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Total Usan Nigeria SERPENT biodiversity survey report

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ABSTRACT

The deep-waters off Nigeria offer many interesting and valuable opportunities for novel science. Through Total E&P Nigeria, and with collaboration with the international SERPENT project as well as with local universities and research organisations, industrial remotely operated vehicles (ROVs) were used to carry out high-resolution imaging surveys and make specimen collections in this deep-water region during periods of stand-by time.

The first phase of the work was to characterise the deep-water megabenthic assemblages found in the Usan region for the first time using fully quantitative ROV imaging. This was carried out during a visit to Usan in July 2009 on the ROV support vessel *Bourbon Diamond*. Because the Usan field contains a diverse series of seabed habitats we were also able to assess in more detail the effect of the variable seabed slope on the seafloor animal assemblage particularly with regard to the number and diversity of organisms.

A total of 24 invertebrate species were observed at Usan from six phyla. Echinoderms, such as sea stars and sea cucumbers, were dominant with 10 species found representing 64% of the animals observed. The sea urchin, *Phormosoma placenta*, was the most common animal which accounted for over half of the animals observed. Eight cnidarian species, particularly anemones, were identified but they only represented 4% of the total density. Crustaceans, such as crabs, were numerically important (31 % total fauna) but only represented by three taxa and only one of these, a squat lobster, accounted for the vast majority of the faunal numbers. Ten species of fish were observed at Usan.

Slope had a major impact on faunal density with a clear and significant linear negative relationship found between total density and slope. Deposit feeders make up the majority of the animals observed display a strong negative linear relationship with slope. Densities of suspension feeders are very low except in the highest slope site, even here mean densities are less than half that of deposit feeders. Slope also has a significant effect on the number of species found.

Maximum observed water temperature was 27.6°C and minimum 4.8°C. Salinities ranged between 26.58 and 36.63 (average 34.8) with the lowest salinities only found in the immediate surface waters during rainy periods. The deepest reading was taken at 815 m water depth (5.20° C temperature; 34.76 salinity). The thermocline depth varied from 41 to 92 m during the survey. The average thermocline depth observed here is greater than suggested in the literature by about 20m. Seasonal fluctuations in temperature are large in the Gulf of Guinea and the period of survey is a transitional time for water mass properties in the area, where climatic data are variable.

A total of 23 species of phytoplankton were captured. Of these most (14 species) were diatoms, 8 species were blue-green algae and 1 species was a desmid single-celled alga. In addition, one species of zooplankton, a copepod, was obtained. These species are all thought to be common in the area.

KEYWORDS

SERPENT, Nigeria, Megabenthic assemblages, Remotely operated vehicle, ROV, Gulf of Guinea, Slope, Usan field, *Phormosoma placenta*, Bourbon Diamond

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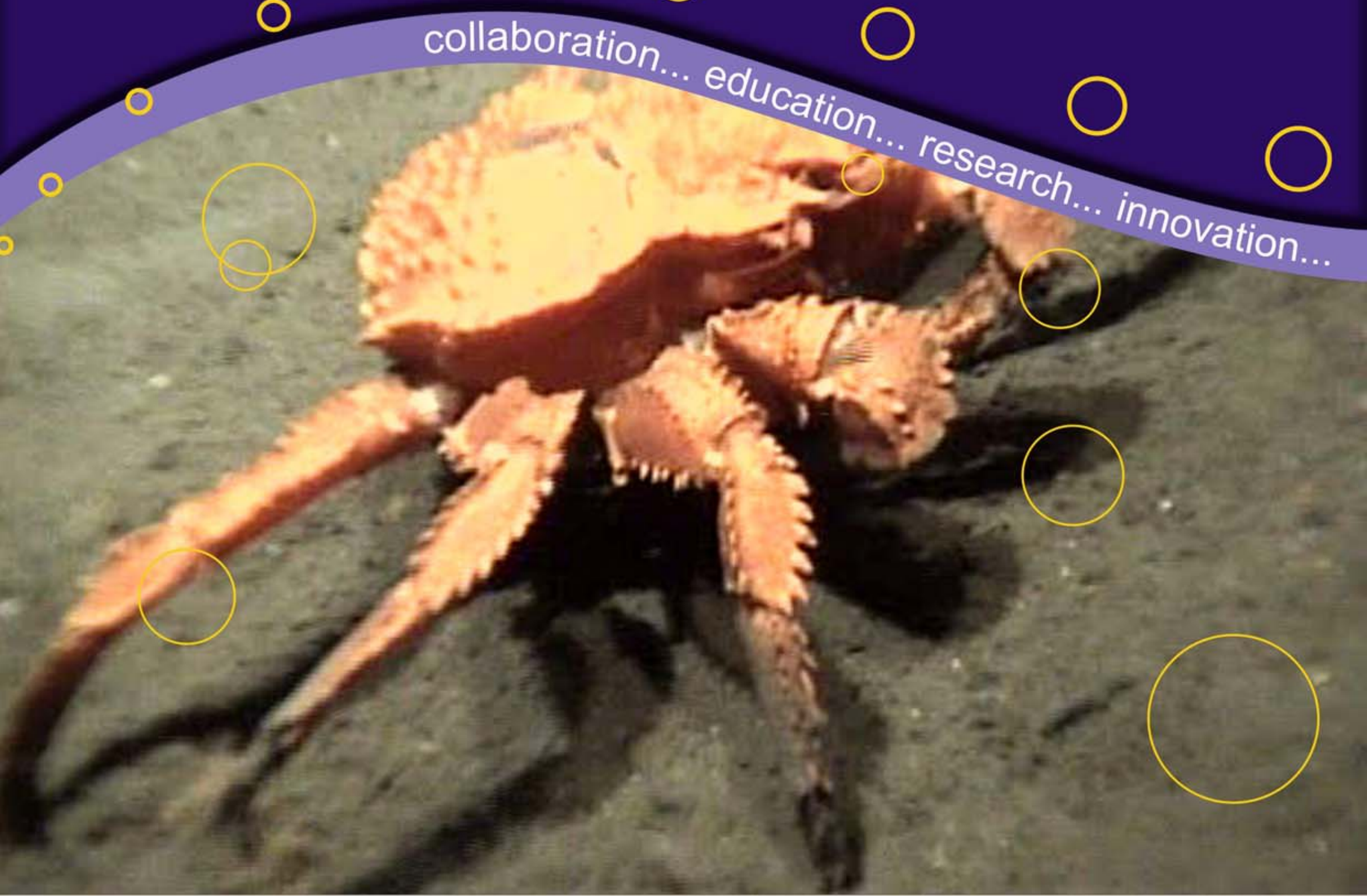
SERPENT

SCIENTIFIC AND ENVIRONMENTAL ROV PARTNERSHIP
USING EXISTING INDUSTRIAL TECHNOLOGY

Usan
Biodiversity Survey Report

January 2010



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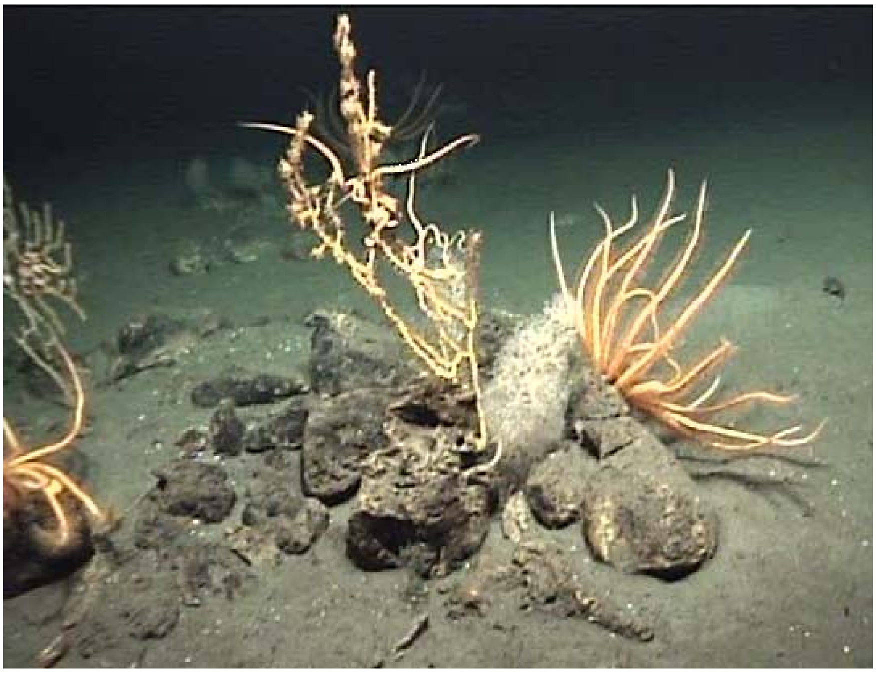


Total E & P Nigeria

Report prepared by Dr Daniel Jones

DISCLAIMER

ACKNOWLEDGEMENTS

We are extremely grateful to Total E&P Nigeria and the Total Foundation for supporting this work. We thank the University of Ibadan, Nigeria, the National Oceanography Centre, Southampton, and the Institute for Oceanography and Marine Research, Victoria Island, Lagos, for providing personnel for the survey. We wish to acknowledge the help of the captain and crew of the *Bourbon Diamond* including the Oceaneering ROV team.

CONTENTS

The report was written in the majority by Dr Daniel Jones, SERPENT, National Oceanography Centre, Southampton, UK. The results in section 3.2 on the plankton observed at Usan were analysed and reported by Prof. Alex Ugwumba, University of Ibadan, Nigeria. Sediment samples and rock samples from the Usan area are available from Dr Adesina Adegbie, Institute for Oceanography and Marine Research, Victoria Island, Lagos. This work was coordinated by Charles Mrabure, Total E&P Nigeria. The personnel directly related to this project that were present on the field work were D. Jones, A. Ugwumba, A. Adegbie, C. Mrabure and Brendon Butcher, an independent cameraman and video producer.

EXECUTIVE SUMMARY

Introduction

At present, there is little information on the benthic communities of the offshore waters of the Gulf of Guinea region and Nigeria is particularly poorly studied. A summary of deep-water biological expeditions to the entire West Africa region reveals only 14 expeditions since 1872. Only 4 expeditions visited the Gulf of Guinea and from these only a few samples were obtained in Nigerian waters. It has never been a more important time for baseline scientific study, the Gulf of Guinea region is heavily exploited for natural resources, primarily hydrocarbon resources and fish, and is subject to high levels of anthropogenic impact from pollution. The limited environmental information is mostly collected by oil and gas companies and not yet available in the scientific literature.

The deep-waters off Nigeria offer many interesting and valuable opportunities for novel science. SERPENT aims to carry out deep-water science in the area offshore Nigeria by collaboration with industry, through Total E&P Nigeria (coordinated by Charles Mrabure), and with local universities and research organisations. Industrial remotely operated vehicles (ROVs) will be used to carry out high-resolution imaging surveys and make specimen collections in this deep-water region during periods of stand-by time, where the ROVs were not being used for normal industrial activity.

Overview of Activities

The first phase of the work was to characterise the deep-water megabenthic assemblages found in the Usan region for the first time using fully quantitative ROV imaging. This was carried out during a visit to Usan in July 2009 on the ROV support vessel *Bourbon Diamond*. Because the Usan field contains a diverse series of seabed habitats we were also able to assess in more detail the effect of the variable seabed slope on the seafloor animal assemblage particularly with regard to the number and diversity of organisms.

Characterisation of the seabed in terms of terrain parameters, such as slope, is a valuable tool for delineating regions of seafloor that may support particular fauna and therefore provide a distinct habitat. These techniques have been trialled with success in shallow waters but have received little attention in deep water. Slope is a vital parameter in these analyses, however the direct effects of slope on the animals of the deep sea floor have not been assessed. Certainly flat areas tend to exhibit different seabed types and support communities that are different to steeply sloping areas. Slope, while probably not often directly important, is thought to be an important factor because it has indirect effects on local near-bottom water movement and sedimentation. These factors, in turn, affect important biological processes such as food supply and colonisation.

In addition, we were also able to carry out detailed hydrographic measurements (salinity, depth and temperature) and collect sediment, rock and plankton samples in the Usan area to drive further research.

Results and conclusions

A total of 24 invertebrate species were observed at Usan from six animal groups (phyla). Echinoderms, such as sea stars and sea cucumbers, were dominant with 10 species found representing 64% of the animals observed. The sea urchin, *Phormosoma placenta*, was the most common animal which accounting for over half of the animals observed. Eight cnidarian species, particularly anemones, were identified but they only represented 4% of the total density. Crustaceans, such as crabs, were numerically important (31 % total fauna) but only represented by three taxa and only one of these, a squat lobster, accounted for the vast majority of the faunal numbers. Although not considered further in this analysis, 10 species of fish were observed at Usan. As a result of limited knowledge of West African megafauna it is difficult to assess how similar the animals at Usan are to other locations. In terms of species, the common species are probably known to science and, the limited evidence suggests, abundant in many areas.

Slope had a major impact on faunal density with a clear and significant linear negative relationship found between total density and slope. When total density is split into more ecologically meaningful units, based on feeding mode, the trends are even clearer. Deposit feeders, the animals that feed directly on the sediment, make up the majority of the animals observed, however, when analysed alone, densities of deposit feeders display an even stronger negative linear relationship with slope. Densities of suspension feeders, the animals that feed from particles in the water, are very low except in the highest slope site, even here mean densities are less than half that of deposit feeders. Slope also has a significant effect on the number of species found.

A total of 46 hydrographic deployments were carried out at Usan and 9600 readings were taken with the instrument. Maximum observed water temperature was 27.6°C and minimum 4.8°C. Salinities ranged between 26.58 and 36.63 (average 34.8) with the lowest salinities only found in the immediate surface waters during rainy periods. The deepest reading was taken at 815 m water depth (5.20° C temperature; 34.76 salinity). The depth of the thermocline (a layer of water with a strong temperature gradient; in the Gulf of Guinea this usually includes water of 20°C) was found to be surprisingly variable. The thermocline depth varied from 41 to 92 m water depth during the survey. The average thermocline depth observed here is greater than suggested in the literature by about 20m. Seasonal fluctuations in temperature are large in the Gulf of Guinea and the period of survey is a transitional time for water mass properties in the area, where climatic data are variable.

A total of 23 species of phytoplankton (drifting plants – usually microscopic) were captured. Of these most (14 species) were diatoms, 8 species were blue-green algae and 1 species was a desmid single-celled alga. In addition, one species of zooplankton (drifting animals), a copepod, was obtained. These species are all thought to be common in the area.

Chapter 1: INTRODUCTION

At present there is little information on the benthic communities of the offshore waters of the Gulf of Guinea region (Le Loeuff 1993, Le Loeuff & von Cosel 1998, Lebrato & Jones 2009). Comparatively more studies focus on the Canary region to the north (Merrett & Marshall 1980, Merrett & Domanski 1985, Duineveld et al. 1993a, Duineveld et al. 1993b, Henriques et al. 2002, Keller & Pasternak 2002). The Benguela region to the south of the Gulf of Guinea has also received some attention, particularly on the shelf and slope (Uriz 1988, Roeleveld et al. 1992, Roy et al. 2007) and the abyss (Vinogradova et al. 1990a, Zibrowius & Gili 1990, Thandar 1999, Levin & Gooday 2001, Kroncke & Turkay 2003, Saiz-Salinas 2007). A summary of deep-water expeditions to the entire West Africa region (and report references) is provided in Table 1.1. The Gulf of Guinea region is heavily exploited for natural resources, primarily hydrocarbon resources (Zabanbark 2002) and fish (FAO Fishery Committee for the Eastern Central Atlantic 1991), and is subject to high levels of anthropogenic impact from pollution (Scheren et al. 2002). The limited environmental information is mostly collected by oil and gas companies and not available in the scientific literature. It is very important that baseline quantitative environmental information is available for successful management of this increasingly exploited ecosystem.

The SERPENT Project (Scientific & Environmental ROV Partnership using Existing iNdustrial Technology) is a collaboration between world leading scientific institutions and companies associated with the oil and gas industry. SERPENT is hosted at the National Oceanography Centre, Southampton (NOCS), one of the world's largest research and teaching organisations specialising in deep-sea science and oceanography. SERPENT encompasses a scientific network of academic partners across the world (USA, Canada, Brazil, Nigeria, Angola, Mauritania, Australia), linked to a network of major oil and gas operators and contractors. The project centres around the opportunistic use of ROVs (Remotely Operated Vehicles) in operational settings during periods of stand-by time, i.e. when the ROVs have no tasked work and would otherwise be effectively idle. The project also aims to maximise the scientific benefit of environmental data collected as part of routine offshore operations and environmental surveys. Through access to ROVs and such environmental data, scientists at NOCS and from the wider SERPENT partnership aim to improve the scientific understanding of deep-sea biodiversity in all its aspects.

In this report we will present the results of a multidisciplinary SERPENT expedition in July 2009 to the Usan field off Nigeria supported by Total E & P Nigeria and the Total Foundation for Biodiversity and the Sea. This report will be divided into four sections:

- The megafaunal biodiversity of Usan: a quantitative assessment of the effects of slope on the assemblage
- Planktonic Communities
- Sediment conditions and surficial geology
- Physical conditions of the water column

Table 1.1: Summary of global deep-water (including deep continental shelf: > 100 m depth) biology cruise programmes to West Africa.

