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A New Monitoring Tool for Assessing Environmental Impact of Offshore Drilling Activities: Benthic Foraminifera

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Abstract

Since 2003 we have tested the use of benthic foraminiferal faunas as bio-indicators of highly biodegradable oil-based drill fluids and cuttings. In this paper we present data for 4 sites off western Africa (Angola, Congo and Gabon), with water depths varying from 30 to 670 m. A very similar faunal response to environmental perturbation is found in these different environmental settings. In the close vicinity of the oil drill mud and fluids disposal, the combination of lowered bottom water oxygenation, the presence of toxic compounds and a general ecosystem enrichment leads to strongly impoverished faunas. More sensitive taxa become very rare in these areas. Moderately impacted sites are characterized by high to very faunal densities, and a strong dominance of opportunistic taxa, that are favored by the increased amount of organic matter in the benthic environment, resulting from the introduction of hydrocarbons. Beyond 500 m of the disposal sites, the faunas progressively become similar to the natural faunas; the relative frequency of opportunistic and stress-tolerant taxa drops to background values.

Two foraminiferal indices are proposed that allow a quantitative evaluation of the impact of the oil drilling activities. A first foraminiferal index, that is based on the cumulative percentage of opportunistic and stress-tolerant taxa, is very effective in continental shelf settings. Severely polluted sites contain more than 70% index species, moderately impacted area between 50 and 70%. In slightly to non impacted sites, the percentage of index species drops from 50 to 20%. A shallow, 30 m deep, area in front of the Ogooué estuary reveals a high percentage of marker species at all investigated stations. This elevated percentage is caused by the presence of naturally eutrophicated conditions due to the supply of important amounts of nutrients and continental organic matter by river outflow. In this a particular setting, oil exploration activities appear to have only a minor environmental impact. At the 670 m deep upper slope site, the impacted stations are characterized by the progressive disappearance of the taxa that are most sensitive to ecosystem perturbation. The cumulative percentage of these taxa strongly decreases at the most impacted areas, which provides a very useful additional quantitative monitoring tool. The present data show that foraminiferal faunas are extremely powerful in monitoring the environmental impact of oil exploration activities. In the near future, the proposed foraminiferal indices will be tested in other areas, and the selected marker species will be formalized for different types of environmental settings, with different water depths and climatic conditions.

Introduction

Oil well drilling operations are responsible for the disposal of large quantities of drill cuttings and fluids. In order to assess the impact of these products on the benthic ecosystem, since 2003 we have studied foraminiferal faunas around production sites off Angola, Congo and Gabon. In fact, foraminifera have several advantages over traditionally used macro- and meiofauna as bio-indicators of offshore drilling activities [1]:

1. They appear with large densities, of several hundreds to thousands of individuals per 100 cm^2 sea floor surface, which makes it possible to perform reliable analyses on the basis of very small samples.
2. They have a high biodiversity, with up to 100 species living at a single site. These species occupy different ecological niches, and show large differences in tolerance to anthropogenic stress parameters, offering a large panel of marker species.
3. Many foraminiferal species have a calcareous shell that is preserved in the sediment. The study of the subfossil faunas deposited several decades ago, allows us to reconstruct the faunas that inhabited the disposal site before the onset of drilling activities.

In this paper, we summarize the results of our investigations of the foraminiferal faunas at 4 continental shelf and upper continental slope settings off western Africa. We will show the general patterns of the faunal response to the disposal of drilling cuttings and fluids in terms of faunal density and species composition. At the end of this paper, we will present tentative foraminiferal indices of the impact of oil drilling activities on the benthic ecosystem. Our results indicate that benthic foraminifera may provide an extremely powerful tool to determine the impact of drilling activities.

Study areas

We investigated four sites (Figure 1) off Gabon (Site 1), Congo (Sites 2 and 3) and Angola (Site 4).

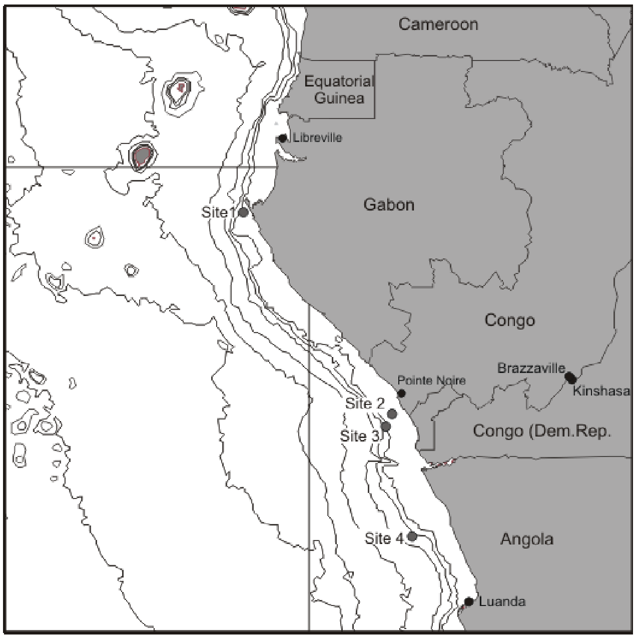

Figure 1. Location of the four study areas.

