linear response model. PCA was performed using the statistical R package.

Trophic level determination

The definition of the trophic categories or groups allows simplifying the complex interactions of the trophic web of an ecosystem. Hence, for this study, we used Grall et al. [32] classification of the trophic categories. The Grall discrimination of trophic groups is based on species diet, whatever its origin (animal or plant) or its state (living or decomposed). Thus, all species found in the ten sampling stations of the IRIS-1drilling zone were grouped into trophic categories according to Grall et al. [32].

Results

Benthic fauna composition

A list of the benthic fauna composition is established for each of the 10 sampling stations where samples were collected (Table 1, Supplementary Table 4). The number of individuals collected for each species was counted and then reported to the volume of the taken sample. Table 1 indicates the results of these analyses. Thus, for all the sampled stations, 44 groups of species were identified (Supplementary Table 4). The most relatively represented among these groups are bivalve mollusks (27.27%), gastropod mollusks (15.91%), annelids (9.09%), and nematodes (9.09%). The most abundant species within these groups, are *Nuculana sp* (bivalve mollusk), followed by *Neanthes kergulensis* (annelid) and *Cyclopten sp* (nematode) while the less represented species are *Cymiidea sp* (bivalve mollusk), *Turridea sp* (gastropod mollusk) and *Crassatellidea sp* (bivalve mollusk) (Figure 2). *Crasostrea gasar*, which is a species with a local economic importance, is moderately represented compared to the other species (Figure 2).

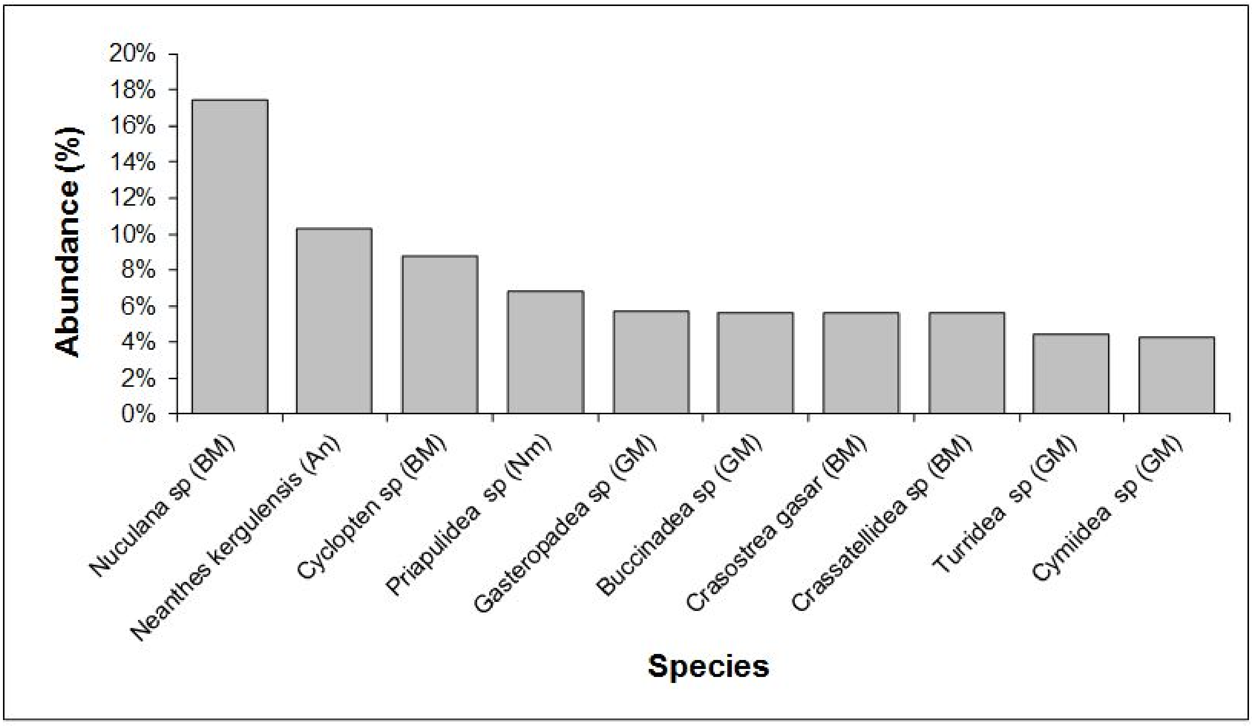

Figure 2: Species diversity of benthic fauna in IRIS-1 drilling area. BM: Bivalve Mollusk, An: Annelid, GM: Gastropod Mollusk, Nm: Nematode.