Date	Name	Lead country / institution	Study area	Purpose	Key References
1872-1876	*Challenger* expedition	UK	Global including northern West Africa	First investigations of deep-water fauna	(Thomson & Murray 1895, Murray & Hjort 1912)
1948-1949	Belgian Expedition	Belgium	Along the coasts of the southern Atlantic	Shelf benthic survey < 200m	(Cherbonnier 1959)
1950	Expedition of the R/V *Atlantide*	Denmark	Along the West African coast	Shelf benthic survey < 200m	(Mortensen 1951)
1950-1952	*Galathea* Expedition	Denmark	Along the West African coast	Assess benthic life in deep waters	(Bruun et al. 1956, Bruun 1957)
1950s	Expeditions of the R/V *Calypso*	France	Gulf of Guinea and the Cape Verde Islands	Shelf benthic survey < 200m	(Fauvel & Rullier 1959, Forest 1959)
1959	Expedition of the R.V. *Africana II*	South Africa	South Africa	Investigate deep-water fauna	(Thandar 1999)
1964-1965	Expedition of the R/V *Pillsbury*	America	Gulf of Guinea	Shelf benthic survey < 200m	(Bayer & Voss 1970)
1970s	Upwelling ecosystems	Germany - Institut fur Hydrobiologie und Fischereiwissenschaft (IHF) and UK - Institute of Oceanographic Sciences (IOS)	From Cape Mazagan, Morocco (35ºN) to Mauretania (17ºN)	Compare benthos under upwelling regions and in other areas of the Northwest African margin	(Thiel 1978, Rice et al. 1979, Merrett & Marshall 1980, Pfannkuche et al. 1983)
1985	R/V *Akademik Kurchatov*	Russia - P. P. Shirshov Institute of Oceanology	Shelf and Slope of Namibia in the Benguela upwelling region (17.5° S – 26° S)	Assess benthic fauna in Benguela upwelling region	(Vinogradova et al. 1990b)
1985-1986	South Atlantic Transoceanic section R/V *Akademik Kurchatov*	Russia - P. P. Shirshov Institute of Oceanology	31° 30' S	Compare benthos along transoceanic section	(Vinogradova et al. 1990a, Vinogradova 1993)
1989-1992 1991-1994	EU MAST I (pilot) EU MAST II	EU	NW African Abyssal Plains and Madeira Abyssal Plain	understand the fundamental processes governing marine systems	(Thurston et al. 1994)
1989–1992	EUMELI	France - IFREMER	NW African margin	Comparison of faunas under different organic matter input regimes	(Sibuet et al. 1993, Galeron et al. 2000)
2000	DIVA I	Germany - Senckenberg	Angola Basin	Latitudinal Gradients in Biodiversity in the deep Atlantic	(Kroncke & Turkay 2003)
2005	DIVA II	Germany - Senckenberg	Cape Basin and Guinea Basin	Latitudinal Gradients in Biodiversity in the deep Atlantic	In preparation

1.1 Megafauna

Megafauna are the size fraction of animals that are visible in photographs, they are typically larger than 1 or 5 cm in maximum size. They play an important role in benthic systems (Smith & Hamilton 1983), contributing significantly to benthic biomass (Schwinghamer 1981, Sibuet & Lawrence 1981, Christiansen & Thiel 1992), organic matter recycling (Smith 1992) and total benthic energy turnover (Walker et al. 1987). Megafauna have an important role in ecosystem function particularly in dispersing and redistributing organic matter and sediment (Smith 1985, Smith et al. 1993) important in the recovery of benthic systems from disturbance (Romero-Wetzel & Gerlach 1991). Quantitative understanding of megafaunal abundances and spatial pattern is important in assessing ecosystem effects and resilience to / recovery from physical anthropogenic disturbance, an impact that is becoming more widespread in the deep sea (Bluhm 2001).

Deep-sea megabenthic ecology has traditionally been reliant on semi-quantitative sampling with trawls and sledges (Thurston et al. 1994), more recent advances have used imaging methods to obtain quantitative data (Jones et al. 2007). It has not been possible, in most cases, to obtain accurate spatial positional information of individual organisms or even communities on the seafloor (Dolan et al. in press). Recent advances and application of detailed navigation technology for deep-sea studies (Barry & Baxter 1992), coupled with the increasing availability of high-resolution, spatially-accurate acoustic data on submarine topography and sediment properties, is allowing the first attempts at linking fine-scale patterns in biology to the broad-scale patterns in habitat type and subsea landscape. Given the sheer size and difficulties of accessing the deep-sea environment, accurate extrapolation of the fine-scale observations using information on the important physical controls for distribution is vital to describe the important broad-scale patterns in benthic biology.

Characterisation of the seabed in terms of terrain parameters such as slope, aspect etc. have been described as a valuable tool for delineating regions of seabed that may support particular fauna and therefore provide a distinct habitat (Wilson et al. 2007). These techniques have been trialled with success in shallow waters (Lundblad et al. 2006) but have received little attention in deep water (Wilson et al. 2007). Slope is a vital parameter in these analyses, however the direct effects of slope on deep-water benthos have not, to the author's knowledge, been assessed quantitatively. Certainly flat areas tend to exhibit different seabed facies and support communities that are different to steeply sloping areas (Lundblad et al. 2006, Schlacher et al. 2007). Slope, while probably not often directly important, is thought to be an important factor in determining benthic habitat through indirect effects on local near-bottom water movement and sedimentation (Noble & Mullineaux 1989). These factors, in turn, affect important biological processes such as food supply and colonisation (Butman 1990, Butman et al. 1994, Gage 1997).

The aim of this section is to describe the deep-water megabenthic assemblages found in this region for the first time using fully quantitative remotely operated vehicle (ROV) imaging. The effect of seabed slope on assemblage density, composition and diversity will be assessed for the Usan region.

1.2 Planktonic communities

It has been demonstrated that the entire Gulf of Guinea is influenced to a large extent by the meteorological and oceanographic processes of the South and North Atlantic Ocean (Merle & Arnault 1985, Fontaine et al. 1999), principally their oceanic gyral currents, which in turn reveal relationships with global atmospheric changes, such as the El Nino Southern Oscillation (ENSO).

Other physical factors that influence plankton production in the Gulf of Guinea are changes in local hydrography and climatic effects. Although not the case in the waters of Nigeria, the Gulf of Guinea has a large region of upwelling from the coast of Cote d'Ivoire around to Benin (Wiafe et al. 2008). The region is also referred to as the Central West African Upwelling, and the coastal oceanography has been described by several authors (Howat 1945, Longhurst 1962, Bakun 1978, Houghton 1983, Binet & Marchal 1993). Four distinct and predictable hydrographic seasons have been described: the minor (December–March) and major upwelling (July– September) interspersed with periods of stratification, typically with a thermocline 30–40 m below the surface (Wiafe et al. 2008).

Plankton studies in the Gulf of Guinea date back to the late 19th century, when several expeditions visited the region and assessed the species composition and diversity of zooplankton (Wiafe et al. 2008). The Danish Atlantide expedition of 1945/1946 provides extensive coverage of the copepods of the region (Vervoort 1963). By the mid-1960s, Ghana, Cote d'Ivoire, Sierra Leone, and Nigeria had set up fishery laboratories which, in addition to stock assessments, also carried out monitoring of the zooplankton biomass in relation to the fishery (Wiafe et al. 2008).

In upwelling areas, where most data exist, during the upwelling, zooplankton are more abundant, though with less species diversity, than during the thermally stratified periods (Bainbridge 1972). This applies mainly to outer-shelf stations because, in the inshore waters, meroplanktonic larvae (e.g. polychaete, echinoderm, and caridean larvae) are very common and mask the effect. During periods of thermal stability formation, the zooplankton is relatively sparse, with high species diversity and a considerable proportion of carnivorous species (Wiafe et al. 2008).

In addition to the annual cycle of abundance, which is clearly related to the annual hydrographic cycle, zooplankton abundance is variable over a longer period (Wiafe et al. 2008). Given the importance of hydrography in shaping the annual cycle, it is logical to relate these variations quantitatively to changes in the physical environment or, more specifically, to climate change, which drives most of the physical factors in the oceans (Wiafe et al. 2008).

The open ocean plankton assemblage of Nigeria is poorly known (Roger 1982) and is likely different to that found in the areas that experience seasonal upwelling nearby

(Binet & Marchal 1993). In particular, although chlorophyll concentrations are known from satellites, little information is available on the phytoplankton composition. In this study we aim to present a simple analysis of plankton presence and relative abundance in the Usan area to drive further research.

1.3 Physical conditions of the water column

The sea surface temperature (SST) is variable in the equatorial Atlantic. These variations are dominated by an annual signal with an amplitude of 1-2°C in the west increasing to 5-7°C in the Gulf of Guinea where the thermocline shoals and where the amplitude of the annual signal is several times greater than the interannual variability (Houghton 1983). The spatial pattern of this annual signal is illustrated in Figure 1.1. During the "cold season", most fully developed in July and August, cold water appears as a broad tongue extending along the equator from the eastern boundary to 30°W separate from a narrow band of cold water along the northern boundary between 2°E and 8°W (Houghton 1983).

The thermal structure in the Gulf of Guinea is characterized by a relatively shallow mixed layer, 20-50 m thick, overlying a sharp thermocline. At the equator the thermocline is broadened by the Equatorial Under Current. Throughout this section the 20°C isotherm is contained within the thermocline making this a good proxy for thermocline position. This is not, however, necessarily the case elsewhere in the equatorial Atlantic (Houghton 1983).

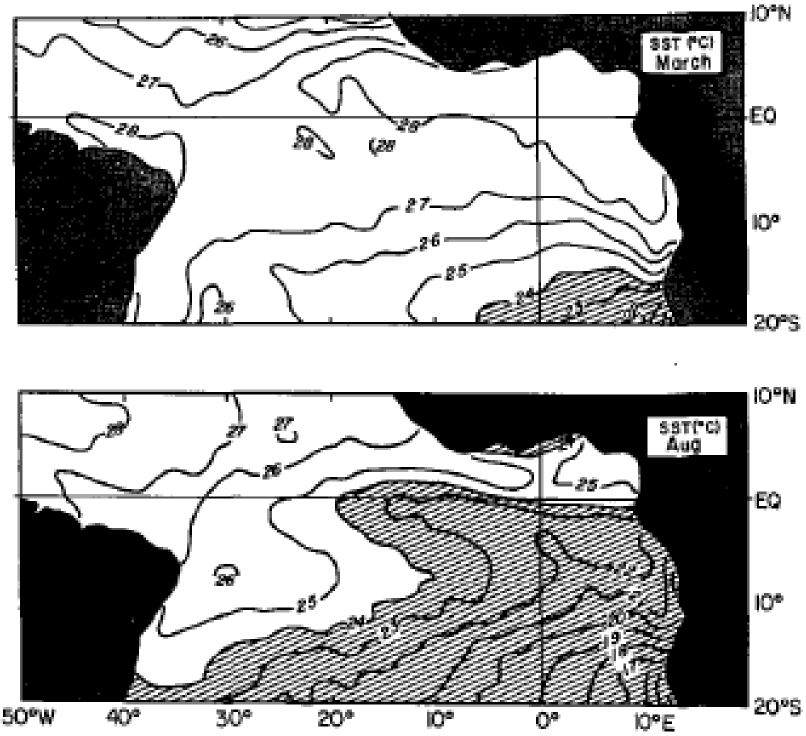


Figure 1.1: Climatic averaged sea-surface temperature for March and August (adapted from (Hastenrath & Lamb 1977)).

Historical hydrographic data is relatively abundant, with over 10,000 records (Figure1.2), especially when compared to biological data. Using the 20°C isotherm depth to represent the thermocline depth it is possible to examine seasonal variations of its zonal structure (Figure 1.3). The figure extends to the west in order to compare thermal variations within the Gulf of Guinea to those throughout the entire equatorial Atlantic. The data are averaged from 1.5°N to 1.5°S with zonal averaging over 5° west of 15°W and 2° east of 15°W. The standard deviation about these calculated means is approximately 10m. In particular during June the thermocline rises in the centre of the basin between 35-15°W prior to tilting in July (Figure 1.4). June in the Gulf of Guinea is a transition month to which it may not be appropriate to ascribe a climatic mean (Houghton 1983).

The aim of this study was to evaluate vertical hydrographic profiles from the surface to the seabed in a small area of ocean, at the Usan field offshore Nigeria at high temporal resolution during the month of July.

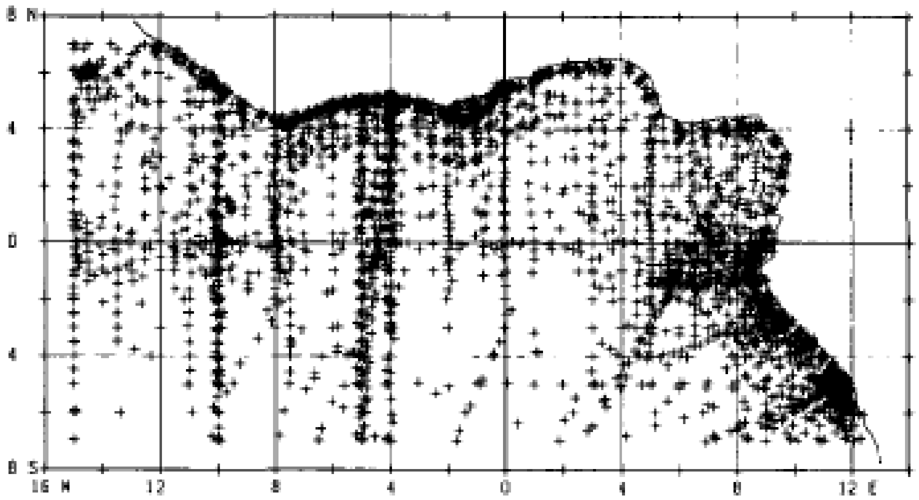


Figure 1.2: Distribution of historical hydrographic data in the Gulf of Guinea (Houghton 1983).

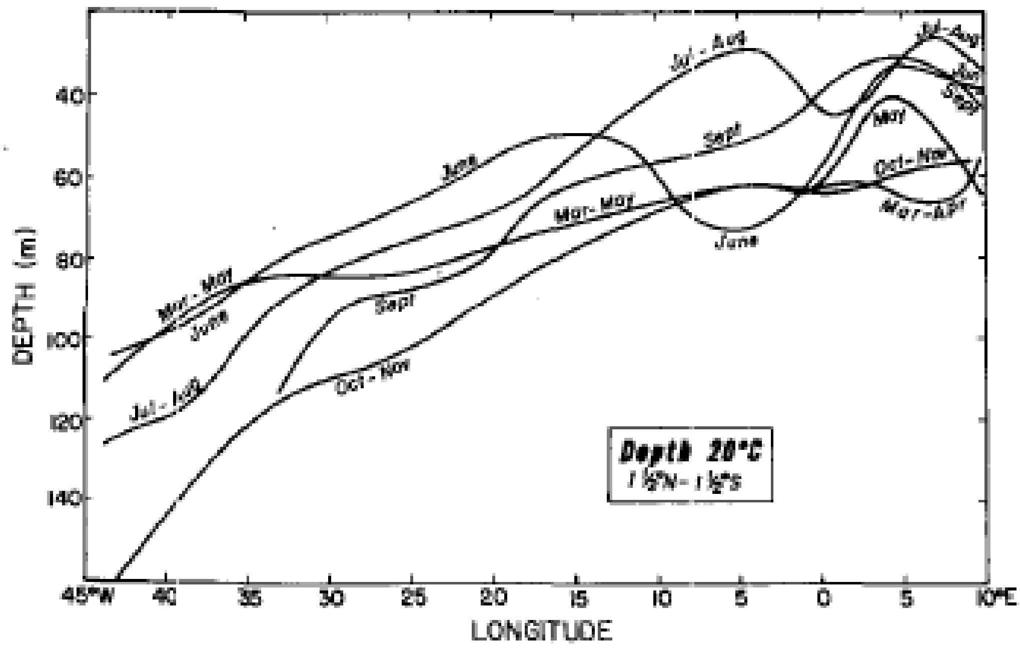


Figure 1.3: Climatic average depth of 20°C between 1.5°N and 1.5°S. Curves are hand drawn to fit points averaged ,every 5° west of 15°W and every 2° east of 15°W. Nearly identical months are averaged together (Houghton 1983).

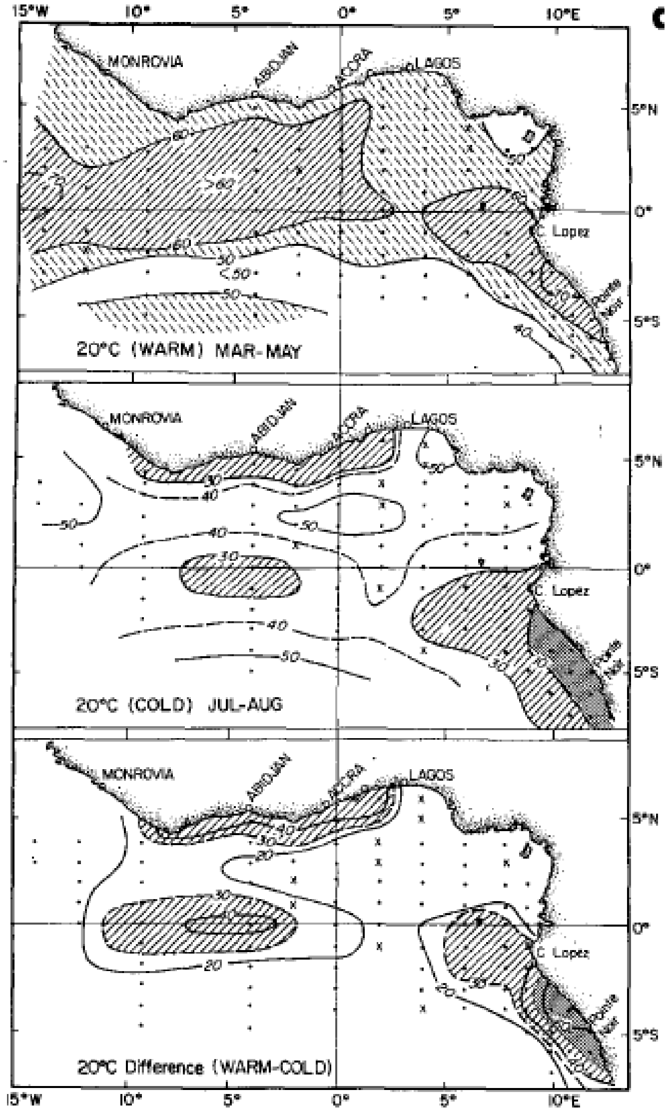


Figure 1.4: Average topography of 20°C isotherm for the (top) warm season and (middle) cold season throughout the Gulf of Guinea. Grid points with fewer than four stations denoted by an x. The vertical displacement field (bottom) is the difference of the upper two (Houghton 1983).

Chapter 2: METHODS

2.1 Megafauna

Survey Design

Data were collected following a one-way design with slope as a random factor. Four slope conditions were assessed (1°, 3°, 11° and 29°; Table 2.1). For each slope condition an area was chosen within the Usan field using detailed bathymetric charts to fulfil the following conditions: constant slope, a depth between 740 and 760 m, no other obvious features and at least 1km from any drilling activity. Three replicate ROV video transects (200 m length) were performed at random within each slope level. Random survey start points and headings were identified using a random number generator in Microsoft Excel. Transects were examined by plotting onto the chart. Any transect that extended beyond the boundaries of identified areas were discarded and another generated using the same method. In the area of highest slope, owing to bathymetric constraints, headings were constrained between 350 to 360°, 0 to 10° and 170 to 190° but otherwise random. Transects were regarded as sampling units (i.e. all organism densities were totalled for each 200 m transect) and used in all subsequent analysis. Three replicate transects at four slope levels resulted in a total of 12 sampling stations.

All positional information was recorded in Universal Transverse Mercator (UTM) zone 32 N based on the World Geodetic Society 1984 datum.