Site 1 is located in the offshore Anguille Marine field, 50 km off Port Gentil, Gabon, at a water depth of 30 m. Cuttings discharge began in 1986 and ended in 1992, but in 2003 an additional well was drilled using highly biodegradable base oil. Twelve stations were investigated between 70 and 11400 m from the discharge point in June 2004 (Figure 2, Table 1).

Site 2 is located off Congo at 90 m water depth. In April 2006, we investigated seven stations between 100 and 2000 m from the discharge point (Fig. 3, Table 1).

Site 3 is located 60 km off Pointe Noire, Congo at a water depth of 180 m. Here, two oil platforms were active from November 1993 to April 1999. Samples were collected from the 7^{th} to the 18^{th} of April 2003 on a radial of six points around the second platform and three sampling stations around the first platform (Fig 4, Table 1).

Site 4 is located off Angola. Five samples were collected in April 2006 around the well (Fig. 5, Table 1), at 670 m water depth.

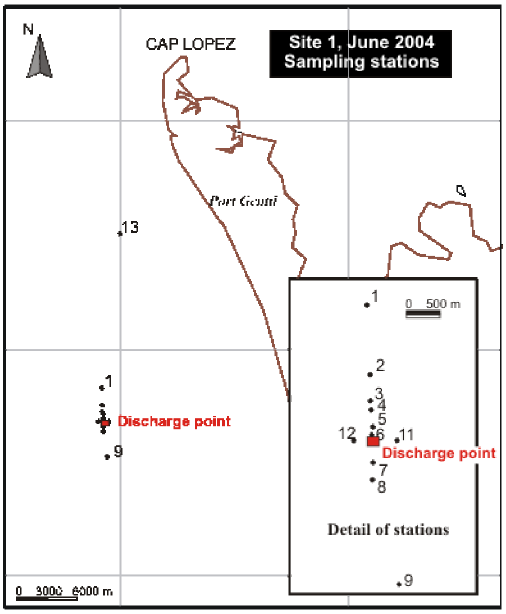

Figure 2. Site 1, off Gabon, water depth 30 m; discharge point and sampling stations.

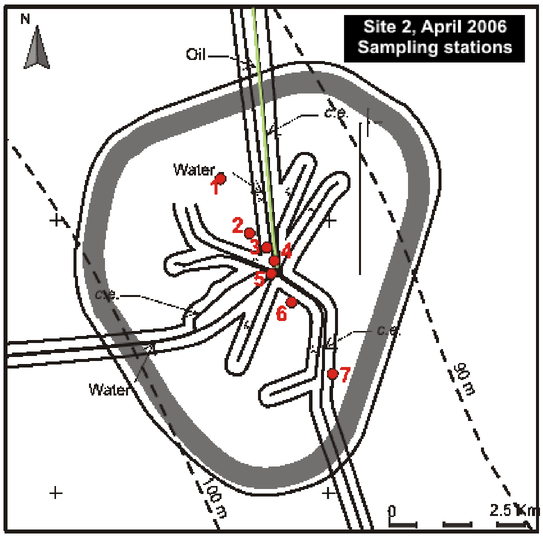

Figure 3. Site 2, off Congo, water depth 90 m; discharge point and sampling stations.

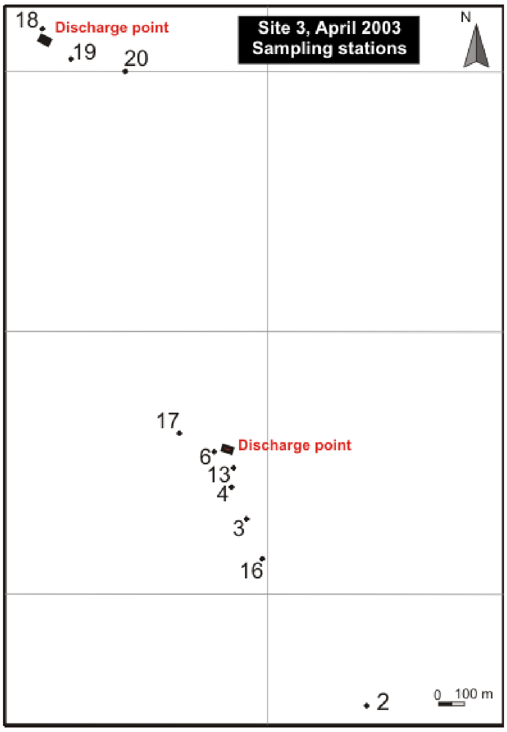

Figure 4. Site 3, off Congo, water depth 90 m; discharge points and sampling stations.

