



# Changes in polychaete standing stock and diversity on the northern side of Senghor Seamount (NE Atlantic)

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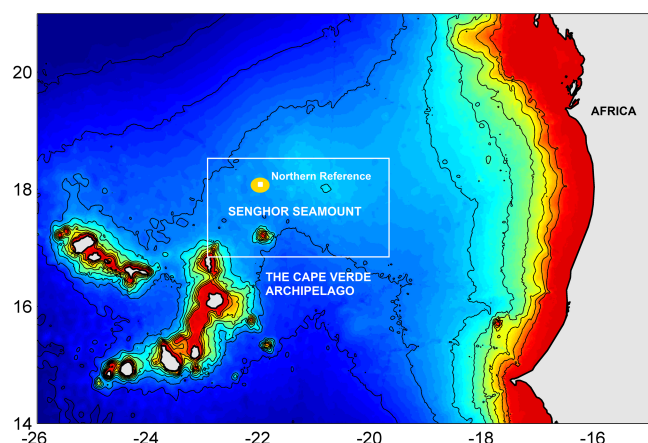
**Abstract.** Interest in seamount research has gathered momentum over the past five years in an effort to understand the physical, geochemical and biological characteristics as well as the interconnectedness of seamount ecosystems. The majority of biological seamount research has concentrated upon the rich and diverse suspension feeding organisms that dominate the megafauna, such as gorgonians and antipatharian corals; by comparison there have been few studies that have investigated the no less enigmatic, but possibly just as important infauna. To help fill this knowledge gap, the macrofaunal community was sampled from a total of five stations along a northerly transect (capturing water depths from ~130 m to ~3300 m), on Senghor Seamount (NE Atlantic). The focus of this study is on the polychaete communities. Polychaete abundance peaked at the summit and a mid-slope station (~1500 m), a pattern mirrored by the biomass values. The polychaete community along the transect appeared to be particularly diverse, with 135 species nominally identified to putative species from a total of 954 individuals. A diversity maximum was identified on the upper slope at ~800 m depth, with species diversity, richness and evenness also all peaking at this station. Depth is likely to be a significant factor in determining levels of similarity between stations.

dance of seamount ecosystems still represents an immense challenge to scientists, thus it is somewhat unsurprising that < 0.3 % have been sampled biologically in any detail, despite significant interest in these features (Ramirez-Llodra et al., 2010). Seamounts are often typified by highly rich and diverse communities of predominantly large suspension feeding organisms such as gorgonians and antipatharian corals, which are often the focus of seamount research (Bartsch, 2008; McClain et al., 2009; Clark et al., 2010; McClain, 2010; Rowden et al., 2010; Simpson and Watling, 2010; Bo et al., 2011; Sautya et al., 2011; Tracey et al., 2011). Many studies have also concentrated upon seamount fish populations (Clark, 1999; Matthiesson et al., 2002; Diekmann, 2006; Christiansen et al., 2009a; Menezes et al., 2009; Morato et al., 2009; Hirsch and Christiansen, 2010) with relatively few focussed upon the infauna (Gillet and Dauvin, 2000, 2003; Richer De Forges et al., 2000; Koslow et al., 2001; Surugiu et al., 2008).

Deep-sea macrofauna communities are known to be strongly influenced by bathymetric gradients; these shape community assemblage structure, diversity and standing stock (Hessler and Sanders, 1967; Grassle et al., 1979; Rex, 1981; Flach and de Bruin, 1999; Narayanaswamy et al., 2005; 2010a, b; 2013). Depth stratification of benthic communities can reflect environmental gradients of temperature, dissolved oxygen concentration and food availability (Clark et al., 2010); these gradients alter faunal composition to such a considerable degree that more faunal change may be witnessed over 1000 m vertically than 1000 km horizontally (Grassle and Maciolek, 1992; Longhurst, 1998; Clark et al., 2010). Consequently depth is thought to be the dominant controlling factor of seamount benthic community composition (Koslow et al., 2001; Schalcher-Hoenlinger et al.,

## 1 Introduction

Seamounts are defined as topographic features that rise > 1000 m above the surrounding seafloor; inactive volcanoes which punctuate the often more featureless abyssal plain. It is estimated that at least 33 000 seamounts exist globally and constitute ~5 % of the global ocean floor (~17 million km<sup>2</sup>) (Yesson et al., 2011). The high global abun-



**Fig. 1a.** Senghor Seamount, located in the Cape Verde Archipelago, 60 nm northeast of the island of Sal and ~550 km from the African mainland. Northern reference station also displayed. Data extracted from Smith and Sandwell (1997) dataset, created by A. Dale (SAMS).

2005; Clark et al., 2010; Rex and Etter, 2010). Whilst the megafauna assemblage structure and abundance variation with depth has been investigated on individual seamounts (McClain, 2010), changes in the macrofauna community in relation to a bathymetric gradient on individual seamounts remains relatively unexplored.