Data collection

Data were collected using an Oceaneering Millennium ROV equipped with a colour video camera (Insite Pacific Pegasus), sonar and ultra-short baseline navigation transponder. Cameras were mounted on a pan and tilt unit at the front of the ROV, which enabled oblique video to be taken. Before each transect the video was zoomed out to maximum extent and the camera was set to its most vertical angle (30° below the horizontal).

In every transect the ROV was run in a straight line, on a set bearing and at a constant speed (~0.3 ms^{-1}). Vehicle altitude (distance from seabed to the base of the ROV) was kept constant at 1m, which equated to a 143 cm camera altitude (from the centre of the camera). Transect width (mean of 1.72 m; max variation ± 0.2 m) was calculated from the camera acceptance angles (Jones et al. 2006). The camera horizontal acceptance angle (at full wide angle) was 55° and the vertical acceptance angle 43°. Transect width was also verified by passing over objects of known size on the seafloor. The optical resolution of the cameras permitted all organisms larger than 50 mm to be reliably distinguished. In addition to the transects, previous ROV suction sampling at Akpo and detailed video inspection of selected individual organisms aided species identifications (Jones et al. 2006).

Table 2.1: Transect names, start and end positions. Slope is represented by letters: F = 1°, M = 3°, H = 11°, E = 29°. Site numbers represent replicates.

start E	start N	end E	end N	feature ID
329883	390569	329689	390517	F1
329135	389240	329249	389403	F2
328857	389538	329050	389585	F3
325248	388398	325189	388589	M1
324864	388283	324826	388086	M2
325005	388655	324949	388462	M3
323359	386764	323334	386565	H1
322799	386011	322754	386205	H2
323564	386891	323377	386963	H3
321285	385530	321298	385729	E1
321333	385436	321329	385635	E2
321319	385654	321287	385456	E3

Data Analysis

Video transects were replayed at half speed and all visible organisms were counted along the entire transect. Colonial organisms were counted as single individuals. Infaunal species, when seen, were counted if enough of their body was visible for identification. Only benthic fish were counted, i.e. those fish that dwell on and feed at the seabed. It was frequently not possible to identify to species level. For the purpose of diversity analyses, when this was only possible to identify organisms to higher taxonomic levels they were classified to separate morphologically distinguishable entities (referred to as taxa). Numbers of organisms are quoted as abundances (numbers in each sampling unit), or as densities (no. m^{-2}).

A range of univariate community parameters were calculated. The number of organisms was evaluated as total density (no m^{-2}). A range of diversity indices were calculated to assess both the dominance and species richness aspects of diversity (Magurran 2003, Gotelli & Colwell 2001). These measures were calculated using PRIMER (Clarke & Warwick 2001).

Multivariate community analysis was based on abundances of all taxa, a square root transformation was applied to buffer the influence of dominant taxa (Field et al. 1982). Similarities were calculated using Bray-Curtis coefficients (Bray & Curtis 1957). The similarity values were subjected to both classification (hierarchical group-average clustering) and ordination (non-metric multi-dimensional scaling) using the software PRIMER (Clarke & Warwick 2001).

Data from well sites were analysed following one-way analysis of variance (ANOVA) design with slope as a random factor. This was implemented in the univariate case by one-way ANOVA and in the multivariate case by one-way ANOSIM (Clarke & Warwick 2001). Univariate community density and diversity responses were tested for normality (Anderson-Darling test) and homogeneity of variance (Levene's test), if not normal or homoschedastic, data were transformed. A one-way ANOVA was used to test differences in sample means (Sokal & Rohlf 1995). If significant differences were found these were explored further using *post hoc* pairwise analyses of the different groups using the Holm-Sidak method (Sokal & Rohlf 1995). Statistical tests were implemented in SigmaStat (Systat Software Inc. 2008).

2.2 Planktonic communities

Plankton assemblages were sampled using a simple baffled tube collector (Figure 2.1). This was attached to the ROV cage and sampled plankton throughout the water column on both the up and down-cast of the ROV. The plankton collected in the 150 mm diameter tube were retained on a cotton mesh. This method was limited, having limited trapping ability, an unknown mesh size, incomplete sample retention and no closure mechanism and hence no depth differentiation. In addition, because of vertical deployment, the number of planktonic organisms sampled was small especially for sparse deep-water taxa. Despite these flaws, the method gave a qualitative assessment of plankton diversity at a number of sites (Table 2.2) and allowed specimen capture for further analysis.

Table 2.2: Sampling sites. All sites were within the degree square 3°N 7°E and seabed depth was 750 m ± 20 m.

Site	Date	Sample code
Extr 2	16/07/09	BD/160709/005#3
P1	15/07/09	BD/150709/002#1
P2	15/07/09	BD/150709/003#1
P3	16/07/09	BD/160709/004#1
P4i	16/07/09	BD/160709/005#1
P4ii	16/07/09	BD/160709/005#2

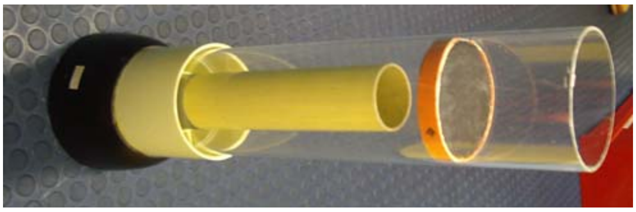


Figure 2.1: Plankton sampling device

2.3 Physical conditions of the water column

A self-contained datalogger was attached to ROV for the duration of the visit recording information every 30 seconds. The datalogger (RBR Model XR-420CTDmTi+pH+DO) records information from temperature, depth and conductivity sensors. It also had pH (AMT UT-pH-EM) and oxygen (Aanderaa AA 3830 Optode) sensors, however neither of these were working properly prior to deployment and had to be disabled.

The depth of the 20°C isotherm was inferred using linear interpolation. The data was interrogated for the point at which the temperature profile crossed the 20°C isotherm. The adjustment factor (*Af*) was calculated as follows from the temperature record above (*Ta*) and the temperature record below (*Tb*) 20°C:

$$Af = (20 - Tb)\ \sqrt{(Ta - Tb)^2}$$

The depth was then corrected using the adjustment factor (*Af*) and the depth above (*Da*) and the depth below (*Db*) the 20°C temperature transition:

Inferred depth = $Da - Af\,(Da\text{-}Db)$

Chapter 3: RESULTS

3.1 Megafauna

The seabed was almost entirely composed of fine grain sized sediment, no individual grains were visible in video, even when fully zoomed in. This would suggest that the largest possible grain size is fine sand (< 0.5 mm) but observations would suggest that it was finer and classified as mud (< 125 µm). At the highest slope areas hard substrata were visible, these apparently comprised igneous rock associated with past volcanism. The hard substratum provided habitat for numerous taxa specialising in these habitats (Table 3.1).

Nature of benthic community

A total of 24 invertebrate megafaunal taxa were observed at Usan from six phyla (Table 3.1). In terms of species richness and numerical abundance, echinoderms were dominant, 64% of the fauna observed were echinoderms represented by 10 taxa. Eight cnidarian taxa were identified but they only represented 4% of the total density. Crustaceans were numerically important (31 % total fauna) but only represented by three taxa and only one of these, a galatheid, accounted for the vast majority of the faunal numbers. Of minor importance were the poriferans, molluscs and enteropneusts all with only one taxon observed and representing a total of < 1% of the total invertebrates.

Of overwhelming dominance, particularly in the flatter areas, was the regular echinothurid echinoid *Phormosoma placenta* which accounted for 53% of the invertebrates observed. Another two taxa were also numerically important: the galatheid *Munidopsis* sp. represented 29% of megafauna and a large ophiuroid represented 8%. Most of the other taxa observed were rare or of minor importance.

Although not considered further in this analysis, fish were observed at all the sites (Table 3.2). The small, dark-coloured, midwater gonostomatid fish were the most abundant representing over 47 % of the fish fauna. The true benthic Lophiiform *Dibranchus* sp. was common and represents 27% of the fish observed. The other major taxon was the Nettastomatid Anguilliform *Nettastoma melanura* which accounted for 18% of the fish observed. The demersal grenadier *Corphaenoides* sp. and the Morid Gadiform *Laenomena laureysi*? each represented around 2% of the fish seen.

Effects of slope

Faunal density

Slope had a major impact on faunal density (ANOVA $F = 5.73$, df = 3,8, $p < 0.05$; Figure 3.1). A clear and significant linear negative relationship between total density and slope was observed (Linear regression $R^2 = 0.67$, $p < 0.01$). When total density is split into more ecologically meaningful units, based on feeding mode, the trends are even clearer. Deposit feeders make up the majority of the megafauna observed, however, when analysed alone, densities of deposit feeders display an even stronger negative linear relationship with slope (Linear regression $R^2 = 0.74$, $p < 0.001$). Densities of suspension feeders are very low except in the highest slope site, even here mean densities are less than half (0.17 m^{-2}) that of deposit feeders (0.40 m^{-2}).

Of the major taxa, *Phormosoma placenta* was negatively correlated with slope ($R^2 = 0.50$, $p < 0.05$) as was the Galatheid *Munidopsis* sp. ($R^2 = 0.30$, $p < 0.001$), the Ophiuroid displayed a slight positive, although not significant correlation with slope ($R^2 = 0.20$, p = ns).

Faunal Diversity

Slope has a significant effect on the number of species found (Table 3.3; ANOVA $F = 5.07$, $df = 3,8$, $p < 0.05$). Pairwise tests, however, only reveal significant differences between the lowest slope (1°) and the highest slope (29°). The principal difference in the sites, in terms of diversity, was in the presence of obligate epilithic species at the sites where hard substratum was exposed (see Table 3.1). In soft sediment areas there was some variation in species complement resulting from apparently random presence or absence of rare species.

Species diversity indices (Table 3.3) reveal that the species richness element of diversity (ES(60) $R^2 = 0.82$, $p < 0.001$) and the evenness component (J' $R^2 = 0.84$, $p < 0.001$) show a highly significant positive linear relationship with increasing slope. A combined index, as would be expected, also follows this significant positive correlation (H' $R^2 = 0.82$, $p < 0.001$; Figure 3.2). There are significant pairwise differences between the highest slope level and all the lower slope levels but there are no significant pairwise differences between the three lower slope levels in any measures (e.g. H' ANOVA pairwise comparisons p = ns).

Multivariate similarity

Multivariate community similarity was significantly different with different slope levels (ANOSIM $R = 0.68$, $p < 0.001$; Figure 3.3). Multivariate community similarity was high (> 60 %) between the lower slope groups (1, 3 and 11°). The highest slope (29°) sites were more heterogeneous. Two sites (E2 and E3) formed a distinct group (with 77.5 % similarity) and one site (E1) was intermediate between the highest and lower slope sites, having slightly higher affinity with the lower slope sites (similarity 58.8%) than with the higher slope sites (similarity 35.86%).

Table 3.1: Invertebrate megafauna densities (no m^{-2}) at each transect at Usan. Slope is represented by letters: F = 1°, M = 3°, H = 11°, E = 29°. Site numbers represent replicates. Asterisked taxa (*) are known to prefer hard substrata and double asterisked (**) only live on hard substrata (obligately epilithic).

	F1	F2	F3	M1	M2	M3	H1	H2	H3	E1	E2	E3
Hexactinellid**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.003
White antipatharian**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047	0.061
whip (sand)	0.000	0.000	0.000	0.000	0.003	0.000	0.003	0.003	0.003	0.000	0.000	0.000
Whip (rock, white)**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009
Pennatulea sp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
Gorgonian fan**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
Actinoscypha sp.	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Edwardsia sp.	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Striped African anemone	0.000	0.000	0.003	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Phormosoma placenta	0.343	0.395	0.302	0.140	0.233	0.352	0.201	0.009	0.012	0.090	0.023	0.081
Red urchin not phormosoma	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.012	0.003
White echinoid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.003
white diadema	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.009	0.006
Ophiuroid	0.012	0.000	0.000	0.009	0.020	0.032	0.064	0.070	0.038	0.029	0.052	0.026
Brisingid*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.003
Aphrodite like holothurian	0.012	0.003	0.000	0.000	0.003	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Mesothuria	0.000	0.009	0.006	0.003	0.000	0.000	0.003	0.003	0.017	0.000	0.000	0.000
Benthothuria	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.003	0.003	0.000	0.000
Commatulid*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
Galatheid	0.090	0.070	0.047	0.142	0.180	0.116	0.180	0.172	0.172	0.032	0.006	0.015
Prawn	0.003	0.009	0.015	0.003	0.009	0.003	0.006	0.003	0.009	0.012	0.000	0.000
Nephrops	0.000	0.000	0.000	0.003	0.003	0.000	0.003	0.003	0.000	0.000	0.000	0.000
Opisthobranch	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Enteropneust	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
TOTAL	0.462	0.485	0.378	0.311	0.451	0.509	0.459	0.262	0.256	0.174	0.183	0.218
Total suspension feeders	0.000	0.000	0.000	0.000	0.003	0.000	0.003	0.003	0.003	0.000	0.081	0.084
Total deposit feeders	0.456	0.477	0.355	0.302	0.436	0.503	0.448	0.253	0.244	0.163	0.102	0.134

Table 3.2: Vertebrate megafauna (fish) densities (no m^{-2}) at each transect at Usan. Slope is represented by letters: F = 1°, M = 3°, H = 11°, E = 29°. Site numbers represent replicates. These species are not considered in any further analysis.

	F1	F2	F3	M1	M2	M3	H1	H2	H3	E1	E2	E3
Nettastoma melanura	0.003	0.003	0.003	0.000	0.000	0.003	0.003	0.017	0.009	0.012	0.009	0.015
Halosaurus sp.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Dibranchus sp.	0.009	0.009	0.009	0.012	0.009	0.015	0.009	0.020	0.012	0.006	0.000	0.006
Gonostomatids	0.000	0.012	0.020	0.003	0.012	0.009	0.073	0.035	0.012	0.012	0.006	0.006
Zoarcid	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corphaenoides sp.	0.000	0.003	0.000	0.000	0.000	0.000	0.003	0.006	0.000	0.000	0.000	0.000
Laenomena laureysi ?	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Dicrolene intronigra	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000
Scorpioniformes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003

Table 3.3: Species diversity indices. N = Total number of individuals found in 200 m transect. S = total number of species in each transect. ES(60) = estimated species richness (rarefaction) in 60 individuals. J' = Pielou's evenness (1= maximal evenness, 0 = minimum evenness or maximum dominance). H'(loge) = Shannon Wiener diversity index to log base e (high numbers = high heterogeneity diversity).

Name	N	S	ES(60)	J'	H'(loge)
F1	159	6	4.461	0.4404	0.7891
F2	167	5	3.839	0.3859	0.6211
F3	130	7	5.054	0.3794	0.7382
M1	107	9	6.531	0.5053	1.11
M2	155	7	4.904	0.5251	1.022
M3	175	6	4.02	0.4772	0.8549
H1	158	7	4.756	0.5935	1.155
H2	90	7	5.632	0.4844	0.9427
H3	88	8	7.006	0.5492	1.142
E1	60	8	8	0.6753	1.404
E2	63	11	10.95	0.8351	2.002
E3	75	11	10.15	0.7272	1.744

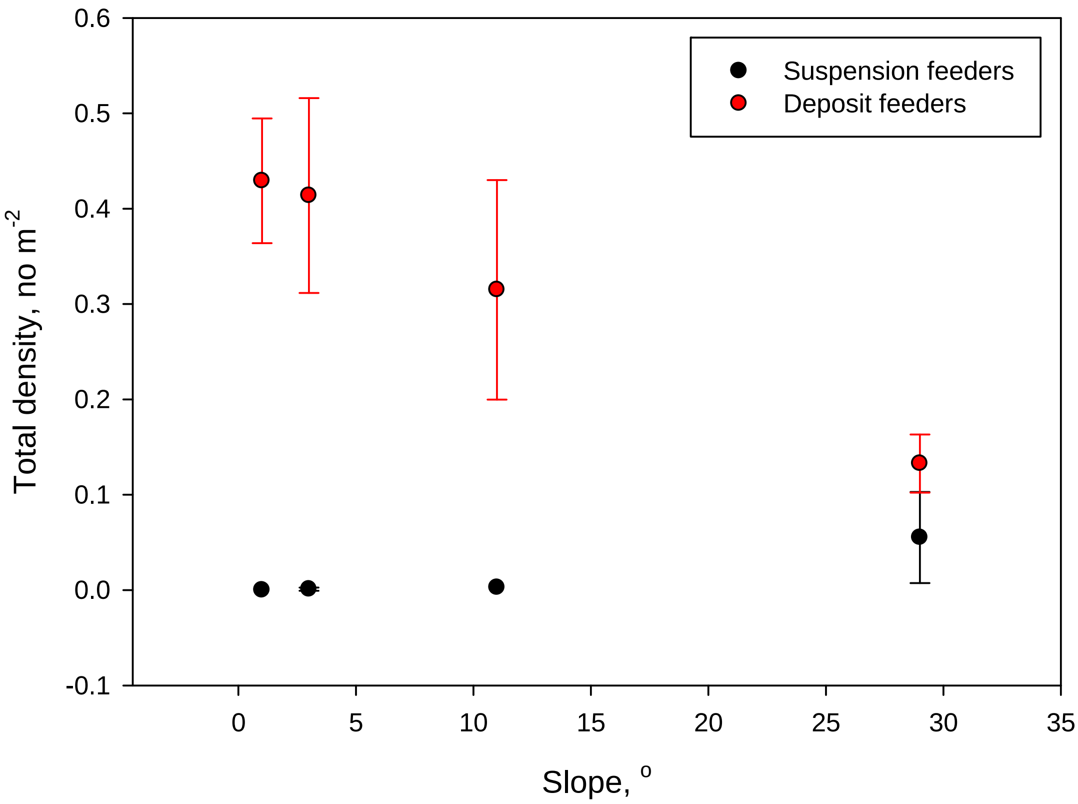


Figure 3.1: Effect of slope on megafaunal invertebrate deposit and suspension feeding assemblage total densities at the Usan area, offshore Nigeria. Errors bars represent standard deviations and points represent the mean density of 3 replicates.