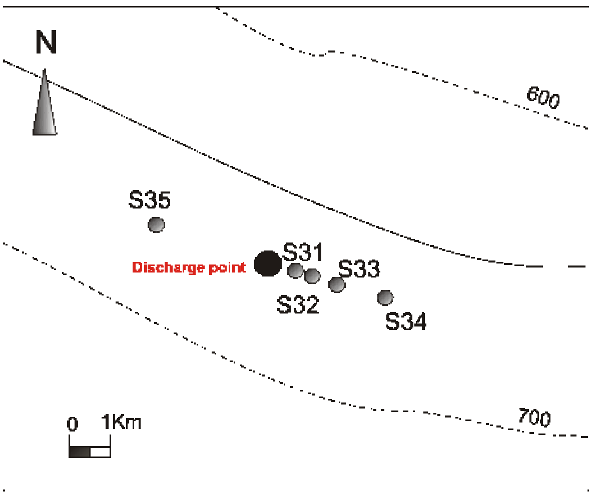

Figure 5. Site 4, off Angola, water depth 670 m, discharge point and sampling stations.

Table 1: Water depth and distance from the discharge point for each station.

Site 1 (off Gabon)		
Station	**Distance**	**Depth (m)**
1	2000 m North	29
2	1000 m North	30
3	750 m North	30
4	500 m North	30
5	250 m North	30
6	70 m North	30
7	250 m South	30
8	500 m South	30
9	2000 m South	30
11	250 m East	30
12	250 m West	30
13	11400 m North	30

Site 2 (off Congo)		
Station	**Distance**	**Depth (m)**
1	2000 m NNW	90
2	1000 m NNW	90
3	500 m NNW	90
4	250 m NNW	90
5	100 m W	90
6	250 m SSE	90
7	2000 m SSE	90

Site 3 (off Congo)		
Station	**Distance**	**Depth (m)**
2	2 km S of well 2	180
3	470 m S of well 2	180
4	230 m S of well 2	180
6	70 m W of well 2	180
13	100 m S of well 2	180
16	730 m S of well 2	180
17	450 m NW of well 2	180
18	70 m N of well 1	180
19	250 m S of well 1	180
20	500 m SE of well 1	180

Site 4 (off Angola)		
Station	**Distance**	**Depth (m)**
S31	300 m E	670
S32	500 m E	670
S33	1000 m E	670
S34	1800 m E	670
S35	2000 m W	670

Materials and methods

For the analysis of the foraminiferal faunas, Van Veen grab cores with apparently intact sediment surfaces were subsampled with a core with a 4 cm inner diameter. On board, these cores were sliced into 0.5 cm levels down to 1 cm and then in 1 cm levels down to 7 cm depth. All samples were preserved in 95% ethanol with 1 g/l Rose Bengal, which colors the cytoplasm of the cells, allowing to distinguish the living specimens from the empty shells [2].

In the laboratory, the collected samples were sieved over 63 and 150 µm sieves. In this study, we focus on the coarser size fraction (>150 µm). Foraminifera of the surface level (0-0.5 cm) were picked without further treatment, under wet conditions (50% ethanol). For all other levels, living foraminifera were concentrated using density separation with trichloroethylene (D=1.46). Living as well as unaltered dead foraminifera should be found exclusively in the floated part. A check of the deposited sediment, revealing the absence of living specimens, showed the efficiency of the method. All individuals were picked and glued on Chapman slides. All foraminifera were determined using taxonomic studies [3], particularly those with emphasis on shelf and upper slope environments [4-8].

Results

Site 1, off Gabon, water depth 30 m

The standardized densities of the living foraminiferal faunal in the top 3 cm of the sediment (figure 6) vary from 0 (stations 2 and 12) to about 80 individuals per 50 cc (stations 4 and 7). We strongly suspect that the absence of living foraminifera at stations 2 and 12 is due to the fact that the Van Veen grab did not adequately sample the sediment surface.

The specific composition varies only slightly along the transects on both sides of the discharge point. *Cancris congolensis*, *Lagenammina* sp. and *Hanzawaia boueana* are the three dominant species, who are characteristic for the eutrophic benthic environments under the direct influence of river outflow (in this case the Ogooué river).

Maximum faunal densities are found at stations 4 at 7, at 250 m S and 500 m S of the disposal site, respectively. On the contrary, station 6, only 70 m from the platform, is characterised by a low faunal density. We interpret these density changes as a minor response to the oil drill activities; somewhat more stressful conditions at station 6, and slightly enriched conditions at stations 4 and 7. We think that the absence of a clear faunal response to the oil drill activities is due to the naturally eutrophicated character of this site influenced by major river runoff.

Site 2, off Congo, water depth 90 m

The living foraminifera are particularly rich; their density in the uppermost 2 cm of the sediment varies from 5 to 150 individuals/10 cm^3 (Figure 7). Stations 2, 4 and 5 present very low densities (5 to 15 individuals/10 cm^3). Intermediate densities (about 75 individuals/10 cm^3), are found at stations 1 and 7, whereas stations 3 and 6 show maximal densities of 130 to 150/10 cm^3.