Benthic fauna structure

There were significant differences in the occurrence and abundance among trophic groups observed on the IRIS-1 drilling area. The macro-invertebrate feeders accounted for 38.89% of the numerical abundance and were found in all ten sampling locations (Supplementary Table 4). The most frequently encountered species in this trophic group is *Neanthes kerguelensis*, which was present in seven of the ten sampling stations. It is followed by *Priapulidea sp*, which was found in six stations. The next most represented species of this trophic group are *Epoitonidea sp* and *Crassatellidea sp*, which was encountered only in three of the ten sampling stations (Supplementary Table 4). The other species that constitute this group are only present in one station. Detritus feeders/Herbivores were the next most important trophic group, accounting for 12.96% of the total abundance (Supplementary Table 4). They were dominated by *Buccinidea sp*,

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which was found in seven locations. Another highly represented trophic group was Plankton and Nutrimental feeders (11.11%), essentially constituted by Sea squirts, which was encountered in six of the ten sampling locations. Zooplankton, filter and bottom feeders are the less important among the trophic groups encountered in the IRS-1 drilling area (Supplementary Table 4).

Species richness, diversity and evenness of benthic fauna

The highest species richness is noted at the sampling stations S8, S5 and S10, with 21, 17 and 16 species, respectively whereas the lowest species richness was recorded at the sampling stations S3 and S4 (8 and 7 species, respectively) (Figure 3). The average richness was recorded at stations S2 and S6 (10 species each) (Figure 3). The specific diversity differs significantly from one sampling station to another. The Shannon index varies between 1.66 and 2.54 with an average of 2.09 (Supplementary Table 5). The values of Shannon index vary slightly between the stations located around the drilling zone. The values of species evenness (Pielou's index) showed a good specific distribution over all sampling stations. The different values of the Pielou equitability index at station level show, at first sight, a quite different specific distribution from one station to another (Supplementary Table 6). We therefore performed a Kruskal-Wallis nonparametric test, which showed observed K of 1.905 with a P-value lower than 0.05. The results of these tests indicated that the values of equitability index calculated for each sampling showed a quite different specific distribution from one station to another. Overall, there is a good specific distribution. However, the species distribution patterns at the ten stations are significantly different as evidenced by the Kruskal-Wallis nonparametric tests of Pielou equitability index.

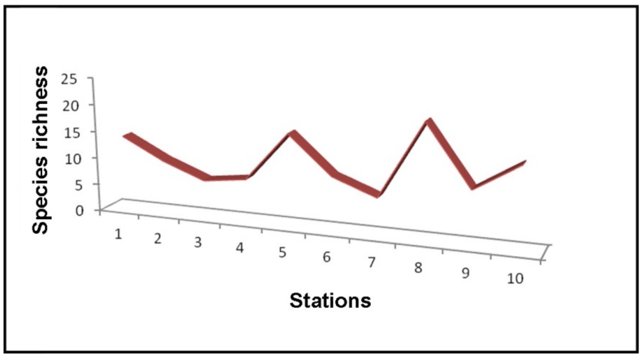

Figure 3: Evolution of the specific richness of benthic fauna in IRIS-1 drilling area.

The PCA analyses are in accordance with these results (Figure 4). The two first PCA axes accounted for 34.14% of total variance and showed that the sampling stations S1, S2, S3, S6, S8 and S10 harbour most of the species richness compared to S4, S7, S9 and S5 where only few species have been recorded (Figure 4). Based on the PCA map, the benthic fauna of the IRIS-1 drilling area formed two distinct clusters in terms of the composition in species group. The cluster formed by the sampling locations S1, S2, S3, S6, S8 and S10 and that constituted by the stations S5 and S9 (Figure 4).