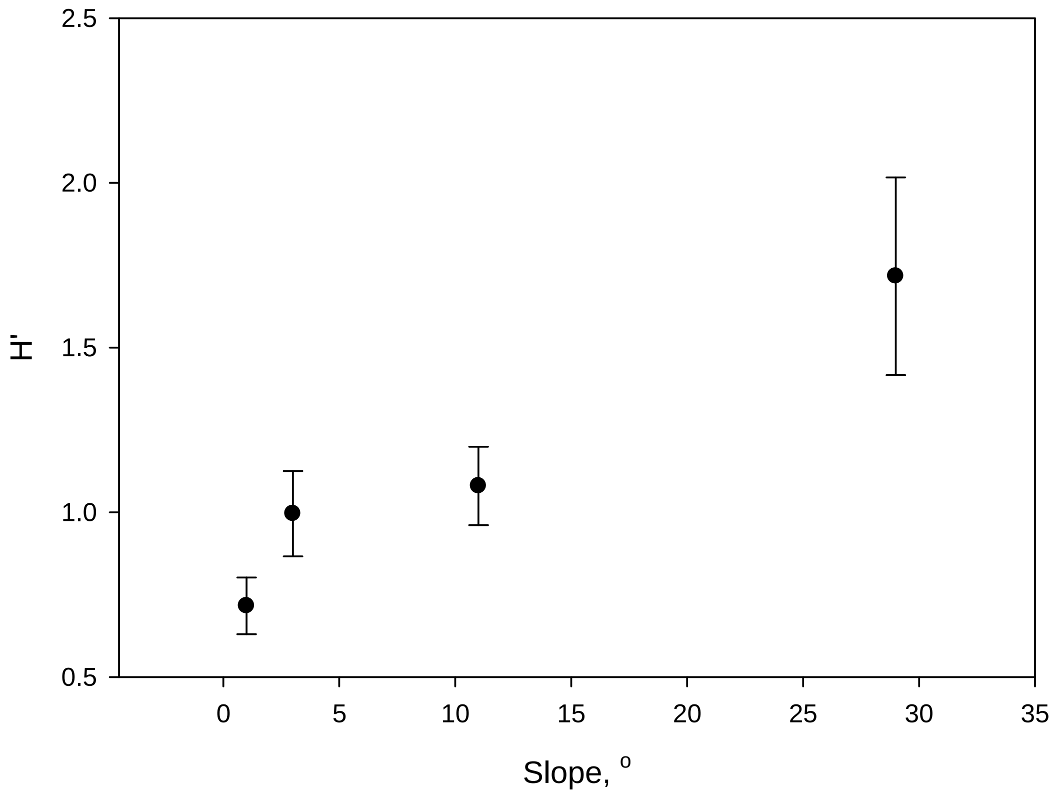


Figure 3.2: Effect of slope on megafaunal invertebrate diversity at the Usan area, offshore Nigeria. Errors bars represent standard deviations and points represent the mean density of 3 replicates.

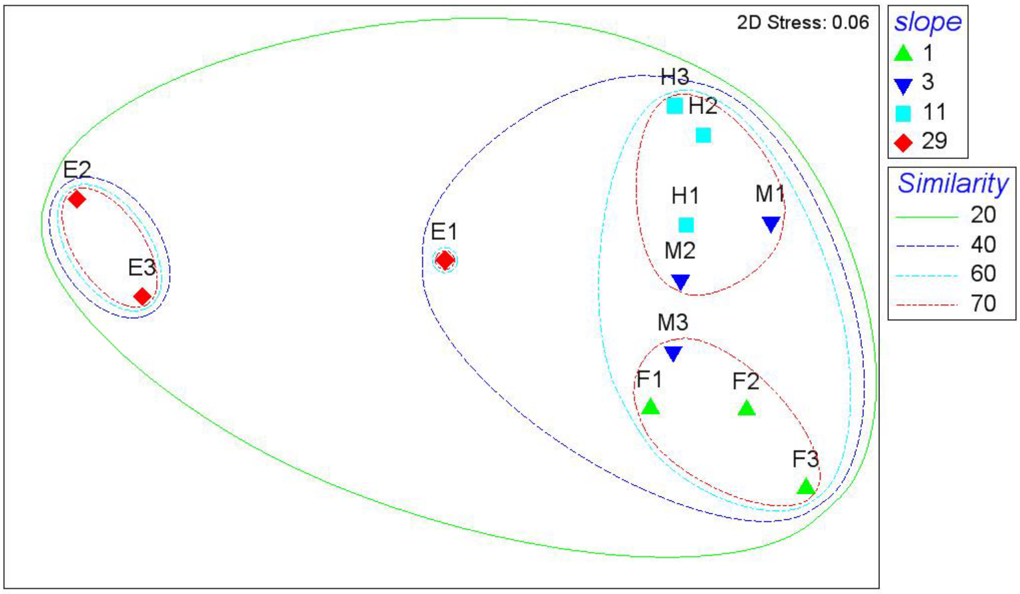


Figure 3.3: Multidimensional Scaling Ordination of Bray-Curtis similarities (4th root transformed) of Usan Invertebrate megafaunal assemblage. Overlaid are similarity levels from hierarchical cluster analysis.

3.2 Planktonic communities

A total of 23 species of phytoplankton were captured. Of these most (14 species) were Bacillariophyceae, 8 species were Cynophyceae and 1 species was in the Desmidaceae. In addition, one species of zooplankton, a copepod, was obtained (Table 3.4).

Table 3.4: Percentage abundance (by number) of plankton in the sampling stations.

PHYTOPLANKTON

Bacillariophyceae (Diatoms)	**SAMPLING STATIONS**					
	Extr 2	P1	P2	P3	P4i	P4ii
Melosira sp.	38.5			30		0.6
Cyclotella sp.	7.7				47.6	
Grammatophora sp.	15.4	14.3				
Biddulphia antadeluviana	11.5					
Diatoma sp.				30		
Coscinodiscus sp.	7.7		4.8			
Cyclotella corpta						3.0
Diatoma vulgare				10		1.2
Rhizoselina stolterfothii	3.8					
Terpsinae musica	3.8					
Meridon arculare						0.6
Stephanodiscus sp.					4.8	
Tubellaria sp.	1.9					
Coscinodiscus limneatus						0.6
Cynophyceae (Blue-green algae)						
Gloeocapsa alpicola						39.4
Microcystis sp.						30.3
Chroococus disperses						13.3
Microcystis margranata			95.2			
Chroococus limneticus						9.1
Oscillatoria sp.		71.4				
Malleochlons sessilis					47.6	
Synechococcus aeruginosa	5.8	9.5		30		
Desmidaceae						
Cosmarium sp.	3.8	4.8				
ZOOPLANKTON (Cyclopod, Copepod)						
Cyclops sp.		1				

3.3 Physical conditions of the water column

A total of 46 dives with the CTD were carried out at Usan and 9600 readings were taken with the CTD (Figure 3.4 and Appendix). Maximum observed water temperature was 27.6°C and minimum 4.8°C. Conductivity ranged from 21.7 to 55.2, this represented salinities of 26.58 to 36.63 with the lowest salinities only found in the immediate surface waters during rainy periods (Figure 3.6 and Appendix). The mean salinity was 34.80. The deepest reading was taken at 815 m water depth (5.20° C temperature; 33.80 conductivity, 34.76 salinity).

The depth of the thermocline was variable (see Appendix). If the 20 °C isotherm is taken to represent the thermocline depth, the depth varied from 41 to 92 m water depth during the survey (from points actually recorded within 0.5°C of 20°C). Inferred 20°C isotherm depths were assessed and found to range between 104 and 47 m with an average depth of 74.9 m (Figure 3.5). There may be some systematic variation as a result of either location or time (Figure 3.6).

The changes in location of the CTD profiles did appear to have a potential influence on the depth of the thermocline. This is best demonstrated during the transect survey phase of work where, on Monday 13th July from 11:30 until 21:00 the ship was moving to steeper seabed areas (towards the large topographic elevation). During this time the running average thermocline depth decreased by around 10 m (see Appendix). Despite this, the change is well within the range of inferred data.

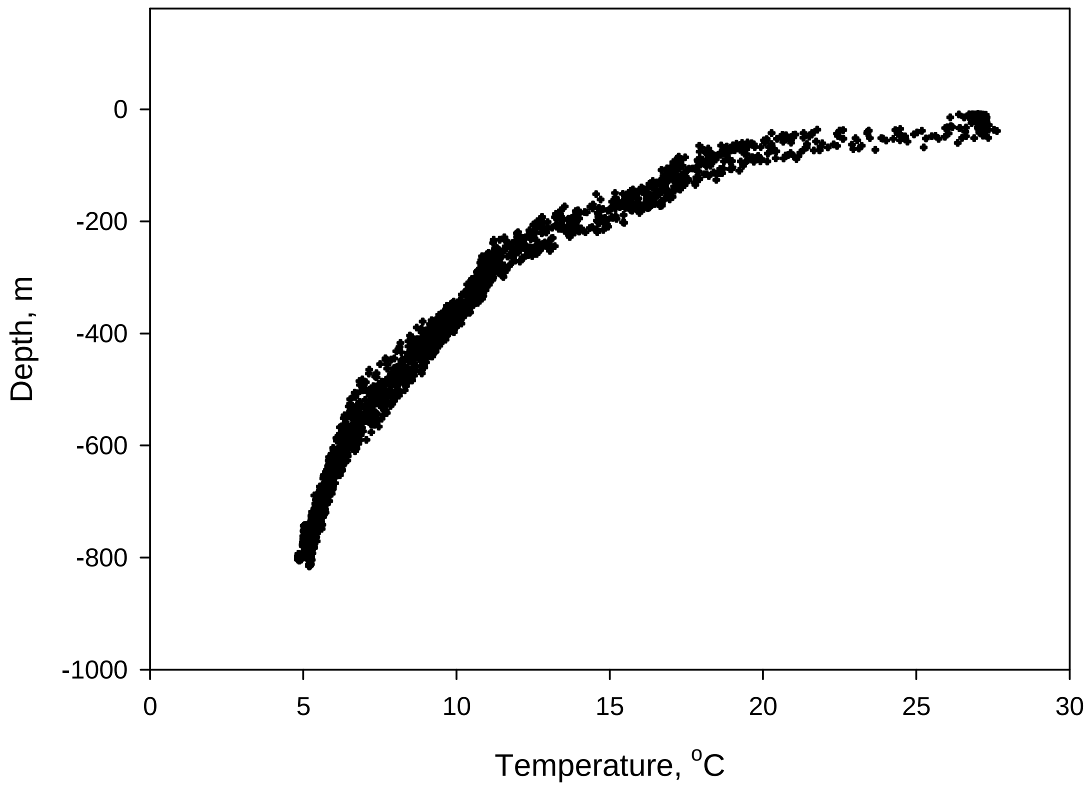


Figure 3.4: Water temperature change with depth of all stations measured at Usan.

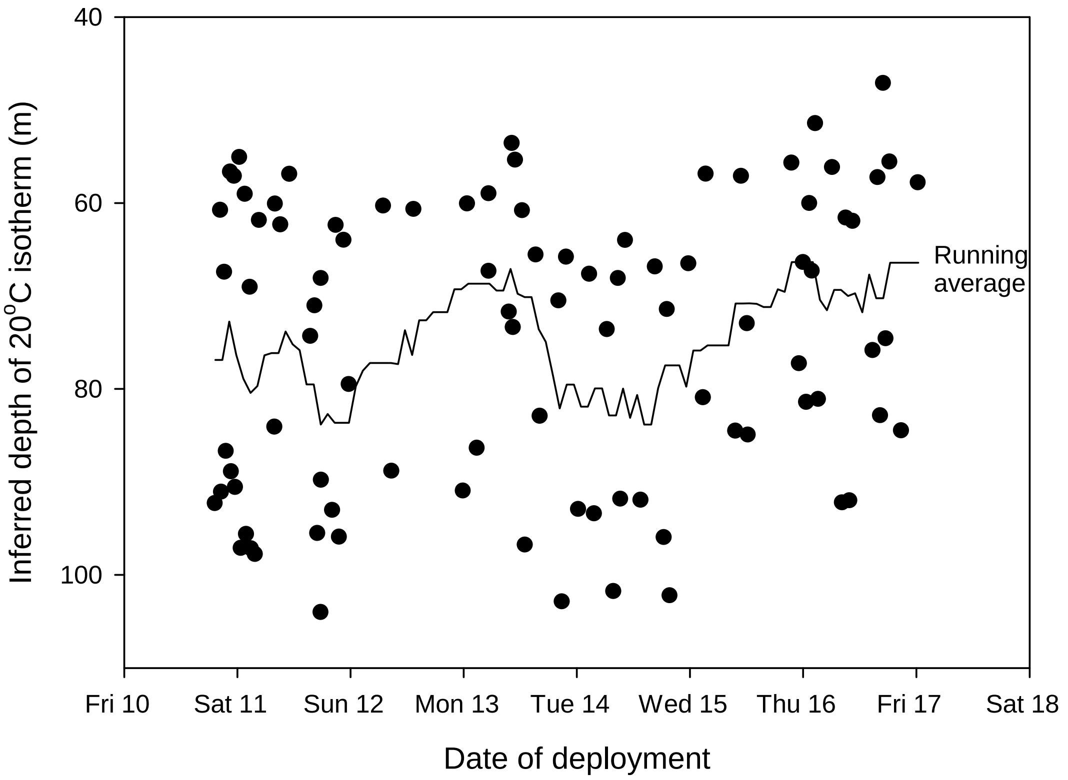


Figure 3.5: Inferred (by linear interpolation between data points) depth of 20°C isotherm (thermocline) over the course of the visit to Usan. The line shows the running average.

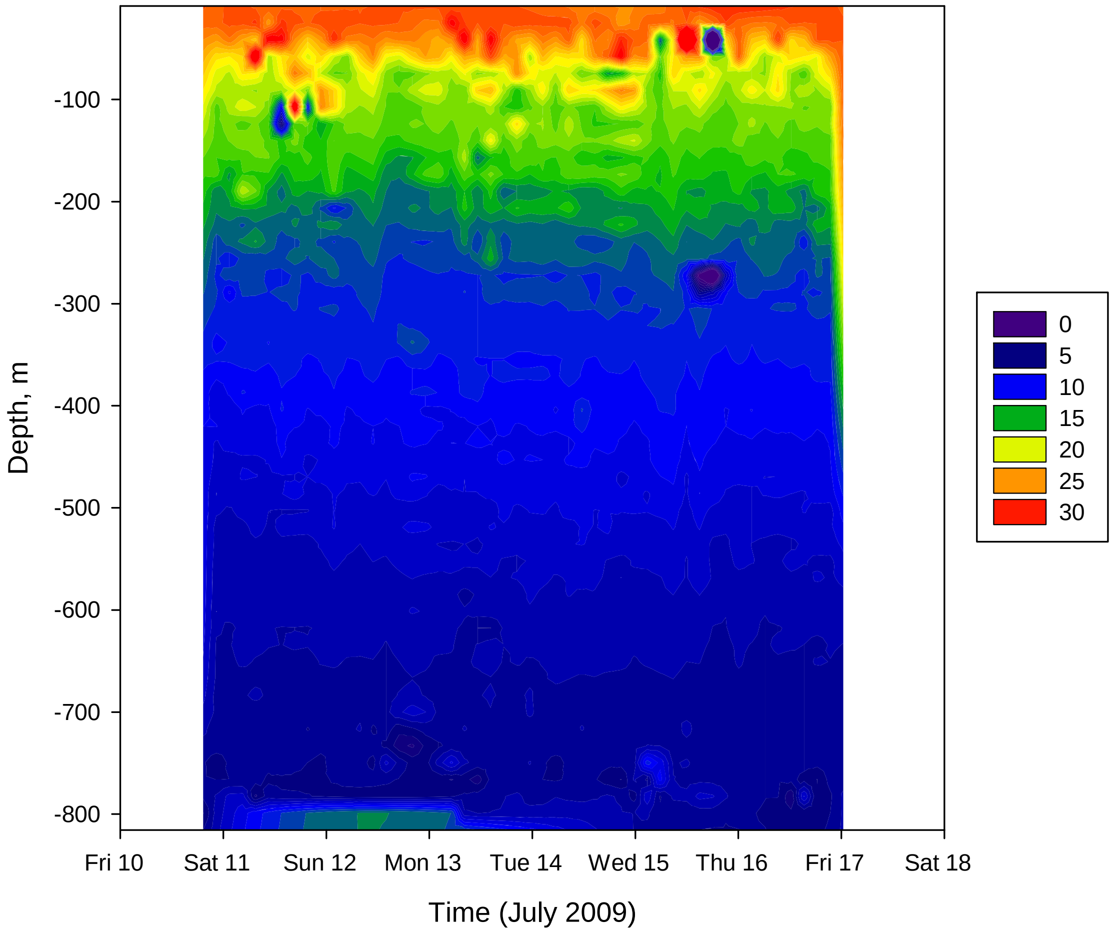


Figure 3.6: Temporal temperature section through the water column at Usan. Ignore the very large temperature changes within a small time/depth space (highly contrasting dots e.g. ~50m and ~275m, Thur 16) as these are interpolation errors.

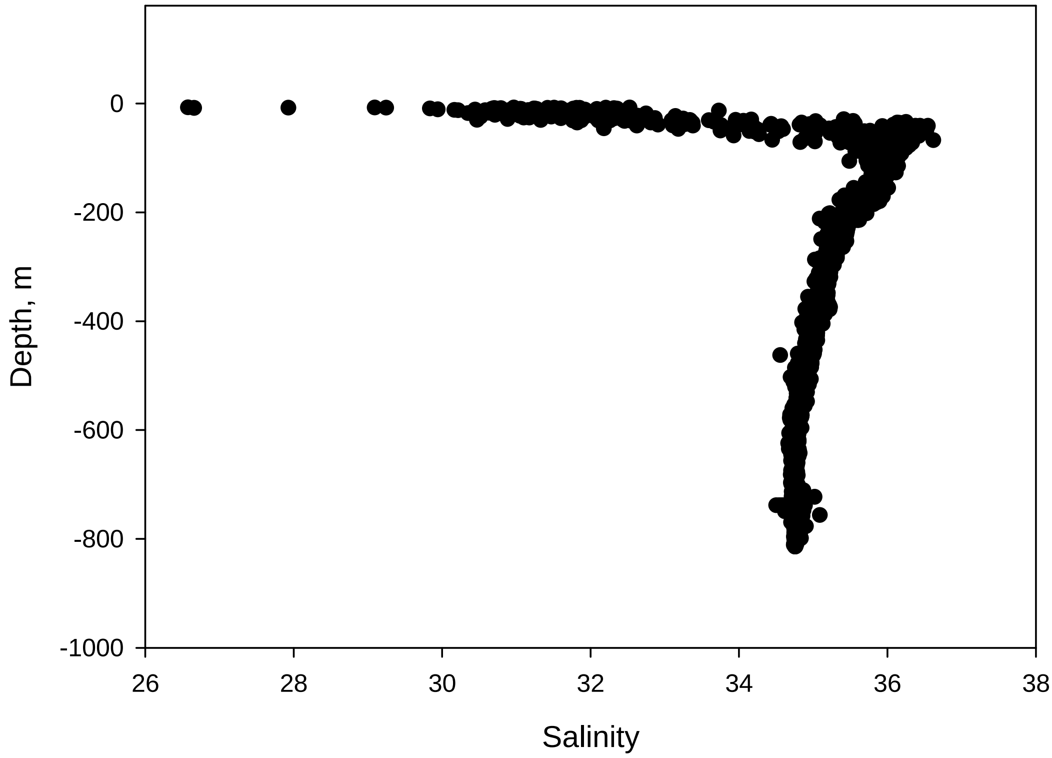


Figure 3.7: Water salinity change with depth of all stations measured at Usan.