Stations 4 (250 m NNW), 5 (100 m W) and 2 (1 km NNW) are characterized by poor faunas, dominated by *Eggerella* sp. 1 and *Nonion scaphum*, which are also present at the reference stations (1 and 7, 2 km N and S of

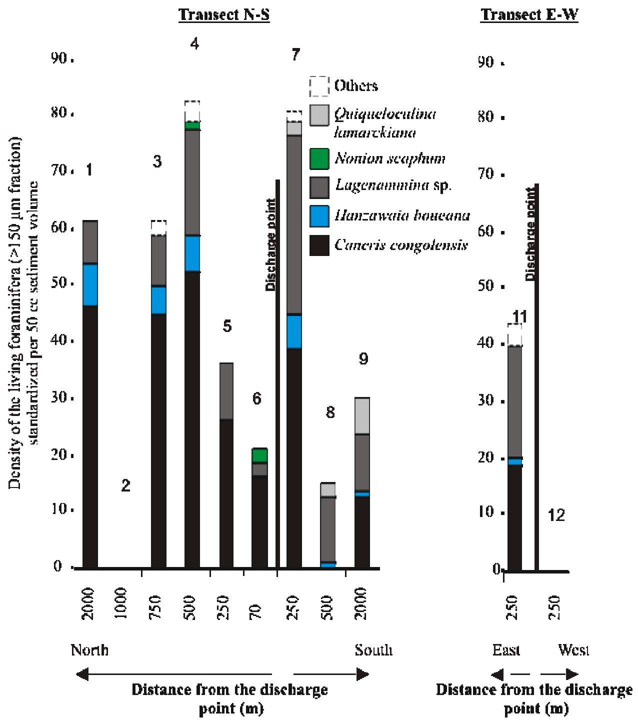

Figure 6. Site 1, water depth 30 m. Composition and density of the living foraminiferal fauna (accumulated for the top 3 cm of the sediment, standardized per 50 cc sediment volume).

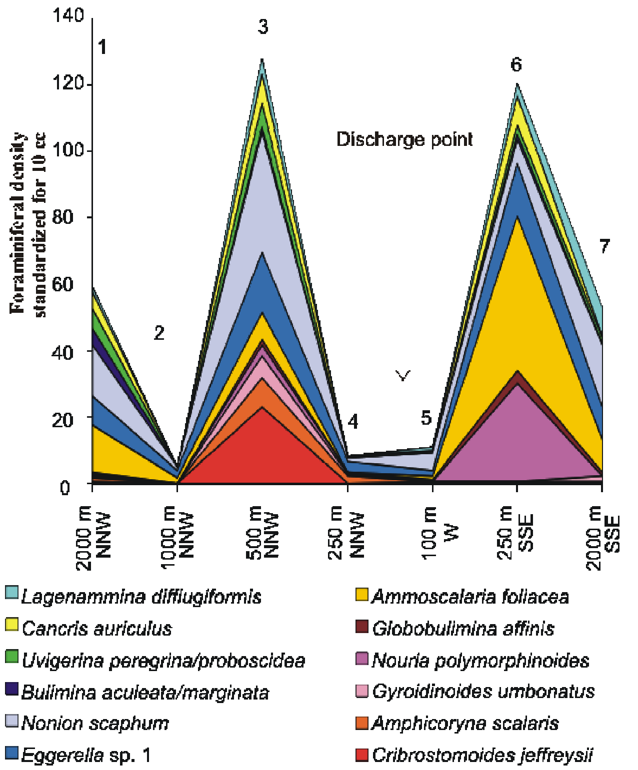

Figure 7. Site 2, water depth 90 m. Composition and density of the living foraminiferal fauna (observed in the first 2 cm of the sediment, standardized per 10 cc

sediment volume).

the disposal site). The presence of some specimens of opportunistic (*Amphicoryna scalaris, Ammoscalaria foliacea*) and low oxygen tolerant taxa (*Globobulimina affinis*) allows us to distinguish stations 4 and 5, from station 2, where these taxa are completely absent. We think therefore that the low faunal density at station 2 is an artefact, caused by inadequate sampling.

The very dense foraminiferal faunas at stations 3 and 6 have a very particular composition. Station 3 (500 m NNW) is characterized by high numbers of *Amphicoryna scalaris, Cribrostomoides jeffreysi* and *Gyroidinoides umbonatus*, whereas station 6 contains rich faunas dominated by *Nouria polymorphinoides* and *Globobulimina affinis.* All these taxa are almost absent at all other stations.

It appears that *Amphicoryna scalaris, Cribrostomoides jeffreysi, Gyroidinoides umbonatus, Nouria polymorphinoides* and *Globobulimina affinis* are indicative of eutrophicated conditions. Although they are also present at stations 4 and 5, their very low densities there are indicative of an elevated environmental stress. At stations 3 and 6 (500 m NNW and 250 m SSE), where they attain maximum densities, these species testify of a strongly eutrophicated character of the benthic ecosystem.

Stations 1 and 7 are populated by the natural background fauna, which is dominated by *Eggerella* sp.1, *Nonion scaphum* and *Ammoscalaria foliacea.* The afore-mentioned opportunistic and stress-tolerant species are only present in small quantities (less than 5% of the fauna).