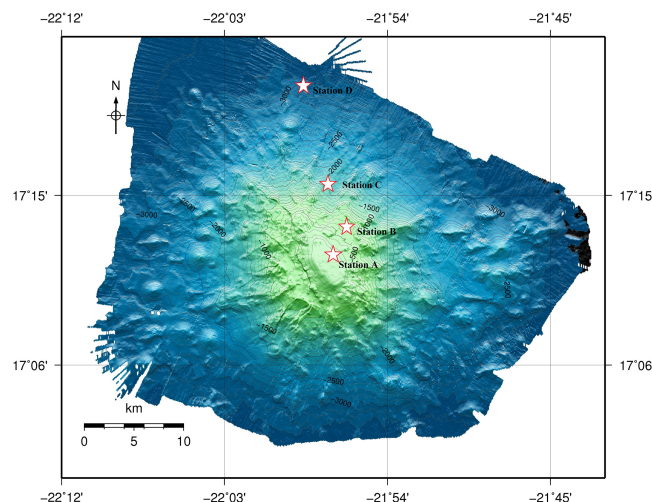
Polychaetes are frequently found to dominate deep-sea environments (Gage and Tyler, 1991; Gage, 2004; Surugiu et al., 2008) including seamount macrofauna communities (Gillet and Dauvin, 2000; 2003; Surugiu et al., 2008). Surugiu et al. (2008) reported that polychaetes represented up to 70 % of the benthic macrofauna communities of some of the NE Atlantic seamounts (e.g. Irving, Plato and Meteor seamounts); the dominance of deep-sea communities by polychaetes enables this taxon to be used as an indicator of overall changes in population and community structure of deep-sea environments.

The aim of this study was to investigate the macro-infauna polychaetes on Senghor Seamount. More specifically, we aimed to determine if there were any changes in standing stock, diversity and composition across a northern transect, starting at the summit, capturing the slope and base environments, and ending at a reference station on the neighbouring plain which was not thought to be directly influenced by any intermediate-scale topography.

## 2 Materials and methods

### 2.1 Sampling region

This current study focussed on Senghor Seamount, a relatively isolated topographical feature located in the Cape Verde Archipelago ~60 nautical miles (nm) northeast of



**Fig. 1b.** Senghor Seamount with the locations of the four stations on the northern transect minus the reference station (summit plateau depth ~130 m, base depth ~3200–3300 m). Adapted by A. Chivers, original data and map created by Thor Hansteen and Alexander Schmidt, GEOMAR.

the island of Sal (17.17°N, 21.92°W) (Fig. 1a). Senghor Seamount is fairly circular and symmetrical in shape, with a summit plateau at just ~130 m water depth and a northern base located at a depth of ~3200–3300 m (Fig. 1b). It is situated in a meso- to oligotrophic region of the ocean and thus the food supply to the seafloor is expected to be somewhat reduced; an oxygen minimum zone (OMZ) is also present, with the lowest values previously detected in the region of ~400 m water depth (Christiansen et al., 2009b).

Data presented in this study were derived from samples that were collected from a northerly transect during cruise M79/3 of R/V *Meteor* in October 2009. Additional transects were sampled across east, west and south aspects; however sampling difficulties prevented the achievement of our full sampling aims. Only data from the northern transect is therefore presented here; this may restrict our ability to fully describe infaunal diversity and to detect expected differences with depth at Senghor Seamount.

### 2.2 Sampling methods

A total of five stations were sampled; four stations on the seamount itself at depths ranging from ~130 to ~3200 m, and a reference station situated 60 nm to the north (depth ~3300 m) (Table 1 and Fig. 1b). The macrofauna were sampled using the German Multicorer (MUC), which has a core diameter of 94 mm, equivalent to 69.4 cm<sup>2</sup> surface area per core. Three deployments were made at each station, with a minimum of three cores taken from each deployment (i.e. a total of nine cores per station) (Table 1). The upper 5 cm of sediment was sliced for faunal analysis and each sediment sample placed into a 4 % formaldehyde solution for

**Table 1.** Depth and position of stations sampled on and near Senghor Seamount.

Station	Depth (m)	Latitude (N)	Longitude (W)	No. of replicate deployments	No. of cores/deployment
A (summit plateau)	133	17°12.30′	21°57.70′	3	3
B (upper slope)	834	17°13.80′	21°57.29′	3	3
C (mid-slope)	1534	17°15.57′	21°59.97′	3	3
D (base)	3241	17°21.75′	21°57.90′	3	3
E (reference)	3295	18°05.00′	22°00.20′	3	3

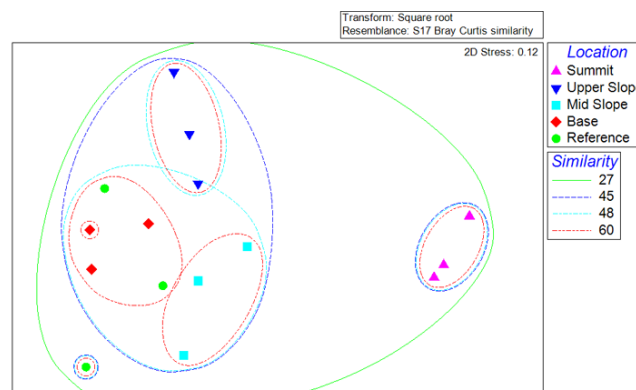
a minimum of two days, enabling the tissues to fix prior to sediment washing and thus to reduce damage to the individuals. The samples were then gently washed on a 250 µm mesh sieve with filtered (20 µm mesh size) seawater, and further rinsed in freshwater before being transferred to 70 % ethanol with added 2 % glycol.