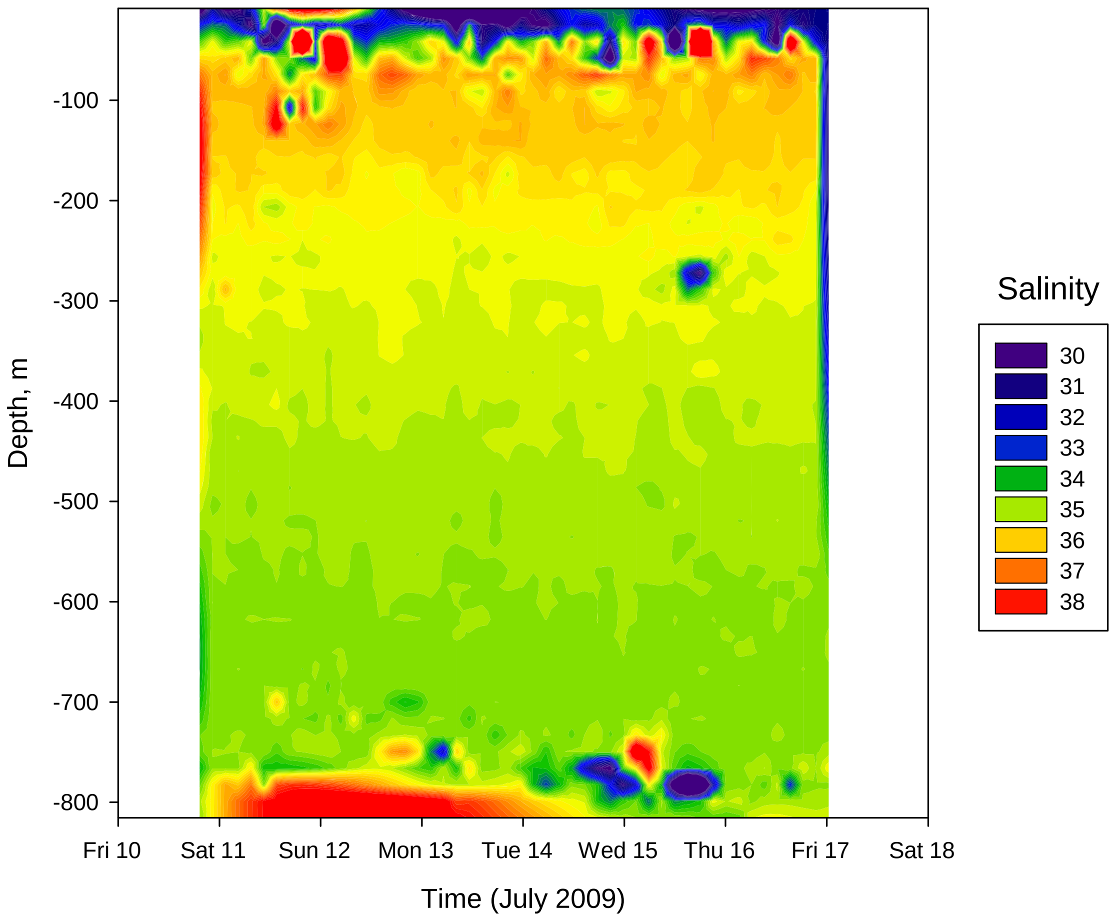


Figure 3.8: Temporal salinity section through the water column at Usan. Ignore the very large salinity changes within a small time/depth space (highly contrasting dots e.g. ~50m and ~275m, Thur 16) as these are interpolation errors.

Chapter 4: CONCLUSIONS

General Patterns

As a result of limited knowledge of West African megafauna it is difficult to assess how similar the assemblage of invertebrates found at Usan was to other locations. In terms of species, the common species are probably known and, the limited evidence suggests, abundant in many areas. *Phormosoma placenta* is a common, often dominant species on both sides of the Atlantic (Laguarda-Figueras et al. 2005, Sanchez et al. 2008), the large ophuiroid observed here has a high similarity to that found off Mauritania, Ivory Coast and Angola (Author's Observation), a similar galatheid to that found here has also been observed off Ivory Coast in image material (Lebrato & Jones 2009). It should be noted that the differences even between genera are not always visible in photographs. The rarer species quantified and those seen outside of the surveys likely include new species, however from standard-resolution video and image data in general it is not usually possible to resolve details necessary for high-resolution taxonomy.

In terms of density the communities of Usan seem to be low, but in the range, of those found elsewhere (Figure 4.1). The nearest sites for comparison, at equivalent depth, are found of the Ivory Coast where megafaunal densities were over three times greater (Lebrato & Jones 2009) although the Ivory Coast site experienced significantly enhanced nutrient inputs. Few other data are available for the East Atlantic at equivalent depths. Other, deeper, studies have a range of megafaunal densities (Figure 4.1) usually lower than the Usan site. The exception has been for areas that are known to have highly productive surface waters, for example the eutrophic EUMELI site off Mauritania (Galeron et al. 2000).

Effects of slope

Many species were present at all the slope levels investigated. For the rarer taxa, assuming a random distribution, presence at sites would appear to result from chance encounters and not necessarily represent habitat preference.

The largest difference in presence/absence of taxa was observed in the highest slope site (E). The highest slope sites had exposed hard substrata and hence a unique community of epilithic megafauna. These taxa are all in groups that only inhabit hard substrata and usually have morphological adaptations for this habitat e.g. gorgonians. Hard substratum is rarely found in the deep sea, usually occurring in areas associated with direct volcanism (e.g. the relic volcanism seen here), seabed fluid flow (e.g. at vents and seeps) (Van Dover 2000), high current flow (Kuijpers et al. 2002), biogenic habitats ((Roberts et al. 2003) or ice related processes (e.g. iceberg rafting) (Gutt 2001). Hard substrate communities are rare off West Africa, having only been described off Mauritania associated with corals (Colman et al. 2005). Other studies in the northern tropical Atlantic are on the mid-Atlantic ridge at non vent (Tabachnick & Collins 2008) and vent sites (Van Dover et al. 2002) and the volcanic island groups e.g. the Azores. The communities found on hard substrata at Usan superficially resemble those found at non-vent hard substrata in the northern tropical Atlantic (in terms of faunal groups present) and from hard substrata in the deep sea in general (e.g. Lundsten et al. 2009), however without accurate species-level identifications either here or commonly in the megafaunal literature, further patterns are difficult to assess.

There are large reductions in density of many species in response to increases in slope likely resulting from reductions in food availability for deposit feeders. Slope is likely to affect food availability in two ways: firstly, increased slope will likely increase lateral advection of food particles, reducing residence times and hence availability for deposit feeders, secondly increases in slope are likely to increase current speeds and hence lead to reductions in deposition and increases in winnowing of fine, nutritious particles (Levin et al. 2001). Reductions in food availability have been repeatedly shown to be responsible for reductions in megafaunal density (Thurston et al. 1994, Galeron et al. 2000).

Increases in slope caused increases in megafaunal diversity at Usan. There were slight (although not significant) diversity increases with slope in the sites without hard substrata and consistent changes in multivariate community composition. In the absence of other factors, reduced food availability tends to lead to reductions in diversity (Waide et al. 1999) and this has been demonstrated in the tropical Atlantic deep sea (Cosson et al. 1997). This is clearly the opposite trend to that observed here. In some cases mid to high levels of organic matter may cause diversity to decline, although this is very rarely the case in the deep sea (Levin et al. 2001) and unlikely off Nigeria as the area is not known for very high surface productivity (Longhurst 1998). Increases in slope will not only affect the organic content of sediment. Slope increases are also likely to affect the heterogeneity of the habitat. Sediment grain size will likely become coarser and potentially more heterogeneous, increasing niche availability and hence deposit feeder diversity (Etter & Grassle 1992, Wheatcroft 1992). At the Usan site the high slope sites have exposed hard substrata, presumably owing to limited deposition, and this increase in habitat heterogeneity is responsible for the clear and significant increases in diversity and changes in multivariate community composition at the highest slope sites. An entirely different range of animals are able to colonise hard substrata and hence, where this is present, diversity will increase (Levin et al. 2001).

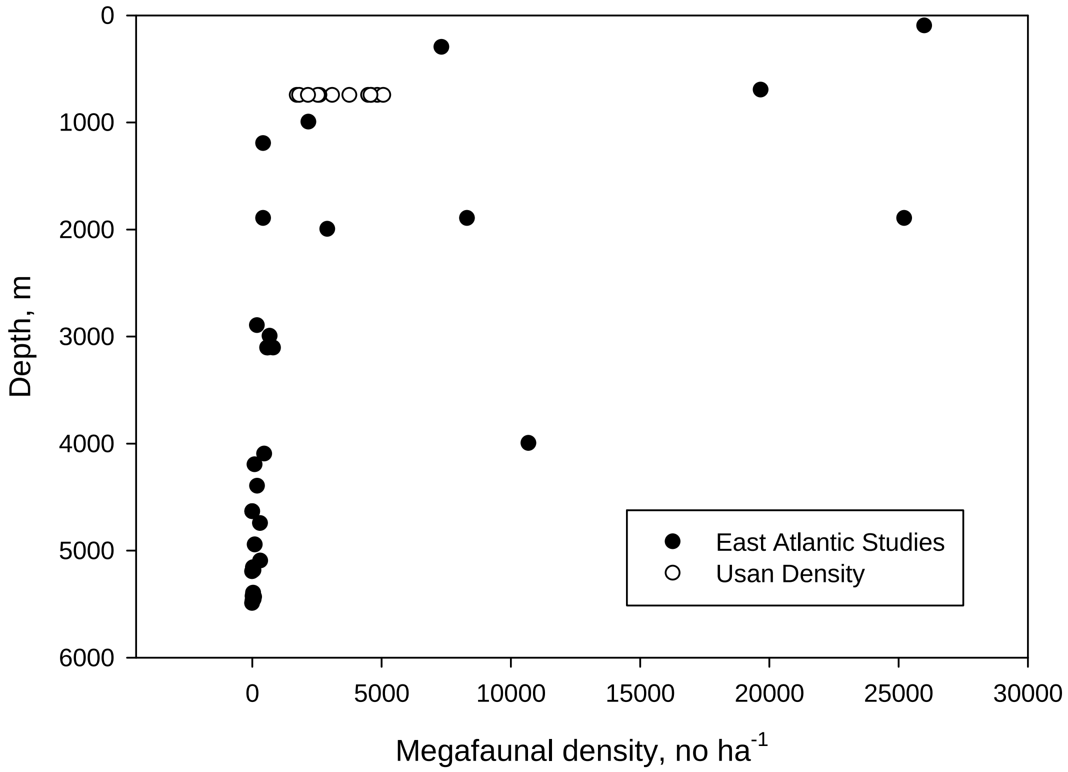


Figure 4.1: Megafaunal density (no 10,000m^{-2}) compared with depth for the Eastern Atlantic. East Atlantic literature data from Bay of Biscay south to Angola (Sibuet et al. 1984, Sibuet & Segonzac 1985, Feldt et al. 1989, Sibuet et al. 1989, Tietjen 1992, Thurston et al. 1994, Galeron et al. 2000, Kroncke & Turkay 2003, Lebrato & Jones 2009)

Ecological highlights

A total of 38 taxa were observed directly. These are shown in the table below and have representatives from 7 phyla. Several of these taxa are likely to be rarely studied. In addition at least 4 species of scavengers were obtained in traps. The scavengers (1 isopod and 3 amphipods) are not shown in this table.

Table 4.1: All species found at Usan. The pictures for species marked with an asterix (*) are from elsewhere but were chosen as they are significantly higher quality than those available from Usan.

Phylum	Species	Notes	Picture
Porifera	Hexactinellid	Around 200 mm in diameter. This sponge is probably *Farrea* sp.	
Cnidaria	White antipatharian	Around 200mm in height	

	Gorgonian sea whip	Found living on rocks only. Up to 700 mm in height.	
	Gorgonian sea whip	This is either a gorgonian or a pennatulid. It is only found on soft sediment. Up to 500 mm in height.	

	Pennatulea	Large pennatulid resembling *Pennatulea phosphorea*. Up to 500mm in height.	
	Gorgonian seafan	Gorgonian seafan probably exceeding 1000 mm in height. Likely very old as growth rate is mm per year.	 

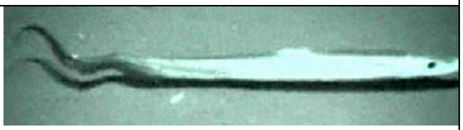
	Actinoscypha	Anemone around 200 mm in length.	
	Edwardsid	12 tentacled anemone found on soft sediment. Burrows rapidly if touched. Around 100 mm in diameter.	
	Striped african anemone	This is most likely another edwardsiid anemone. Also has 12 tentacles. Around 150mm in diameter.	
	Ceranthid	Possibly a cerianthid anemone. Only seen once in apparent symbiotic relationship with decapod. Could not see tube to confirm that it was a cerianthid. Approximately 150 mm in diameter.	
Echinodermata	*Phormosoma placenta*	This is the most abundant megafaunal organism at Usan. It is from 50 to 120 mm in diameter.	

	Red urchin not phormosoma	This urchin is distinct from *Phormosoma*. It never has fluid filled sacs on dorsal surface. It has many more rows of spines. It is up to 150 mm in diameter although usually smaller.	
	White echinoid	Bright white echinoid. Spherical. Spines not exceeding radius. Around 80 mm in diameter.	
	white diadema	Long spined white urchin. Total diameter (including spines) around 150 mm.	
	Ophiuroid	Large ophiuroid. Can swim quickly when approached by the ROV. It is approximately 150 mm in total diameter (arm tip to arm tip)	
	Euryalid ophiuroid	Probable euraylid ophiuroid. Only seen once associated with hard substrata. Diameter 200 mm.	

	Brisingid	Large brisingid asteroids. Seen throughout rocky area. Arm length is approximately 300-400 mm.		
	Aphrodite like holothurian	Probable holothurian seen on soft sediment. The other possibility is that it is a polychaete of the genus *Aphrodite*. Approximate length 150 mm.		
	Mesothuria	Large white holothurian. Probably mesothuria. Possibly *Paeloriza pallens*. Seen pairing. Length up to 400 mm.		

	Benthothuria*	Possibly *Benthothuria funebris*. It is around 400 mm in total length.	
	Comatulid crinoid	Comatulid crinoid observed once on gorgonian (sea whip) in rocky area. Approximate diameter 100 mm.	
Crustacea	Galatheid	This squat lobster is probably in the genus *Munnidopsis*. It is very common. Up to 100 mm in length.	
	Prawn	Common small prawn. Up to 60 mm in total length.	

	Large Prawn	Large prawns, potentially of several species. The swimming *Plesiopennaeus* was not included. This species was up to 150 mm in length.	
	Nephrops	Large decapod most likely in the genus *Nephrops*. Up to 120 mm in length.	
	Paralomis cristulata	Large lithodid crab seen in the rocky areas only. Up to 500 mm in total width. Has the body shape and gait you would expect from local species *Paralomis cristulata* and *africana*. It doesn't look exactly like either of them, although it is probably closely related. For now, it is most like *Paralomis cristulata* – previously known from the Ivory Coast and Guinea-Bissau.	
Mollusca	Opisthobranch*	One opisthobranch observed. This species is much more common in the deeper waters of Akpo. Around 60 mm in total length.	
Enteropneusta	Enteropneust	One potential enteropneust observed. Several spoke traces seen on soft sediment areas. Enteropneust up to 400 mm in length.	

Pices	Ray	Large ray around 900 mm in total length (including tail). Image is not of good enough quality to do much identification. There are multiple spine rows on the tail and dorsal midline. The thorns are large and the disc is rather deeply indented marginally (spade-shaped). Need a count of thorns and other details for ID.	
	Nettastoma melanura	Up to 1000 mm in total length. not a synaphobranchid, but a Nettastomidae (sharp elongate snout, dorsal fin is very high, and tapers unlike a synaphobranchid, pectoral fins may be absent or very small (usually these are prominent in synaphos and held out laterally). My initial guess is *Nettastoma*, maybe *N. melanura*, which is known from the Gulf of Guinea, depth range overall 300-900 m.	
	Halosaurus sp.	Halosauridae, or genus *Halosaurus* (single median dorsal fin, anal fin tapering to a fine tip). The snout tip is rounded and a bit inflated, consistent with genus *Halosaurus*, as opposed to the otherwise similar genus *Aldrovandia*.	

	Dibranchus sp.	Common monkfish. Usually around 200 mm in total length. Has walking anal fins. Ocgocephalidae, probable genus either *Dibranchus* or *Halieutichthys*. The fundamental shape is that of *Dibranchus*, but I cannot see the details necessary in this low-res image. The close resemblance to *Dibranchus* would suggest this is the correct genus, if so the species found commonly in the Gulf of Guinea from 45-1300 m depth is *Dibranchus atlanticus*. One other species *Dibranchus tremendous* is found in the region but typically deeper than this survey (750-2300 m). The details necessary to resolve the species are not visible in the photograph.	
	black fish	Common dark coloured fish. Possibly represents a number of species. Up to 100 mm in total length. My guess is that this in not a demersal fish, but a midwater fish swimming over the bottom. Gonostomatids and other midwater fishes often associate with the bottom as large adults.	
	stripey fish	Possibly zoarchid fish. Up to 300 mm in total length.	

	grenadier	Up to 600 mm in total length. A Macrouridae The picture is the best view. Without lateral view it is impossible to identify with any accuracy. It is tough to do much more with an overhead image. However, the snout is short and not very pointed, pectoral fins large, body tapers gradually. My guess is the genus *Corphaenoides*, which has a large number of species.	
	Laenomena laureysi ?	Up to 500 mm in total length. not a *Bathypterois*, but is a Gadidae or Moridae, both of which families have species of this general body form with multiple dorsal fins, a fan-like caudal, but most prominently - elongate, barbel-like pelvic fin-rays. The genus here is probably the Moridae genus *Laenomena*. This looks *like L. laureysi*, the Guinean codling, except known only down to 500 m. There are other choices from this area, but the taxonomy of these fishes in not so good. The other option is the genus *Urophycis* in the Gadidae. Nearly all *Laemonema* and *Urophycis* species have a small terminal chin barbel at the tip of the lower jaw (this extends forward and might be visible in a higher quality image). Many species also have the leading ray of the first dorsal fin elongated into a projecting filament. Most species of both genera have the pelvic rays elongated and conjoined for about 1/2 of	

		their length, then they split apart at the distal end.	
	Dicrolene intronigra *	Around 300 mm in total length. This fish was also observed in Mauritania. This is definitely the ophidioid *Dicrolene*. The elongate free pelvic rays directed forward are characteristic of this taxon, and the large eye and white lateral line pores help. The full ID is probably *D. intronigra*, common between 800-1800 m both sides of the Atlantic at tropical latitudes. There are about 10 nominal species, but probably only about 4-5 are valid. A key characteristic is the short sharp preopercular spine. In *D. intronigra*, it is short, straight, and not visible in photos. In the next most likely possibility, *D. kanazawai*, the spine is longer, curved upward, white, and would be visible in a photo of the present quality.	
	Scorpionfish	Potential scorpion fish observed hiding under rock in rocky areas. Total length 200 mm.	