Site 3, off Congo, water depth 180 m

The total number of living individuals found in the uppermost 3 cm of sediment (volume = 37.7 cm^3) varies between 7 and 215, corresponding to a density of about 2 to 60 individuals per 10 cm^3 (Figure 8).

The combination of the density and composition of the foraminiferal faunas allows us to subdivide the 9 stations into four groups:

1) Station 6, 70 m west of the second platform, contains a rather poor fauna, that is dominated by *Bulimina aculeata, Bulimina marginata* and *Uvigerina peregrina*.

2) Stations 4, 13 and 18, all at 250 m or less from the disposal sites, contain abundant foraminiferal faunas, which are dominated by *Bulimina marginata* and *Bulimina aculeata*. *Uvigerina peregrina* is common at stations 13 and 18, whereas *Eggerella* sp. 1 contributes significantly to the fauna at stations 4 and 18. *Bulimina costata*, *Trifarina bradyi* and *Textularia sagittula* are taxa that occur mainly at these three sites, albeit in lower numbers. Most of these species are known in the literature as opportunists, which are typical of organic carbon enriched environments.

3) Stations 2, 3, 17 and 19, all more than 250 m from the disposal sites, are characterized by poor faunas, without clearly dominant species.

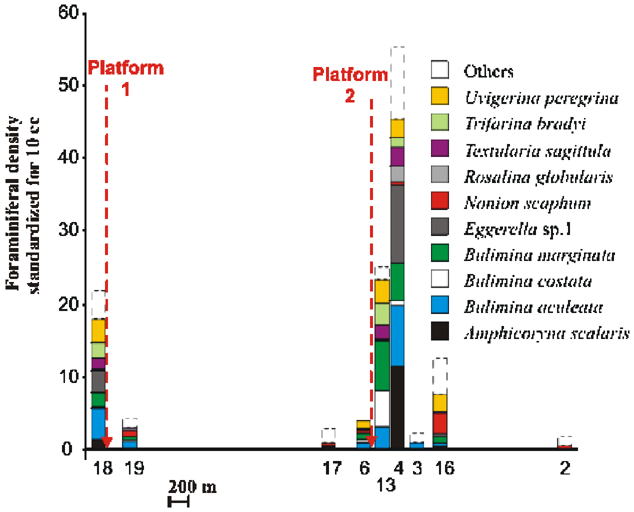

Figure 8. Site 3, water depth 180 m. Density and composition of the living foraminiferal faunas observed in the first 3 cm of the sediment) standardized for 10 cm^3 sediment volume.

4) Station 16, 730 m south of NKF2, contains intermediate numbers of foraminifera; the fauna is dominated by *N. scaphum, U. peregrina, C. auriculus* and *B. marginata.*

We conclude that the faunas found at stations 2, 3, 16, 17 and 19 (all farther than 250 m from the disposal sites) represent faunas, that are not (station 2), or little impacted by the drilling cutting deposits. Stations 4, 13 and 18 (between 70 m and 250 m from disposal sites) contain very rich faunas with increased percentages of opportunistic species, indicating a significant impact of the oil drill activities, resulting in eutrophicated conditions. The poor faunas of station 6, only 70 m from the disposal site, finally, testify of a maximal environmental impact.

Site 4, off Angola, water depth 670 m

The total number of living individuals found in the uppermost 3 cm of sediment (volume = 37.7 cm^3) varies between 7 and 50 individuals per 10 cm^3 (Figure 9). A maximum faunal density is found at station S31, 300 m east of the disposal site. Towards the east densities gradually decrease towards station S34, 1800 m from the platform. At station S35, 2000 m W of the site, we observed an intermediate faunal density (15 individuals per 10 cm^3).

At stations S33 and S34, the faunas are dominated by *Uvigerina peregrina, Karreriella bradyi, Cancris auriculus, Globobulimina affinis* and *Cribrostomoides subglobosus*. All these taxa are typical of unpolluted upper continental slope settings

At station S31, 300 m SE of the disposal site, where the faunal density is maximal, *U. peregrina, C. auriculus* and *C. subglobosus* have almost disappeared, whereas *Chilostomella oolina, Reophax scorpiurus* and *Bolivina*

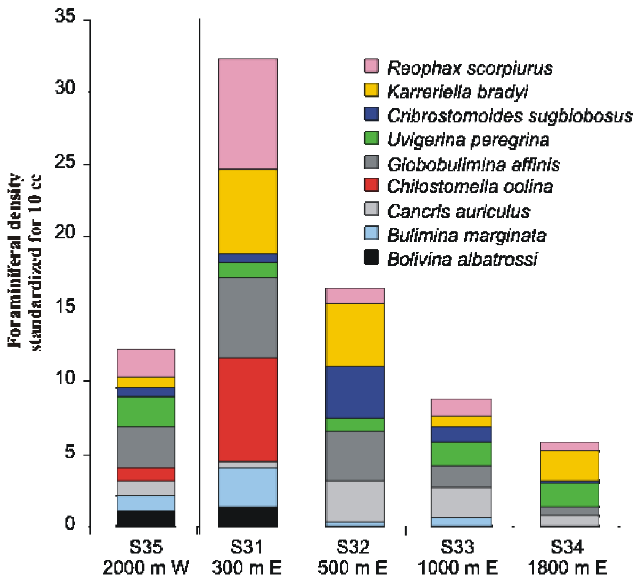

Figure 9. Site 4, water depth 570 m. Density and composition of the living foraminiferal faunas (observed in the first 3 cm of the sediment) standardized for 10 cm^3 sediment volume.

albatrossi have become dominant faunal elements. *Chilostomella oolina* is totally absent at all other stations SE of the disposal site.