The macrofauna were initially sorted into major taxonomic groups and then counted. The polychaete fauna were then pooled and a wet weight biomass value obtained using a Sartorius BP61S balance. The polychaetes were then further identified to the lowest possible taxonomic level, nominally to putative species level (collectively referred to as species from here on in). Additional samples were also collected for the analysis of a number of environmental variables. Sediment characteristics (mean grain size and mud content) were obtained from MUC cores and are representative of the sediment characteristics at each depth site. Temperature, salinity and oxygen concentration values were obtained from CTD (conductivity/temperature/depth profiler) deployments at each depth range.

### 2.3 Data analysis

Polychaete abundance and biomass values per core were pooled as pseudo-replicates to form one replicate per deployment. These standing stock values were then averaged and standardised for each station to either number of individuals per m<sup>2</sup> or grams of wet weight biomass per m<sup>2</sup>. A number of diversity indices were calculated: Margalef's richness ( $d$ ), Shannon's diversity ( $H'/\log_e$ ), Pielou's evenness ( $J'$ ) and Simpson's dominance ( $1-\lambda$ ), for each station using PRIMER v6 (Clarke and Warwick, 2001). The use of these diversity indices enables analysis of between station alpha diversity values, with each index varying in its sensitivity to the species richness and evenness components of a species data set; they also vary in the degree to which they are influenced by sample size. It was therefore deemed prudent to include four diversity indices within the diversity analysis. An ANOVA (analysis of variance) test was used to evaluate any significant differences between abundance, biomass and the diversity indices for each station.

Multivariate analysis was undertaken using both cluster analysis and non-metric multi-dimensional scaling (MDS)



**Fig. 2.** Non-metric multi-dimensional scaling (MDS) ordination of the polychaete families along the northern transect on Senghor Seamount (27, 45, 48, and 60 % similarity levels defined by cluster analysis).

also using the PRIMER package v6 (Clarke and Warwick, 2001), in order to investigate the similarity between depth stations in terms of both family (Fig. 2) and species community composition (Figs. 4, 5). Square root transformation of the species abundance data was undertaken and a Bray–Curtis similarity matrix generated. A similarity profile test (SIMPROF) was undertaken to determine if the differences seen in the cluster analysis were significant (SIMPROF < 0.05). In addition a similarity percentage test (SIMPER) was undertaken to determine the dissimilarity between stations, and which species contributed > 5 % to dissimilarity between stations (Clarke and Warwick, 2001; Clarke and Gorley, 2006). A global ANOSIM (analysis of similarity) test was also conducted to determine if depth was a significant factor in separating deployments and a Pearson correlation test performed to determine which environmental parameters were correlated with depth.

**Table 2.** Total abundance (ind. m<sup>-2</sup>) and biomass values (g m<sup>-2</sup>) per depth station (standard error values included). Environmental variables also included\*: temperature (°C ITS-90), salinity (PSU), oxygen (μmol L<sup>-1</sup>), sediment characteristics: mean grain size (μm), mud content (%), sorting, skewness, kurtosis.

Station	Environmental variables								Standing stock	
	Temperature (°C ITS-90)	Salinity (PSU)	Oxygen (μmol L <sup>-1</sup> )	Mean grain size (μm)	Mud content (%)	Sorting (μm)	Skewness	Kurtosis (μm)	Abundance (ind. m <sup>-2</sup> )	Biomass (g m <sup>-2</sup> )
Summit	14.07	35.619	75.71	619.3	6.8	476.2	0.736	2.589	10160 (±1943)	2.97 (±0.63)
Upper slope	6.94	34.92	112.38	–	–	–	–	–	1136 (±232)	0.48 (±0.14)
Mid-slope	4.22	34.982	228.82	269.3	32.16	271.92	1.360	4.551	1744 (±251)	1.22 (±0.30)
Base	–	–	–	165.5	58.06	235.83	1.595	4.593	1264 (±122)	0.25 (±0.05)
Reference	2.58	34.90	247.35	168.5	53.15	225.45	1.442	4.176	960 (±269)	0.33 (±0.12)

\* Environmental values taken from CTD deployments located in the closest vicinity to multiple corer deployments. Sediment grain size and mud content values taken from the same deployment drops as polychaete fauna.

### 3 Results

#### 3.1 Environmental parameters

Our results indicated that there were clear differences between each station in terms of the environmental parameters. The summit (Station A) was characterised by coarse sand, with a mean grain size of > 600 μm and the lowest mud content of all the stations sampled (~ 7 %) (Table 2). At the mid-slope station (Station C) fine sand tended to predominate with a higher mud content (~ 30 %) compared to Station A (Table 2). The two deepest stations (on and off seamount) had very similar sediment characteristics with high mud content values and poorly sorted coarse silt (Table 2).

Our data support the presence of an OMZ, with the lowest O<sub>2</sub> value detected on the summit plateau (~ 75 μmol L<sup>-1</sup>) and an increase at Station B (Table 2). Lowest oxygen saturation values are therefore likely to occur at an intermediate depth between these two stations. At the mid-slope Station C, O<sub>2</sub> values were more than double (~ 230 μmol L<sup>-1</sup>) compared to Station B, and increased further at the reference station, Station E (Table 2). Salinity values were similar across all stations, with the highest value at the summit station and the lowest at the reference site (Table 2). Temperature declined with increasing depth from ~ 14 °C to a low of ~ 2.5 °C at the reference station (Table 2). A correlation between depth and the suite of environmental variables was undertaken and this revealed strong correlations between all variables and depth (temperature  $r = -0.86$ , salinity  $r = -0.68$ , oxygen  $r = 0.98$ , mean grain size  $r = -0.95$ , mud content  $r = 0.99$ , sorting  $r = -0.92$ , skewness  $r = 0.92$  and kurtosis  $r = 0.78$ ).