The average thermocline (taken as 20°C) depth observed here is greater than suggested in the literature by about 20m (compare Figure 11 with Figure 7). Seasonal fluctuations in temperature are large in the Gulf of Guinea and the period of survey is a transitional time for water mass properties in the area, where climatic data is variable (Houghton 1983). There may also be some evidence for warming of surface waters compared with literature values (Hastenrath & Lamb 1977), perhaps a result of anthropogenic global atmospheric warming.

The effect of moving location did not seem to be large. It would be possible that the large topographic feature to the west of the Usan field may influence local hydrography, as shown in seamounts (Noble & Mullineaux 1989). However the thermocline depth is very shallow, it is unclear if even an extreme topographic feature would influence the water column 700 m above it.

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APPENDICES

APPENDIX 1. GENERAL INFORMATION:

Company: Total
Vessel operator: Bourbon
Vessel name: Bourbon Diamond
Location: Usan, Nigeria
Vessel position: 003°29.179 N 007°27.940 E (WGS 84: 9/7/09 18:20)
Seabed depth: 750 m
Seabed temperature: 6°C
ROV operator: Oceaneering
ROV: Millennium 73
ROV team:

ROV supervisor days	Stuart Jones
ROV pilot days	David Cox
ROV pilot days	Jayselan Naidoo
ROV tech days	Usif Abdulatif
ROV supervisor nights	Neil Purdie
ROV pilot nights	Steve Fisher
ROV pilot nights	Michael Clark

Science team:

Dr Daniel Jones	Science leader (SERPENT)
Charles Mrabure	Total E & P Nigeria
Prof. Alex Ugwumba	University of Ibadan, Department of Zoology, Ibadan, Nigeria Tel: +234 8030497460 +234 8051970791 Email: adiaha4me@yahoo.co.nz
Dr Adesina Adegbie	Institute for Oceanography and Marine Research, 3 Wilmot Point Road P.M.B. 8010 8 Victoria Island, Lagos Tel: +234 8055210651 +234 1 8750963 Email: adeadegbie@yahoo.com sadegbie@niomr.gov.ng

APPENDIX 2. GEAR:

- Millenium 73 ROV
- Standard video camera (Insite Pegasus)
- ROV large push core as scoop
- 2 x small (57mm ID, 63mm OD) ROV push core

- Aandera Seaguard Current Meter (RCM DW rated 6000m) with salinity sensor (Serial number 100)
- CTD Datalogger Titanium body RBR Model XR-420CTDmTi+pH+DO. Includes conductivity (Marine Conductivity), temperature, pressure, pH (AMT UT-pH-EM) and Oxygen (Aanderaa AA 3830 Optode) sensors (Serial number 17023)

Unfortunately the SERPENT box that was sent to Nigeria was lost by Transocean in Port Harcourt. All the equipment that was used was hand carried by D. Jones (73kg) on the aeroplane. The equipment was temporarily exported under the UK Customs Duplicate Lists procedure and processed in a similar way in Nigeria.

Plankton sampler

We used a plankton sampler made by one of the members of crew (Diego Fernandes Torres). This simple device is shown.

APPENDIX 3. NARRATIVE:

Tuesday 7th July 2009

Flew from London to Lagos, transferred to Millennium hotel. Had some trouble getting in through customs owing to the expensive survey equipment. Fortunately my UK customs duplicate list paperwork was sufficient to persuade the Nigerian Customs to let me fill out the equivalent paperwork for temporary import. The equipment was valued very highly £27,000 exacerbating the problem. In the future they recommended that I contact Nigerian customs in advance. I suspect that transfer of equipment may be easier under a carnet.

Wednesday 8th July 2009

Picked up from the Millennium hotel (Victoria Island) and transferred to the Total Usan offices with my equipment. I met with Charles Mrabure and Eric Mentzer. After spending some time in the Total Offices I joined the shuttle bus to the airport. I Flew on Aero jet from Lagos Local airport to the Port Harcourt International Airport. From Port Harcourt we transferred via minibus to the Novotel Hotel in Port Harcourt.

Thursday 9th July 2009

Met at Charles' room at the hotel to discuss the workplan. We were picked up from Novotel and transferred to the NAF base. We checked in all my luggage (73kg…) and I proceeded to immigration where they were concerned about my business visa. I did not work out how this problem could be resolved, perhaps with a letter from Total and by declaring that I worked for the University and not Total. We got on to a Sikorsky 76 helicopter and took the approx 1 hour journey south (100km) to Usan. We landed on West Capella (the dual derek drill ship drilling the wells at Usan) and had lunch. We transferred on Billy Pugh crane lift onto the Bourbon Diamond support vessel. We met with the ROV team and they dived on DIVE 1 at 14:37. They had to inspect a transponder then we had a chance to carry out some initial survey work. The DVD Hardrive was started at 15:54 while we were on the seabed at 740m depth.

Time	Observation
15:55:59	Phormosoma placenta
16:03:30	Ophiuroid – moving very quickly
16:04:05	Holothurian fecal cast
16:07:53	Galatheid
16:09:42	Close up of Galatheid
16:21:20	Synaphobranchid eel
16:23:24	Hole on the seafloor
16:26:09	Small monkfish like fish
16:30:24	Cerianthid ?and small crustacean in large burrow, possible symbiotic relationship
16:34:26	Synaphobranchid
16:41:31	Other eel like fish (more robust tail fin)
16:46:48	Monkfish
16:53	End Dive

The seabed temperature was measured on the parascientific sensor as 6.02°C. Seabed position was recored at 30 second intervals by the surveyor (Etien). The surveyors data was all datum WGS 84 and recorded as UTM zone 32 N (with a central meridian of 9) the first number recorded was eastings (starting 325…) and the second northings (starting 389…). The initial position of the dive was 325198.96 E 389340.75 N. There was not a huge amount of movement while we were carrying out the sampling. The West Capella was drilling well USN – 432 at the moment and just about to spud.

Friday 10th July 2009

Met the ROV team at 6:00 and spent the morning testing the CTD, carrying out pH calibrations (unsuccessful – there appeared to be no difference in pH between the buffers). The calibration used buffer solutions and went from pH 7 (7:03:42 to 07:05:30); pH 4 (07:06:30 to 07:08:30); pH 10 (07:10:00 to 07:12:10). I assembled the ROV push cores and made a crab trap out of an old oil drum. The ROV was on standby all day in the cage at depth. The ROV was brought up on deck prior to collecting transponders at around 18:00. I assembled the CTD and started logging at 18:09 logging every 30 seconds. The optode was shorting the logger (battery voltage was dropping rapidly) so I had to fill the connector with grease and deploy the logger without the optode. The battery was estimated to run out on 18th July. The ROV was launched around 19:10 and the position of the ship at 19:41 (unchanged since launch) was 3°31.538 N 7°26.392 E.

Saturday 11th July 2009

ROV was busy retrieving then deploying transponders in the morning. I designed a survey to encompass different bathymetric slopes. The methodology was as follows.

Areas were identified on bathymetric charts with constant slope (a random factor for subsequent statistical analysis) and a depth between 740 and 760 m. Within each area three random survey start points and headings were identified using a random number generator in Microsoft excel. Transects were 200m long and examined by plotting onto the chart. Any transect that extended beyond the boundaries of identified areas were discarded and another picked using the same method. In the area of extreme slope, owing to bathymetric constraints, headings were constrained between 350 to 10° and 170 to 190° but otherwise random.

Waited all day for opportunities for work but none came. In the night a petal shaped survey of the proposed drill location was carried out.

Sunday 12th July 2009

ROV was busy in the morning. At 13:00 a potential opportunity for survey occurred, however the West Capella Total company man wanted permission from the office which was not granted despite Charles' intervention. I spent the afternoon refining the survey. I also assembled Diego's plankton net. ROV dived in the night (DIVE 2) while I was asleep.

The survey plan was for 12 x 200 m transects as follows (Datum UTM 32N; WGS 84):

start E	start N	heading	end E	end N	Name
329883	390569	255	329689	390517	Flat-1
329135	389240	35	329249	389403	Flat-2
328857	389538	76	329050	389585	Flat-3
325248	388398	343	325189	388589	Med-1
324864	388283	191	324826	388086	Med-2
325005	388655	196	324949	388462	Med-3
323359	386764	187	323334	386565	High-1
322799	386011	347	322754	386205	High-2
323564	386891	291	323377	386963	High-3
321285	385530	4	321298	385729	Extr-1
321333	385436	359	321329	385635	Extr-2
321319	385654	189	321287	385456	Extr-3

The headings in reality seemed to be incorrect.

Monday 13th July 2009

ROV collected one core of sediment from the seabed at 3:00 (BD/130709/001#1). We tried to section it in the morning however the sediment was very liquid and I was worried we would loose the sample. For that reason I froze the core whole for later sectioning. After the ROV team had completed a magnetograph of the umbilical we were allowed the afternoon to do some survey work. At 11:05 we commenced our **DIVE 3** and the ROV was at the seabed by 11:16:58. We carried out surveys at 1m altitude from the base of the ROV (143 cm from the centre of the camera). The camera was zoomed out to maximum extent and maximum down tilt (30 degrees calculated from measuring the camera position at the surface). The camera was a Insite Pacific Pegasus camera, the horizontal acceptance angle at full zoom out (wide angle) was 55° and the vertical acceptance angle 43°. This, at 1 m altitude (143cm camera height) gave a length of the base of the screen at 172cm.

Time	Event
11:34:29	Flat 1 survey: start
12:08:10	Flat 1 survey: end
12:30	ROV back on deck
13:00	ROV launch for **DIVE 4**
13:32:10	Start Flat 2 survey
13:57:10	End Flat 2 survey
	Transit in cage to next site
14:49:29	Start Flat 3 survey
15:09:04	End Flat 3 Survey
	Bring ROV up to surface
15:30	ROV on deck
16:12	ROV off deck for **DIVE 5**
16:25	ROV at depth
16:37:27	Start Med 1 survey
17:00:10	End Med 1 survey
	Transit in cage underwater
18:09:41	Start Med 2 survey
18:37:29	End Med 2 survey
	Transit in cage
19:27:45	Start Med 3 survey
19:55:46	End Med 3 survey
	Bring ROV to surface
20:25	ROV on deck
20:52	ROV off deck for **DIVE 6**
21:09:49	Start High 3 survey
21:35:03	End high 3 survey
21:38	Return to cage
21:50	ROV on deck
	Handover to surveyor to carry out marker buoy checks

NOTE – The High 3 survey was incorrectly referred to as High 1 in the audio of the survey please ignore the audio

Tuesday 14th July 2009

ROV had to position the marker buoy for the next well over night. At 6:00 am the ROV became free for a few hours. I also finished the plankton sampler.

07:49	ROV off deck for **DIVE 7**
08:11:45	Start High 1 survey
08:35:21	End high 1 survey
08:39:32	Return to cage
08:50	ROV on deck
09:15	ROV off deck for **DIVE 8**
09:44:37	Start High 2 survey
10:08:35	End high 2 survey
10:10	Return to cage
10:27	ROV on deck
	Had to stop survey as West Capella requested cargo transfer

In the afternoon the ROV team were doing beacons so there was no possibility for our work.

Wednesday 15th July 2009

ROV was doing beacon work all day. I attached the plankton sampler for our **DIVE 9** which was predominantly for their work. We got some sample which was preserved in formalin. The cameraperson, Brendan Butcher (HardHat Media) was due on the Bourbon Diamond today to film our work but he was delayed on the Capella.

DIVE 10, which was a operations dive, also collected plankton sample 2.

Thursday 16th July 2009

ROV was busy for the morning although on **DIVE 11** we collected some plankton samples (P3). We spent the morning doing filming of short documentary for Total E&P Nigeria with Brendan Butcher (HardHat Media) who arrived on the Diamond (via basket transfer from West Capella) at around 07:00.

20:44	ROV off deck for **DIVE 12**
21:13:41	Start Extreme 1 survey
21:45:	End Extreme 1 survey
21:51:25	Observe lithodid crab

	Return to cage
22:13	Leave cage
	Observed Brisingid asteroid
22:19:39	Start Extreme 3 survey
22:49:26	End Extreme 3 survey
	Change DVD
	In cage for transit
23:09	Out of cage
	Community video
23:23:30	Start Extreme 2 survey
23:53:45	End Extreme 2 survey
23:59	Collect rock sample
00:26	ROV on deck

Plankton sample 4 was also collected on dive 12. When examined the rocks appeared to be igneous, possibly basalts with volcanic ash.

Friday 17th July 2009

I retrieved the CTD from the ROV at around 12:00 midday and downloaded the data. On **DIVE 13** we collected the amphipod trap. There were two components of the trap, an old oil barrel with a larger entrance and a smaller bottle type trap attached (made from a 2 litre water bottle). The smaller bottle trap had tiger prawns as bait, the larger trap had two fish as bait. Unfortunately the bait had been left outside for approximately 30 hours and had started to smell bad… The bait had been wrapped in 1mm mesh, this was fortunate as it retained many more amphipods than would have been retained without. Amphipods and isopods were caught in both traps and preserved separately. I preserved one of each apparent species in RNAlater for subsequent genetic analysis. The rest were preserved in 4% formaldehyde. The amphipods were all apparently dead on the surface, presumably owing to the large temperature differences between the seabed and surface waters.

At 20:00 the ROV was off deck for DIVE 14 at the proposed site of well 454 (approximately 385330 N 322870 E). The ROV was at the seabed at 20:20. We took two core samples. Core one (rotating top design) was started 20:36:28 and completed 20:44:59. We moved to a new location, the well marker was 11m due south of the ROV. The second core was stowed 21:13:24. The ROV was in cage 21:21:46 and returned to the surface at around 21:50. We suffered an unlikely double failure, the base of the one core holder had come out (first one taken) and the material had washed out. The other core had somehow been dislodged from the holster during return to the surface and was missing.

In the evening we had a large science wash up meeting to discuss the visit.

Saturday 18th July 2009

We left the Bourbon Diamond on the Billy Pugh crane operated basket at around 07:00 and transferred onto the West Capella Drill ship. We got onto the Skorsky S76 helicopter and returned to Port Harcourt. I stayed overnight at the Novotel hotel (3 Stadium Road, Rumuomasi).

Sunday 19th July 2009

We left Novotel at 14:00. Flew from Port Harcourt International Airport to Lagos on Aero at 18:10. Arrived in Lagos Muhammed Murtala Airport at 19:30 and got Total armed convoy to Total Offices in Lagos. From there I got transported to Eko Hotel.

Monday 20th July 2009

Went to Total offices and visited the Nigerian Institute for Oceanography and Marine Research.

Tuesday 21st July 2009

Went to Total offices and gave a talk on our work at Usan.

APPENDIX 4. SAMPLES:

CODE STRUCTURE:

BD/020509/001#1
Bourbon Diamond/ Date / station number # replicate

SAMPLE STATIONS:

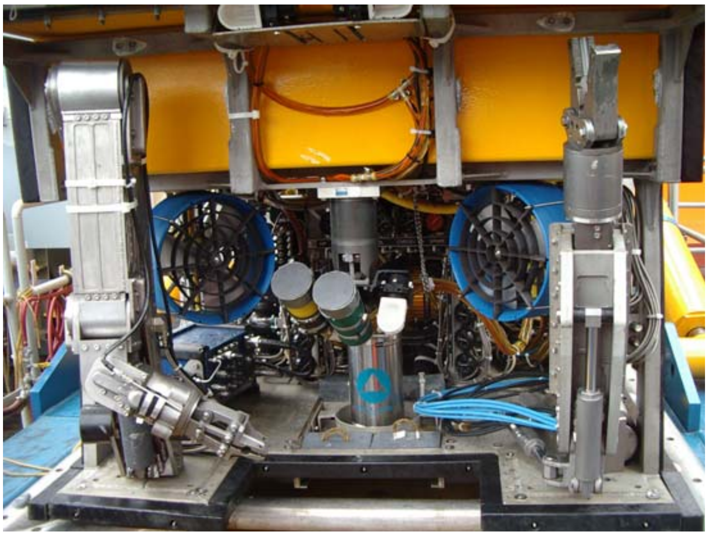
Station	Location	Sample type	Preservation	Picture
BD/130709/001#1	390352 N 325354 E depth 732.5m	Core sample	Frozen	
BD/150709/002#1	3°N 7°E	Plankton sample 1	Formalin	
BD/150709/003#1	3°N 7°E	Plankton sample 2	Formalin	
BD/160709/004#1	3°N 7°E	Plankton sample 3	Formalin	
BD/160709/005#1	3°N 7°E	Plankton sample 4	Formalin	
BD/160709/006#1	321329 E 385635 N	Rock sample from 7-function manipulator	cold	

BD/160709/006#2	321329 E 385635 N	Rock sample from 5-function manipulator	Cold	
BD/160709/006#3	321329 E 385635 N	Epifauna from rock sample	Formalin	
BD/170709/007#1	3°N 7°E	Prawn baited trap scavenger sample	Formalin	
BD/170709/007#2	3°N 7°E	Isopod from prawn baited trap	RNAlater	
BD/170709/007#3	3°N 7°E	Amphipod from prawn baited trap	RNAlater	
BD/170709/008#1	3°N 7°E	Scavenger sample from fish baited trap	Formalin	
BD/170709/008#2	3°N 7°E	Isopod from fish baited trap	RNAlater	
BD/170709/008#3	3°N 7°E	Amphipod 1 from fish baited trap	RNAlater	
BD/170709/008#4	3°N 7°E	Amphipod 2 from fish baited trap	RNAlater	

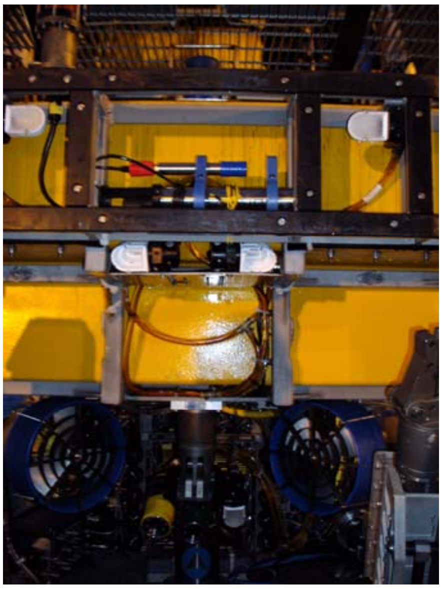
APPENDIX 5. GEAR REPORT

ROV Millennium 73

The ROV was good and highly suitable for the job. We had very few problems with the vehicle during my visit. It was equipped with a video camera, 5- and 7-function manipulator.