The fauna of stations S32, 500 m SE of the disposal site, shows intermediate characteristics. Although the relative frequency of *Uvigerina peregrina* is already low, *Cancris auriculus* is still present with a high relative frequency. The maximum percentage of *Cribrostomoides subglobosus* at this station is remarkable.

Also the faunal composition at station S35, 2 km NW of the disposal site, shows intermediate characteristics. Because of the presence of *C. oolina* and the low percentages of *C. auriculus* and *C. subglobosus*, the faunas resemble those of station S31, but the elevated percentage of *U. peregrina* is similar to the faunas at stations S33 and S34.

This faunal distribution pattern indicates a significant environmental impact of drill mud disposal at station S31, 300 m SE of the disposal site. At station S32, 500 m SE of the disposal site, a minor environmental stress can still be distinguished, whereas the faunas of stations S33 and S34, 1 and 2 km from the disposal site, respectively, appear to represent the background faunas. The fauna of station S35 suggests a slightly different sedimentological context, which complicates the comparison with the faunas of the four other stations.

Discussion

In order to quantify the impact of pollution due to drill cutting disposal, we tentatively developed a foraminiferal index based on the cumulative relative abundance (percentage of the total fauna) of all taxa indicative of stress and/or ecosystem eutrophication. Since the natural environmental conditions are very different in the four studied areas, with water depths varying from 30 to 670 m, different indicator species had to be selected for each area.

At well AGM6, off Gabon, *Cancris congolensis* and *Lagenammina* sp. are used as indicators of eutrophicated conditions level at the sea floor, at a water depth of 30 m.

In figure 10, the cumulative percentage of these two taxa is plotted against the distance from the disposal site. It can be seen that at stations the fauna contains more than 70% of these two taxa. This is due to the fact that this site is under the direct influence of the Ogooué River, which supplies large amounts of organic matter, and caused a natural eutrophication of the benthic ecosystem. The impact of the supplementary stress due to oil drill activities appears to be minimal, and as a consequence, the foraminiferal index of ecosystem perturbation does not reveal significant differences between stations.

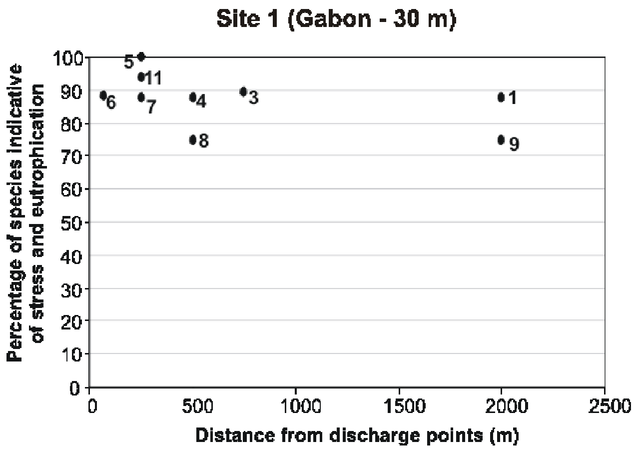

Figure 10. Cumulative percentage of taxa indicative of natural and/or anthropogenic eutrophication and ecosystem stress, in function of distance to the drill cutting disposal site (Site 1, off Gabon, water depth 30 m).

At site 2 (90 m water depth) off Congo, Amphicoryna scalaris, Ammoscalaria foliacea, Cancris auriculus, Eggerella sp. 1, Globobulimina affinis, Gyroidinoides umbonatus, Cribrostomoides jeffreysii, Nouria polymorphinoides have been selected indicators of eutrophicated conditions and/or environmental stress (Figure 11). With the exception of station 5, the cumulative percentage of these taxa shows a strong logarithmic correlation with the distance to the disposal site (r^2 = 0.83). The foraminiferal index makes a clear distinction between strongly impacted stations (4 and 6, > 70% indicator species), moderately impacted stations (2 and 3, 50-70% indicator species), and weakly or non impacted stations (1 and 7) with less than 50% of indicator species. At station 5, closest (100 m) to the disposal site, the foraminiferal index does not correctly represent the stressed conditions. This is due to the poverty of the fauna, which makes the use of percentage data inappropriate.