#### 3.2 Standing stock

On the summit plateau (Station A), the number of polychaete individuals was high, with > 10 000 ind. m<sup>-2</sup> and was followed by a noticeable decline on the upper slope (Station B: ~ 1150 ind. m<sup>-2</sup>) (Table 2). The total number of individu-

als increased slightly at the mid-slope station, (Station C: ~ 1750 ind. m<sup>-2</sup>) before declining again at the base of the seamount (Station D: ~ 1250 ind. m<sup>-2</sup>) and at the reference station (Station E: ~ 960 ind. m<sup>-2</sup>). Polychaete biomass values showed a pattern very similar to that of the abundance values (Table 2), with a primary maximum at the summit (Station A) and a secondary maximum at the mid-slope (Station C). The ANOVA test revealed a significant difference between Station A abundance values and all other stations ( $p < 0.01$ ), this was also reflected in the biomass values. No significant differences were observed between the standing stock values of the other stations.

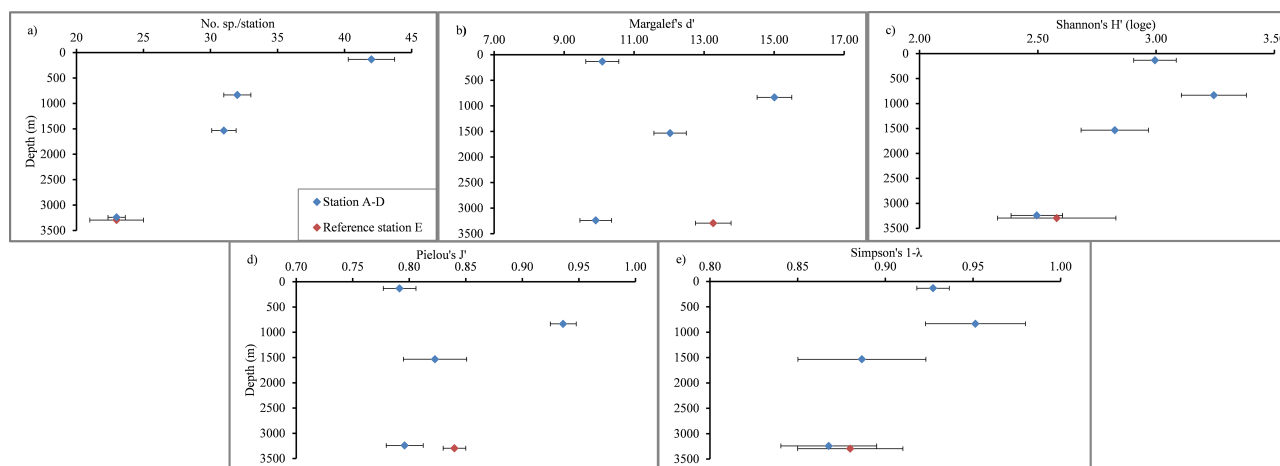
#### 3.3 Polychaete family analysis

In total 34 polychaete families were identified from the 954 polychaete individuals collected. The dominant families (in terms of total individuals) were the Syllidae (34 %), Spionidae (10 %), Cirratulidae (13 %), Chrysopetalidae (7 %) and Sabellidae (5 %) (Table 3). In terms of total number of species per family, the Syllidae dominated with 19 species in total, followed by the Spionidae (16), Cirratulidae (11), Paraonidae (9) and the Capitellidae (7). Several families were present at all stations, including the Cirratulidae, Paraonidae, Spionidae and the Syllidae, whilst the Arbellidae, Serpulidae, Nephytidae and Ampharetidae were only observed at depths > 1500 m (Table 3). The Dorvilleidae, Eunicidae and Lacydoniidae were only found at the summit station. A non-metric MDS plot (Fig. 2) (all cores grouped per deployment) showed that at family level, all stations were broadly grouped with a similarity of 27 %. The upper-slope (834 m) and deeper stations had a 45 % similarity in terms of family composition, whilst the base (~ 3200 m) and reference station (~ 3300 m) were 60 % similar.

#### 3.4 Polychaete species diversity

The 954 polychaete individuals collected were nominally separated into 135 species. Changes in polychaete species





**Fig. 3.** Diversity of the macrobenthic polychaetes along the north transect; (a) number of species/station, (b) Margalef's richness ( $d'$ ), (c) Shannon's diversity ( $H'$  loge), (d) Pielou's evenness ( $J'$ ), (e) Simpson's dominance ( $1-\lambda$ ).

diversity along the transect are illustrated in Fig. 3. Species diversity, richness and evenness were highest on the upper slope at Station B, whereas evenness and richness were lowest at both the summit Station A and the base station on the seamount. Shannon–Wiener diversity was noticeably lower at the base station. The reference station had a higher richness value than the base station, but not diversity or dominance and only a slightly higher evenness value. The ANOVA test revealed no significant differences between any of the stations for evenness and dominance. Station A was significantly different ( $p < 0.01$ ) to all other stations in terms of Shannon–Wiener's diversity and significantly different to Station C at a lower level ( $p < 0.05$ ). This observation also held true for richness whereby the summit station was significantly different from all other stations ( $p < 0.01$ ). There were no significant differences between all other stations in terms of the measured diversity indices.