RBR CTD



The CTD was problematic during this trip. The core components C,T, D and the logger worked very well. Unfortunately the optode was broken, when attached it quickly drew down the voltage on the logger, presumably as a result of a short circuit or ground fault. In the end I had to fill the connector with white lithium based grease (as per manufacturers recommendation) and put a pierced plastic cap on it. This seemed to pose no problems. The pH sensor was attached throughout but during calibration (before any work) there were no changes in voltage output from the sensor despite using standard pH of 4,7 and 10. No pH data were obtained during the visit.

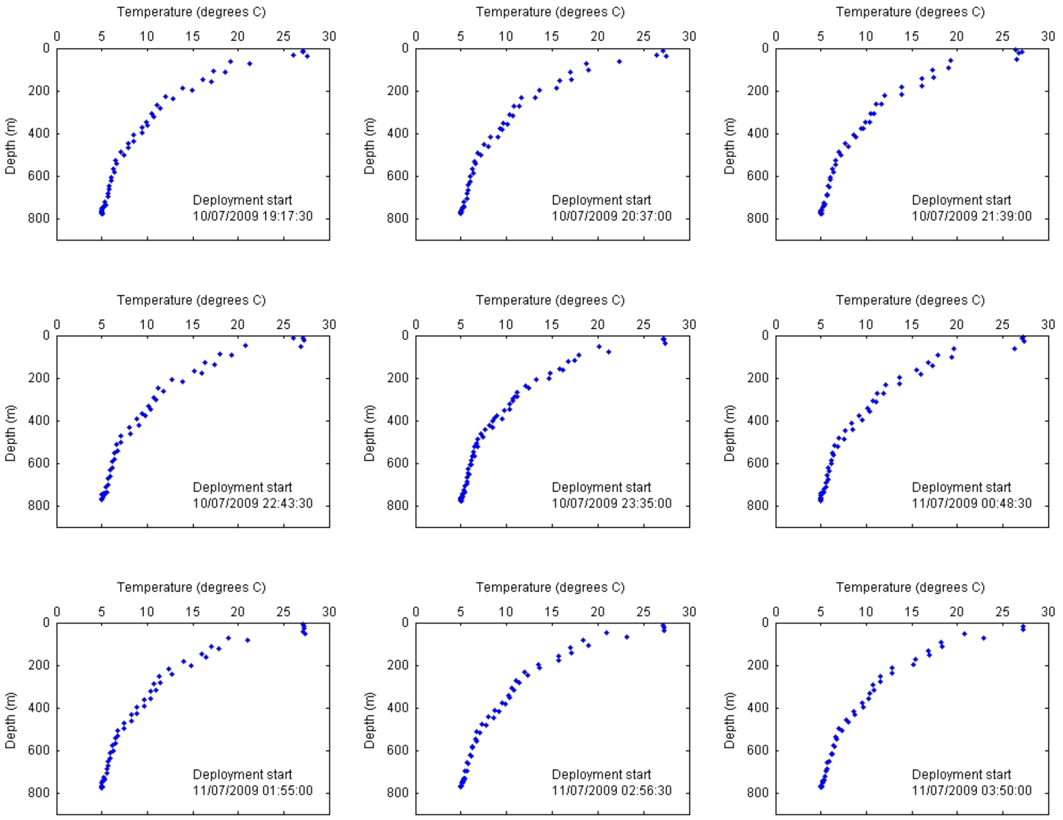
The CTD was mounted on the upper bar of the front of the ROV. This area was also used to mount the acoustic transponder used to navigate the vehicle with high accuracy and precision.

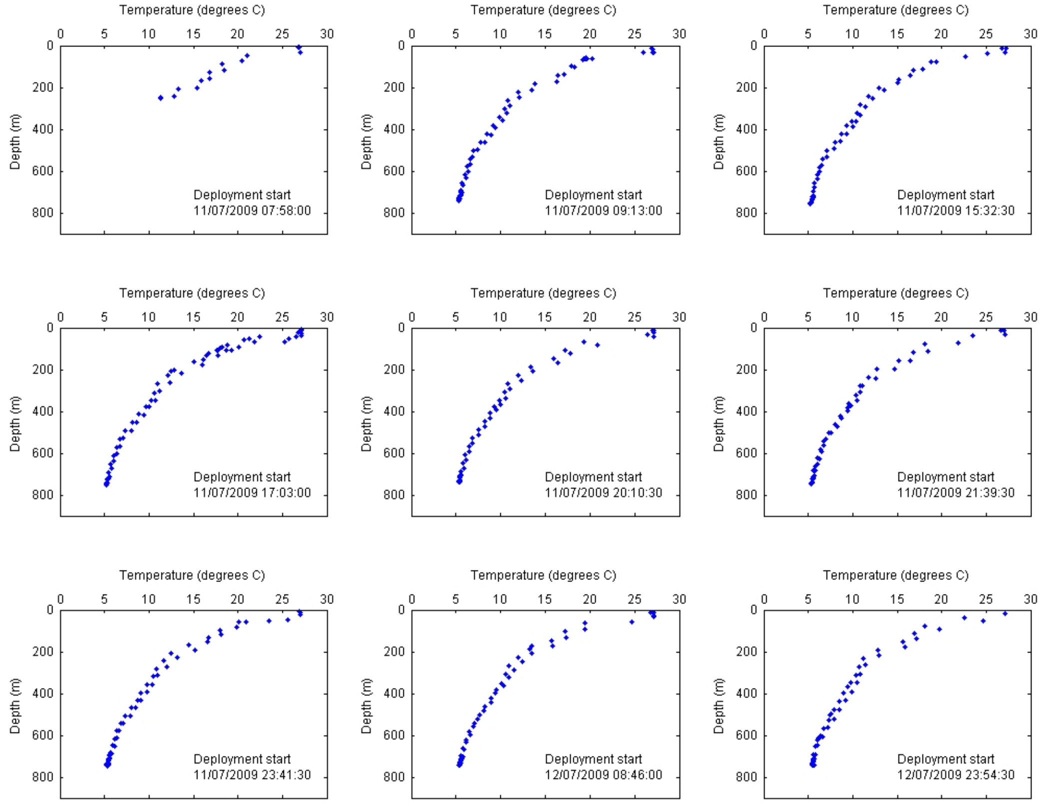
Current meter

The current meter needs a stable and locatable place for it to be deployed. As this was essentially unexploited there was nowhere to deploy the current meter. The only option was to use the ROV to deploy and monitor the meter to ensure that we did not loose it. There was not time for this.

APPENDIX 6 – Physical data

TEMPERATURE

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Depth (m)
Deployment start
11/07/2009 07:58:00
Deployment start
11/07/2009 09:13:00
Deployment start
11/07/2009 15:32:30
Deployment start
11/07/2009 17:03:00
Deployment start
11/07/2009 20:10:30
Deployment start
11/07/2009 21:39:30
Deployment start
11/07/2009 23:41:30
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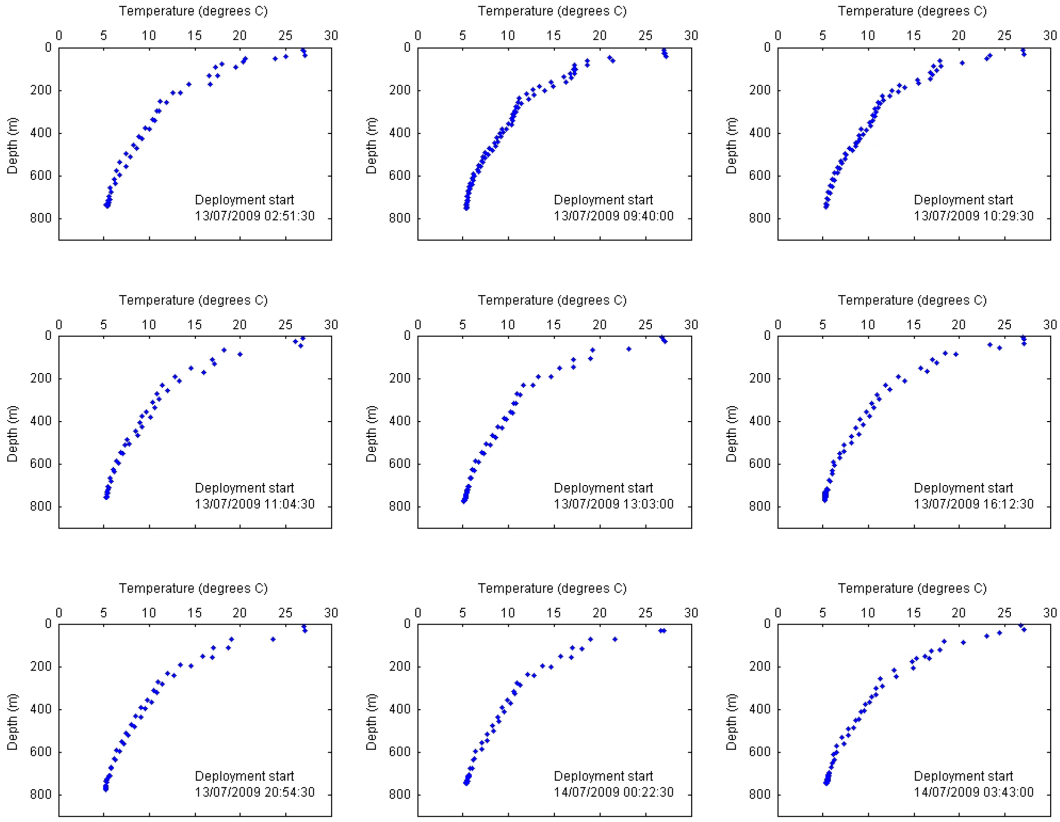
12/07/2009 08:46:00
Deployment start
12/07/2009 23:54:30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Depth (m)
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13/07/2009 02:51:30
Deployment start
13/07/2009 09:40:00
Deployment start
13/07/2009 10:29:30
Deployment start
13/07/2009 11:04:30
Deployment start
13/07/2009 13:03:00
Deployment start
13/07/2009 16:12:30
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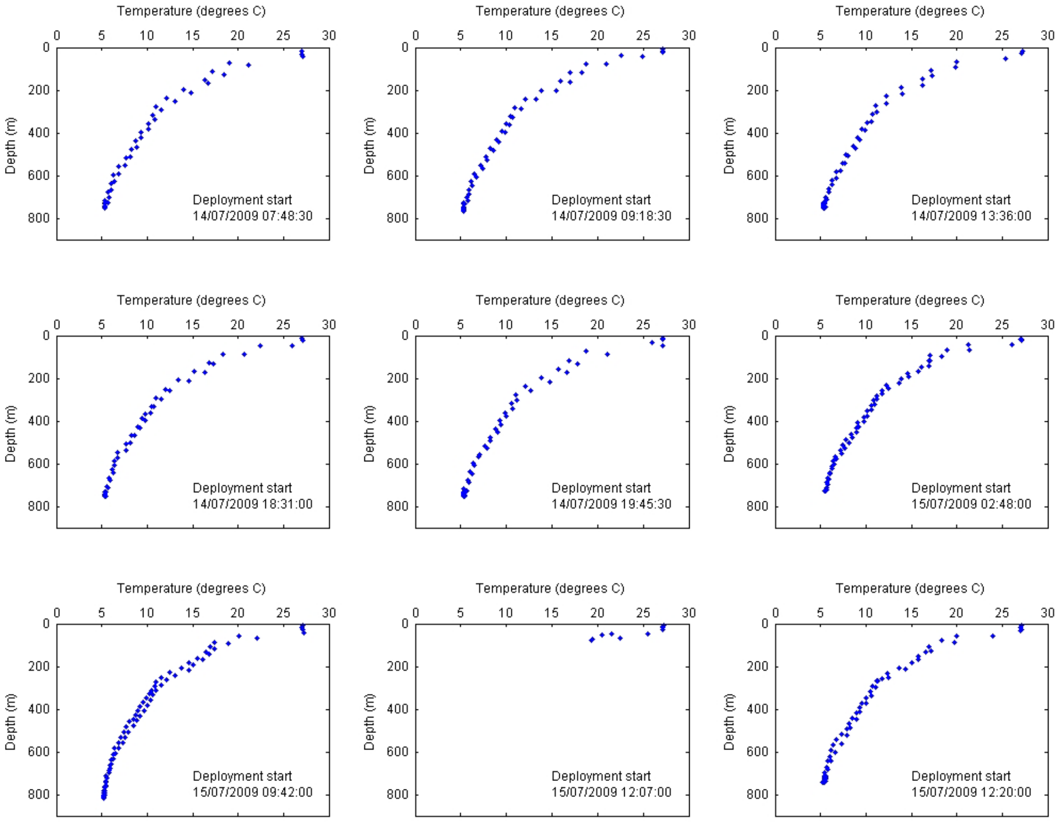
Deployment start
14/07/2009 03:43:00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Deployment start
14/07/2009 19:45:30
Deployment start
15/07/2009 02:48:00
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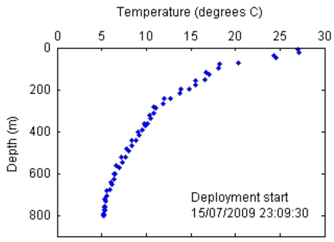
15/07/2009 12:20:00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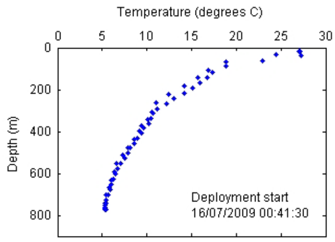
15/07/2009 23:09:30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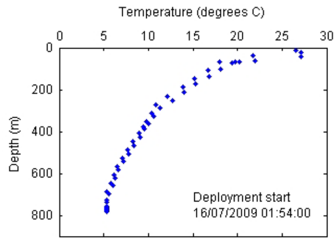
16/07/2009 00:41:30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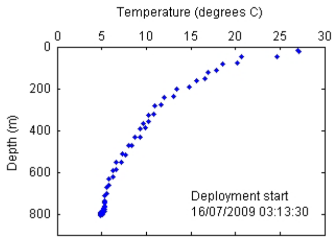
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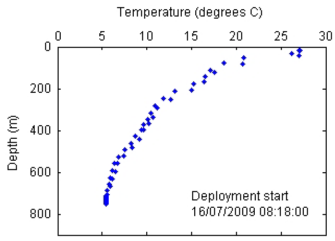
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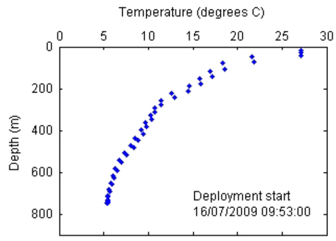
16/07/2009 08:18:00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Depth (m)
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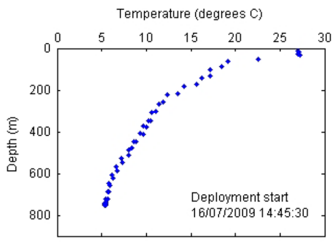
16/07/2009 09:53:00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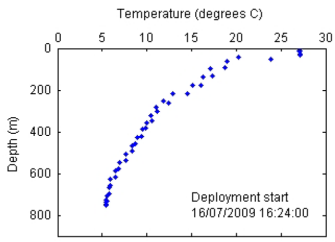
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Depth (m)
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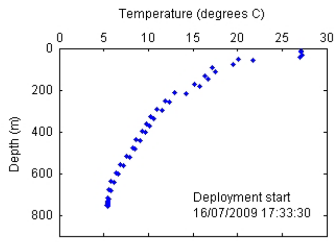
16/07/2009 16:24:00