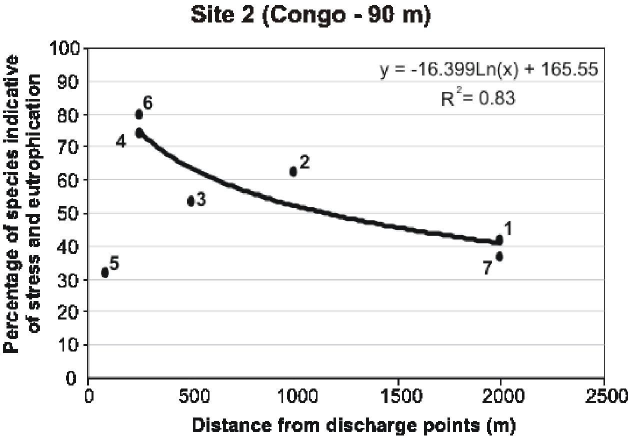

Figure 11. Site 2, off Cango, water depth 90 m. Cumulative percentages of taxa indicative of eutrophication and/or ecosystem stress, in function of distance to the drill cutting disposal site. NB. Station 5 has been omitted from the calculation of the correlation.

At site 3, at 180 m water depth, the foraminiferal indicators of environmental stress and/or eutrophication are *Amphicoryna scalaris*, *Bolivina striatula*, *Bulimina aculeata*, *Bulimina costata*, *Bulimina marginata*, *Cribrostomoides subglobosus*, *Eggerella* sp1, *Globobulimina affinis*, *Haplophragmoides* sp., *Jadammina macrescens*, *Rosalina globularis*, *Nouria polymorphinoides*, *Textularia sagittula*, *Trifarina bradyi* and *Uvigerina peregrina* (Figure 12). For this area, a very good logarithmic correlation (R^2 = 0.83) is found between the cumulative percentage of the marker species and the distance from the discharge sites.

A clear distinction can be made between strongly impacted stations (3, 6, 13 and 18), with more than 70% marker species, moderately impacted stations (4, 17 and 19, 50 to 70% index species), weakly impacted stations (16, 20-50% marker species) and non impacted stations (2), with less than 20% index species.

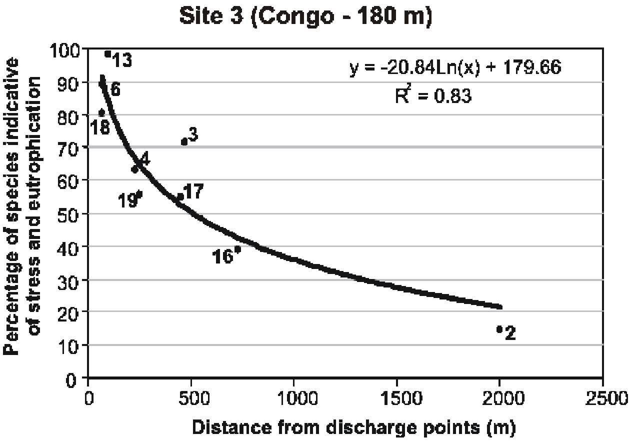

Figure 12. Site 3, off Congo, water depth 180 m. Cumulative percentages of taxa indicative of eutrophication and/or ecosystem stress, in function of distance to the drill cutting disposal site.

At the much deeper site (4; water depth 670 m), the faunal response to ecosystem perturbation is slightly different. In this continental slope setting, the disposal of drill cuttings and fluids does only lead to a weak frequency increase of opportunistic species. In this area, the overall density increase of the fauna at the most impacted stations is accompanied by a disappearance of the more sensitive taxa. For this reason, the cumulative percentage of species indicative of ecosystem eutrophication and/or environmental stress (*Chilostomella oolina*, *Amphicoryna scalaris*, *Bolivina* spp, *Bulimina* spp. *Buliminella rotundata*, *Cribrostomoides subglobosus*, *Fursenkoina complanata*, *Lagenammina difflugiformis*, *Reophax scorpiurus* and *Technitella legumen*) does not attain very high values, and shows only limited differences between stations (figure 13). Station S31, closest (300 m) to the disposal site, is the only station with more than 50% marker species, which in the other areas was considered as the lower limit of moderately impacted conditions. Station S35, with a slightly different sedimentological context, does not follow the tendency of the eastern (S31-S34) transect.

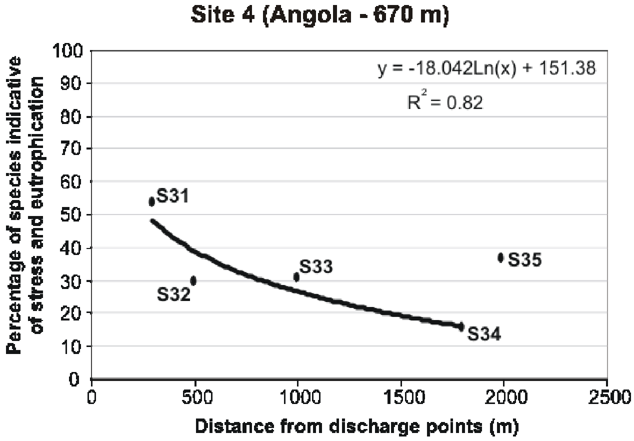

Figure 13. Site 4, off Angola, water depth 570 m. Cumulative percentages of taxa indicative of eutrophication and/or ecosystem stress, in function of distance to the drill cutting disposal site (Site 4, Angola). Station S35 has been omitted for the calculation of the regression curve.