### 3.5 Multivariate analysis

The group-average linked cluster analysis and the SIMPROF permutation test showed a remarkably low level of similarity between stations at the species level (Fig. 4), the summit station (Station A) showed no similarity to any other station ( $p < 0.005$ ). The remaining four stations also showed relatively little similarity to one another (7 % similarity). The mid-slope, base and reference stations (Stations C, D and E) displayed a similarity level of < 10 %, with the seamount base Station D and the reference Station E showing the greatest similarity at 26 % ( $p < 0.005$ ). It is worth noting that the similarity of 26 % is still low and it seems that, despite very similar depths, the base and reference stations differ in terms of polychaete species composition. There was no statistical evidence for any other sub-structure within each group (samples connected by dotted lines).

The non-metric MDS plot (species level, all cores grouped per deployment) (Fig. 5) also showed similar groupings of deployments and stations compared with the cluster analysis whereby the three deployments for each station formed one group. The three deployments for the summit plateau (Station A) formed one group at a similarity level of 62 %, quite distinct from the other four stations. In addition, the base and reference stations (Stations D and E) were quite similar in their sub-grouping (Station D deployment similarity 51 %, Station E deployment similarity 32 %). Using the global ANOSIM test, depth was found to be a significant factor driving deployment clustering at this seamount ( $r = 0.75$ ,  $p < 0.001$ ). However, it appears that despite very similar depths, the base and reference stations still form two distinct clusters in terms of their polychaete species composition.

Using SIMPER, the dissimilarity between stations based on the contribution of different species was calculated (Table 4). Dissimilarity between the summit plateau (Station A) and other stations was particularly high (> 99 %) and was the result, predominantly, of a single syllid species (sp. 909) which contributed > 7.5 % to the total dissimilarity. Whilst sp. 977 of the family Spionidae contributed 12.6 % to the dissimilarity between Station B and C, it was also found to be important in contributing to the differences between Station C and D and between Station C and E.

The absence of sediment characteristic data from the upper slope (Station B, ~ 800 m) and CTD data from the base of the seamount (Station D, ~ 3300 m) resulted in depth being the only measured variable for each station. It is therefore not possible to undertake an ANOSIM test to determine which environmental variable was driving observed standing stock/diversity trends at Senghor Seamount, only depth could be tested in this way.

**Table 3.** Polychaete family analysis (total no. of species, total no. of individuals, presence (Y)/absence (–), according to depth).

Polychaete family	Total no. of sp.	Total no. of ind.	133 m Stat. A	834 m Stat. B	1534 m Stat. C	3241 m Stat. D	3295 m Stat. E
Acrocirridae	5	24	Y	Y	Y	Y	Y
Ampharetidae	2	9	–	–	Y	–	–
Amphinomidae	3	6	Y	Y	Y	–	Y
Aristobranchidae	3	7	–	Y	–	–	–
Arabellidae	1	1	–	–	–	Y	–
Capitellidae	7	24	Y	Y	Y	–	–
Chrysopetalidae	3	62	Y	Y	Y	Y	–
Cirratulidae	11	123	Y	Y	Y	Y	Y
Dorvilleidae	2	6	Y	–	–	–	–
Eunicidae	1	30	Y	–	–	–	–
Flabelligeridae	2	3	Y	–	–	–	Y
Fauveliopsidae	1	9	–	Y	–	–	–
Glyceridae	1	1	–	–	–	Y	–
Hesionidae	5	40	Y	–	Y	–	Y
Lacydoniidae	2	2	Y	–	–	–	–
Lumbrineridae	1	3	Y	–	Y	–	–
Magelonidae	1	1	–	–	–	Y	–
Maldanidae	6	12	Y	–	Y	–	Y
Nephtyidae	1	1	–	–	Y	–	–
Nereididae	3	11	Y	Y	Y	Y	Y
Onuphidae	2	9	Y	–	–	–	Y
Opheliidae	4	17	–	Y	Y	Y	Y
Paraonidae	9	37	Y	Y	Y	Y	Y
Pholoidae	4	6	Y	Y	–	–	–
Phyllodocidae	1	1	–	–	–	–	Y
Pilargidae	2	2	–	Y	–	–	Y
Poecilochaetidae	1	1	–	–	Y	–	–
Sabellidae	3	47	Y	–	–	Y	Y
Serpulidae	3	3	–	–	–	Y	Y
Sigalionidae	5	7	–	Y	–	Y	Y
Sphaerodoridae	1	2	–	–	Y	–	–
Spionidae	16	97	Y	Y	Y	Y	Y
Syllidae	19	324	Y	Y	Y	Y	Y
Terebellidae	3	23	Y	Y	Y	–	Y