Temperature (degrees C)
0 5 10 15 20 25 30
Depth (m)
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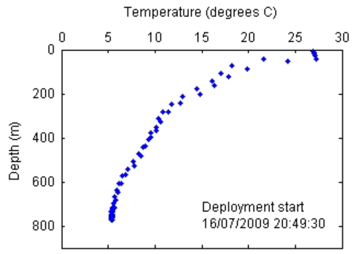
16/07/2009 17:33:30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Depth (m)
0 200 400 600 800
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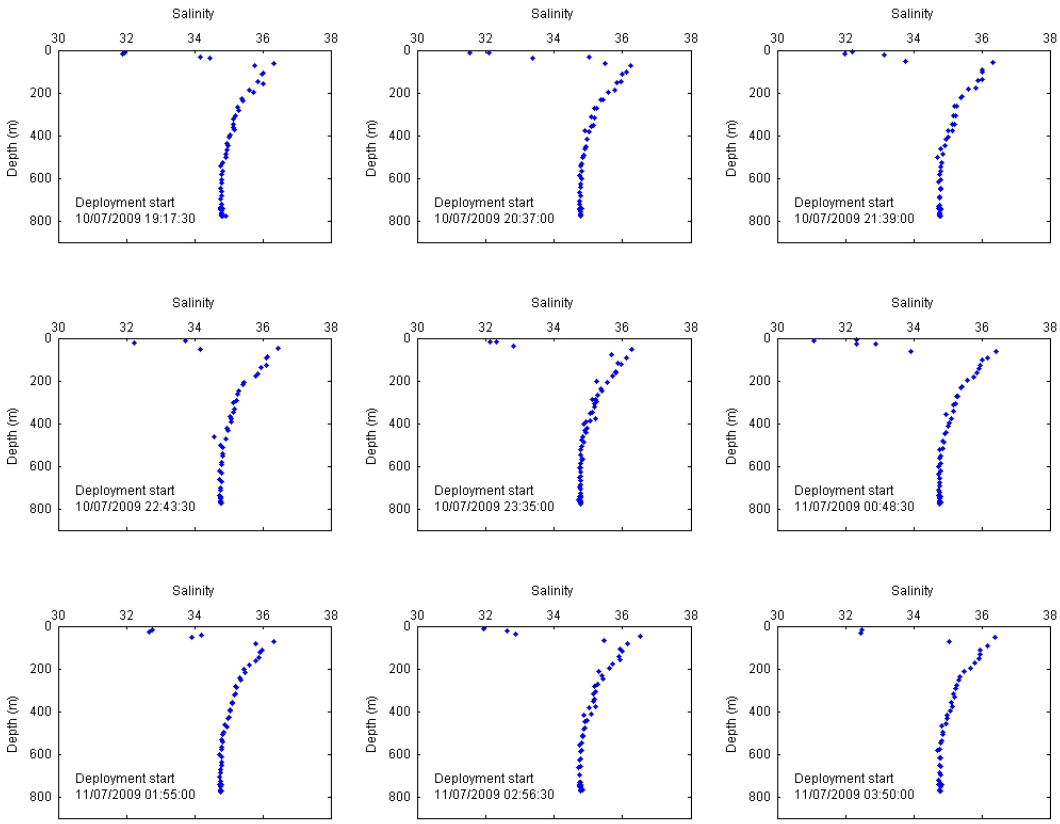
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Depth (m)
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Salinity
Depth (m)
Deployment start
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Depth (m)
Deployment start
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Depth (m)
Deployment start
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Depth (m)
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Depth (m)
Deployment start
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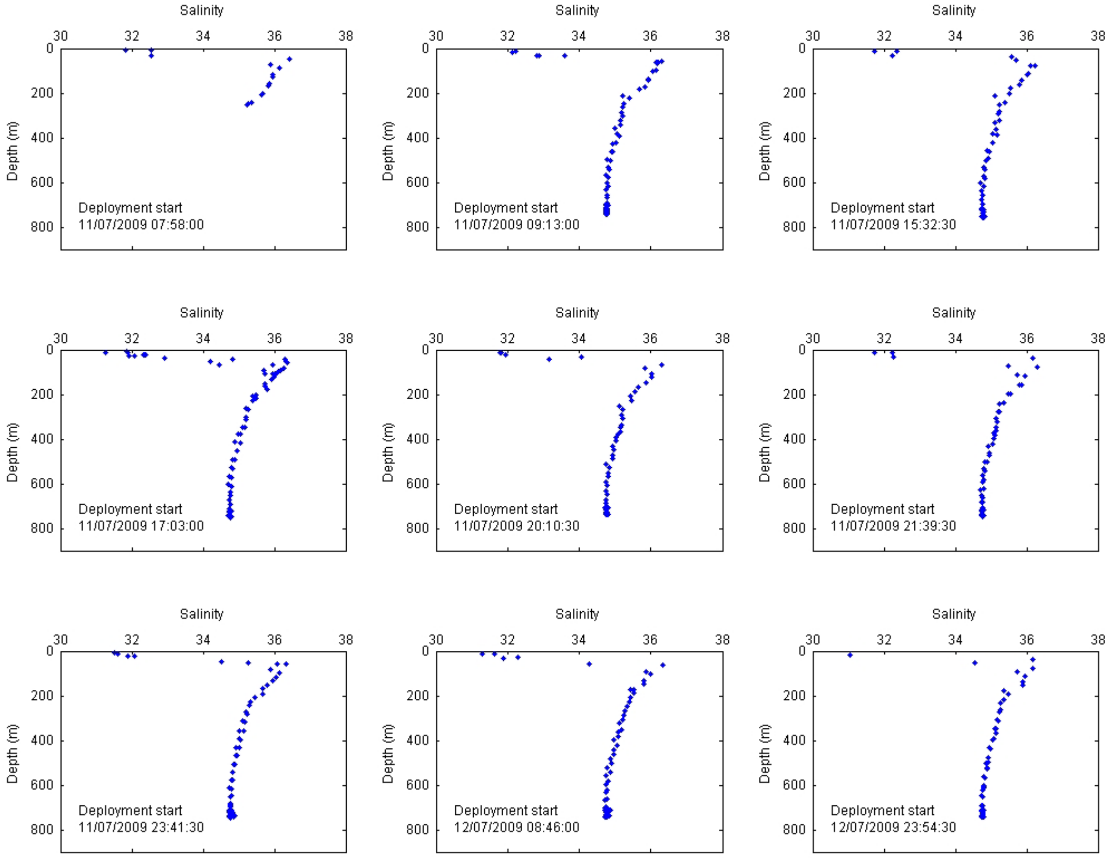
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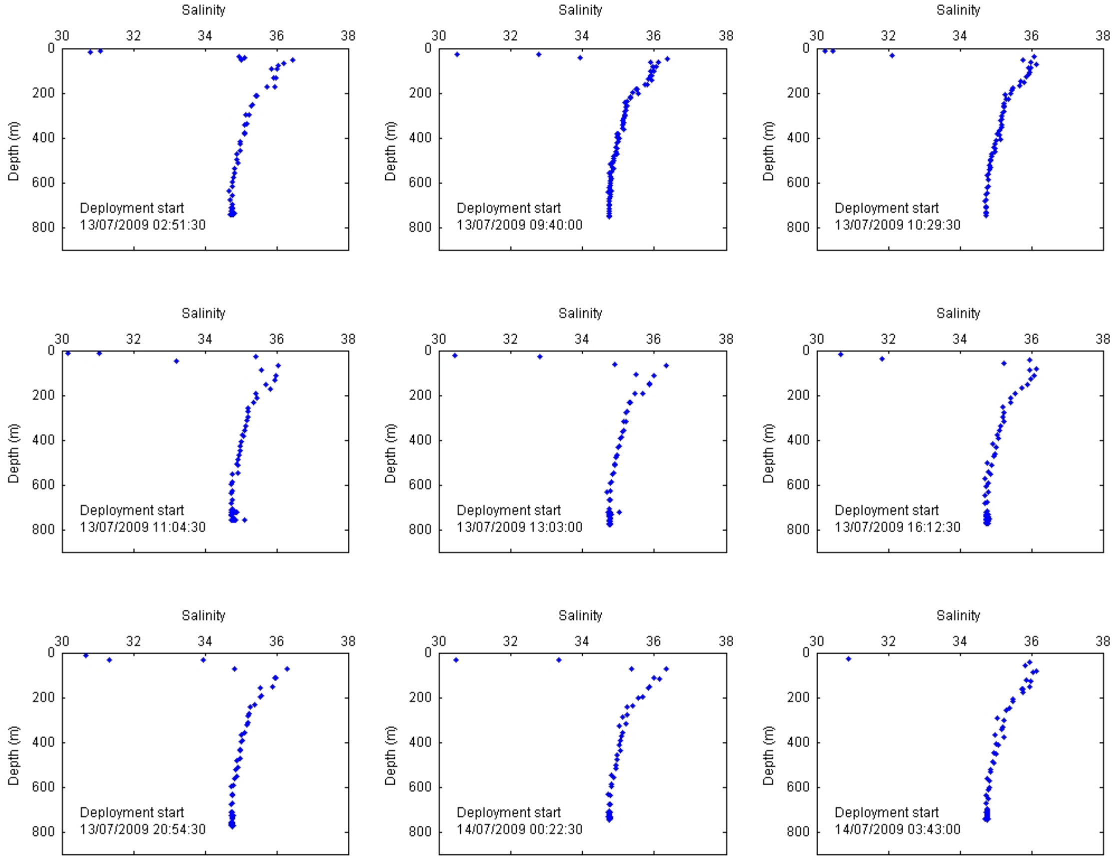
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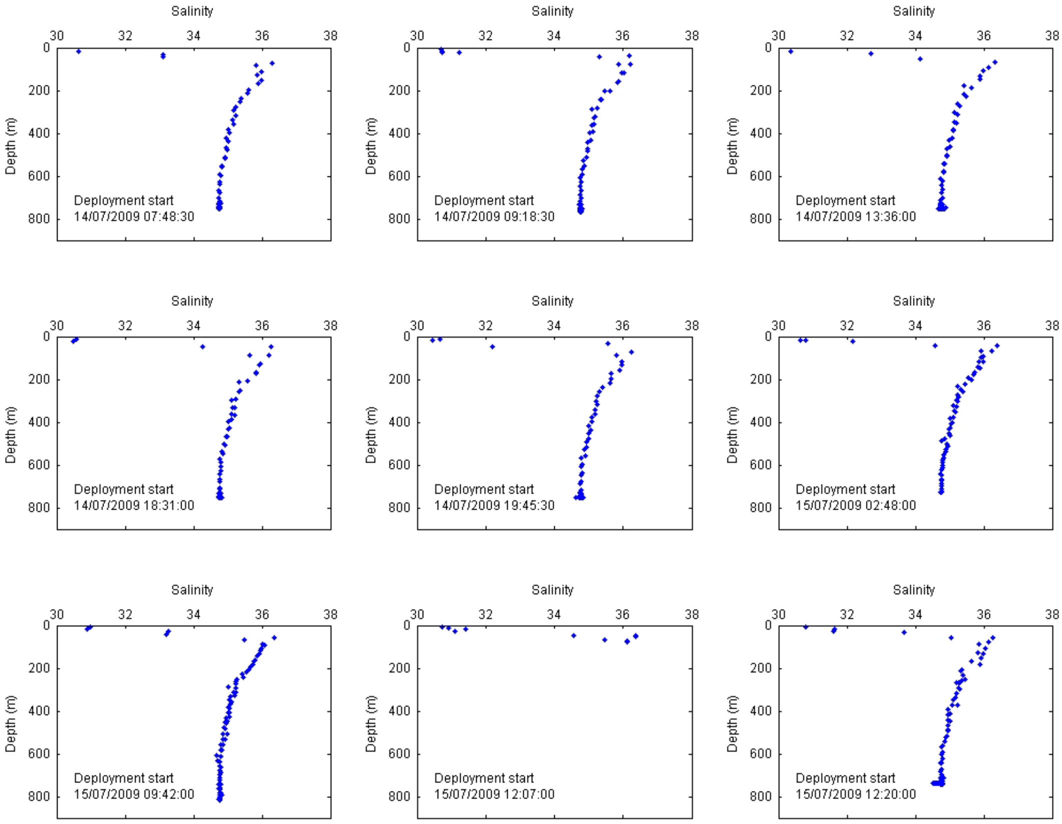
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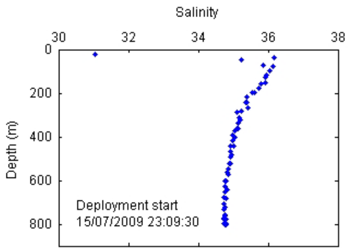
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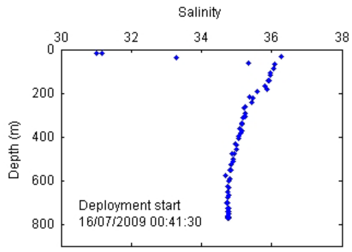
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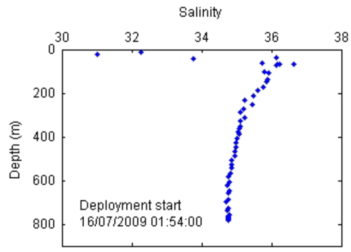
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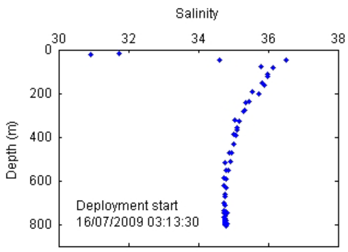
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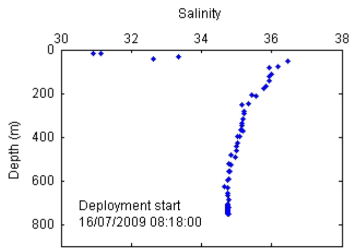
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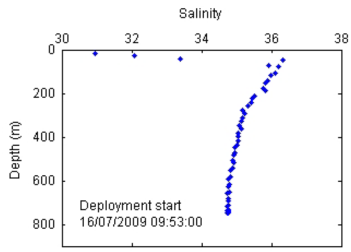
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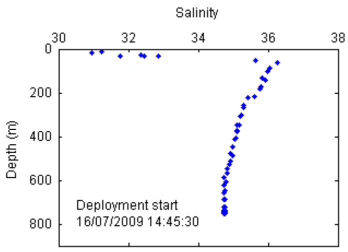
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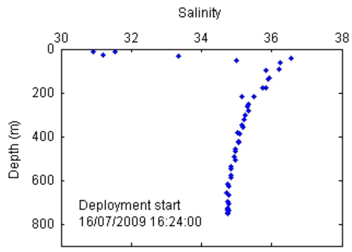
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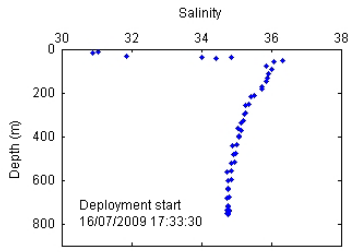
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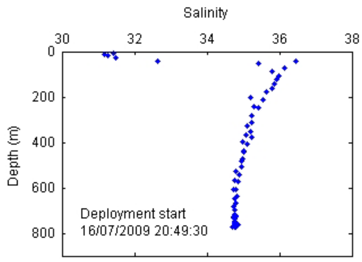
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APPENDIX 7 – Megafaunal taxa observed at Akpo field, offshore Nigeria (1366m depth). Data provided for comparison.

Phylum	Species	Notes	Picture
Cnidaria	Actinarian 1	50 mm diameter	
	Actinarian 2	Extremely common anemone. 10-30 mm diameter.	
	Actinarian 3	50 mm diameter	

	Edwardsiia sp.	120 mm diameter	
	Cerianthus sp.	60 mm diameter	
	Umbellula sp.	300 mm stalk length	
	Pennatulid 1	600 mm stalk length	

	Pennatulid? 2	200 mm stalk length. May also be gorgonian.	
	Scyphomedusae 1	200 mm bell diameter	
	Scyphomedusae 2 *	150 mm bell diameter	

	Scleractinian	Possibly from surface growth on vessel. 50 mm in diameter.	
Mollusca	Opisthobranch? 1	60 mm in length on seafloor	
	Squid *	250 mm in total length	
Crustacea	Penneid	60 mm length	

	Prawn *	40 mm length	
	Plesopenneius sp.	120 mm body length (excluding antennae). Probably *Plesiopenaeus armatus* (Family: Aristaeidae) as seen off Angola.	
	Lithodes ferox	1000 – 1500 mm maximum dimension. Seen attracted to tuna bait. It is either of the genus *Lithodes* or *Neolithodes* (although sadly the distinguishing feature is on the abdomen which is not visible). Two likely candidates are known from this region – *Neolithodes asperrimus* or *Lithodes ferox*. Unless the video distorts the secondary spines	

		(which should cover *N.asperrimus*), it is most likely to be a *Lithodes ferox* with a malformed or regenerating rostrum.	
	Paralomis sp. nov.*	1000 – 1500 mm maximum dimension. The crab seen most abundantly in these videos (and possibly the species to which the small specimen actually belongs) definitely belongs to the genus *Paralomis*. It is also not any of the species that are currently known from the coast of Africa. It is dissimilar to any known from the Indian or North Atlantic Oceans. It bears quite striking resemblance to some species from off Venezuela and Brazil (*Paralomis pectenata*), and has a similar form to several other *Paralomis* from South America. I think this is probably a new species.	

	Lithodes sp. 3 *	800 – 1500 mm maximum dimension. Not enough detail to resolve taxonomy.	
Echinodermata	*Peniagone* sp.	70 mm total length. Body flattened. Mouth placed on a posteriorly directed, retractile tube. Tubefeet 4 pairs, enclosed in a brim bordering the hind edge of the body. Velum broad, forwardly directed, forming the anterior continuation of the dorsal surface; the four papillae composing the velum project only slightly from the anterior edge.	
	Enypniastes sp.	180 mm total length	

	Holothurian *	250 mm total length. Synallactid holothurian. This is most likely Mesothuria sp. There is a possibility that the genus is Paroriza.	
	Echinoid 1	20 – 80 mm diameter. Echinothurid urchin.	
	Hymenaster sp. *	150 mm diameter	

Pices	Chimera 1	>1000 mm length. This is a Chimaeridae of either genus *Chimaera* or *Hydrolagus*. The distinction depends on whether or not the anal fin is divided, and that feature cannot be checked from this perspective. Ken Sulak's guess from overall shape of the body is Chimaera. There are several parasitic laernaid copepods attached to the head and tip of the dorsal fin.	
	Rhinochimera *	>1000 mm length. A Rhinochimeridae, looks like the genus *Harriotta*, but this is tentative.	
	Centroscyllium fabricii	>1000 mm length. A dogshark, family Squalidae, and looks very much like the widely distributed *Centroscyllium fabricii*, known from 200-1,600 m, including off W. Africa. Color, robustness, caudal fin, size and placement of dorsal fins are all right - need a better image to	

		see spines on leading edges of dorsal fins.	
	Rajella sp.	>1200 mm length. Shape fits genus *Rajella*	
	Dipturus sp.	>1000 mm length. Genus *Dipturus*, very similar to *D. linteus* of W. Atlantic, and depth range is right, 400-2,200 m.	
	Bathyraja richardsoni	>1000 mm length. Very probably *Bathyraja richardsoni*	
	Pachycara sp.	500 mm length. A member of the Zoarcidae, but this is not genus *Lycodes*. More likely it is *Pachycara* (short blunt snout).	
	Xyelacyba myersi	>1000 mm length. This is an the neobythitine ophidioid species *Xyelacyba myersi*. This is a definite ID. Ken Sulak has recently imaged this same species in the Bahamas. Nothing else looks like this fish.	

	Corphaenoides rupestris *	500 mm length. This is a Macrouridae, and is undoubtedly the species *Corphaenoides rupestris*, the roundhead grenadier. Colour pattern, proportions, large eye, very far forward dorsal fins are all correct.	
	Antimora rostrata	800 mm length. Distinctive.	
	Halosauridae. Probably *Aldrovandia*.sp.	600 - 1000 mm length. Not a Synaphobranchidae, but a Halosauridae, of either the genus Halosaurus or Aldrovandia. If we had a better image, I could zoom in on the top of the head to see if scales are present (*Halosaurus*) or absent (*Aldrovandia*). However, since the brain is visible through the occipital 'window', scales are probably absent.	

	Halosauridae. Probably *Halosaurus* sp.	600 - 1000 mm length. A Halosauridae. Brain not visible.	
	Simenchelys parasitica	800 - 1200 mm length. Family Synaphobranchidae. This is the species *Simenchelys parasitica*, which behaves much like a hagfish. It has a very muscular head with a small mouth, used to rip flesh from a carcass.