The progressive disappearance of taxa sensitive to ecosystem perturbation (*Cancris auriculus*, *Cribrostomoides sugblobosus* and *Uvigerina peregrina*) towards the disposal site offers the possibility to present a second biotic index, based on their cumulative frequency. In figure 14 it can been seen that along the transect east of the discharge point (S31-S34), their cumulative density shows a clear correlation with the distance from the discharge point. Once again, station S31 stands out as the only station with a clear environmental impact.

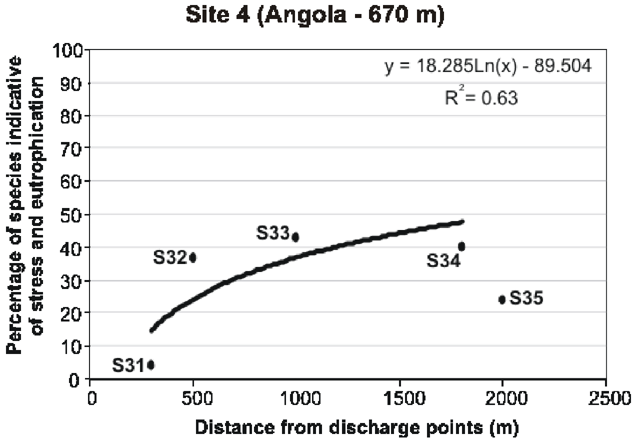

Figure 14. Site 4, off Angola, water depth 570 m. Cumulative percentage of taxa sensitive to ecosystem stress, in function of distance to the drill cutting disposal site.

Conclusion

Foraminiferal faunas provide an extremely powerful tool to determine the environmental impact of oil drill activities in open marine environments. The combination of faunal density, species composition and diversity (not treated in this paper) allows in all investigated continental shelf and slope environments to distinguish between severely, moderately, slightly and non impacted ecosystems.

A foraminiferal index, based on the cumulative percentage of opportunistic taxa, characteristic of eutrophicated conditions, and taxa tolerant of the stressed conditions caused by oxygen depletion and the eventual presence of toxic compounds, allows to describe the environmental impact quantitatively. Severely impacted sites contain more than 70% index species, whereas faunas with 50-70% index species are characteristic for moderately impacted conditions. Faunas with less than 50% marker species are representative for weakly impacted or non impacted conditions.

This foraminiferal index is particularly adequate in our two deepest continental shelf settings (90 and 180 m water depth, respectively). At a shallow site (30 m water depth) in front of the Ogooué river, all stations attain values above 70%, which appears to be due to natural eutrophication resulting from abundant nutrient input due to riverine outflow. At a 680 m deep upper slope setting, this index is less selective. Here, the cumulative percentage of stress-sensitive taxa, which are the first to disappear in case of ecosystem perturbation, describes the environmental impact particularly well.

The foraminiferal indices presented in this paper, appear to describe the extent of environmental impact very adequately. However, supplementary tests are still needed, and the choice of the marker species in different ecological settings and water depth has still to be formalised.

Acknowledgments

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References

1. Mojtahid, M., *et al.*: *"Benthic foraminifera as bio-indicators of drill cutting disposal in tropical east Atlantic outer shelf environments", Marine Micropaleontology* 61 (2006) 58-75.
2. Walton, W.R.: *"Techniques for recognition of living foraminifera", Contributions from the Cushman Foundation for Foraminiferal Research* 3 (1952) 56-60.
3. Jones, R.W.: *"The Challenger Foraminifera"*, Oxford University Press, Oxford (1994) 149 pp.
4. Duchemin, G., *et al.*: *"Living benthic foraminifera from "La Grande Vasière", French Atlantic continental shelf: Faunal composition and microhabitats", Journal of Foraminiferal Research* 35 (2005) 198-218.
5. Kouyoumontzakis, G.: *"Les associations de foraminifères benthiques du plateau continental congolais : une radiale au large de la lagune Conkouati", Tethys* 10 (1981) 121-128.
6. Loeblich, A.R., Tappan, H.: *"Foraminifera of the Sahul shelf and Timor sea", Cushman Foundation for Foraminiferal Research Special Publication n°* 31 (1994) 1-661.
7. Schiebel, R., Rezente bentische Foraminiferen in Sedimenten des Schelfes und oberen Kontinentalhanges im Golf von Guinea (Westafrika). Geologisch-Paläontologisches Institut und Museum, Christian Albrechts Universität, Kiel, 1992, p. 160.
8. Sgarrella, F., Moncharmont Zei, M.: *"Benthic foraminifera of the Gulf of Naples (Italy): systematics and autoecology", Bollettino della Società Paleontogica Italiana* 32 (1993) 145-264.