## 4 Discussion

### 4.1 Changes in polychaete standing stock with depth

In many deep-sea environments, macrofaunal abundance is observed to decrease exponentially or linearly with depth (Etter and Rex, 1990; Cosson-Sarradin et al., 1998), however on the northern transect at Senghor Seamount, this does not appear to hold true. High polychaete abundance, which corresponds with high biomass levels, were observed on the summit of Senghor Seamount, Station A ( $\sim 10,000$  ind.  $m^{-2}$ ) (Table 2). This was not unexpected as the summit of the seamount at  $\sim 130$  m water depth lies at the bottom of the surface ocean layer from where organic carbon is exported into deeper waters. Comparison of macrofaunal standing stock values with total organic material was not possible due to a lack of data, however, mud content (%) was used as a

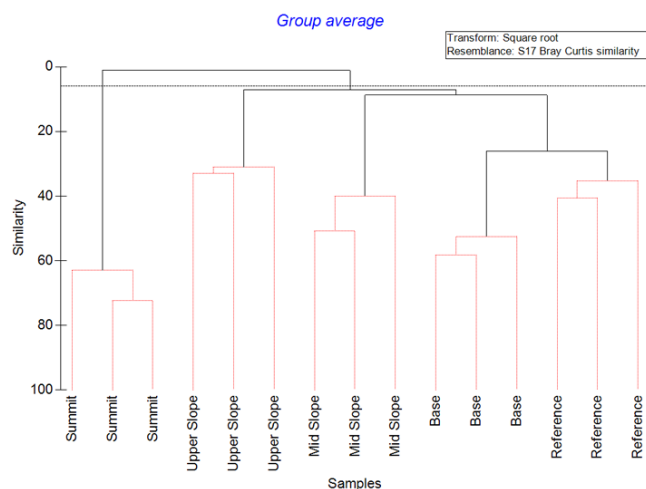
proxy for organic material availability within the sediment, as total organic material and sediment mud content are often positively correlated (Lohse et al., 1995; Janssen et al., 2005; McBreen et al., 2008; Serpetti et al., 2012). Mud content was positively correlated with depth at Senghor (Table 2), suggesting an increased availability of organic material with increasing depth. Standing stock was highest at Station A, which implies that organic material availability was not driving abundance and biomass at this station, but other variables such as temperature or current velocity may be a significant factor influencing the community at this depth (Table 2). It is known that high current velocities can re-suspend deep-sea sediments, stimulating bacterial growth and influencing immigration rates to an area (Thistle et al., 1985), this may have also contributed to the high abundance observed at the summit station.

**Table 4.** Cluster dissimilarity percentages as identified by similarity percentages (SIMPER). The number of species contributing to total dissimilarity between stations. Species contributing to > 5 % dissimilarity included.

Stations	Dissimilarity %	No. sp. contributing dissimilarity	Sp. contributing to > 5 % dissimilarity		
			Family	Species	Contribution %
A–B	99.5 %	42	Syllidae	sp. 909	8.3
			Cirratulidae	sp. 997	6.2
			Chrysopetalidae	sp. 900	6.0
			Syllidae	sp. 907	5.6
A–C	99.5 %	44	Syllidae	sp. 909	7.6
			Cirratulidae	sp. 997	5.7
			Syllidae	sp. 907	5.2
			Spionidae	sp. 977	5.0
A–D	99.9 %	37	Syllidae	sp. 909	8.0
			Cirratulidae	sp. 997	6.0
			Chrysopetalidae	sp. 900	5.7
			Syllidae	sp. 907	5.5
A–E	100.0 %	41	Syllidae	sp. 909	8.4
			Cirratulidae	sp. 997	6.2
			Chrysopetalidae	sp. 900	6.0
			Syllidae	sp. 907	5.6
B–C	97.2 %	41	Spionidae	sp. 977	12.6
			Cirratulidae	sp. 1000	5.1
B–D	97.1 %	37	Paraonidae	sp. 991	11.8
			Cirratulidae	sp. 1002	10.1
			Sabellidae	sp. 968	6.7
B–E	98.7 %	42	Spionidae	sp. 970	8.2
			Cirratulidae	sp. 1002	6.2
C–D	91.6 %	34	Spionidae	sp. 977	10.8
			Spionidae	sp. 981	10.5
			Cirratulidae	sp. 1002	8.9
			Sabellidae	sp. 968	5.9
			Cirratulidae	sp. 1000	5.0
C–E	97.6 %	40	Spionidae	sp. 977	13.5
			Spionidae	sp. 970	6.9
			Cirratulidae	sp. 1000	5.7
			Cirratulidae	sp. 1002	5.2
D–E	82.4 %	33	Spionidae	sp. 981	15.1
			Spionidae	sp. 970	9.1
			Sabellidae	sp. 968	7.5
			Cirratulidae	sp. 1002	7.1

At the “upper” mid-slope station (Station B ~ 800 m) the presence of the oxygen minimum zone may have had an influence upon standing stock. Levin et al., (2000) noted that standing stock increased in the lower boundary zone below an OMZ centre in the Arabian Sea, and that was related to the increased organic material at these depths. Station B has a considerably lower standing stock compared to stations sampled shallower and deeper, yet is located be-

low the OMZ centre. As there was not a station sampled from within the centre of the OMZ (~ 400 m) we are unable to say whether this “low” value for Station B is the minimum value found for stations along this northern transect. A lack of quantitative macrofaunal studies of NE Atlantic seamounts prevents any direct comparisons to this study. However, three sites at depths comparable to our study, with different productivity regimes, were sampled as part of