Discussion

This study represents the first scientific survey of the marine and coastal ecosystem on oil platform of West Africa. This work provides an overview of the benthic microfauna present in the IRIS-1 drilling area in front of Cap Skiring (Casamance, Senegal). The results show an important diversity of the benthic species, dominated by marine mollusks, essentially sessile species. These organisms are sensitive to oil disturbances, which at long-term, may have serious effects on their biological and physiological functions. Indeed, the drilling operation mainly produce two types of waste, cuttings generated by the equipment used to drill the oil well and the mud resulting from the drilling operations. The drilling mud is a mixture of clay (*netonic*) that may be loaded with organic polymers, salts and other chemicals suspended in liquid, used for drilling purposes and other activities related to oil prospecting. The sludge may contain heavy metals, which together with the clay, are the main source of heavy metal pollution from drilling rejects [33,34] and their presence in the sediment is essential to better appreciate the potential impacts due to heavy metals. During drilling, the drill cuttings (drilling muds) are continuously discharged and are reprocessed and recycled before being recovered in containers designed for this purpose [35]. The fate of the chemicals used in drilling, which are often located in the water column depends on local oceanographic conditions in the area (current strength, the height of the bottoms), the sediment particle size, their hydrophobic properties, and the amount of drilling waste produced [36]. These chemicals can thus end up in benthic organism's body living around the drilling area, which can concentrate them in their body [37]. The benthic fauna around IRIS-1 could be exposed to such a type of risk. It is, therefore, necessary take into accouter this possibility by advocating mitigation and mitigation measures for this impact.

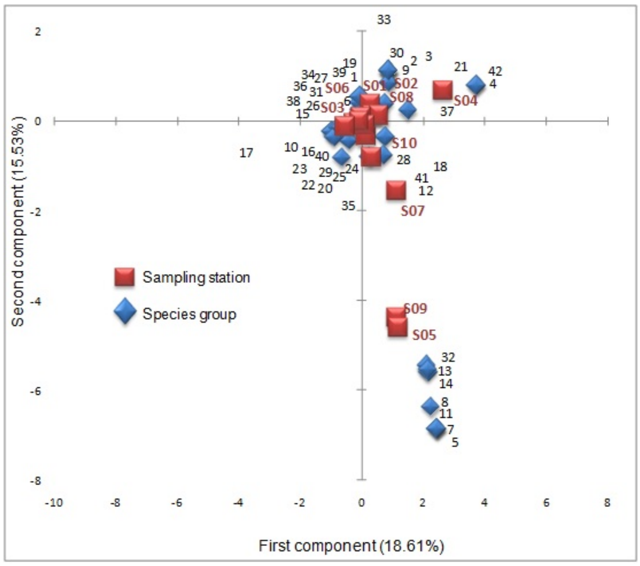

Figure 4: Principal component analysis of 44 species groups collected in 10 sampling stations in the IRIS-1 drilling zone. S1 to S10 indicate the 10 sampling stations and the numbers 1 to 44 indicate the different groups of species.

Fish food organisms may also be contaminated by this source of pollution, especially for marine invertebrates, found in benthic fauna and zooplankton. The importance of such a contamination varies according to the species and the development stages, with post-larvae and juveniles being more vulnerable than adults [38]. Sessile species of benthic fauna are more vulnerable to petroleum products, but mobile species can be also impacted, although these impacts are less important for this latter group [39]. Apart from choking mortality, petroleum products may cause changes in species composition, metabolism and feeding efficiency in marine mollusks [10,25]. These phenomena have been well studied in France since they happened during the accident at sea of Amoco Cadiz in 1978 on the coasts of Brittany [40] that resulted in. chronic and deleterious effects on benthic invertebrates. These studies showed that some macrofauna species (benthic invertebrates such as the violon crab and some clam species) can survive in sediments strongly affected by oil spills, which can be explained by feeding behaviors of certain marine invertebrates. Some species feed elsewhere than in the sediment and are therefore less vulnerable than those whose living areas closely related to the sediments. Sediments contaminated by mixtures of products from offshore drilling operations can act in synergy with other chemicals present in the water column and cause death of benthic organisms and/or cause major changes in the trophic chain.

In conclusion, the benthic microfauna around the IRIS-1 drilling well in front of Cap Skiring in Casamance have a medium specific diversity of about 44 species with more or less pronounced spatial variability. Marine mollusks, consisting essentially of sessile species (gastropods, bivalves), constitute the most important group. These organisms are quite sensitive to oil disturbances. The proposed mitigation and mitigation measures for the IRIS-1 should focus on elements that are least harmful for the environment and living species the area. An alternative would be to use dispersants to reduce the toxicity of products discharged into the sea.

Consent for Publication

Not applicable.

Availability of Data and Material

All datasets supporting the results of this article are included in the article and its additional files.

Competing Interests

Eventual conflicts of interest (including personal communications or additional permissions, related manuscripts), sources of financial support, corporate involvement and patent holdings are disclosed.

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Authors' Contributions

ADD, AD and MS collected the data. MT and ADD performed the data analysis. MT drafted the manuscript. All the authors have read and contributed to the manuscript preparation.

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