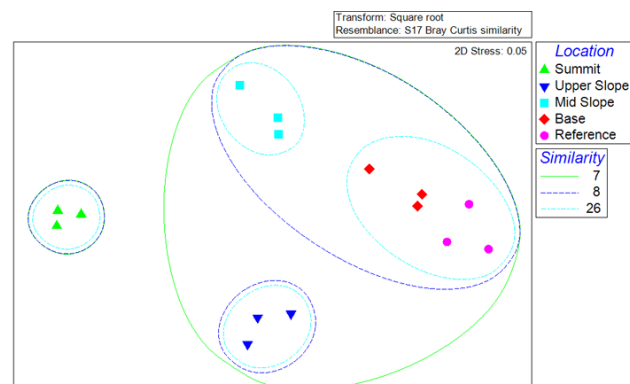


**Fig. 4.** Hierarchical, group-average linkage Cluster analysis on deployment replicate resemblance for polychaete species along the northern transect of Senghor Seamount. The similarity profile (SIMPROF) test ( $p < 0.05$ ) defines non-random clusters in the analysis.

the EUMELI-JGOFS (EUtrophic, MEsotrophic and oLIg-trophic sites-Joint Global Ocean Flux Study) benthic program on the Cape Verde Rise (Galeron, et al., 2000). Polychaete abundance at the eutrophic site was almost double that found at a comparable depth on Senghor Seamount (Station C  $\sim 1500$  m) and the mesotrophic site had similar abundance values compared to the deep stations sampled in this study ( $\sim 3200$  m). Abundance values at Senghor are also roughly comparable to sites sampled during the BIOZAIRE 2 project where deep-sea canyon systems were investigated in the southeast Atlantic (Galeron et al., 2009).

#### 4.2 Changes in polychaete family diversity

At Senghor Seamount a total of 34 polychaete families were identified from 954 individuals. When comparing our results with those of Gillet and Dauvin 2000, 2003; and Surugiu et al., 2008, we found our values were higher than those from seamounts in the nearby Azores region whereby Atlantis Seamount had 18 families and 403 individuals, whilst Hyeres Seamount had 13 families and 346 individuals. A ratio of polychaete families/total individuals collected was compared from the different seamounts and clear similarities between Senghor ( $34/954 = 0.036$ ), Atlantis ( $18/403 = 0.045$ ) and Hyeres ( $13/346 = 0.038$ ) seamounts were observed. Five families dominated the polychaete fauna at Senghor, contributing  $> 95\%$  of the total polychaete abundance (see Table 3). Surugiu et al., (2008) also identified a number of dominant polychaete families, e.g. the Onuphidae ( $\sim 28\%$ , 1053 ind.), Syllidae ( $\sim 18\%$ , 699 ind.), Eunicidae ( $\sim 16\%$ , 600 ind.), and the Amphinomidae ( $\sim 12\%$ , 439 ind.); in total



**Fig. 5.** Non-metric multi-dimensional scaling (MDS) ordination of the polychaete species along the northern transect on Senghor Seamount (7, 8, and 26 % similarity levels defined by cluster analysis).

10 families were identified which represented  $> 90\%$  of the total fauna collected.

Few similarities were observed between Senghor Seamount and the Azores seamounts. Many more families were identified at Senghor Seamount, although this may be the result of the higher number of individuals collected, it may also be a result of different sampling gear and mesh size used in this study. It is difficult to draw direct comparisons with the seamounts sampled by Gillet and Dauvin, 2000, 2003; and Surugiu et al., 2008, as a variety of qualitative sampling gear was used, e.g. epibenthic dredges and beam trawls (with a mesh size of 2–5 mm), which in turn sampled the hard substrate, e.g. stones, corals. Dominant families were also very different, the only similarity being the Syllidae family which dominated on Josephine and Meteor seamounts (Gillet and Dauvin, 2000, 2003). On Senghor Seamount there does not appear to be such a distinct bathymetric zonation of families, with a relatively high degree of similarity between stations in terms of family similarity (Fig. 2).

#### 4.3 Changes in polychaete species diversity and composition

At the summit and deeper stations on Senghor Seamount, species richness and evenness were both relatively low, with a peak observed at the upper-slope station ( $\sim 800$  m depth). This peak in diversity was found at a shallower depth compared to many other deep-sea polychaete studies where the observed diversity maxima occurred at 1400–1800 m along the Hebridean Slope (Paterson and Lambshead, 1995), whereas in the tropical NE Atlantic, Cosson-Sarradin et al. (1998) found polychaete diversity peaked at  $\sim 2000$  m. In the Faroe–Shetland Channel polychaete species- and genus-level diversity occurred at depths between 450–550 m (Bett, 2001; Narayanaswamy et al., 2005, 2010a, b). By removing

the summit station (Station A) from our analysis a different diversity versus depth pattern is observed; polychaete diversity appears to show a gradual and almost linear decrease in diversity with increasing depth across the remaining seamount stations. The results of the ANOVA test revealed no significant differences between all stations in terms of dominance and evenness but species diversity was significantly different at the summit compared to the other stations (Station B, D and E;  $p < 0.01$ ) and to Station C at a lower level ( $< 0.05$ ).

As already highlighted the environmental conditions at the summit station are very different to the others on Senghor Seamount. The summit may experience increased current velocities which may explain the poorly sorted coarse sand sediment with low particle size diversity (Table 2) as well as having a low oxygen concentration. Particle size diversity is known to strongly correlate with faunal diversity (Etter and Grassle, 1992) and this, combined with reduced habitat heterogeneity may be some of the dominant factors reducing species diversity on the summit. It is likely that lower oxygen concentration may be driving the high evenness, diversity and richness witnessed on the upper slope (Station B), the converse of what was seen with abundance. Levin et al. (2000), observed a dramatic increase in diversity below the centre of an OMZ in the Arabian Sea, and suggested that in the lower boundary below the OMZ, diversity may increase, potentially due to low oxygen levels acting as a physical disturbance and thus limiting competitive exclusion.

There is a noticeable difference in species richness and evenness when comparing the base and reference stations (Fig. 3c). However, in terms of species composition, the base and reference stations displayed the highest between-station similarity ( $> 30\%$ ); however, this is still a relatively low degree of similarity, suggesting different community composition at each site, despite very similar depths. In terms of sediment characteristics, the two stations were also very similar. Unfortunately additional environmental information is not available for Station D, so it is unclear why richness and evenness may differ at these sites.

At species level the polychaete communities along the northern transect of Senghor Seamount were found to be significantly different from one another ( $p < 0.005$ ), with the summit station (Station A) showing very low similarity ( $< 1\%$ ) to the remaining four stations (Figs. 4, 5). The base and reference stations (Stations D and E at  $\sim 3200$ – $3300$  m depth) did not have a high level of similarity ( $< 30\%$ ) and community composition appeared to be different even though standing stock values were found to be very similar at these sites (Table 2 and Sect. 3.2). The dominant species found at the base station (sp. 981) and the reference station (sp. 970) both belonged to the same family, Spionidae; however, sp. 981 was absent from the reference station and sp. 970 was absent from the base station, thus contributing  $\sim 15\%$  to the dissimilarity between the stations. Both species were examined to determine if there were any differences

in morphology and/or functional traits. Both species were found to belong not only to the same family but also the same genus (*Prionospio*). Under close examination a number of small morphological differences were discovered which separate the two species. Since both species are very similar we feel they probably occupy a similar ecological niche. The only discernible difference between these two stations is a slightly lower mud content at Station E (Table 2). Unfortunately CTD data was unavailable from Station D preventing us from examining other environmental variables which may explain the observed differences in community composition at the sites.

Seamounts may enable many species to co-exist over a wide bathymetric range, creating a distinct, individual and complex environment with a suite of environmental and evolutionary factors (local hydrodynamic regime, oxygen concentration and sediment characteristics) acting in concert to shape community diversity (Clark et al., 2010). Koslow et al. (2001) found that most seamount species were distributed over a wide depth range on a southern Tasmanian seamount whereas at Senghor Seamount each station appeared to have very different species compositions. However, the results here do support the theory proposed by Longhurst (1998), that more change may be witnessed over 1000 m vertically than 1000 km horizontally. In addition the findings of McClain (2010) indicate that substantial change in assemblage structure may be observed over vertical scales, often as much as a 50 % change over a vertical distance of only 1500 m, which supports our findings. Depth is a significant factor driving the clustering of deployments at Senghor Seamount (Global ANOSIM,  $r = 0.75$ ,  $p < 0.001$ ), with depth often correlated to changes in environmental conditions (Grassle et al., 1979; Clark et al., 2010). It appears that at Senghor Seamount this effect is more pronounced, with a more marked change in community composition observed between stations, in as little as a vertical distance of 700 m.

At Senghor the explanation for observed standing stock and diversity patterns is likely to be multivariate and complex, with high temperatures, low oxygen and a coarse grain size driving differences on the summit and within the OMZ. A number of ecological theories have been proposed to explain the uni-modal patterns of species diversity observed with depth. These theories focus upon the influence of disturbance upon diversity (the intermediate disturbance hypothesis, Connell, 1978) and productivity and disturbance models, e.g. the Dynamic Equilibrium Model (DEM) (Huston, 1994). These models predict a uni-modal relationship of species diversity and depth, as observed at Senghor Seamount. The models predict low diversity at high and low productivity levels and highest diversity at intermediate productivity, with a similar prediction for disturbance (intermediate disturbance resulting in high diversity). When the effects of disturbance and productivity are combined, the situation becomes much more complex. Kondoh (2001) modified Huston's DEM model to explicitly include disturbance and



productivity, predicting highest diversity at mid to low productivities and intermediate disturbance and lowest diversity at highly disturbed/low productivity sites or high productivity/low disturbance sites. Unfortunately the lack of environmental data for Senghor Seamount negates the possibility of testing these hypotheses for the benthic macrofauna at this seamount.

This study though based upon low sample numbers and a less than comprehensive coverage of a full bathymetric range, still adequately explores the relationship between polychaete assemblages and depth, and also a range of environmental variables on a single seamount. Due to these limitations, polychaete standing stock and diversity trends may not be fully described, but these results do suggest seamounts in the Cape Verdean region support abundant and diverse polychaete assemblages. Further investigation of this and other seamount macrobenthic assemblages in this region and worldwide will be important when seeking to gain an integrated understanding of seamount ecosystem processes.

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